

EFFECTIVENESS OF THE COMPLEX MICROBIAL FORMULATION FOR DISEASE PROTECTION AND PRODUCTIVITY ENHANCEMENT OF PLANTS

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Usage of the potential of beneficial soil microorganisms is one of the most promising areas for crop production enhancement. Of special interest are innovative multifunctional complex bioformulations based on associations of bacteria with phytoprotective and growth-stimulating properties. The study aimed to investigate the effectiveness of the new complex microbial preparation Ecophosphoryn. It was created based on associative growth-stimulating phosphate-mobilizing and nitrogen-fixing bacteria *Bacillus*, *Azotobacter* and *Agrobacterium* genera. Ecophosphoryn was used to treat the seeds of corn (*Zea mays* L.), white-headed cabbage (*Brassica oleracea* var. *capitata* L.), spray tomato (*Solanum lycopersicum* L.) and cabbage (*Brassica oleracea* var. *capitata* L.) during the growing season in laboratory, vegetation and field research. The protective effect of Ecophosphoryn against alternaria of tomatoes averaged 76%. Against fusarium wilt of white cabbage on an artificial infectious background, the effectiveness of Ecophosphoryn was at the level of 78–83%, and against alternaria head blight in the field on a natural infectious background – at the level of 45–53%. The damage of corn by powdery mildew during the growing season decreased by 33%. The obtained results proved that various methods of using bioformulation contributed to increasing the resistance of plants against phytopathogenic micromycetes. The yield of white cabbage grew by 12%, tomatoes – by 14.9%, and corn – by 26.6%. In most cases, the protective effect of the biological preparation and crop yields were not less effective than those of chemicals. In all field experiments, the use of Ecophosphoryn resulted in an increase in healthy fruit harvest compared to the control. The obtained data expand knowledge about the capabilities of biological formulations for ecologically oriented phytosanitary optimization of agrocenoses.

Key words: polyfunctional bioformulation, corn, fungal infections/diseases, phytoprotective properties, tomatoes, white cabbage, yield

The interest in environmentally friendly crop production technologies is growing annually. The ever-increasing use of pesticides leads to environmental pollution, their accumulation in crop products, the appearance of resistant strains and populations of pests, etc.

Infectious diseases of cultivated plants each year lead to a large decrease in yield and sometimes even crop deaths. Crop yield losses from the harmful effects of phytopathogens in different countries of the world are an average of 20% (Azizbekyan 2019). Increasing plant productivity and their resis-

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tance to adverse abiotic and biotic factors is possible by using special methods of plant breeding and protection (Shoham 2020). One of the ways to solve the problem of environmentally friendly agricultural practice is to use biological plant protection products that exhibit phytoprotective, immunostimulating and growth-regulating properties (Compant 2005; Perez-Garcia *et al.* 2011; Azizbekyan 2019). Biological methods of plant protection have priority over the chemical methods, they are the most suitable ones approved for use in organic farming (Pandit *et al.* 2022). The introduction of biological control agents into technological schemes changes the relationship between plants, pathogens and the environment and causes several biological and physical interactions that affect pathogen activity, plant health and the ecological situation in agrophytocenoses (Tariq *et al.* 2020; He *et al.* 2021). The implementation of such measures in production makes it possible to completely refuse or significantly reduce the use of chemical protection agents. This is especially important for vegetable crops, as it makes it possible to improve product quality and safety. Crop production was grown using environmentally safe technologies. It is promising and has a wide demand on the market. The application of bacteria useful for plants has a positive effect on product quality: the content of vitamins, flavonoids and antioxidants increases. Microbial preparations based on them act as plant probiotics for agricultural crops (Jimenez-Gomez *et al.* 2017).

The market for biological pest control products is constantly growing. The supply of biological control agents and biostimulants is growing by more than 10% per year (Shoham 2020). Bioformulations can significantly reduce or eliminate the biotic stress caused by pests, diseases and weeds. These biotechnological products trigger processes that improve plant nutrient utilization and increase tolerance to abiotic stresses such as drought and extreme temperatures (Compant 2005; Köhl *et al.* 2019).

Biological products with complex action based on microorganisms with various beneficial properties are especially important. They are environmentally friendly, increase yields and product quality, are cheaper than chemicals, are based on bacteria that promote plant growth and provide biocontrol aimed at limiting the reproduction and dominance of

pests in agrophytocenoses, as well as improving soil fertility and microbial biodiversity (Kolomiyets' *et al.* 2016; Iutynska *et al.* 2017; Manasfi *et al.* 2018).

The most common biocontrol agents are microbial preparations based on representatives of the genera *Bacillus*, *Azotobacter*, *Agrobacterium*, etc. (Clare 1990; Perez-Garcia *et al.* 2011; Köhl *et al.* 2019; Aasfar *et al.* 2021). Some authors consider that *Azotobacter chroococcum* is promising in the creation of multicomponent biological compositions that include several strains of bacteria or biologically active substances characterized by greater efficiency of action compared to mono-inoculants (Kirichenko & Kots' 2011; Borzykh *et al.* 2022).

The scientists of the D.K. Zabolotny Institute of Microbiology and Virology of the National Academy of Sciences of Ukraine had developed a complex bioformulation Ecophosphoryn based on selected highly effective strains of the genera *Bacillus*, *Azotobacter* and *Agrobacterium* (Patent of Ukraine No. 105276). The bioformulation's component strains are characterized by a wide range of agronomically useful biological properties: the ability to fix atmospheric nitrogen and mobilize insoluble phosphates, improve plant mineral nutrition, stimulate their growth and development due to the synthesis of biologically active metabolites such as vitamins, phytohormones, amino acids, organic acids, etc. Ecophosphoryn has received the Organic Standard Certificate of Quality.

In this regard, our work aimed to study the phytoprotective and growth-stimulating properties of the complex polyfunctional bioformulation Ecophosphoryn when used in crop cultivation technologies.

MATERIAL AND METHODS

Microorganisms and fungicides

The research was conducted in the conditions of laboratory and vegetative experiments on the background of artificial infection of plants with pathogens and in field conditions on the natural infectious background. To protect plants from diseases and increase their productivity, the liquid biological preparation Ecophosphoryn was used, which includes living cells of strains: *Bacillus megaterium* IMV B-7168, *Azotobacter chroococcum* IMV B-7171 and

Agrobacterium radiobacter IMV B-7246 (Patent of Ukraine №105276), as well as the cultural medium where they were grown. These strains have different physiological properties (phosphate mobilization, nitrogen fixation, synthesis of exopolysaccharides, phytohormones, and antibiotic compounds for biocontrol of pathogens). Ecophosphoryn can be used both for seed treatment and for spraying plants. We used the recommended rate of consumption – 1.0 L/t and 2.0 L/ha. The “Organic Standard” Quality Certificate authorizes the use of Ecophosphoryn in organic agriculture according to Commission regulation (EC) No. 889/2008.

The protective effect of Ecophosphoryn against *Alternaria solani* Ell. et Mart. and *Alternaria brassicae* (Berk.) Sacc. (alternarioses), *Fusarium oxysporum* f. sp. *conglutinans* (Wr.) (fusarium wilt), *Ustilago zeae* (Beckm.) Unger (blister smut) was compared with the effectiveness of chemical preparations in the recommended consumption rates, namely: dimetomorph, 90 g/kg+mancozeb, 600 g/kg (fungicide Acrobat MC WDG, 2.0 kg/ha); azoxystrobin, 250 g/L (Quadris 250 SC, 0.6 L/ha); fluopyram, 200 g/L+tebuconazole, 200 g/L (Luna Experience 400 SC, 0.75 L/ha); fludioxonil, 25 g/L+metalaxyl-M, 10 g/L (Maxim XL 035 FS, 1.0 L/t); metalaxyl-M, 40 g/kg+mancozeb, 640 g/kg (Rydolil Gold MC 68 WDG, 2.5 kg/ha) (Ministry of Environmental Protection of Ukraine, 2024).

Laboratory and vegetative experiments

In laboratory and vegetative experiments, the protective effect of bioformulation against pathogens was determined by Krayntsburg-Eggert's method in our modification (Borzykh *et al.* 2022). Tomato plants (*Solanum lycopersicum* L.) of the early-ripening cultivar Flora were grown in the greenhouse (6 pots per variant with 5 plants in each were used) until the phases of budding (BBCH 51-53) and flowering (BBCH 61-63) and then were sprayed with the bioformulation Ecophosphoryn (0.5%), as well as with metalaxyl-M, 40 g/kg+mancozeb, 640 g/kg (Rydolil Gold MC 68 WDG, 0.6%) for comparison. Plants of the control variant were sprayed with sterile water. One day after the treatment, leaves of different tiers were collected and infected by spraying in the laboratory with a suspension of *Alternaria*

solani spores isolated from tomatoes. The experiment was repeated 6 times. The concentration of micromycete spores was 10^5 – 10^6 spores/ml. On the 5–6th day after artificial infection, data on the disease of tomato leaves were recorded on a 6-point scale: 0 – there is no lesion; 0.1 – single spots; 1 – up to 10 minor spots on a leaf (1–5% of the area is affected); 2 – the lesion covers up to 10% of the leaf surface; 3 – the lesion covers up to 25% of the leaf surface; 4 – the lesion covers up to 50% of the leaf surface; 5 – severe damage, up to 75% of the surface is affected; 6 – complete damage, the leaf rots and dies (more than 75% damage of the leaf area). Thus, we were determining the degree of disease development and the effectiveness of the bioformulation (Sergiienko 2001; Trybel 2001).

White-headed cabbage (*Brassica oleracea* var. *capitata* L.) seeds of the Ukrayins'ka osin' cultivar were first treated with Ecophosphoryn at a consumption rate of 1.0 L/t, then sown in pots and grown in a greenhouse (6 pots per variant with 3 plants in each were used). The seeds of plants of the control variant were treated with sterile water. Plants were grown until the phases of 1–2 (BBCH 11-12) and 4–5 true leaves (BBCH 14-15) and then were sprayed with the bioformulation Ecophosphoryn (0.5%) or fluopyram, 200 g/L+tebuconazole, 200 g/L (Luna Experience 400 SC, 0.75 L/ha) for comparison. One day after the treatment, leaves were selected and infected by spraying with a suspension of spores of the causative agent of fusarium wilt of cabbage, *Fusarium oxysporum* f.sp. *conglutinans* (Wr.) as described above. Experiments were carried out in 6-fold repetition. Phytopathogens for artificial infection were previously isolated by us from affected plant tissues of natural foci of infection.

Records of the degree of damage to plants by phytopathogens were carried out 5–6 days after artificial infection. The degree of disease development (disease severity) and the effectiveness of the preparations (action effectiveness) were determined. Data on the disease of white-headed cabbage leaves by fusarium wilt were recorded on a 4-point scale: 0 – no signs of damage; 1 – 1-2 leaves have turned yellow; 2 – 3-4 leaves have turned yellow; 3 – yellowed half of the plant surface; 4 – the whole plant has turned yellow.

Field experiments

Field experiments with corn, white cabbage and tomatoes were conducted during the years 2012–2018 in the Kyiv region belonging to the Central Forest-Steppe zone of Ukraine on the typical chernozem with a low humus content of 2.6–2.8 %, pH – 5.6–6.0. In field experiments, plots with an area of 25 m² were used to evaluate the development of the disease in 4-fold repetition, that is, an area of 100 m² was used for the 1 variant of the experiment. The effectiveness of the preparations was evaluated in comparison with the control variant. Pre-sowing treatment of TK-202 corn (*Zea mays* L.) seeds was carried out with the bioformulation Ecophosphoryn at the rate of 1.0 L/t, as well as with fludioxonil, 25 g/L+metalaxyl-M, 10 g/L (Maxim XL 035 FS, 1.0 L/t) for comparison. The protective effect of Ecophosphoryn against the spread of corn mold was studied in comparison with the fungicidal effect. Treatment was not carried out during the growing season. Tomato plants of the Flora cultivar and cabbage of the Yana cultivar were treated with Ecophosphoryn during the growing season by 2-3-fold spraying at a consumption rate of 2.0 L/ha, as well as with dimetomorph, 90 g/kg+mancozeb, 600 g/kg (Acrobat MC WDG, 2.0 kg/ha) and azoxystrobin, 250 g/L (Quadris 250 SC, 0.6 L/ha) respectively for comparison. Treatments were carried out before the onset of the first signs of the disease or at the first symptoms of the disease and 8–10 days after the previous treatment. During the ontogeny of the cultures, their disease damage was recorded and the effectiveness of the studied preparations was

evaluated as described above, necessarily before each spraying and 10 days after the last treatment. A 4-point scale was used to assess damage to cabbage plants by alternaria: 0 – no signs of damage; 1 – slight damage, dark spots on individual leaves; 2 – many spots on different leaves, part of the spots merge, some spots have rotted, the lesion covers up to 25% of the plant surface; 3 – affected half of the plant; 4 – the whole plant is affected.

Statistical data analysis

All laboratory and vegetative experiments with 6 repetitions and the field experiments with 4 repetitions were analysed by using the MSTATC software. For statistical analysis, we used the analysis of variance (ANOVA) method.

RESULTS

The study of the protective effect of the bioformulation Ecophosphoryn in the laboratory and vegetative experiment against tomato alternariosis showed its high efficiency. The bioformulation restrained the development of the disease under artificial infection 3.8 times in the budding phase and 3.6 times in the flowering phase. At the same time, its effectiveness was 73.7% and 72.2%, respectively (Table 1).

The effectiveness of the fungicide metalaxyl-M, 40 g/kg+mancozeb, 640 g/kg (Rydomil Gold MC 68 WDG) in these periods of tomato ontogenesis was at the level of 93.6% and 80.8%.

T a b l e 1

Protect action of Ecophosphoryn against tomato alternariosis compared to fungicide effect in laboratory and vegetative experiments (Flora cultivar)

Variants	Disease severity [%]		Action effectiveness [%]	
	budding phase (BBCH 51-53)	flowering phase (BBCH 61-63)	budding phase	flowering phase
Control	43.7 ^a	48.6 ^a	–	–
Ecophosphoryn	11.5 ^b	13.5 ^b	73.7	72.2
Metalaxyl-M, 40 g/kg+mancozeb, 640 g/kg (Rydomil Gold MC 68 WDG)	2.8 ^c	9.3 ^b	93.6	80.8

Note: Figures with the same letters in each column have no significant difference at the 0.05 level of probability (*LSD* test), *LSD* – least significant difference; BBCH (Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie) is a universal scale for describing phenological stages of plants.

In the field experiments on the natural infectious background, Ecophosphoryn also effectively limited the development of tomato alternariosis (Table 2).

The development of the disease during the entire growing season was decreased by 2.4 times. Both at the beginning of the disease development (first decade of July) and at the end of the growing season (last decade of August), the degree of disease development was almost at the level of the variant with chemical fungicide. The yield of tomatoes in the control was 45.7 t/ha. The use of Ecophosphoryn application increased the yield of tomatoes up to

14.9%, and the fungicide dimetomorph, 90 g/kg + mancozeb, 600 g/kg (Acrobat MC) – up to 16% (Table 2).

Thus, studies conducted in laboratory-vegetative and field conditions with tomatoes of the Flora cultivar showed that Ecophosphoryn limited the development of alternariosis both under artificial and natural infection backgrounds. The efficiency of the bioformulation averaged 72.9% and 68.4% during the growing season, respectively, and that of metalaxyl-M, 40 g/kg+mancozeb, 640 g/kg (Rydolil Gold MC 68 WDG) and dimetomorph, 90

T a b l e 2

Efficacy of Ecophosphoryn against tomatoes alternaria compared to that of fungicide in the field experiment under natural infection background (Flora cultivar)

Variants	Disease severity [%]		Action effectiveness [%]		Productivity	
	in the initial period of the disease development (BBCH 51-53)	at the end of the growing season (BBCH 85-87)	in the initial period of the disease development	in the midst of the entire growing season	[t/ha]	% to control
Control	7.2 ^a	31.3 ^a	–	–	45.7 ^a	–
Ecophosphoryn	0.8 ^b	18.5 ^b	88.9	68.4	52.5 ^a	114.9
Dimetomorph, 90 g/kg + mancozeb, 600 g/kg (Acrobat MC WDG)	0.6 ^b	14.9 ^b	91.7	74.8	53.0 ^a	116.0

Note: Figures with the same letters in each column have no significant difference at the 0.05 level of probability (*LSD* test), *LSD* – least significant difference; BBCH (Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie) is a universal scale for describing phenological stages of plants.

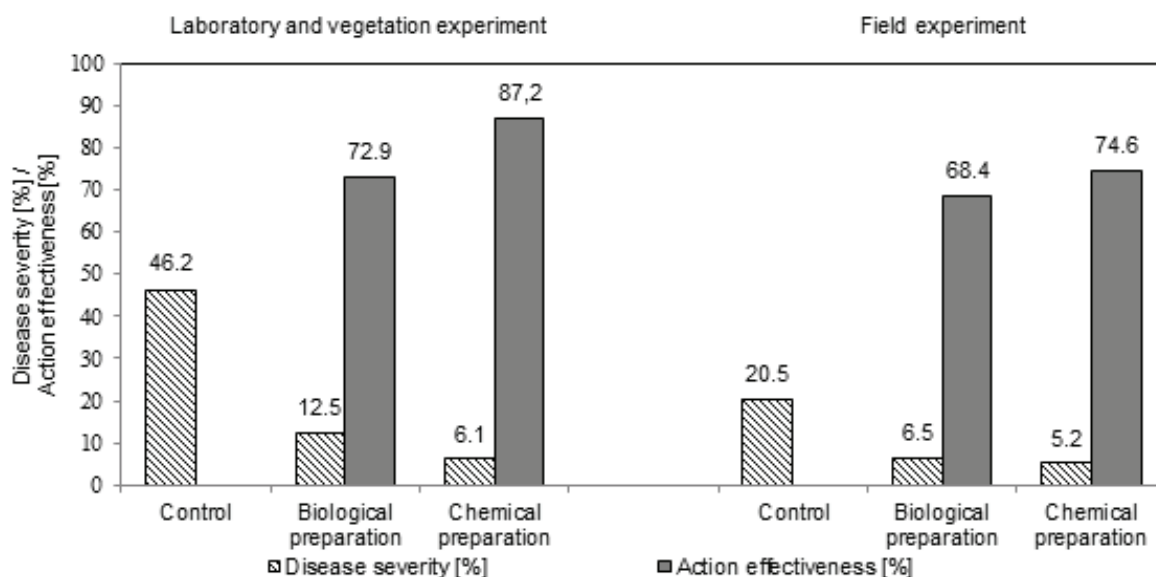


Figure 1. The efficiency of the protection of the bioformulation Ecophosphoryn and chemical fungicides against alternaria of tomatoes on artificial and natural infection backgrounds (average data for the growing season).

g/kg+mancozeb, 600 g/kg (Acrobat MC) fungicides in doses recommended by manufacturers – 87.2% and 74.6%, respectively (Figure 1). That is, the effectiveness of the complex biological preparation Ecophosphoryn under different experimental conditions was close to the effectiveness of chemical fungicides.

The high protective effect of Ecophosphoryn was obtained in experiments on the cultivation of white cabbage, both in the laboratory and vegetative experiments under artificial infection with the pathogen of fusarium wilt and in the field under natural infection against alternaria.

The treatment of cabbage seeds with Ecophosphoryn in the laboratory and vegetative experiment helped to reduce the degree of disease development in the phase of 1–2 true leaves 6.0 times, in the phase of 4–5 true leaves – 4.5 times (Table 3).

The protective effect of Ecophosphoryn in different phases of cabbage ontogenesis was 83.2% and 77.9% and was similar to the level of effectiveness of the chemical preparation fluopyram, 200 g/L+tebuconazole, 200 g/L (Luna Experience 400 SC).

In the field, the late cultivar of cabbage Yana was affected by *Alternaria brassicae* (Berk.) Sacc. The use of Ecophosphoryn by spraying vegetative plants increased their resistance to the disease, as a result of which the development of the disease decreased during the growing season 2 times on average. In the phase of head formation, the effectiveness of Ecophosphoryn was 44.5%, and the fungicide azoxystrobin, 250 g/L (Quadris 250 SC) – 49.5% (Table 4).

Ecophosphoryn application contributed to an increase in the yield of white cabbage by 12% and fungicide – by 13% compared to the control. Thus, the efficacy of Ecophosphoryn against alternaria did not statistically differ from the effect of the chemical fungicide azoxystrobin, 250 g/L (Quadris 250 SC).

Pre-sowing treatment of corn seeds of TK-202 cultivar with Ecophosphoryn showed an increase in plant resistance to blister smut (pathogen – *Ustilago zae* (Beckm.) Unger). The disease appeared at an early stage of grain formation (BBCH 71-75). The spread of the disease decreased 1.5 times, while the protective effect was 33.3%. The efficacy of Ecophosphoryn under these conditions exceeded the influence of the chemical fungicide fludioxonil, 25 g/L+metalaxyl-M, 10 g/L (Maxim XL 035 FS) by almost 2 times (Table 5).

The yield of corn when using Ecophosphoryn was 10 t/ha compared to 7.9 t/ha in the control, which is 26.6% higher and was like the yield under application of the fungicide fludioxonil, 25 g/L+metalaxyl-M, 10 g/L (Maxim XL 035 FS).

DISCUSSION

Disease control with the use of beneficial micro-organisms is an alternative method of plant protection compared to chemical ones and is becoming increasingly widespread in the world. The implementation of environmentally friendly plant protection systems in agricultural production allows reduction

T a b l e 3

The protective action of Ecophosphoryn against fusarium wilt of white cabbage compared to fungicide effect (laboratory and vegetative experiment, Ukrayins'ka osin' cultivar)

Variants	Disease severity [%]		Action effectiveness [%]	
	Phase of 1–2 true leaves (BBCH 11-12)	Phase of 4–5 true leaves (BBCH 14-15)	Phase of 1–2 true leaves	Phase of 4–5 true leaves
Control	16.7 ^a	41.7 ^a	–	–
Ecophosphoryn	2.8 ^b	9.2 ^b	83.2	77.9
Fluopyram, 200 g/L+tebuconazole, 200 g/L (Luna Experience 400 SC)	1.7 ^b	8.3 ^b	89.8	80.0

Note: Figures with the same letters in each column have no significant difference at the 0.05 level of probability (*LSD* test), *LSD* – least significant difference; BBCH (Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie) is a universal scale for describing phenological stages of plants.

T a b l e 4

Efficacy of Ecophosphoryn against white cabbage alternaria compared to fungicide effect (field experiment, Yana cultivar)

Variants	Disease severity [%]		Action effectiveness [%]		Productivity	
	phase of formation of the first true leaves (BBCH 11-12)	head forming phase (BBCH 41-42)	phase of formation of the first true leaves	head forming phase	[t/ha]	% to control
Control	12.4 ^a	40.0 ^a	–	–	40.0 ^a	–
Ecophosphoryn	5.8 ^b	22.2 ^b	53.2	44.5	44.8 ^b	112.0
Azoxystrobin, 250 g/L (Quadris 250 SC)	4.6 ^b	20.2 ^b	62.9	49.5	45.2 ^b	113.0

Note: Figures with the same letters in each column have no significant difference at the 0.05 level of probability (*LSD* test), *LSD* – least significant difference; BBCH (Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie) is a universal scale for describing phenological stages of plants.

T a b l e 5

The protective action of Ecophosphoryn against corn blister mold compared to fungicide effect (field experiment, TK-202 cultivar)

Variants	Disease spread [%]	Action effectiveness [%]	Productivity	
			[t/ha]	% to control
Control	30.0 ^a	–	7.9 ^a	–
Ecophosphoryn	20.0 ^b	33.3	10.0 ^b	126.6
Fludioxonil, 25 g/L + metalaxyl-M, 10 g/L (Maxim XL 035 FS)	25.0 ^b	16.7	10.2 ^b	129.1

Note: Figures with the same letters in each column have no significant difference at the 0.05 level of probability (*LSD* test), *LSD* – least significant difference.

or minimize the use of chemicals in cultivation technologies, reduces the negative impact of pesticides on the environment and improves the quality of crop production (He *et al.* 2021; Pandit *et al.* 2022).

After biological preparations application, a decrease in the infectious background due to changes in the composition of the phytosphere microbiota is observed. This effect can further reduce the number of plant protection chemicals applications (He *et al.* 2021). O'Brien (2017) emphasizes that the degree of disease suppression achieved by biological agents is comparable to that of chemicals.

The most effective in this context is the use in agricultural practice of multifunctional combined biological preparations. They have a wide spectrum of action and are composed of microorganisms with

different properties (Aipova *et al.* 2020). According to Kumar *et al.* (2017), the use of PGPB bacteria is one of the environmentally friendly, safe and effective alternatives for controlling the plant diseases, in particular, tomatoes. The high potential of combined microbial preparations and their advantages over monoinoculants against *Phytophthora parasitica* were established by Manasfi *et al.* (2018). The effectiveness of biological preparations must be proven not only in the laboratory but also in the field conditions. Köhl *et al.* (2019) state that the potential of microorganisms *in vitro* does not always correlate with their antagonism *in situ*.

The development of biotechnologies gave impetus to the intensive development of organic agriculture and the production of safe food products.

Since the middle of the 20th century, and especially over the past 20 years, in economically developed countries the researchers' attention has been focused on organic agriculture and the production of environmentally friendly and nutritious food. Organic agriculture is based on the reduction or complete prohibition of the treatment of plants and soil with synthetic mineral fertilisers, chemical pesticides, plant growth regulators, and genetically modified organisms. Organic farming aims to maximise the use of biological preparations and biotechnologies at all stages of agricultural production (Aipova *et al.* 2020).

Our studies with the complex bacterial preparation Ecophosphoryn based on the association of microorganisms with an extended range of ecological and trophic functions have made it possible to establish its effectiveness in increasing the resistance of cultivated plants to diseases and their productivity, which opens the possibility for complete or partial rejection of chemical plant protection products against diseases.

The results obtained both on artificial and natural infectious backgrounds against the most common pathogens of various crops (white cabbage, tomatoes, corn) showed the high efficiency of the phytoprotective effect of Ecophosphoryn. The protective effect of bioformulation against alternaria of tomatoes averaged 76%. Against fusarium wilt of white cabbage on an artificial infectious background, the effectiveness of Ecophosphoryn was at the level of 78–83%, and against alternaria head blight in the field on a natural infectious background – at the level of 45–53%. When corn seeds were sprayed with this bioformulation, the damage to plants by powdery mildew during the growing season decreased by 33%. At the same time, the protective effect of the biological preparation and crop yields in most cases were not less than those of chemicals. In our opinion, the bioagents of Ecophosphoryn can restore and activate in plants the mechanisms of self-regulation to prevent the aggravation of pathological processes. Microbial biocontrol agents affect both the pathogen directly and plant metabolism, contributing to the formation of protective reactions against pathogens through the salicylate or jasmonate pathway, stimulating the production of phytohormonal compounds,

improving growth and its mineral nutrition (Köhl *et al.* 2019; Legein *et al.* 2020; Elnahal *et al.* 2022).

The microbiome of plants greatly enhances their ability to adapt to a changing environment. The use of beneficial interactions between plants and microorganisms is an opportunity to optimize crop yields. Further understanding of the system of interactions between plants and soil microorganisms is a promising way to develop agriculture by utilizing the various benefits offered by the plant microbiome (Liu 2019). The use of microbial preparations to improve the effective adaptation and survival of crops, can contribute to stable yields and restore soil fertility (Karnwal 2019).

Thus, stable biocontrol and increased productivity of agricultural crops can be achieved by creating effective innovative bioformulations and biotechnologies for their application.

The advantages of bio-controlling microorganisms over chemical plant protection products are that there is no contamination of the environment and plant products with pesticides, and phytopathogens have a much harder time developing “addiction” to the appropriate bioagent or do not develop it at all.

CONCLUSIONS

The studies conducted with white cabbage, tomatoes, and corn showed that the use of the complex biological preparation Ecophosphoryn helped to reduce the incidence of the most common fungal diseases and increased yields. In most cases, the protective effect of the biological preparation and crop yields were not less effective than those of chemicals. In all field experiments, the use of Ecophosphoryn increased the yield of healthy products compared to the control. The development and production of complex polyfunctional biological preparations with phyto-stimulating and protective properties is a promising area in the creation of regenerative biotechnologies for crop production. This opens up the possibility of wider implementation of environmentally friendly methods in the practice of growing and protecting agricultural crops.

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