



ECOLOGICAL PROTECTION OF PLANTS USING BIOLOGICAL PRODUCTS FROM THE BASIDIOMYCETE FUNGUS FOMES FOMENTARIUS

KORNIYENKO VALENTINA^{1*}

National University of Life and Environmental Sciences of Ukraine, 03041, Kyiv, Herouiv Oborony Street, house 15

SENIUK OLGA²

LLC «Mikoton-Original», 08003, Kyiv region, Buchansky district, village of Gavronshchyna, lane Polyovy, house 3-A

GOROVIJ LEONTIJ³

"Mikoton Aglicon" LLC, Ukraine

***Corresponding Author: KORNIYENKO VALENTINA**

ABSTRACT

The constant use of pesticides and mineral fertilizers, which destroy biological diversity in the soil, reduce the humus content and lead to a decrease in the yield of plants (corn, soybeans, rice, wheat) with the most valuable consumer properties and high susceptibility to diseases.

The effectiveness of the best resistance-inducing drugs reaches only 60-80% of the effectiveness of biocidal drugs. But they are not toxic, do not have a detrimental effect on the ecological system, are safe for humans (they do not have residual amounts of toxic chemicals in the product), increase immunity to pathogens, and increase resistance to drought, cold, temperature changes, and pests.

*Only the successful provision of the world's population with a quality product depends on the development of organic farming, which involves the use of only natural means to combat plant pests. Therefore, the main focus of our work was on testing a plant resistance inducer of an aqueous extract of the glucan-melanin complex (GMC) of the cell wall of the basidiomycete fungus *Fomes fomentarius* called mikosan, which exhibits powerful antioxidant, antibacterial, fungicidal, and antiviral activities. It is GMC that induces plant resistance to diseases by enhancing the synthesis of enzymes to resist infection and switching some metabolic reactions from the biosynthesis of constitutive metabolic compounds to the synthesis of phytoalexins and other antipathogenic substances.*

Mikosan underwent a full program of laboratory, small-scale, field industrial tests on many agricultural crops in different climatic zones of Ukraine, as well as toxicological studies, starting in 1998. It belongs to the fourth, lowest category of toxicity registered in Ukraine at the beginning of 2002.

Keywords: *Plant protection, Plant resistance, Resistance inducer, Biological products, Glucans, Melanins*

DOI:-10.5281/zenodo.17301016

Manu script # 348

INTRODUCTION

The constant use of pesticides and mineral fertilizers destroys biological diversity in the soil, reduces humus content, leads to annual losses of 10–15 million hectares of agricultural land, and the yield of corn, soybeans, rice, and wheat has already decreased [1]. Phytopathology - the science of plant disease-causing agents (phytopathogens) has accumulated high achievements in mycology, microbiology, virology, genetics, molecular biology, physiology, and other disciplines. But today, even in highly developed countries, the biocidal method prevails by 90-95%. It kills or greatly weakens the plant pathogen, and the yield efficiency cannot be considered satisfactory.

In artificial agrocenoses, pathopathogenic organisms receive ample opportunities for more intensive development [2] and reports of new pests are becoming more frequent [3]. According to the forecast [4, 5], the vast majority of the world's most powerful crop-producing countries will be oversaturated with pathogens and pests by the middle of the 21st century. There is hope that preventive measures (strategy of integrated plant protection and biosecurity measures) can slow down or stop the process of global expansion of pests and pathogens, especially in developing countries [6].

The successful provision of the world's population with quality food depends on the development of organic farming. It does not aim to return to the level of productivity of a century ago and involves the rejection of:

- 1) chemical plant protection products against pests and diseases,
- 2) herbicides, mineral fertilizers and other chemicals that are toxic or have a long decomposition period in the environment,
- 3) GMOs, synthetic growth stimulants, inoculants.

The created biological products are prophylactic agents, they are used before sowing or at the initial stages of disease development. The source of their creation is special strains of bacteria, microscopic fungi or viruses, a variety of secondary metabolites of microorganisms, as well as fungi or plants [7].

A large and diverse group of higher basidiomycetes has practically disappeared from the field of view of researchers, although the bactericidal and fungicidal properties of many representatives of these fungi have long been well known [8, 9].

The authors worked on enhancing the ability of plants to resist pathogens through systemic acquired resistance. It is realized by glucans and melanins from the basidial fungus *Fomes fomentarius*. And these compounds that reliably protect plants from infections.

INDUCED DISEASE RESISTANCE OF PLANTS

The plant cell wall, wax coating of the cuticle, hairs, a developed system of receptors form structural elements. After overcoming them, the pathogenic microorganism is resisted by intracellular systems of perception of danger signals and molecular mechanisms of resistance [10 -13]. This cell wall can change dynamically in the process of interaction with the pathogen, depending on the type of pathogen, a bacterium, virus, fungus, oomycete, or nematode, as well as depending on the behavior of parasites (necrotrophs or biotrophs) [14, 15]. It is known that a biotrophic fungal pathogen keeps the host alive and suppresses signaling pathways leading to tissue necrosis. Necrotrophic fungal pathogens secrete toxins and activate signaling pathways to cause tissue necrosis [16, 17].

Substances that induce protective reactions in plants are called elicitors. They appear in pathosystems from the first stages of interaction between the pathogen and the plant as a result of mutual enzymatic influence. Damage to tissues causes depolarization of cell membranes, movement of calcium and hydrogen ions into the cytosol, formation of reactive oxygen species, phosphorylation of receptor proteins. ATP and mini-RNA molecules can also act as danger signals [18, 19]. Elicitors, as signal molecules of the first contact of a plant with a pathogenic microorganism, warn the plant about an attack and activate phenolic metabolism [13, 20]. They stimulate the synthesis of phytoalexins; increase the sensitivity of plants to external influences and increase the sensitivity of phytopathogens and parasites to plant protection agents. All the listed elicitors are able to interact with receptor transmembrane proteins PRRs (pattern recognition receptors). The signal about external danger is transmitted through it along molecular chains inside the cell and causes the development of an immune response in plants [21 - 24]. And the elicitor ability is inherent in the molecules of many oligo- and polysaccharides - β glucans, oligomers of chitin and chitosan, oligogalacturonides, alginates, fucans, carrageenans, ulvans, etc. [25]. β -glucans are the most numerous and diverse group of polysaccharides. β -1,4 glucans are cellulose and its oligomers. β -1,3; β -1,6 and α -1,3 glucans are the main components of the cell wall of fungi and algae. Their oligomers with a degree of polymerization up to 30 exhibit elicitor properties and can participate in signal

transmission chains from receptor proteins. Molecules of oligomers of β -glucans and chitin show the ability to induce the expression of protective genes and increase resistance in most studied plants [26] and are considered one of the strongest elicitors [12, 27 - 30].

Activation of the oxidative burst (peroxidase and NADPH oxidase) is an important block in the further development of the defense response. The rapid formation of reactive oxygen species is a weapon of direct plant action against the pathogen, as well as in the induction at the gene level of special resistance proteins.

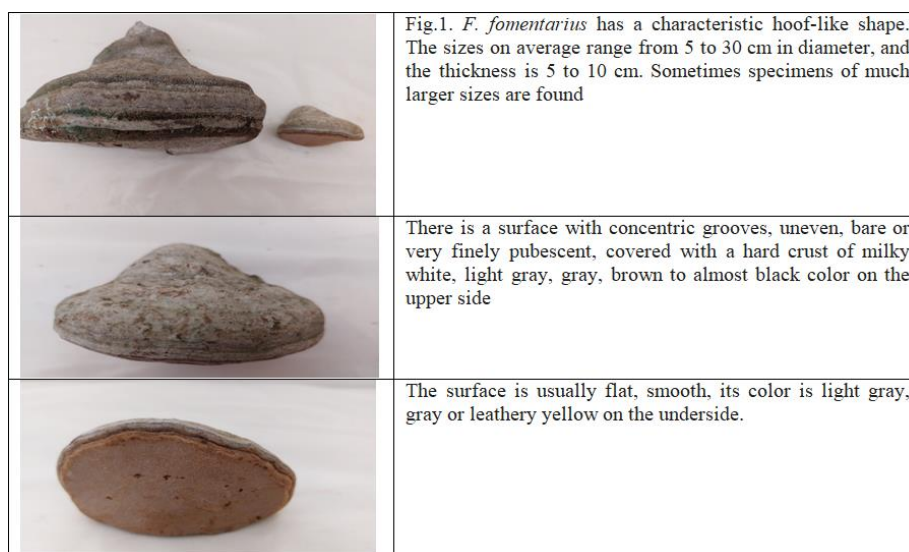
Today, melanins play the most powerful role in controlling the balance between oxidation and antioxidant protection [31]. Glucans have a plant immunization function and a direct protective effect due to the formation of a selective film on the surface of plant tissues [10].

The effectiveness of the best resistance-inducing drugs reaches only 60-80% of the effectiveness of biocidal drugs. An important advantage of inducers over chemopreparations is the absence of toxicity and harmful effects on the ecological system. They are safe for humans, increase the immunity of plants not only to pathogens, but also increase endurance to drought, cold, temperature changes, to animal pests [32].

FOMES FOMENTARIUS AS A POTENTIAL OF INDUCERS DRUGS

Fomes fomentarius (L.:Fr.) Fr. (Basidiomycota, Polyporales) (*F. fomentarius*) (Fig. 1) satisfies to the greatest extent all technical and economic criteria and contains a chitin-glucan-melanin complex, in which 70% is chitin, 20% is beta-glucans (β -1,3 and β -1,6-glucans) and 10% are occupied by melanin pigments.

This fungus is widespread in the Northern Hemisphere and is found mainly as a saprotroph on dead or dying hardwood: birch, poplar, beech, aspen, ash, linden, oak, willow, etc. Causes white rot of wood. The fruit bodies of this mushroom are perennial and can be collected throughout the year.



The characteristic features of this mushroom are the presence of a tinder-like fibrous mass in the middle and attachment to the wood only in a small area of the central part of the hat by the core. Fruiting bodies are relatively easy to break off from tree trunks due to the soft consistency of the core. In this way, *F.fomentarius* is quite different from its outwardly similar mushrooms - false tinder (*Phellinus igniarius*) and flat tinder (*Ganoderma applanatum*). This mushroom has been known in folk medicine since prehistoric times. The culture filtrate after growing the mushroom showed high activity against the tobacco mosaic virus [33]. Aqueous extracts from fruit bodies have strong antibacterial, fungicidal and antiviral properties [34]. And alcoholic extracts showed powerful bactericidal properties against a number of pathogenic bacteria [35].

Our work on creating a plant resistance inducer was based on understanding the importance of using β -glucans and cell wall melanins of *F. fomentarius* [36]:

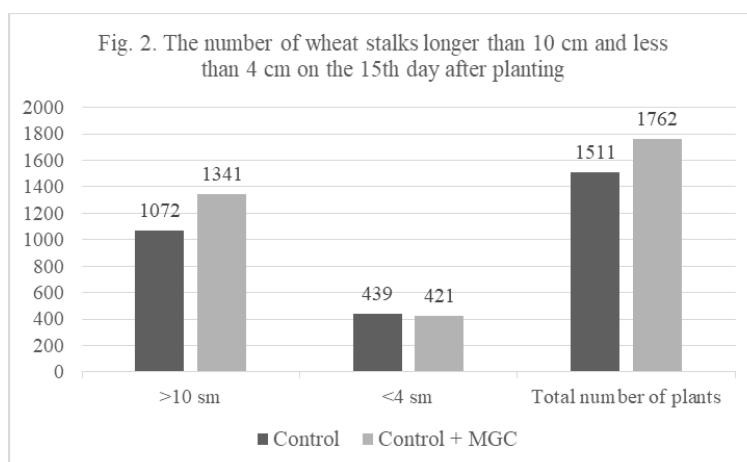
- 1) glucans make up the outer layers of the cell wall of fungi, and they are the first to come into contact with the cell wall of the host plant;
- 2) melanins to increase the resistance of plants actively regenerate oxygen, increase the oxidative explosion in the cell and affect the internal environment of plants in an unfavorable direction for the pathogen, and also have a fungicidal effect and strengthen the cell wall [37, 38].

The elicitor properties of glucans have been known for a long time [13, 27]. They are able to include resistance genes and lead to increased synthesis of glucanases and other phytoalexins. Our research was directed to the search for biologically active glucans and other biologically active compounds in higher basidial fungi, which has been studied to the smallest extent [10, 11].

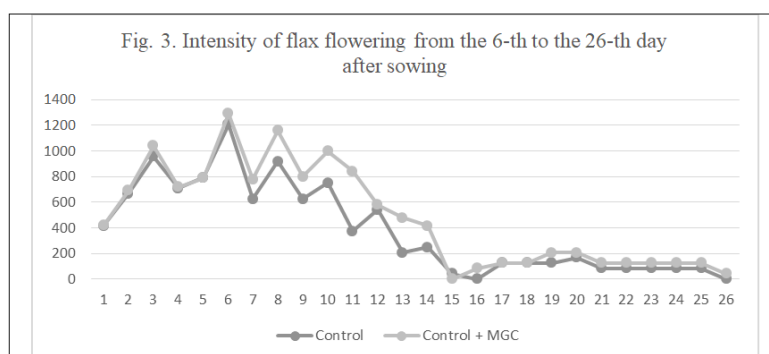
Melanins are a separate class of biological polymers that are common among all types of organisms, except for viruses. Melanin is a pigment that gives color to human skin, hair and eyes. Important consequences that determine the properties of melanins and the increased interest in these materials by physicists and material scientists:

- 1) melanins - polylinked polymers related to organic metals and semiconductors; they are able to demonstrate electrical conductivity at the level of metals under certain conditions;
- 2) melanins are excellent matrices for stabilizing unpaired electrons (radicals); the concentration of radicals in melanins under physiological conditions can reach colossal values — about 10^{18} – 10^{19} units per gram of substance, these values are impossible for any other biological materials; this, on the one hand, relates melanins to artificial organic magnetic materials, and on the other hand, makes them important natural antioxidants;
- 3) melanins effectively absorb dangerous short-wave photons that can irreversibly damage complex biological molecules and convert them into relatively safe thermal radiation.

In our experiments, the ability of the water-soluble melanin-glucan complex from *F.fomentarius* (MGC) to reduce the time of plant emergence and increase the number of plants that emerge after treating grain with it for 5 to 10 minutes was shown (Fig. 2). Under these conditions, the number of sprouted wheat plants increased by 16%.



The study of the rate of flowering of flax flowers under the influence of MGC testified to an increase in the number of plants that bloomed after the treatment of MGC seeds (Fig. 3).



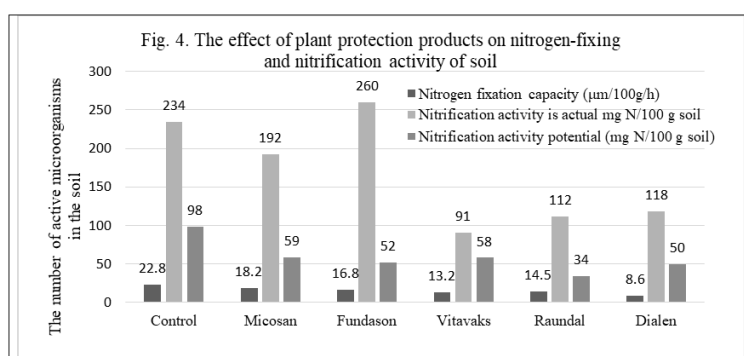
Similar convincing data have been obtained on the beneficial effects of bacterial melanin on the Manet cucumber crop. The length of the stem and the length of the rhizome, the fruitiness of the plant, the growth and development of the aerial part of the plant increased, the formation of generative organs accelerated, and the yield of the treated plants increased [39]. Melanin can exhibit both antioxidant and pro-oxidant effects depending on the nature of the initiating factors and its concentration in the reaction medium [40].

These and other studied parameters strongly indicate that the soluble components of the cell wall - low molecular weight glucans and melanins - have a direct antibacterial, antiviral and fungicidal effect. They retain their properties both in in vitro and in vivo systems [41]. To protect plants from pathogenic microflora, the inducer of plant resistance biofungicide mikosan was created. It is a complex of 1,6-beta-glucan and oligomers of 1,3-beta-glucan, oligochitin, melanin, oligochitosan and it exists in two modifications: mikosan-N for pre-sowing seed treatment and mikosan-B for plant treatment during the growing season. Both modifications of mikosan carry out biological protection against fungal, bacterial and viral diseases, suppressing pathogens of root and stem rots, gray and white rots, powdery mildew; phytophthora, macrosporosis, snow mold, clusterosporosis, helminthosporosis, alternariosis, cercosporosis, spotting, rhizoctoniosis, scab, oidium, mildew, ascochitosis, anthracnose, septorosis, etc. The use of mikosan increases the germination and energy of seed germination. This unique biological agent stimulates the growth and development of the plant, increases resistance to extreme weather conditions, improves the phytosanitary condition of the soil and the activity of soil microorganisms. mikosan-N is used for watering shrubs, trees, and seedlings. The advantages of mikosan-B are that it works throughout the growing season, is effectively used during the fruiting period, strengthens plant immunity and stimulates their growth, improves mineral and water nutrition of plants. It is intended for the cultivation of gardens, berry orchards, vineyards, vegetable gardens, vegetable, grain and ornamental low-growing crops, fruit and berry and ornamental crops, as well as for the protection of indoor plants from pathogens of various kinds of diseases. These biological preparations belong to the fourth, the lowest category of toxicity, are environmentally safe, do not require special protective equipment and do not disturb the microbiological cenoses of the soil [42].

The ability to manage microbiological processes not only in plants, but also in the soil where they develop is of great importance to increase productivity and improve the quality of agricultural products. Nitrogen (nitrogen) is part of many natural organic compounds vital for plants: protein substances, lipoids, chlorophyll, alkaloids, phosphatides, nucleoproteins, various enzymes. Increasing the level of nitrogen nutrition increases the assimilation of other elements by plants: P, K, Ca, Mg, S, Cu, Fe, Mn, Zn and stimulates their growth, the formation of strong stems and bright green leaves, and improves their productivity. On soils poor in available nitrogen, plants develop poorly.

An important link in the nitrogen cycle is the ability of some bacteria to fix it from the atmosphere, thanks to the enzyme nitrogenase. With its help, they are able to fix molecular nitrogen and transform it into compounds that can be assimilated by other organisms - plants, animals, etc. Therefore, the nitrogenase activity of the soil can be considered as an indicator of the state of the soil, which depends on the nitrogen-fixing microflora and clearly responds to the use of pesticides. The mass of grain from soybean plants was higher by 1.7 g, the weight of 1000 grains by 10.2 g, the yield was higher by 3.6 c/ha in the areas where mikosan was applied. A symbiotic system with high nitrogen fixation activity is formed in this way. Given these circumstances, we investigated the effect of toxic doses of pesticides, namely fundazol, vitavax 200 FF (hereinafter vitavax), roundup and dialen, as well as the possible effect of the biofungicide mikosanTM on the nitrogen-fixing and nitrogenase activity of the soil.

It was established that the nitrogenase activity of the microbial community of the soil under the influence of the studied pesticides decreased compared to the control variant. The greatest decrease in the activity of the nitrogenase complex (by 62%) was observed with the use of dialne. The nitrogen-fixing capacity of the microbial group under the influence of vitavax and roundup was 36% and 42% lower, respectively, compared to the control. It practically did not differ from this indicator under the action of fundazol (20% decrease). The effect of the biofungicide Mikosan was insignificant, the nitrogenase activity of which was 18.0-18.2 μM in 100 g of soil per hour, which is 20-21% lower than the control.



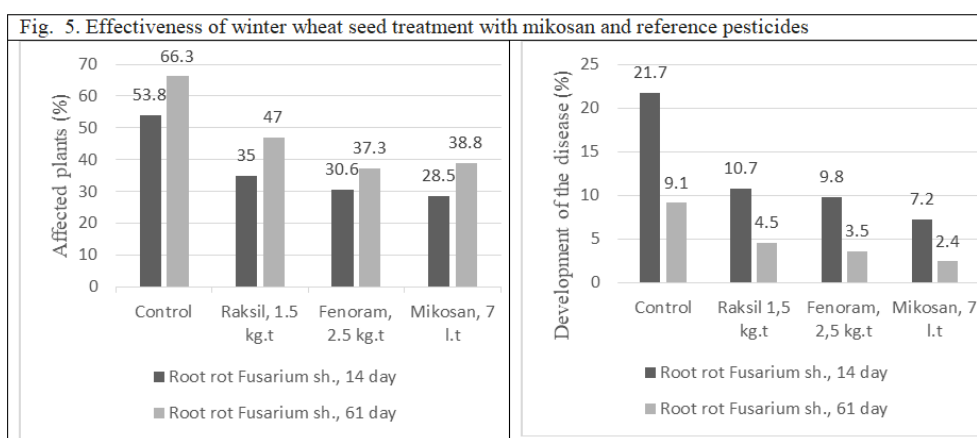
Note. The content of nitrates in sterile soil before the experiment was 21.0 $\mu\text{g}/100\text{g}$ of soil

Studies have shown that the action of the chemical fungicide Vitavax was the most harmful: actual nitrification activity was reduced by 2.6 times, compared to the control. actual nitrification activity decreased by 2 times as a result of treatment of microbial coenosis with roundup and dialen. Treatment of the microbial community with the Roundup herbicide caused a 3-fold decrease in the potential activity of nitrification, and with other pesticides, it decreased by a factor of 2 (Fig. 4). Thus, the changes occurring in the microbial community of the soil under the influence of the studied pesticides negatively affected the activity of binding atmospheric nitrogen.

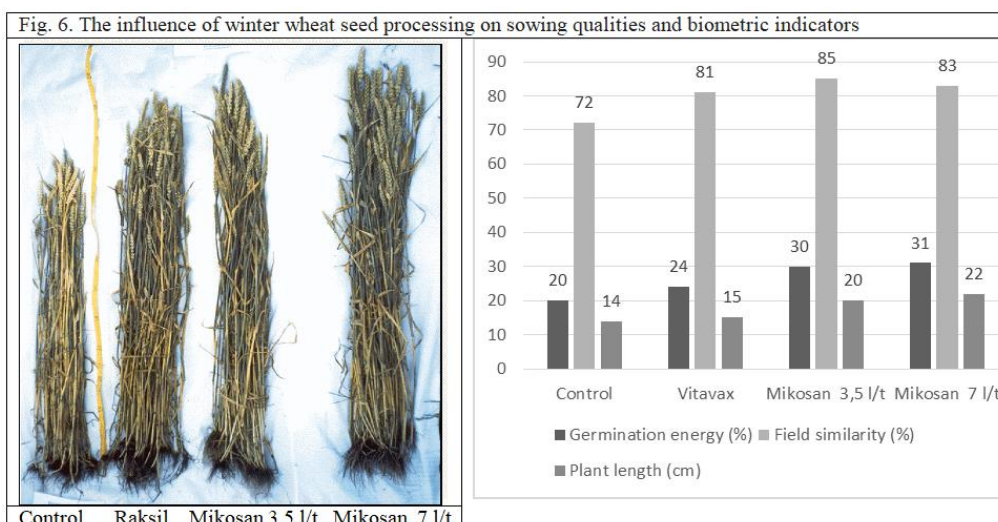
An indicator of the after-effect of pesticides on the ecologically important functions of soil microbial groups is the intensity of their decomposition of cellulose, which enters the soil as part of detritus. The conducted studies showed that the intensity of cellulose decomposition by soil microorganisms under the influence of mikosan changed insignificantly. At the same time, the cellulolytic capacity of microbial communities treated with vitavax, roundup, dialen, as well as the systemic fungicide fundazol decreased by 2,5-3,4 times.

The use of pesticides leads to suppression of the biological activity of soils and prevents the natural recovery of fertility, causes a loss of nutritional value and taste qualities of agricultural products, reduces the yield of many crops due to the death of pollinating insects. As a rule, a person spends a much larger amount of pesticides than is necessary to destroy the pest due to a mistaken understanding of the reliability of soil treatment. Therefore, pesticide residues accumulate and bioconcentrate in trophic chains; residual quantities of pesticides are removed to the borders of the cultivated area; pesticide-resistant forms of harmful organisms appear; some useful organisms die and there are deep violations of relationships in biocenoses; the probability of remote consequences associated with the pathological and genetic effect of a number of drugs on the biota increases.

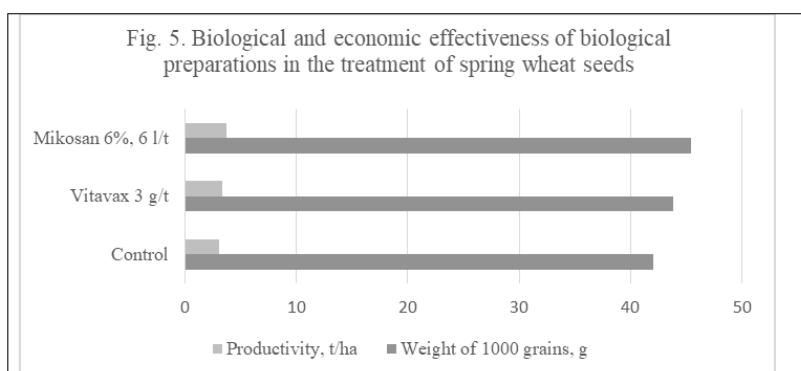
Wheat is the main food product in 43 countries of the world and occupies one of the first places among the grain group of crops in terms of sown areas and gross harvests of high-quality grain in world agriculture. The potential opportunities for increasing the yield of winter and spring wheat are limited by soil and climatic conditions, favorable for the development of pathogens, of which more than 50 species have been described [43]. Therefore, the largest studies on the use of mikosan for seed treatment were conducted on wheat. Seeds were treated when seedlings appeared on day 14 and after the start of spring regrowth (day 61) (Fig.5).



During the growing season of winter wheat, the biofungicide mikosan did not show any phytotoxic effect, at the same time the phytosanitary conditions of the plants improved and the proportion of diseased plants was the smallest - from 7.2% to 2.4% (Fig. 5). The number of plants affected by root rot, under the influence of pesticides, on the 14th day after sowing was about a third (30.6 - 35.0%) compared to the control and did not decrease on the 61st day of development (was 37.3% and up to 47%), and the development of the disease in comparison with control values decreased to 10.7-9.8% (14 days) and to 4.5-3.5% (61 days) on pesticides and to 7.2% and 2.4% on mikosan in the same terms. Treatment of spring wheat seeds with the biopreparation mikosan had a positive effect on plant productivity. Compared to the control, the length of the plants increased by 10-11 cm, the root by 0.5 cm, and the spike length by 0.8 cm. The number of grains in the ear was greater than in the control by an average of 7.7 pieces (Fig. 6). The mass of grains increased by 3.4% when treated with mikosan



and by 1.6% when treated with vitavax. At the same time, the productivity of spring wheat increased by 22.2% and 8.4%, respectively, under the conditions of application of mikosan and vitavax (Fig.7).



Plant protection through induced immunity requires them to constantly maintain a high level of resistance [46]. Productivity decreases in plants when resistance to the pathogen is induced and biometric indicators deteriorate due to high costs of protection against it [47]. However, in our experiments with mikosan on many types of plants, there was no decrease in productivity. Positive results of comparative tests of the biological product mikosan and reference pesticides were obtained on seeds of various plants: cereal and cereal crops (winter and spring wheat, rye, barley, corn, oats, buckwheat, millet); legumes (peas, soybeans, lupine, vetch); technical (sugar beets, sunflower, tobacco, hops); vegetables (tomato, cucumber, lettuce, onion, garlic, parsley, dill, carrot, pepper, celery, sorrel and spinach); potatoes; fruit seeds (apple, pear, quince); stone fruit (cherry, cherry, apricot, peach); berries (currants, raspberries, gooseberries, strawberries); grapes; decorative (roses, carnations, phloxes, tulips, dahlias, chamomile, lily, etc.); medicinal and lawn herbs. Plants in general were better than in the control and when using reference biocidal preparations. Therefore, ideas about large additional costs for protection are not well-founded.

Conclusions

The drugs, obtained from the basidiomycete fungus *Fomes fomentarius*, are actually the first group of drugs that satisfies all three main criteria for plant protection: effectiveness, cost-effectiveness, environmental safety, and harmlessness to humans. In terms of effectiveness, mikosan is not inferior to modern biocidal preparations of the world's leading companies, and in some indicators it even exceeds them. Mikosan is not expensive to produce and is offered at lower prices than other modern chemical preparations. Extensive tests of the biological preparation mikosan showed that it is non-toxic and safe in all respects, has a protective effect on almost all cultivated plants.

References

- Iizumi T., Yokozawa M., Sakurai G., Travasso M. I., Romanenkov V., Oettli P., Newby T., Ishigooka Y., Furuya J. Historical changes in global yields: major cereal and legume crops from 1982 to 2006. *Global Ecology and Biogeography*, (Global Ecol. Biogeogr.) (2014) 23, 346–357.

2. Stukenbrock EH¹, McDonald BA. The origins of plant pathogens in agro-ecosystems. *Annu Rev Phytopathol.* 2008;46:75-100. DOI: 10.1146/annurev.phyto.010708.154114.
3. Huang, D., Haack, R.A. & Zhang, R. (2011) Does global warming increase establishment rates of invasive alien species? A centurial time series analysis. *PLoS ONE*, **6**, e2473].
4. Fisher, M.C., Henk, D.A., Briggs, C.J., Brownstein, J.S., Madoff, L.C., McCraw, S.L. & Gurr, S.J. (2012) Emerging fungal threats to animal, plant and ecosystem health. *Nature*, 484, 186–194. 5.Bebber D.P., Ramotowski M.A.T. & Gurr S.J. (2013) Crop pests and pathogens move polewards in a warming world. *Nature Climate Change*, **3**, 985–988. DOI:10.1038/nclimate1990.
6. Bebbler D.P., Holmes T., Gurr S.J. The global spread of crop pests and pathogens. *Global Ecology and Biogeography*. Vol. 23, Issue 12, p. 1398–1407, Dec. 2014 DOI: 10.1111/geb.12214.
7. Reignault P., Walters D. Topical application of inducers for disease control. In: *Induced resistance for plant defence: a sustainable approach to crop protection*. Eds: Walters D., Newton A., Lyon G. D. Blackwell Publishing Ltd., Oxford, UK. 2007, pp. 179-200. ISBN: 978-1-4051-3447-
8. Anke T., Oberwinkler F. (1977). The strobilurins new antifungal antibiotics from the basidiomycete *Strobilurus tenacellus*. *J. Antibiot.* 30, 806-810. Robles-Hermandes L., Cecikia-Gjyzales-Franco A., Soto-Parra J. M., Montes-Dominguez F. Review of agricultural and medicinal applications of basidiomycete mushrooms. *Technociencia*, Vol. II, No. 2. 2008 95-107;
9. Lorenzen, K. & Anke, T. (1998). Basidiomycetes as a sources for new bioactive natural products. *Current Organic Chemistry*, 2, pp. 329-364.
10. Gorovoy, L.F. Induced resistance and development of new generation preparations for plant protection // *Quarantine and plant protection*. -2004. № 11. pp. 8-11 (ukr);
11. Gorovyi L.F., Koshevsky I.I., Teslyuk V.V., Redko V.V. Method of increasing plant resistance to diseases. Patent of Ukraine for a utility model № 29953. 11.02.2008 (ukr);
12. Lyon G. Agents that can elicit induced resistance. In: *Induced resistance for plant defence: a sustainable approach to crop protection*. Eds: Walters D., Newton A., Lyon G. D. Blackwell Publishing Ltd., Oxford, UK. 2007, pp. 9-30. ISBN: 978-1-4051-3447-7;
13. Mishra A. K., Sharma K., Misra R. S. Elicitor recognition, signal transduction and induced resistance in plants. *Journal of Plant Interactions*. Volume 7, Issue 2, 2012 pages 95-120. DOI: 10.1080/17429145.2011.597517.
14. Garcion C., Lamotte O., Métraux J.-P. Mechanisms of defence to pathogens: biochemistry and physiology. In: *Induced resistance for plant defence: a sustainable approach to crop protection*. Eds: Walters D., Newton A., Lyon G. D. Blackwell Publishing Ltd., Oxford, UK. 2007, pp. 109-132. ISBN: 978-1-4051-3447-7.
15. Bellincampi D., Cervone F., Vincenzo L.. Plant cell wall dynamics and wall-related susceptibility in plant–pathogen interactions. *Front Plant Sci.* 2014; 5: 228. Published online 2014 May 28. DOI: 10.3389/fpls.2014.00228.
16. Vleeshouwers V. G. A. A., and Oliver R. P. Effectors as Tools in Disease Resistance Breeding Against Biotrophic, Hemibiotrophic, and Necrotrophic Plant Pathogens. *Molecular Plant-Microbe Interaction*. CURRENT REVIEWS: FOCUS ISSUE March 2014, Volume 27, Number 3 Pages 196-206. DOI: 10.1094/MPMI-10-13-0313-1A;
17. Cho Y. How the Necrotrophic Fungus *Alternaria brassicicola* Kills Plant Cells Remains an Enigma. *Eukaryotic Cell* April 2015 vol. 14 no. 4 335-344. DOI: 10.1128/EC.00226-14.
18. Dunoyer P., Melnyk C., Molnar A., Slotkin R. K. Plant Mobile Small RNAs. *Cold Spring Harb Perspect Biol* July 2013;5:a017897.
19. Gandhi S. G., Mahajan V., Bedi Y. S. Changing trends in biotechnology of secondary metabolism in medicinal and aromatic plants. *Planta. An International Journal of Plant Biology* 2014 241:2232. DOI: 10.1007/s00425-014-2232-x.
20. Thakur M., Sohal B. S. Role of Elicitors in Inducing Resistance in Plants against Pathogen Infection: A Review. *ISRN Biochemistry*, Volume 2013 (2013), Article ID 762412, 10 pages. DOI: 10.1155/2013/762412.
21. Newman M.-A., Sundelin T., Nielsen J. T., Erbs G. (2013). MAMP (microbe-associated molecular pattern) triggered immunity in plants. *Front. Plant Sci.* 4:139. DOI: 10.3389/fpls.2013.00139;
22. Zipfel C. Plant pattern-recognition receptors. *Trends Immunol.* 2014 Jul;35(7):345-51. DOI: 10.1016/j.it.2014.05.004;
23. Lannoo N. Damme E. J. M. Van. Lectin domains at the frontiers of plant defense. *Front Plant Sci.* 2014; 5: 397. DOI: 10.3389/fpls.2014.00397;
24. Liu X., Grabherr H. M, Willmann R., Kolb D., Brunner F., Bertsche U., Kühner D., Franz-Wachtel M., Amin B., Felix G., Ongena M., Nürnberger T., Gust A. A. Host-induced bacterial cell wall decomposition mediates pattern-triggered immunity in *Arabidopsis*. *eLife* 2014;3:e01990. DOI: 10.7554/eLife.01990
25. Tanaka K., Choi J., Cao Y., Stacey G. Extracellular ATP acts as a damage-associated molecular pattern (DAMP) signal in plants. *Front Plant Sci.* 2014; 5: 446. DOI: 10.3389/fpls.2014.00446.

26. Trouvelot S., Héloir M.-C., Poinssot B., Gauthier A., Paris F., Guillier C., Combiér M., Trdá L., Daire X., Adrian M. Carbohydrates in plant immunity and plant protection: roles and potential application as foliar sprays. *Front Plant Sci.* 2014; 5: 592. DOI: 10.3389/fpls.2014.00592.
27. Lyon G. Agents that can elicit induced resistance. In: *Induced resistance for plant defence: a sustainable approach to crop protection.* Eds: Walters D., Newton A., Lyon G. D. Blackwell Publishing Ltd., Oxford, UK. 2007, pp. 9-30. ISBN: 978-1-4051-3447-7.
28. Reignault P., Walters D. Topical application of inducers for disease control. In: *Induced resistance for plant defence: a sustainable approach to crop protection.* Eds: Walters D., Newton A., Lyon G. D. Blackwell Publishing Ltd., Oxford, UK. 2007, pp. 179-200. ISBN: 978-1-4051-3447-7.
29. Kombrink A¹, Sánchez-Vallet A, Thomma BP. The role of chitin detection in plant--pathogen interactions. *Microbes Infect.* 2011 Dec;13(14-15):1168-76. DOI: 10.1016/j.micinf.2011.07.010.;
30. Sánchez-Vallet A., Mesters J. R., Thomma B.P.H.J. The battle for chitin recognition in plant-microbe interactions. *FEMS Microbiology Reviews.* 2015 Volume 39, Issue 2 Pp. 171 - 183 DOI: 10.1093/femsre/fuu003
31. Nicolaus G.L. *Melanins* – Paris: Herman, 1968. – 127 p.
32. Ramegowda V., Senthil-Kumar M. The interactive effects of simultaneous biotic and abiotic stresses on plants: Mechanistic understanding from drought and pathogen combination. *Journal of Plant Physiology* Volume 176, 15 March 2015, Pages 47–54 DOI: 10.1016/j.jplph.2014.11.008.
33. Aoki M., Tan M., Fukushima A., Hieda T., Kubo S., Takabayashi M., Ono K., Mikami Y. (1993) Antiviral Substances with Systemic Effects Produced by Basidiomycetes such as *Fomes fomentarius*, *Bioscience, Biotechnology, and Biochemistry*, 57:2, 278-282, DOI: 10.1271/bbb.57.278.
34. Seniuk O.F., Gorovoj L.F., Beketova G.V., Savichuk N.O., Rytik P.G., Kucherov I.I., Prilutskaya A.B., Prilutsky A.I. Anti-Infective Properties of the Melanin-Glucan Complex Obtained from *Fomes fomentarius*. *International Journal of Medicinal Mushrooms*, 2011, V. 13, N 1, pp. 7-18.
35. Dresch P., D'Aguzzo M. N., Rosam K., Grienke U., Rollinger J. M., Peintner U. Fungal strain matters: colony growth and bioactivity of the European medicinal polypores *Fomes fomentarius*, *Fomitopsis pinicola* and *Piptoporus betulinus*. *AMB Express* (2015) 5:4. DOI: 10.1186/s13568-014-0093-0.
36. Gorovoy L.F., Burdyukova L.I. The cell wall of higher basidial fungi. *Cytology and genetics.* 1997, T. 31, 1. pp. 70 – 81 (ukr).
37. Walters D.R., Ratsep J., Havis N.D. Controlling crop diseases using induced resistance: challenges for the future. *J. Exp. Bot.* (2013) 64 (5): 1263-1280. DOI: 10.1093/jxb/ert026.
38. Anand Y.R., Singh S.J., Verma D.K., Panyam K.R., Sumitra P, Meitei KH. M., Gurumurthy S., Asthir B. 2014. Recent Advances In Induced Resistance for Plant Disease Management: An Overview. *Innovation in Plant Science and Biotechnology.*
39. Bogaeva D., 2021; SPECIAL PROPERTIES AND USES OF MELANIN Student Resource Center «Medical Sechenov Pre-Universarium» FGAOU VO «First Moscow State Medical University».
40. Yu. Vlasova AND. Influence of UV radiation and metal ions of variable valence on the antioxidant activity of melanin. Proceedings of the 69th scientific conference of students and postgraduates of the Belarusian State University, May 14-17, 2012, Minsk. At 3 p. I.- Minsk, 2013. pp. 7-10 (rus).
41. Gorovoj L., Seniuk O., Beketova G., Savichuk N., Amanbaeva G. Use of the chitin-containing preparation Mycoton in pediatric gastroenterology Chitosan in pharmacy and chemistry / eds Muzzarelli R.A.A. Atec, 2000. – P. 151-155.
42. Iutynskaya G.A., Ponomarenko S.P., Andreyuk E.I. and others. Bioregulation of microbial and plant systems: / Under general editor. HA. Iutynskoi, S. P. Ponomarenko. - K.: Nychlava, 2010. – 464 P (rus).
43. Pletnikova N.V. Root rots of winter wheat. *Protection of crops // Agroviznyk of Ukrain–2008.* –№3. – pp.54–56 (ukr).
44. Gorovoi L.F. Biological means of plant protection and biotechnology of their production. Prospects and problems of the development of biotechnology within the framework of the common economic space of the Commonwealth of Nations. Materials of the international scientific and practical conference. May 25-28, 2005 Minsk - Naroch, Republic of Belarus. Minsk, 2005.pp. 50-51 (rus).
45. Gorovoi L.F. Biologically active substances of cap mushrooms. Biologically active substances of plants in medicine, agriculture and other industries. Materials of the international scientific and practical conference (Narochanskies chtenia - 2). Minsk-Naroch, September 27-30. 2006. Minsk, 2006, pp. 27-37 (rus).
46. Trade-offs associated with induced resistance. In: *Induced resistance for plant defence: a sustainable approach to crop protection.* Eds: Walters D., Newton A., Lyon G. D. Blackwell Publishing Ltd., Oxford, UK. 2007, pp. 157-178. ISBN: 978-1-4051-3447-7.
47. Walters D, Heil M. 2007. Costs and trade-offs associated with induced resistance. *Physiological and Molecular Plant Pathology* 71, 3–17.