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Application of biologically active substances in agriculture preparations

Abstract. High-quality, naturally protected seeds prior to sowing, along with growth activation of seedlings, represent a promising approach to stabilising crop yield and quality. Enhancing plant resistance to dynamic environmental stresses, including harmful organisms, is one of the strategies for realising the biological potential of crop yields in breeding and seed production. This research aimed to experimentally evaluate a preparation based on humic substances, film formers, a nanocomposite, succinic acid, and microbiological carotene. Experiments were conducted using spring barley and wheat seeds. A seed encrustation technology employing a functional preparation

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was applied. Laboratory and field experiments were conducted at V. Dokuchaev Kharkiv National Agrarian University, Department of Plant Growing, over two years. The experimental design and economic efficiency assessment of the functional preparation in enhancing yield was carried out according to established methodologies. Pre-sowing seed treatment with the preparation resulted in improved field germination, synchronised seedling emergence, and increased yield. Comprehensive studies revealed that the preparation was compatible with fungicides, demonstrating a synergistic effect of their joint protective effect. Experimental results confirmed that seed incrustation with protective and stimulating formulations based on water-soluble polymers is an effective method for protecting plants from seed- and soil-borne infections while reducing the level of environmental pollution. The extended and enhanced fungicidal activity of film-forming protective and stimulating compositions was also demonstrated. Agricultural production tests indicated that the developed preparation was user-friendly, environmentally safe, and economically efficient, contributing to increased crop yields. The positive test results support practical recommendations for its application in both seed encrustation and grain crop spraying during the tillering and milky-wax ripeness phases

Keywords: growth stimulators; film-forming agents; fungicides; root rot disease; grain crop yield

INTRODUCTION

The development of biologically active preparations for plant growth is of both great scientific and practical significance. According to numerous studies, the use of plant growth regulators or biostimulants is a key component of environmentally sustainable, resource-efficient technologies for cultivating various agricultural crops. These technologies contribute to increased yield and improved nutritional quality of the resulting products (Bezpalko *et al*., 2020; Slobodianyk *et al*., 2022). As noted by D. Volhin & V. Havii (2023), modern agricultural science prioritises the identification of novel methods for enhancing crop production and quality. This research focuses on strategies that minimise reliance on fertilisers and other agricultural chemicals. Simply intensifying farming by increasing fertiliser application has not resulted in proportional yield improvements. Furthermore, pesticide use can degrade soil quality and adversely affect the chemical composition of crops, including levels of vitamins, enzymes, and other essential components (Nepran *et al*., 2021). Consequently, the search for alternative compounds capable of improving crop yields and productivity in food production remains highly relevant.

M. Matkovska (2020) presented findings from a comparative study on winter barley yield under different fungicidal protection methods across three mineral nutrition regimes ($N_{40}P_{30}K_{40}$, $N_{80}P_{60}K_{80}$, $N_{120}P_{90}K_{120}$). The impact of mineral nutrition on disease development and the effectiveness of fungicide application in controlling net blotch, powdery mildew, and dark brown blotch in the Vintmalt winter barley variety was examined. The study concluded that fungicidal protection was beneficial across all nutrition levels: however, the greatest yield increase from fungicides was observed in the $N_{120}P_{90}K_{120}$ treatment.

A proven approach for improving the sowing quality of seeds is pre-sowing treatment with growth stimulants, particularly those derived from humic substances and biologically active additives. For instance, I. Nepran *et al*. (2021) and A. Bahan & S. Nevodnychyi (2023) investigated the effects of various growth stimulants on the sowing qualities of common chickpea varieties. The impact of the studied preparations on germination energy, laboratory germination, and fungicidal activity was analysed. The effect of a growth stimulant with antifungal properties on the seed quality was also examined. A minor influence of the growth stimulants on the germination energy, laboratory germination, and uniformity of germination in common chickpea varieties was observed.

Currently, there is considerable scientific interest in plant growth stimulators, as evidenced by numerous publications. These substances are being explored both as standalone treatments and in combination with traditional organo-mineral fertilisers as bioadditives. Research also investigates their potential synergy with fungicides (Siroshtan & Kavunets, 2021). Among the most promising approaches is the development of preparations based on plant growth regulators, including biostimulants obtained through microbiological processes or chemical synthesis (Zhang *et al*., 2024). However, the feasibility of applying microorganisms as biostimulants and biofertilisers remains uncertain due to potential risks to human health. Developing effective and safe biological agents that promote plant growth presents a significant scientific and technical challenge.

L. Krychkovska *et al*. (2024) developed and tested experimental batches of microencapsulated barley and wheat seeds under laboratory and field conditions following a formulated composition that included natural components – hydrated fullerenes, sodium humate, microbiological carotene, and succinic acid – in a specific ratio. The preparation also contained an adhesive additive, which enhanced seed adherence and plant contact, thereby improving the penetration efficiency of the preparation into the seed coat. This formulation was conditionally named Humir.

This research aimed to experimentally and practically evaluate a growth-stimulating preparation with fungicidal properties developed by the authors for application to spring barley and spring wheat using encrusted seeds. Seed encrustation with the developed preparation enhanced the uptake of biogenic nutrients by plants during the growing season. Bioadditives were continuously released from the multilayered seed coating. The primary factor contributing to growth intensification was the bioadditive, which contained plant growth stimulants and exhibited fungicidal and bioprotective properties.

LITERATURE REVIEW

According to an analysis of cereal cultivation data, particularly for spring barley, the cultivated area of this grain crop in Ukraine has declined by 56% over the past 15 years (Kasatkina & Gamayunova, 2018). As a result, interest among commercial producers in barley cultivation has diminished in recent years. To enhance cereal yield and improve plant quality, a study was conducted to examine the impact of a formulation developed using humates, fullerene, succinates, and microbiological carotene on the yield and quality of spring barley and spring wheat. In addition, the use of film-forming compositions to ensure more stable retention of bioadditives on seeds has been justified. In the review by O. Matyshevska *et al*. (2010), the high biological efficacy and antioxidant properties of fullerene – which was incorporated as an antioxidant in the aforementioned composition – were discussed under the literature data.

In the study by T. Kasatkina & V. Gamayunova (2018), the current state and trends in the cultivation of spring barley – a valuable food, feed, and industrial crop – in southern Ukraine were analysed. The factors influencing the realisation of the crop's biological potential through the implementation of modern, competitive cultivation technologies were highlighted. Such technologies should prioritise the selection of high-yielding varieties adapted to the conditions of southern Ukraine, along with optimisation of nutrition through modern growth regulators, biological agents, and organomineral fertilisers. The study also described various methods of fertiliser application within traditional barley cultivation technologies. It was concluded that the use of plant growth regulators represents a modern strategy to increase barley grain yield. M. Marenych & S. Yurchenko (2016) noted that humic substances positively influence cell membrane permeability, activate enzymes involved in protein and carbohydrate synthesis, and enhance respiration and water exchange processes.

According to a study conducted by T. Kasatkina & V. Gamayunova (2018), the most effective and economically advantageous methods of applying growth regulators were seed treatment and foliar feeding of vegetative plants. Upon contact with the leaf surface, growth regulators penetrate plant tissues and become involved in the biochemical reactions of metabolism. Overall, the use of biostimulants in seed production – an advanced branch of plant breeding – and their impact on seed quality and yield characteristics of major grain crops require further investigation. In particular, the application of biostimulants compared to pesticides, which have the potential to enhance seed germination and emergence while exhibiting as fungicidal and bactericidal properties, warrants detailed research and development.

The use of nano-formulations in crop production, which contain components with nano-sized particles, is an effective approach to enhancing the yield of major crops (Rouphael & Colla, 2018). Nanoparticles enable more effective delivery of micronutrients to plants, increasing their absorption and impact on plant health while significantly reducing fertiliser costs and minimising the environmental impact of plant protection chemicals. Research into the use of nanotechnologies in agriculture is continuously expanding (Tarazona *et al.*, 2019; Slobodianyk *et al.*, 2022). According to O. Matyshevska *et al.* (2010), nano-sized carbon materials, particularly hydrated fullerenes, are increasingly utilised in agriculture, cosmetics, and the food industry due to their high biological activity and antioxidant, antiviral, and antimicrobial effects.

Organic non-microbial plant biostimulants, which include humic substances and seaweed extracts, continue to play a leading role in crop production, where they are used to stimulate growth, increase plant stress resistance, and improve the nutritional value of agricultural products (Marenych & Yurchenko, 2016; Godara & Bakshi, 2021). According to Z. Chen *et al.* (2023), algae serve as an important source of biologically active substances, chlorophyll, carotene, and other natural pigments. Phytohormones, which are carotene derivatives – particularly abscisic acid – function as components of plant growth regulators, providing a protective effect and enhancing plant resistance to various types of stress, as noted by T. Sun *et al.* (2022). According to H. Slobodianyk *et al.* (2022), succinic acid acts as a universal plant growth stimulant that significantly enhances seed germination promotes root formation, and boosts yield. Pre-sowing treatment of soybean seeds with formulations containing succinic acid complexes with specific elemental ions exhibited both growth-stimulating and fungicidal effects.

MATERIALS AND METHODS

Studies on the effects of a specific preparation on spring barley and wheat growth and development were conducted at the Department of Plant Growing at V. Dokuchaev Kharkiv National Agrarian University during 2020-2021. These studies included both laboratory and field experiments. Laboratory germination involved placing seeds on a gauze-covered cotton wool pad in Petri dishes and rolled paper strips. Nutrient solutions (90 mL) were added beneath the pad. During the initial stage of seed germination, Petri dishes were covered with lids, each with a small hole to allow air penetration. Once the first seedlings emerged, the lids were removed. In the test variants, a 0.01% solution of each component under study was applied to the growing plants (the optimal concentration was determined through preliminary experiments). Tap water served as the control. Throughout the study period, the ambient temperature was regulated between 21-23°C during daylight hours and 1718°C overnight. Plant growth was monitored daily, with measurements taken of seedling count and length. At the conclusion of the study, yield was evaluated by harvesting and weighing the plants' fresh biomass.

Field experiments were conducted following the variety testing method. Spring wheat of the Kharkivska 26 variety (super elite) and spring barley of the Zvershennia variety (super elite) were sown at optimal times using a continuous row method, with a seeding rate of 5.5 million and 5 million viable seeds per 1 hectare, respectively, using an SSFK-7 seeder (Ukraine). The plot area was 10 m^2, with three replications. Seed encrustation with a fungicide in a film-forming solution containing the growth regulator Humir (2% solution) was performed in the laboratory using specialised equipment. The working solution was prepared with varying concentrations of the encrusting mixture components. Humir is a complex formulation containing biologically active substances of natural origin and water-soluble polymers with a mild mode of action. It includes polyethylene glycol (PEG; polyethylene oxide) with a molecular weight of 500 (230 g/L) and PEG-1500 (540 g/L), as well as sodium humate (35 g/L), fullerene, and microbiological carotene.

The harvest was recorded continuously and systematically. The yield data were processed using the analysis of variance method. Seed quality before and after treatment was determined in the laboratory according to DSTU 4138-2002 "Seeds of Agricultural Crops. Methods for Determining Quality" (2004). Monitoring of insect population dynamics and plant damage across ontogenetic phases was conducted through weekly observations, where the incidence of diseases and insects by crop type, dominant species, and their role in plant damage were established according to the methodology of the Institute of Plant Protection (Omeliuta, 1986). During the growing season, phytosanitary inspections of crops, as well as assessments of sooty mould, Fusarium ear rot, and Fusarium root rot, were conducted following the "Methodology for Conducting Phytopathological Studies under Artificial Infection of Plants" (2016). The experiments were conducted in the microbiology laboratory of the Yuryev Plant Production Institute of NAAS of Ukraine.

The degree of crop resistance to common diseases was determined following the scale presented in the manual by L. Babayants *et al.* (1988) "Methods of Selection and Assessment of Resistance of Wheat and Barley in the CMEA Member Countries" (Table 1).

Table 1. The rating scale for crop resistance to common diseases

Resistance, point	Disease incidence, %
9	0
8	0.1-5.0
7	5.1-10.0
6	10.1-15.0
5	15.1-25.0
4	25.1-40.0
3	40.1-65.0
2	65.1-90.0
1	91.0-100

Source: compiled by the authors

Field experiments were conducted under the climatic conditions of the moderate continental zone. The average annual air temperature ranged from 6 to 10°C. Annual rainfall totalled 450-460 mm, with the majority (320-340 mm) occurring between June and October. Meteorological conditions during the 2020-2021 growing season, compared with long-term averages, were characterised by an increase in air temperature of 1-3°C.

The soil in the experimental fields was a strongly developed, slightly leached black soil on siltyloamy loess, characterised by an agronomically valuable granular-lumpy structure with a total humus content of 5.89-6.15%. The arable soil layer contained 1.9-2.0% potassium, 0.28-0.29% nitrogen, 0.17-0.18% phosphorus, 12 mg/kg of mobile zinc, 20 mg/kg of manganese, and 0.17 mg/kg of molybdenum. Soil pH ranged from 6.8 to 7.5. The microelement content was measured using an X-ray energy spectrometer, SER-01 "ElvaX ProShector LE" model (Ukraine). The research was conducted in compliance with national laws and regulations, following ethical guidelines for plantrelated experiments (Convention on International Trade in Endangered Species of Wild Fauna and Flora, 1973; Convention on Biological Diversity, 1992).

RESULTS AND DISCUSSION

The phytosanitary situation in grain crop agrocenoses is worsening each year. The increasingly contrasting weather conditions in recent years have contributed to a decline in plant resistance to environmental stresses, including diseases and insect pests. This has increased the prevalence and aggressiveness of many harmful organisms. The greatest impact of the phytophagous complex on plants was observed in low agrotechnical conditions, with disruptions to agricultural practices, as well as delays in sowing. During 2020-2021, the phytosanitary condition of spring barley and spring wheat crops in crop rotations was monitored. Diseases and pests were identified at different stages of plant ontogenesis (Table 2).

Table 2. Phytosanitary condition of spring barley and spring wheat crops in 2020-2021

No.	Type of pathogen	Disease	Spring barley		Spring wheat	
			Prevalence rate of disease			
			%	point	%	point
1	*Fusarium culmorum Sacc.*	Fusarium root rot	25	5	20	5
2	*Helminthosporium sativum P.*	Common root rot	30	4	25	5
3	*Erysiphe graminis (DC.)*	Powdery mildew	20	5	20	5
4	*Drechslera graminea* Ito.	Leaf stripe	20	5	–	–
5	*Rhynchosporium graminicola Heinsen*	Rhynchosporiosis	10	7	–	–
6	*Ustilago nuda* Kell. et Sw.	Loose smut	0.01	0	–	–
7	*Ustilago tritici Jens.*	Loose smut	–	–	0.03	0
8	*Tilletia caries Tul.*	Hard wheat smut	–	–	0.1	8
9	*Ustilago hordei* Kell. et Sw.	Covered smut	0.1	8	–	–
10	*Puccinia graminis* Pers.	Stem rust	15	5	20	5

Source: compiled by the authors

The data in Table 2 indicate that, in 2020-2021, root rots were the predominant disease in barley and wheat crops. Fusarium root rot leads to seedling death, resulting in crop thinning, reduced grain mass, decreased 1,000-grain weight, empty ears, lodging, and deterioration of grain quality. Infection occurs at temperatures between 3 and 35°C, with an optimal range of 15-22°C, and in soils with moisture levels exceeding 40%. The pathogen persists on grain, plant residues, and in the soil. The unfavourable conditions for plant growth and development in 2020-2021 facilitated disease proliferation. In this context, plant protection and growth stimulation measures are crucial, which could be achieved using film-forming growth regulators such as Humir, which combines the properties of a growth regulator, adaptogen, cryoprotectant, fungicide, bactericide, and film-forming agent.

Polyethylene glycols (PEG-500 and PEG-1500) were selected as film-forming agents due to their low toxicity to humans and their ability to mitigate plant stress under adverse environmental conditions. High molecular weight PEGs administered orally to living organisms are practically nontoxic. For PEGs with a molecular weight up to 2,000, LD50 values range from 14 to 50 g/kg when taken orally. The toxicity of PEG decreases with increasing molecular weight (Hartwig *et al.*, 2020). According to a study by L. Ma *et al.* (2024), pre-sowing seed treatment with polyethylene oxides increased osmotic pressure and cell membrane permeability, resulting in positive changes in plant metabolism. Consequently, plant resistance to stress was enhanced, and grain quality improved, particularly with an increase in protein content in grain crops.

According to the studies, the preparation had no adverse effect on seed germination, so it can be used as a film-forming agent (Table 3).

As illustrated in Table 3, seed germination increased in all treatments involving PEG500 + PEG1500 mixtures as film formers, which was attributed to the enhanced retention of the functional compound on the seeds. Furthermore, the inclusion of hydrated fullerenes and succinic acid in the formulation of the functional compound reduced the level of root rot development in germinating seeds. This finding suggests the potential of these components for use in growthstimulating formulations.

Table 3. The impact of film formers, fullerenes and succinic acid in the composition of Humir on seed germination and effectiveness against root rot for spring wheat

Film former	Film former consumption rate[1]	Degree of retention, %	Germination %	Development of root rot disease *Fusarium ssp.*, %[2]
Control: sodium humates (2.0 kg/t)	–	85.6	88.2 ± 5.3	33.3 ± 3.5
Humates + PEG-500	0.2 kg/t	94.4	93.3 ± 3.0	30.4 ± 3.4
Humates + PEG-500 + PEG-1500	0.1 kg/t	94.7	96.0 ± 2.8	28.7 ± 3.2
Humates + PEG-500 + PEG-1500 + fullerenes + succinic acid	0.1 kg/t	92.3	97.0 ± 1.9	21.0 ± 2.1

Note: laboratory experiment, average values over two years, 2020-2021; [1] – the volume of working fluid was 20 L/t; [2] – root rot development was assessed in seedlings at 20 days of age
Source: compiled by the authors

In preliminary laboratory experiments with wheat and barley seeds, the optimal concentration of the preparation for pre-sowing seed treatment was determined to be within the range of 1.5-2.5%. At this concentration, the seeds retained their flowability, and the added fungicide (with filler) remained intact during subsequent planting. Field and laboratory studies on seed germination concerning preparation concentration, as well as the vigour of early growth, demonstrated that seed treatment with Humir at concentrations ranging from 0.1 to 4.0% did not exert an inhibitory effect on these parameters. However, further increases in concentration led to reductions in both laboratory and field germination, as well as growth vigour. From a physiological perspective, the positive effect was attributed to the activation of metabolic processes. As a result, the seeds progressed through the germination stages more efficiently, which was positively reflected in subsequent plant growth and development, resulting in increased yield and improved quality.

In the studies conducted in 2020-2021, the potential for combining Humir with fungicides for seed encrustation was investigated. Field experiments demonstrated that the combination of a fungicide with Humir for the seed treatment of spring barley and spring wheat significantly increased grain yield compared to conventional fungicide treatment. The effectiveness of the growth-stimulating compound Humir was also confirmed for both pre-sowing seed treatment and foliar application in spring barley and spring wheat (Table 4).

Table 4. Phytosanitary condition of crops, yield and nutritional quality of spring barley seeds Zvershennia depending on the application of the Vitavax fungicide and Humir growth stimulants, 2020-2021

Variant	Root rot infection in the MWR phase[1]		Infection by loose smut	Crop yield, c/ha	Protein content in grain, %	Starch content in grain, %
	damage, %	infection rate, %				
Control (seeds and seedlings untreated)	29.0	9.0	0.1	24.0	12.75	58.50
Standard (seeds treated with Vitavax (2.5 L/t))	18.0	6.0	–	25.7	11.28	59.43
Seeds treated with Vitavax (2.5 L/t) + Humir (2.0 kg/t)	6.0	2.0	–	27.5	12.24	59.25

Table 4, Continued

Variant	Root rot infection in the MWR phase[1]		Infection by loose smut	Crop yield, c/ha	Protein content in grain, %	Starch content in grain, %
	damage, %	infection rate, %				
Same as above + spraying with Humir during tillering (250 g/ha)	6.0	2.0	–	28.0	12.25	59.30
Same as above + spraying during tillering (250 g/ha) and MWR phases (250 g/ha)	6.0	2.0	–	28.3	12.50	60.53

Note: [1] – milky-wax ripeness (MWR) phase
Source: compiled by the authors

According to the data presented in Table 4, the maximum barley yield obtained in the seed encrustation treatments was 27.5 c/ha (+ 3.5 c/ha, or 15% compared to the control, and + 1.7 c/ha, or 7% compared to conventional seed treatment). Subsequent spraying of barley seedlings with Humir led to an additional increase in grain yield of 2.6 c/ha (+ 10%) compared to the standard treatment. Furthermore, it was found that conventional fungicide treatment of barley seeds resulted in a 1.47% decrease in protein content compared to the control. In contrast, in the Humir treatment variant, the protein content returned to near control levels, reaching 12.24%. Additionally, subsequent spraying of barley seedlings with Humir further improved grain quality. For instance, in the variant where plants were sprayed during the tillering phase and again at the MWR phase, the protein content in barley grain was 12.5%, while starch content increased by 2.03% compared to the control and by 1.1% compared to the standard.

In all seed encrustation variants, no deviations were observed in the progression of phenological phases compared to the control. However, significant trends and differences were noted for other indicators influencing crop formation. In 2021, the field germination rate of the studied crops in the pre-sowing seed treatment variants with Humir, a plant growth stimulator, generally exceeded the control values by an average of 3-4%. As can be seen from Tables 4 and 5, conventional seed treatment with only a fungicide significantly reduced plant damage caused by root rot and the overall infection rate, while also completely disinfecting seeds from loose smut. In contrast, seed treatment using the encrustation method with Humir, a film-forming growth stimulator, more than doubled the protection of spring wheat against root rot, which positively influenced crop yield (Table 5).

Table 5. Phytosanitary condition of crops and grain yield of spring wheat Kharkivska 26 depending on the application of the Vitavax fungicide and Humir preparation, 2020-2021

Variant	Root rot infection in the MWR phase		Infection by loose smut	Crop yield, c/ha
	damage, %	infection rate, %		
Control (seeds and seedlings untreated)	25.0	12.0	0.2	33.2
Standard (seeds treated with Vitavax (2.5 L/t))	15.0	7.0	–	35.9
Seeds treated with Vitavax (2.5 L/t) + Humir (2.0 kg/t)	7.0	2.0	–	37.2
Same as above + spraying with Humir during the tillering phase (250 g/ha)	7.0	2.0	-	38.1
Same as above + spraying during tillering (250 g/ha) and MWR phases (250 g/ha)	7.0	2.0	-	38.9

Source: compiled by the authors

As shown in Table 5, the maximum wheat yield obtained through seed encrustation treatments was 37.2 c/ha (+ 4 c/ha, or 12% compared to the control, and + 2.7 c/ha, or 8% compared to conventional seed treatment). Subsequent spraying of wheat seedlings with Humir led to an additional grain yield increase of 3.0 c/ha (+ 8%) compared to the standard treatment. It was assumed that the positive effect of spraying plants with the Humir growth stimulator was largely attributable to its high wettability and film-forming properties. After application to the leaf surface, a thin film of the compound was observed, and its active components were gradually absorbed by the plant over several days. As a result, Humir was effective in combating diseases such as powdery mildew, late blight, and bacterial infections. When infection foci appeared on the leaves and stems, careful treatment with the Humir film-forming preparation facilitated the fixation of fungal spores, effectively blocking the spread of infectious plant diseases.

Satisfying the growing food demands of the population has increased the environmental impact of chemical use and requires alternative methods to produce more food (Barros-Rodríguez *et al*., 2020). The use of biostimulants and biofertilisers deserves attention as an alternative solution to this problem. In this regard, plant biostimulants appear to be among the most appropriate solutions due to their natural origin and potential to replace traditional agricultural methods. According to M. Baltazar *et al*. (2021), humic substances, seaweed extracts, and microorganisms have demonstrated the potential to accelerate plant growth, increase crop yield and quality, and mitigate the effects of stress. Thus, humate- and bioadditive-based formulations are particularly relevant for increasing cereal yields.

To protect seeds from mould fungi, fullerenes and succinic acid were included in the developed encrusting preparation as bactericidal agents. This is especially important for pre-sowing seed treatment. Fullerenes were studied for their impact on the microbiological stability of solutions containing biologically active substances and compared with carbon-containing water infused with shungites crushed to nanosize. It was experimentally proven by L. Krychkovska *et al*. (2024) that the inclusion of hydrated fullerene C60 (C60FWS, nanoparticle size 1.6-1.8 nm) in the composition of the functional preparation Humir resulted in high resistance to microbiological contamination.

The development of new complex formulations containing succinic acid is of particular interest in the creation of a functional preparation with multifaceted biological properties, including antimicrobial, growth-stimulating, and antifungal activity. Succinic acid, as a natural analogue of salicylic acid, has shown potential for increasing plant resistance to pathogens when combined with antimicrobial and growth-stimulating components. This approach enhances growth, induces antimicrobial properties, and ultimately leads to increased yields. N. Levchyck *et al*. (2017) investigated the effect of succinic acid solutions using biotesting methods under field conditions and in vitro culture. The test object was cucumber seedlings (*Cucumis sativus* L.). The study demonstrated that aqueous solutions of succinic acid can be effectively used for growing agricultural plants both *in vivo* and *in vitro*.

In the research by S. Kabdrakhmanova *et al*. (2023), the biological effectiveness of succinates in soybeans was investigated, with the aim of increasing the germination rate while reducing the presence of phytopathogens and dwarfism. Complexes of succinic acid with copper, silver, and boron ions exhibited a distinct morphology with a monoclinic crystal structure. These complexes demonstrated a dual effect – both stimulating and fungicidal – significantly increasing the germination rate by 19.7-24.4 times and reducing susceptibility to phytopathogenic organisms such as Fusarium and Alternaria tenuis Nees by 2.75-8.66 times compared to the control sample.

In the study by L. Krychkovska *et al*. (2024), it was found that the treatment of spring wheat seeds with the carotene-containing Humir preparation resulted in an increase in the number of plants and spikelets, as well as the dry weight of plants, compared to the same preparation without carotene. Thus, the composition and effects of the developed preparation on seed germination align with the general trend in the combined application of its components, as demonstrated by multiple studies cited above.

PEG enhances osmotic regulation and antioxidant capacity, succinic acid and fullerenes exhibit antifungal activity, and their synergistic action contributes to increased crop yields.

The method of seed encrustation using water-soluble polymers has been identified as the most successful form of pre-sowing seed treatment, as demonstrated in the overview by M. Baltazar *et al*. (2021). This method improves the adhesion of preparations, does not impede seed respiration and moisture absorption, and increases resistance to drought and low temperatures. Ultimately, seed encrustation with biologically active substances enhances crop yields in plant growth technologies. Recently, the number of studies on the development of film-forming compositions has increased. These formulations include, in addition to pesticides and polymers, organic and mineral nutrients, growth stimulants, and surfactants. Their application strengthens and expands the fungicidal and bactericidal effects on phytopathogenic and mould fungi. Increased adhesion of preparations and the creation of a nutrient reserve on the seed surface enhances germination and improve the physiological status of plants.

Enhancing grain yield through the use of biostimulants has shown a positive trend in response to changing climatic conditions in Ukraine. However, sustainable grain production under sharp fluctuations in weather conditions is only possible through improvements in agrotechnological schemes. Therefore, testing the developed preparation, as conducted in this research, is relevant for increasing crop yields and antifungal activity. It has been demonstrated that the seed treatment method involving the encrustation of grain seeds with plant growth regulators is ecologically safe and increases crop yields by up to 20%.

CONCLUSIONS

A complex preparation for crop production, named Humir, containing biologically active substances of natural origin and water-soluble polymers with mild effects, has been tested for its properties as a growth regulator, adaptogen, cryoprotectant, fungicide, bactericide, and film-forming agent. Presowing treatment of grain seeds with Humir led to increased field germination, synchronised seedling emergence, and higher yield. Comprehensive studies have revealed that Humir is compatible with fungicides, demonstrating a synergistic protective effect when used together. Experiments have shown that encrusting seeds with protective and stimulating formulations based on water-soluble polymers is an effective method for protecting plants from seed- and soil-borne infections and contributes to reducing environmental pollution. A range of film formers based on water-soluble polymers, suitable for the development of protective and growth-stimulating formulations for presowing seed treatment, has been identified. The use of two-component polymer systems has been shown to enhance the adhesion of preparations to seeds and increase the biological activity of protective and stimulating formulations. The effectiveness of film-forming protective and stimulating compositions in enhancing and prolonging the fungicidal action of treatments has been demonstrated. The prospects of seed encrustation with protective and stimulating formulations based on watersoluble polymers have been confirmed for growing healthy plants and reducing environmental pollution.

Agricultural production tests have shown that the Humir preparation is convenient to use, environmentally safe, and economically beneficial, as evidenced by increased crop yields. The positive test results provide a basis for practical recommendations for its use in agricultural production, both for seed encrustation and for spraying grain crops during the tillering and milkywax ripeness phases. Further research on this topic will explore synergistic biostimulant effects and contribute to the development of next-generation plant biostimulants for sustainable agriculture.

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CONFLICT OF INTEREST

None.

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Застосування біологічно активних речовин у препаратах для сільського господарства

Анотація. Високоякісне, природно захищене в посіві насіння та ростактивація сходів є перспективним напрямом стабілізації величини і якості урожаю. Одним із шляхів реалізації біологічного потенціалу урожайності сільськогосподарських культур в селекції і насінництві є підвищення стійкості рослин до динамічних екологічних стресів, в тому числі і до шкідливих організмів. Метою дослідження було експериментальне тестування препарату на основі гумінових речовин, плівкоутворювачів, нанокомпозиту, янтарної кислоти та каротину мікробіологічного. Експерименти проведено на насінні ярого ячменю та ярої пшениці. Використано технологію інкрустування насіння функціональним препаратом. Лабораторні та польові експерименти проводили на базі Харківського національного аграрного університету ім. В.В. Докучаєва на кафедрі рослинництва протягом двох років. Постановку експериментів та оцінку економічної ефективності функціонального препарату у підвищенні врожаю проводили за встановленими методиками. Передпосівна обробка насіння зернових культур препаратом забезпечувала зростання польової схожості, синхронності сходів і урожайності. Різносторонні випробування довели, що препарат сумісний з протруювачами насіння, при цьому проявляється синергізм їх спільної дії, а саме підвищення фунгіцидного ефекту. Результати експериментів показали, що інкрустація насіння захисно-стимулюючими препаратами на основі водорозчинних полімерів є ефективним методом захисту рослин від насіннєвих та ґрунтових інфекцій і способом зниження рівня забруднення навколишнього середовища. Доведено посилення та пролонгація дії фунгіциду при застосуванні в плівкоутворюючих захисно-стимулюючих композиціях. Виробничі випробування показали, що препарат зручний при використанні, екологічно безпечний, а господарська ефективність препарату проявляється у збільшенні урожайності. Позитивні результати випробування дали підстави для рекомендацій щодо його застосування у виробничих умовах як для інкрустації насіння, так і для обприскування рослин зернових колосових культур у фазу кущення та молочно-воскової стиглості

Ключові слова: стимулятори росту; плівкоутворювачі; фунгіциди; кореневі гнилі; урожайність зернових культур