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IMPACT OF THE BIOLOGICAL PREPARATION EXTRAKON ON PHOTOSYNTHETIC APPARATUS, ENZYMATIC ACTIVITY OF ANTIOXIDANT ENZYMES AND PERFORMANCE OF SPRING WHEAT PLANTS IN THE HOST-PATHOGEN SYSTEM

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Aim. A complex study of the impact of the consortium of humus-forming microorganisms in the composition of the biological preparation Extrakon, introduced into the rhizosphere, on the intact plants and plants, infected with phytopathogenic microorganisms *Pseudomonas syringae* pv. *atrofaciens* st. 9771 and *Acholeplasma laidlawii* var. *granulum* st.118. **Methods.** Microbiological, physiological and biochemical, biophysical, statistical. The impact of the multifunctional biological preparation Extrakon, introduced into the soil, was studied using physiological and biochemical indices, in particular, catalase and peroxidase activity of tissues and the content of chlorophylls *a* and *b*, the photochemical activity of the photosynthetic apparatus and the grain performance of the intact spring wheat plants, Pechernianka cultivar, and plants, infected with phytopathogenic microorganisms *P. syringae* pv. *atrofaciens* st. 9771 and *A. laidlawii* var. *granulum* st. 118. **Results.** The application of the consortium of humus-forming microorganisms in the composition of the biological preparation Extrakon resulted in registered stabilizing protective impact on the pigment composition of the leaves of spring wheat plants and their photochemical activity, especially when infected with phytopathogenic bacteria. If the wheat plants were infected on the background of the introduction of preparation Extrakon into the soil, the losses in grain performance were reduced. **Conclusions.** The biological preparation Extrakon neutralizes the destructive effect, conditioned by the phytopathogens of species *P. syringae* pv. *atrofaciens* st. 9771 and *A. laidlawii* var. *granulum* st. 118, on the photosynthetic apparatus of the host plant. This impact leads to the increase in the content of pigments in the leaves and induces the development of the resistance to damage in the conditions of the oxidative stress with the increase in the level of antioxidant enzymes activity, especially catalase, in the tissues. This is accompanied with the increase in the photosynthetic activity of leaves and the grain performance of plants.

Keywords: *Triticum aestivum L.*, *Pseudomonas syringae* pv. *atrofaciens*, *Acholeplasma laidlawii* var. *granulum* st. 118, consortium of humus-forming microorganisms, activity of antioxidant enzymes, pigments, induction of chlorophyll fluorescence.

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INTRODUCTION

In recent decades the aggravation of the global ecological crisis in the world led to the paradigm change for agrobiology. The chemization of agriculture, inherent to intense technologies, gave way to adaptive agriculture, based on optimization and minimization of chemical intrusion, the use of the potential of a vegetative organism and symbiotic relations between plants and microorganisms.

Due to the focus of selection on the performance, cultivated plants of agroecosystems are less resistant compared to wild species, and even the potential of resistant

species is limited due to the mutational variability of phytopathogenic microorganisms. The other side of the problem is anthropogenic contamination of soils which both reduces their fertility and destroys natural microbiota, capable of restoring the humus layer [1–3]. All this has considerable negative impact on agriculture, resulting in significant harvest loss and subsequently in reduced profitability of agrobusiness.

Therefore, selection of resistant species is as relevant as the use of different components of ecological agriculture, including alternative technologies of soil restoration using core soil microorganisms on the background of the impact of phytopathogenic microorganisms on the plant in the host-phytopathogens and species-pathogen-agroecosystem systems and the determination of physiological specificities of this impact.

The population of microorganisms, which are present in a thin layer around the roots in a great amount, is called rhizosphere microflora, and this zone is called rhizosphere. Numerous studies demonstrated that some species of bacteria (*Pseudomonas* genus), which typically inhibit the rhizosphere, are capable of decomposing cellulose, dissolving phosphates, using proteins and sugars, synthesizing vitamins and bacterial polysaccharides [2]. Feeding on root exudations of organic substances, synthesized by plants, in their turn, microorganisms induce the system resistance of a plant, producing antibiotic substances, etc. In this respect it is important to determine the impact of specially selected species of the natural consortium of microorganisms in the composition of Extrakon preparation, which are rhizosphere components, on the enzymatic activity, photosynthetic apparatus and performance of wheat plants. By its action, this preparation is intended for soil improvement and impacts the phytoimmunity of wheat plants. The studies of physiological effects of plants, infected with phytopathogens at early stages of disease development, and the course of bacterial and mycoplasmal diseases are of additional interest [2].

It is known that mycoplasmoses are capable of practically eliminating winter wheat yield; in some cases (in particular, in case of epiphytoties) the loss may be as high as 90 % [4]. The complexity of detecting this disease at early stages is the reason why it is possible to determine its remarkable features only with time. The most common hazardous phytopathogenic representative of this class is *Acholeplasma laidlawii* var. *granulum* st. 118, which conditions pale green dwarfism of wheat. It was determined that having been infected by phytopathogenic acholeplasma, the metabolism of the host plant changes, leading to excessive accumulation of starch and destruction of chloroplasts as well as the decrease in the amount of chlorophyll, and, as a result, in slowing down the productive process of wheat plants [5].

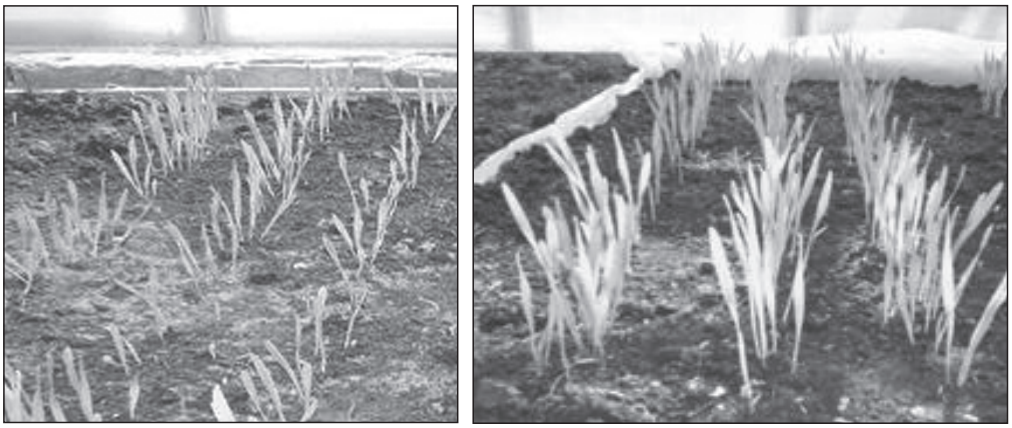
Noteworthy is the study of the most common bacterial diseases and their agents, which decrease the productivity of wheat plants considerably and degrade quality characteristics of grain. One of these diseases is basal glum rot of wheat (agent − *Pseudomonas syringae* pv. *atrofaciens*) [6], the incidence of which in EU countries is about 15 %, and sometimes (in favorable months) – 30−80 %. At a higher level of development the disease has the most negative impact on physical, technological, and biochemical qualities of grain [6, 7].

The photosynthetic activity of leaves is known to be the most important link in the production process of plants, as it is in rather a close correlation with economic performance of plants [8]. The photosynthesis intensity is usually determined by gasometric method. However, at present it is rather more common to apply the method of inducing chlorophyll fluorescence, which is rather convenient due to its expressiveness and accuracy and which does not require destroying the study object [2, 9–13, 14–19].

Aim of this study was at determining the impact of infecting with the most common and hazardous phytopathogens on the condition and activity of the photosynthetic apparatus and the enzymatic activity of components of antioxidant protection of a host plant in the pathosystem of "plant–host–phytopathogen" at the action of the consortium of soil humus-forming microorganisms in the composition of the biological preparation Extrakon.

MATERIALS AND METHODS

The plants of Pecherianka spring wheat cultivar were grown in vegetative experiments on gray podzolic soil in a greenhouse for 65–68 days until the phase of complete ripeness. The induced infecting with bacterial suspension of *P. syringae* pv. *atrofaciens* 9771 strain was performed using 7-day-old plants, and with the phytopathogenic acholeplasma *A. laidlawii* var. *granulum* st. 118 – using 10-day-old plants of spring wheat. The agent of pale green dwarfism of wheat, *A. laidlawii* var. *granulum* st. 118 (UKM VM-34), was obtained from the Ukrainian collection of microorganisms of D. K. Zabolotny Institute of Microbiology and Virology, NAS of Ukraine.



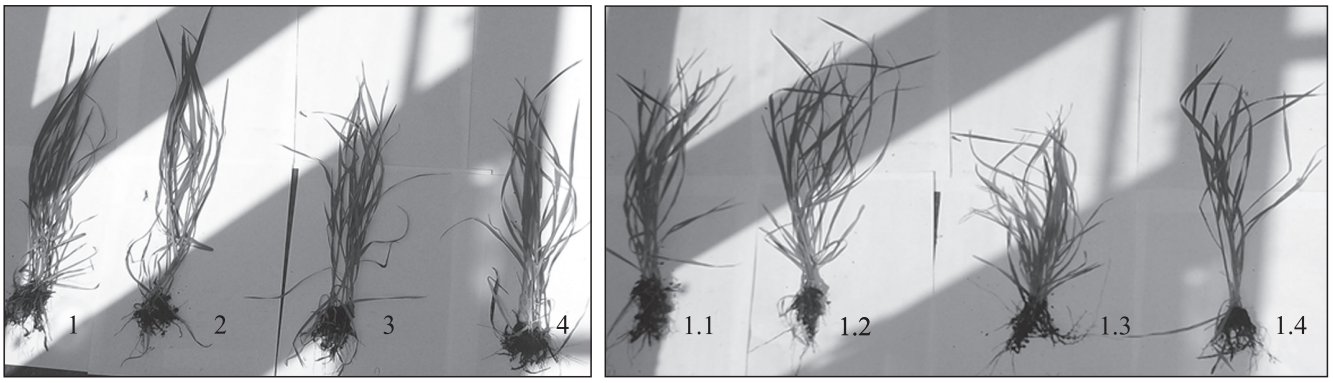
a *b*

Fig. 1. The impact of Extrakon preparation at early stages of the development of Pecherianka spring wheat cultivar (*a* − control, *b* – inoculation of Extrakon into soil)

The biological preparation Extrakon, containing the consortium of humus-forming microorganisms, was used to inoculate soil [2]. The norm of the prepared preparation was 3 kg/ha, and that of the working solution – 250 l/ha. The optimal conditions of the preparation activity in soil: pH 5.0−7.0 at the temperature of 20−35 °C, humidity – at least 40 %.

The scheme of the experiment: 1 − control (uninfected wheat plants); 2 – introduction of the biological preparation (BP) Extrakon into soil (uninfected plants); 3 – plants, intentionally infected with mycoplasmas of *A. laidlawii* var. *granulum* st. 118, grown on the soil with the introduction of BP Extrakon; 4 – combined infection (agent *P. syringae* pv. *atrofaciens* 9771 + mycoplasmas *A. laidlawii* var. *granulum* st. 118); 5 − plants, intentionally infected with the culture (agent *P. syringae* pv. *atrofaciens* 9771 + *A. laidlawii* var. *granulum* st. 118); 6 − plants, intentionally infected with the mixed culture (agent *P. syringae* pv. *atrofaciens* 9771 + *A. laidlawii* var. *granulum* st. 118), cultivated on the soil with the addition of BP Extrakon; 7 − wheat plants, infected with *P. syringae* pv. *atrofaciens*; 8 − wheat plants, infected with *P. syringae* pv. *atrofaciens,* cultivated on the soil with the addition of BP Extrakon. The experiment was set up in three replicates. The activity of peroxidase was determined by Boyarkin's method and expressed in units of optic density per 1 g of raw material per 1 s ($\Delta D_{670} \cdot g^{-1} \cdot s^{-1}$), and that of catalase − by titrometric method, expressed in the amount of O_2, which was formed due to the activity of the enzyme for 1 min per 1 g of raw material (ml $O_2 \cdot g^{-1} \cdot min^{-1}$) [20]. The pigment composition of leaves was established in 19−21-day-old plants on the 10th and 14th day after infecting with phytopathogens by the extraction method in DMSO with further spectrometry [21]. The changes in the functional condition of the photosynthetic apparatus were revealed a week after infecting. The impact of infecting with phytopathogenic microorganisms on the condition and activity of the photosynthetic apparatus of healthy and infected plants of Pecherianka spring wheat cultivar was determined by the biophysical method of chlorophyll fluorescence induction (CFI) [16]. The data were registered using Floratest, the portable device of domestic production. The device is equipped with liquid crystal screen (128 × 64 pixels) and portable optic electronic sensor with the radiation wavelength of 470 ± 15 nm, the radiation area of the spot is at least 15 mm^2 and illumination in its range of at least 2.4 W/m^2. The spectral range of measuring fluorescence intensity is from 670 to 800 nm. The software Floratest, which is supplied along with the device, takes the data, measured by the device, via USB-port of the computer and reflects them in the table or a chart [16]. CFI was measured 12 days after the intentional infecting with basal glum rot *P. syringae* pv. *atrofaciens* and pale green dwarfism of wheat *A. laidlawii* var.*granulum* st. 118.

The obtained data file was presented in a graphic form. The corresponding parameters of CFI were calculated which reflected changes in the functional links of the photosynthetic system [9, 10, 12, 15, 17, 22]. The following parameters were determined: background fluorescence (F_0); F_{pl} – index of the "fluorescence plateau"; fluorescence quenching ($qF = (F_m - F_t)/F_t$); the number of Qb-non-reversible complexes, which do not take part in linear transportation of electrons ($K_{pl} = (F_{pl} - F_0)/(F_m - F_0)$) of the link of dark fixation



a *b*

Fig. 2. The impact of Extrakon preparation and infecting with *P. syringae* pv. *atrofaciens* (*a*) and *A. laidlawii* var. *granulum* st. 118 (*b*) on the growth of spring wheat plants (tillering phase): 1 − control; 2 − biological preparation Extrakon; 3 – infecting with *P. syringae* pv. *atrofaciens*; 4 – infecting with *P. syringae* pv. *atrofaciens* on the background of Extrakon; 1.1 – control; 1.2 – Extrakon; 1.3 – infecting with *A. laidlawii* var. *granulum* st. 118; 1.4 – infecting with *A. laidlawii* var. *granulum* st. 118 on the background of Extrakon

of carbon ($K_t = (F_m - F_t)/F_m$) [9, 10−13, 23]. The data of experiments were calculated using Excel tables and processed statistically using Statistica 8.0 program.

RESULTS AND DISCUSSION

The phenological observations revealed the stimulating effect of the biological preparation Extrakon: better germination and more intense growth of spring wheat sprouts (Fig. 1, *b*; Fig. 2, *a* (2); Fig. 2, *b* (1.2)).

There was some inhibition of the growth of infected wheat plants in the tillering phase, when they had been intentionally infected with phytopathogenic microorganisms (Fig. 2, *a* (3); Fig. 2, *b* (1.3)), especially when infected with pale green dwarfism of wheat (Fig. 2, *b* (1.3)).

Infecting with phytopathogens on the background of introducing the consortium of humus-forming microorganisms in the composition of Extrakon preparation into the soil improved growth indices, decreased the inhibiting effect, caused by the infection development due to efficient competition with pathogens and induction of plant resistance (Fig. 2, *b* (1.4)).

It was determined that the pigment composition of leaves of Pecherianka spring wheat cultivar on the background of introducing the multifunctional consortium of microorganisms of Extrakon preparation into the soil was at the same level with control plants (Table 1). Infecting wheat plants with *A. laidlawii* var. *granulum* strain 118 facilitated a considerable decrease in the amount of chlorophylls *a* (by 45 %), *b* (by 50 %), and carotinoids (by 40 %).

Although infecting with acholeplasmas on the background of BP Extrakon decreased the concentration of chlorophyll *a*, it was not significant (by 33 %). There were no changes observed in the concentration of chlorophyll *b* and carotinoids in these conditions (see Table 1). At the same time the content of pigments in the

Table 1. The pigment composition of the leaves of spring wheat plants, infected with the agent of pale green wheat dwarfism, *Acholeplasma laidlawii* var. *granulum* st. 118 on the background of BP Extrakon

Experiment variant	Pigments, mg/g of raw material		
	Chlorophyll *a*	Chlorophyll *b*	Carotinoids
Control *	0.90 ± 0.04	0.40 ± 0.02	0.50 ± 0.02
Infecting [1]	0.40 ± 0.02	0.20 ± 0.01	0.30 ± 0.01
BP Extrakon *	0.90 ± 0.04	0.40 ± 0.02	0.40 ± 0.02
Infecting1 on the background of BP Extrakon	0.60 ± 0.03	0.20 ± 0.03	0.30 ± 0.01

Note. * No infecting; [1] *Acholeplasma laidlawii* var. *granulum* st. 118.

leaves of wheat plants, infected with the agent of basal glum rot had the same dependence: the content of chlorophyll *a* decreased considerably − by 45 %, and that of chlorophyll *b* – by 67 % with the double amount of carotinoids (Table 2).

When infected with pathogens on the background of Extrakon, the content of chlorophyll a in the leaves was almost the same and had a tendency to increase, whereas the content of chlorophyll *b* and carotinoids increased by 33 and 50 % respectively. Therefore, the application of the consortium of humus-forming microorganisms in the composition of BP Extrakon demonstrated the stabilizing protective impact on the pigment composition of the leaves of winter wheat plants, especially when it was used together with infecting with phytopathogenic bacteria.

The antioxidant system is the mechanism of system phytoresistance, in particular, it relates to such components as catalase and peroxidase. Being components of the antioxidant system, catalase (EU 1.11.6) and peroxidase (EU 1.11.7) reduce hydrogen peroxide to water, using different compounds as reducing agents [24–27]. It envisages that catalase protects the cell from hydrogen peroxide, generated inside the cell, whereas peroxidase conditions specific intracellular oxidative processes, involving peroxide, which promotes the formation of relevant metabolites [24, 28].

The studies have established the changes in the activity of terminal oxidases in the tissues of leaves both when plants were infected with phytopathogenic microorganisms and when they were grown on soil with introduced consortium of humus-forming microorganisms (Table 3, 4).

The decrease of catalase activity by 8.7 % was demonstrated in case of infecting with phytopathogenic acholeplasmas along with a considerable increase in peroxidase activity − by 60 %, which is reasonable due to the known ability of *A. laidlawii* var. *granulum* st. 118 to inhibit the activity of antioxidant enzymes [29]. The activity of terminal oxidases allows both slowing down possible impairment of plant metabolism and ensuring maximal economy of energetic and structural resources. In this case infecting on the background of BP Extrakon increases considerably both catalase (by 31 %) and peroxidase activity (2.3 times) (see Table 3). Contrary to the impact of phytoplasma, infecting with the agent of basal glum rot promotes a more considerable increase in the activity of terminal oxidases. The catalase activity in the wheat plant leaves, infected with the agent of *P. syringae* pv. *atrofaciens*, increases by 23 %, and that of peroxidase – 3-fold (see Table 4). When infecting on the background of BP Extrakon, the catalase activity increases more considerably (3-fold) in wheat plant leaves. At the same time the increase in peroxidase activity became more moderate, though the level of increasing it was significant – 85 % (see Table 4). Thus, the ratio of the activity of terminal oxidases changes towards catalase activity.

The following stage in the studies was the determination of the photochemical activity of the leaves using the biophysical method of chlorophyll fluorescence induction [12, 13, 15].

It is known that chlorophyll *a* of photosystem II (PS) is the one to mainly fluorescent. The changes in its fluorescence reflect the fluctuations in the redox condition of the reactive centers (RC) of this photosystem [9–14, 19].

The background fluorescence (F_0) is characterized by the emission of photons at the beginning of the fast phase of fluorescence, when all RC of molecules of chlorophyll-detectors are open, and the absorbed energy migrates along the pigment matrix. Usually this fluorescence is minimal – about 3 %, and its increase testifies to the impairment of connections between

Table 2. The pigment composition of the leaves of spring wheat plants, infected with the agent of basal glum rot, *P. syringae* pv. *atrofaciens*, on the background of BP Extrakon

Experiment variant	Pigments, mg/g of raw material		
	Chlorophyll *a*	Chlorophyll *b*	Carotinoids
Control *	0.90 ± 0.04	0.60 ± 0.02	0.20 ± 0.01
Infecting [2]	0.40 ± 0.01	0.20 ± 0.01	0.10 ± 0.003
BP Extrakon *	0.70 ± 0.03	0.50 ± 0.02	0.20 ± 0.007
Infecting1 on the background of BP Extrakon	1.00 ± 0.04	0.80 ± 0.03	0.30 ± 0.01

Note. *No infecting; [2] *P. syringae* pv. *atrofaciens* 9771.

chlorophyll molecules, their degradation or synthesis of new molecules. A more significant increase in background fluorescence is only in case of infecting with phytopathogenic acholeplasmas – by 47 %. At the same time, when infecting with acholeplasmas occurs on the background of inoculation of the consortium of humus-forming microorganisms into the soil, the level of F_0 increases, but less significantly – by 22 %.

In case of mixed infecting this parameter was almost no different from the control. A similar situation was observed for mixed infecting on the background of BP Extrakon.

Therefore, with simultaneous infection by both agents − *P. syringae* pv. *atrofaciens* and *A. laidlawii* var.*granulum* st. 118 − in conditions of mixed infection the antenna of the light-absorbing complex is more stable than in case of infecting with acholeplasmas only (Table 5). The mechanism of this impact may be explained by the inhibition of the development of some pathogens in presence of others with combined infecting, which may be caused both by the activity of exometabolites and competition for energetic material. At the same time the index of variable fluorescence, determined by the redox status of Q_A and serving as an index of photochemical redox processes [13] increased by 39 % in the plant leaves on the soil, inoculated with BP Extrakon, which testifies to the enhancement of the course of the rapid phase of photosynthesis, in particular, the transfer of electrons in electron-transporting chain.

When infected with acholeplasmas, the decrease in this index by 82 % was eliminated on the soil with the inoculation of BP Extrakon and reached 13 %. The agent of basal glum rot inhibited F_v by 17 %, whereas F_v increased considerably on the soil with the addition of BP Extrakon – by 42 %. A similar tendency was observed in conditions of mixed infecting: a considerable decrease of the variable fluorescence at the impairment (by 41 %) and the increase when infected at the background of BP Extrakon (by 23 %). Therefore, due to the saturation of soil with biologically active substances and available nutrients, the consortium of soil microorganisms promotes the maintenance of the resistance of the photosynthetic apparatus to impairment in conditions of the oxidative stress at the destructive impact of phytopathogenic microorganisms of different genera.

The following analyzed index − K_{pl} − is the reflection of the number of Qb-non-restoring complexes, which do not participate in the linear transport of electrons to the reaction centers of PS II [30]. The analysis of the induction curve by this parameter revealed its considerable increase in the leaves of wheat plants, infected with acholeplasmas (by 59 %), whereas in case of infecting on the background of BP Extrakon its increase was insignificant (by 9 %). It is noteworthy that the value of K_{pl} of leaves on the background of BP Extrakon decreased considerably – by 23 %. Infecting with the agent of basal glum rot impacted the balance of redox and non-redox complexes, doubling the number of the latter, whereas in case of infecting on the background of BP Extrakon their number increased rather considerably, but in a lesser degree – by 59 % (see Table 5).

The value of the induction coefficient, which is in direct correlation with the activity of the key enzyme of Calvin's cycle of Rubisco [11] and in indirect correla-

Table 3. The activity of antioxidant enzymes of the leaves of spring wheat plants, infected with *A. laidlawii* var.*granulum* 118 on the background of BP Extrakon

Experiment variant	Enzymatic activity	
	Catalase, ml $O_2 \cdot g^{-1} \times \times min^{-1}$	Peroxidase, $\Delta D_{670} \cdot g^{-1} \times \times s^{-1}$
Control *	3.91 ± 0.71	1.10 ± 0.015
Infecting [1]	3.57 ± 0.17	1.76 ± 0.087
Infecting [1] on the background of BP Extrakon	5.13 ± 0.25	2.57 ± 0.13

Note. * No infecting; [1] *Acholeplasma laidlawii* var. *granulum* st. 118.

Table 4. The activity of antioxidant enzymes of the leaves of spring wheat plants, infected with *P. syringae* pv. *atrofaciens* on the background of BP Extrakon

Experiment variant	Enzymatic activity	
	Catalase, ml $O_2 \cdot g^{-1} \times \times min^{-1}$	Peroxidase, $\Delta D_{670} \cdot g^{-1} \times \times s^{-1}$
Control *	1.73 ± 0.08	1.06 ± 0.05
Infecting [2]	2.13 ± 0.10	3.33 ± 0.12
Infecting [2] on the background of BP Extrakon	5.78 ± 0.28	1.97 ± 0.09

Note. *No infecting; [2]*P. syringae* pv. *atrofaciens* 9771.

Table 5. The induction parameters of fluorescence at the impact of intentional infecting with different kinds of pathogenic microorganisms of spring wheat plants, cultivated on the soil with the addition of biological preparation Extrakon

Experiment variant	Fluorescence parameter, relative units					
	F_0	F_v	K_{pl}	K_l	qF	F_l
Control *	432	842	0.22	0.73	0.90	627
Infecting [1]	637	688	0.35	0.44	0.59	777.6
BP Extrakon *	470	1172	0.17	1.31	2.02	518.4
Infecting1 on the background of BP Extrakon	528	950	0.24	1.04	1.27	630.4
Infecting [2]	1430	701	0.45	0.17	0.40	1478
Infecting [2] on the background of BP Extrakon	941	1193	0.35	0.64	0.83	1120
Combined infecting of plants [3]	992	496	0.48	0.10	0.33	1078.4
Combined infecting of plants [3] on the background of BP Extrakon *	886	1037	0.17	0.51	0.72	1097.6

Note. *No infecting; [1]*Acholeplasma laidlawii* var. *granulum* st. 118; [2]*P. syringae* pv. *atrofaciens* 9771; "[3]" – infecting with both agents – *P. syringae* pv. *atrofaciens* 9771 and *A. laidlawii* var. *granulum* 118.

tion – with the efficiency of the dark phase of carbon fixation, increases considerably – by 79 % and when the parameter is elevated, the fluorescent quenching is doubled in the leaves of plants, which grew in the soil, inoculated with BP Extrakon. The value of K_i in the leaves, infected with acholeplasmas, decreased by 40 %, whereas the addition of BP Extrakon had a positive impact on this index, increasing it by 43 %. Mixed infection had a greater inhibiting effect on the activity of Rubisco (by 86 %), but when infected on the background of BP Extrakon it increased by 30 %. Infecting with the agent of basal glum rot alone decreased K_i somewhat less than mixed infecting (by 77 %), whereas this value decreased only by 12 % when infected on the background of BP Extrakon.

Table 6. The impact of BP Extrakon on grain productivity of spring wheat at the infection with phytopathogenic microorganisms

Experiment variant	Grain productivity **
Control*	17.0 ± 0.7
BP Extrakon*	17.1 ± 0.6
Infecting with *A. laidlawii* var. *granulum* 118	11.6 ± 0.37
Infecting with *A. laidlawii* var. *granulum* 118 on the background of BP Extrakon	13.3 ± 0.5
Infecting with *P. syringae* pv. *atrofaciens*	13.0 ± 0.4
Infecting with *P. syringae* pv. *atrofaciens* on the background of BP Extrakon	14.2 ± 0.6

Note. *No infecting; **g/20 plants.

The highest inhibition of the fluorescence quenching parameter was observed in the following variants: infecting with acholeplasmas – by 34 %, mixed infecting – by 63 %, and infecting with the agent of basal glum rot – by 56 %. Infecting on the background of BP Extrakon increased the value of fluorescence quenching in case of acholeplasma by 41 % and decreased this index by 20 and 8 % for mixed and bacterial infecting respectively. The value of F_t, which corresponds to the stationary level of fluorescence and is related to its quenching, changed in a similar way, having the highest increase for infecting with acholeplasmas and for mixed infection, except for the variant with the activity of the basal glum rot, where this index increased considerably – by 79 % (see Table 5). The fluctuations of the fluorescence quenching parameter testify to the redox status of the components of electron transport chain and the primary transmitter of electrons Q_A. It is known that the increase in fluorescence quenching corresponds to the intensity increase of reactions, using ATP and $NADPN_2$, and the restoration of Q_A pool in chloroplasts.

In case of adding BP Extrakon into soil the grain productivity calculated per 20 plants remained at the level of control plants (Table 6). Infecting with acholeplasmas and the agent of basal glum rot decreased it by 32 and 24 % respectively, and infecting on the background of BP inoculation allowed decreasing the pathogenic impact agents of diseases on this parame-

ter, which was reflected in a lesser degree of inhibition of grain productivity of inoculated plants – by 22 and 17 % respectively.

Having analyzed the obtained data, the conclusion was made that an insignificant increase in grain productivity along with the increase in K_i (activation of Rubisco) may be related to the increase in the photorespiration process, which in C3 plants may be 50 % from the photosynthesis intensity and thus is competitive for it, resulting in the decrease in the efficiency of reserving energy due to spending it in the glycolate cycle [31].

The positive role of the photorespiration process consists in protecting the photosynthesis apparatus from photooxidation. It is also known that the oxidation of glycolic acid in peroxisomes in the photorespiration process is the main source of toxic hydrogen peroxide in the photosynthesizing plant cell [25]. This is indirectly confirmed by the data on the increase in catalase and peroxidase activity of plant leaves on the background of BP Extrakon, the main substrate of which is hydrogen peroxide.

At the same time the activity of the consortium of humus-forming microorganisms was directed at the formation of a plant-microbe system [32] and thus indirectly supported the photoimmunity of plants without any direct impact on phytopathogenic microorganisms.

CONCLUSIONS

The inhibition of growth processes and the content of pigments – chlorophylls *a*, *b,* and carotinoids was demonstrated in the leaves of infected wheat plants in the tillering phase, intentionally infected with phytopathogenic microorganisms *P. syringae* pv. *atrofaciens* and *A. laidlawii* var. *granulum*. The cultivation of plants on the soil with the addition of the biological preparation Extrakon eliminates the impact of phytopathogens on the growth and pigment composition of spring wheat plants, especially the phytopathogenic activity of *P. syringae* pv. *atrofaciens*.

The determination of the activity of terminal oxidases demonstrated its increase at the impact of *P. syringae* pv. *atrofaciens* and the inhibition of catalase and the increase in peroxidase activity at the impact of *A. laidlawii* var. *granulum*. The highest increase in catalase activity was observed in the leaves of plants, infected with phytopathogens, on the background of Extrakon.

Infecting wheat plants with *P. syringae* pv. *atrofaciens* and *A. laidlawii* and mixed infecting with these pathogens decreased the photochemical activity of the leaves of infected plants and thus the efficiency of involving light energy in the rapid and slow (dark) phase of carbon photoassimilation, especially on the background of mixed infecting. The application of the consortium of humus-forming microorganisms decreased the negative effect of artificial infecting and promoted the increase in the photosynthetic activity of the leaves. The investigated factors influenced grain productivity of spring wheat plants in the same way.

Therefore the soil improvement due to the application and multifunctional activity of the consortium of humus-forming microorganisms in the composition of the biological preparation Extrakon promotes the development of the resistance of the photosynthesis apparatus of wheat to damage and the decreased loss of grain productivity in conditions of the oxidative stress and phytopathogenic impact of the agents of basal glum rot and pale green dwarfism of wheat, which may serve as a basis for modern ecologically safe resource-preserving agrotechnologies.

Вплив біологічного препарату «Extrakon» на фотосинтетичний апарат, ферментативну активність антиоксидантних ферментів та продуктивність рослин ярої пшениці в системі фітопатоген−хазяїн

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Мета. Комплексне дослідження впливу внесеного в ризосферу консорціуму гумусоутворюючих мікроорганізмів у складі біологічного препарату «Extrakon» на інтактні рослини та рослини, інфіковані фітопатогенними мікроорганізмами *Pseudomonas syringae* pv. *atrofaciens* шт. 9771 і *Acholeplasma laidlawii* var. *granulum* шт.118. **Методи.** Мікробіологічні, фізіолого-біохімічні, біофізичні, статистичні. **Результати.** Проаналізовано й узагальнено результати впливу внесеного в ґрунт мультифункціонального біологічного препарату «Extrakon» на фізіолого-біохімічні показники, зокрема – каталазну і пероксидазну активність тканин і вміст хлорофілів *a* і *b*, фотохімічну активність фотосинтетичного апарату та зернову продуктивність інтактних і уражених фітопатогенними мікроорганізмами *P. syringae* pv. *atrofaciens* шт. 9771 і *A. laidlawii* var. *granulum* шт.118 рослин ярої

пшениці сорту Печерянка. Внаслідок застосування консорціуму гумусоутворюючих мікроорганізмів у складі біологічного препарату «Extrakon» зафіксовано стабілізувальну захисну дію на пігментний склад листків рослин ярої пшениці та їхню фотохімічну активність, особливо при інфікуванні фітопатогенними бактеріями. За інфікування рослин пшениці на фоні внесення в ґрунт препарату «Extrakon» зменшувалися втрати у зерновій продуктивності. **Висновки.** Біологічний препарат «Extrakon» нівелює деструктивний ефект, спричинений фітопатогенами видів *P. syringae* pv. *atrofaciens* і *A. laidlawii* var. *granulum* шт. 118 на фотосинтетичний апарат рослини-хазяїна. За його дії зростає вміст пігментів у листках та відбувається індукування розвитку стійкості до пошкоджень в умовах окиснювального стресу при збільшенні в тканинах активності антиоксидантних ферментів, особливо каталази. Разом з тим спостерігається підвищення фотосинтетичної активності листків, а також зернової продуктивності рослин.

Ключові слова: *Triticum aestivum L.*, *Pseudomonas syringae* pv. *atrofaciens*, *Acholeplasma laidlawii* var. *granulum* шт. 118, консорціум гумусоутворюючих мікроорганізмів, активність антиоксидантних ферментів, пігменти, індукція флуоресценції хлорофілу.

Влияние биологического препарата «Extrakon» на фотосинтетический аппарат, активность антиоксидантных ферментов и продуктивность растений яровой пшеницы в системе фитопатоген–хозяин

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Цель. Комплексное исследование действия инокулированного в ризосферу консорциума гумусообразующих микроорганизмов в составе биологического препарата «Extrakon» на интактные растения и растения, инфицированные фитопатогенными микроорганизмами *Pseudomonas syringae* pv. *atrofaciens* шт. 9771 и *Acholeplasma laidlawii* var. *granulum* шт. 118. **Методы.** Микробиологические, физиолого-биохимические, биофизические, статистические. **Результаты.** Проанализированы и обобщены результаты влияния инокулированного в почву мультифункционального биологического препарата «Extrakon» на физиолого-биохимические показатели, в частности, каталазную и пероксидазную активность тканей и содержание хлорофиллов *a* и *b*, фотохимическую активность фотосинтетического аппарата и зерновую продуктивность интактных и пораженных фитопатогенными микроорганизмами *Pseudomonas syringae* pv. *atrofaciens* шт. 9771 и *Acholeplasma laidlawii* var. *granulum* шт.118 растений яровой пшеницы сорта Печерянка. Вследствие применения консорциума гумусообразующих микроорганизмов в составе биологического препарата «Extrakon» зафиксировано стабилизирующее защитное действие на пигментный состав листьев растений яровой пшеницы и их фотохимическую активность, особенно при инфицировании фитопатогенными бактериями. При инфицировании растений пшеницы на фоне инокуляции в почву препарата «Extrakon» уменьшались потери в зерновой продуктивности. **Выводы.** Биологический препарат «Extrakon» нивелирует деструктивный эффект, вызванный фитопатогенами видов *P. syringae* pv. *atrofaciens* и *A. laidlawii* var. *granulum* шт. 118, на фотосинтетический аппарат растения–хозяина. При его действии возрастает содержание пигментов в листьях и индуцируется устойчивость к повреждению в условиях окислительного стресса наряду с увеличением в тканях активности антиоксидантных ферментов, особенно каталазы. Вместе с тем наблюдается повышение фотосинтетической активности листьев, а также зерновой продуктивности растений.

Ключевые слова: *Triticum aestivum L.*, *Pseudomonas syringae* pv. *atrofaciens*, *Acholeplasma laidlawii* var. *granulum* шт. 118, консорциум гумусообразующих микроорганизмов, активность антиоксидантных ферментов, пигменты, индукция флуоресценции хлорофилла.

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