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The biological basis for the use of acrylic hydrogel and protein growth stimulant in the soft wheat and triticale cultivation

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Abstract. The development of technologies for the environmentally friendly biopreparations production and use including biopreparations based on acrylic hydrogel and protein growth stimulant, which is obtained by chemical hydrolysis from by-products of slaughtered animals processing is carried out as part of the optimization of the phytosanitary condition of wheat crops and creation of favourable agro-ecological conditions for its cultivation. An important feature of acrylic hydrogel is the ability to retain and release water to plants when needed. At the same time, protein hydrolysate can provide plants with an additional source of nitrogen which is a component of plant proteins, chlorophyll and it is necessary for normal growth and development of plants during the vegetation. The addition of the protein growth stimulant to acrylic hydrogel expands the potential application of Super Moisture Absorbent (SMA) due to the long-term growth-stimulating effect on plants. The acrylic hydrogel and protein growth stimulant were added to the soil when wheat sowing in the certain concentrations and proportions. Wheat productivity was studied by the indicators complex, characterized the plants morphological features and the yield structure. Assessment of the degree of plant affection caused by pathogens was carried out both according to the generally accepted phytopathological indicator - conditional intensity of development, and using additional parameters. In the research, it was found that acrylic hydrogel and protein growth stimulant provide an increase in wheat yield and reduce the pathogens harmfulness. In combined application, they can be used in agriculture for wheat cultivation as a low-cost and environmentally friendly soil conditioner.

Key words: acrylic hydrogel, plant diseases, productivity elements, protein growth stimulant, soft wheat, triticale.

INTRODUCTION

Currently, research aimed at finding ways to increase the yield and quality of grain crops is becoming especially relevant, in particular, using techniques that improve the moisture supply and nutrition of plants, reduce the harmfulness of pathogens and optimize the phytosanitary state of agrocenoses (Pavlyushin et al., 2016). The production of agricultural crops in the world is accompanied by the depletion of fresh water resources as a result of irrigation of cultivated areas, chemical and biological pollution, and the growth of greenhouse gas emissions (Falkenmark & Rockström, 2014). At the same time, the annual production of cereals in the world should grow by almost a billion tons, as the world's population may exceed nine billion people by 2050 (Shewry et al., 2016). Factors that reduce the yield of grain crops are the decrease in agricultural land suitable for cultivation, climate change, unpredictable stress factors of an abiotic and biotic nature In addition, the decline in the genetic diversity of wheat in the pursuit of elite high-yielding varieties, in particular, leads to the formation of new races of pathogens, contributes to the accumulation of the infectious potential of pathogens that lead to epiphytosis (Figueroa et al., 2018; Novakazi et al., 2020). In the world, the total loss of grain crops caused by climate change and pollution can reach 37% (Burney & Ramanathan, 2014). According to Gupta et al. (2017) an increase in the average daily maximum and minimum temperatures by 1 °C will lead to a decrease in wheat yield by 2–4%. In the conditions of global warming and aridization, in general, in Russia by 2030, grain yields may decrease by 15%, and in the Volga region, in the south of Western Siberia and the North Caucasus - by 20% (Zhuchenko, 2004). The grain shortage can reach by 27% if the increase in the aridity of the climate will appear combined with soil degradation (Gundyrin et al., 2016).

Polymer materials are widely used in various priority areas of science, technology and engineering development. They are easily processed and chemically modified, and have valuable physical and mechanical properties (Zhang et al., 2013).

Recently, among the most promising polymer materials, a special group of ‘soft’ polymer materials - hydrogels, which are usually a three-dimensional matrix consisting of linear (or branched) hydrophilic weakly cross-linked polymers with the ability to absorb large amounts of liquid, may to be of great interest (Pourjavadi et al., 2004; Chang et al., 2010). The radical copolymerization of monomers in aqueous solutions using crosslinking agents containing two or more unsaturated groups is the most common method for the synthesis of chemically crosslinked acrylic hydrogels (Zoolshoev et al., 2016). The radical polymerization of acrylic monomers can be carried out in aqueous or organic medium, suspension, mass, or emulsion (Kabiri et al., 2011; Iqbal et al., 2016). Bi - or polyfunctional low-molecular-weight compounds of the acrylate type, such as divinylbenzene, methylene bis-acrylamide, guanidine methacrylate, etc., are usually used as a crosslinking agent during radical polymerization, which leads to crosslinking of the macrocains (Chavda et al., 2012). The method of crosslinking polymer macromolecules in solution is also used to create hydrogels from natural polymers, such as cellulose or chitosan (Bigi et al., 2001; Zhang et al., 2006).

A hydrogel particle, which is a cross-linked hydrophilic polymer (superabsorbing polymer, SAP), can rapidly swell up to 1,000 times its dry volume and retains a large amount of water (Yamaguchi, 2014). In agriculture, hydrogels are mainly used as soil structure-forming agents and polymer carriers for the release of nutrients necessary for the growth and development of crops, as well as in the production of chemical plant protection products (Guilherme et al., 2015). Hydrogel, especially in southern Russia, reducing the moisture deficit and improves the moisture availability of plants, reduces the risk of crop losses leading culture of winter wheat, and therefore, improve stability of grain production. In particular, according to Gundyrin et al. (2016), when using hydrogel, the value of the increase in wheat yield can vary from 4.0 to 24.7 c per ha (8.8–44.0%).

Advances in the synthesis of tetrazole derivatives have increased the possibility of obtaining new macromolecular compounds, which has significantly increased interest in this class of (co)polymers, since the introduction of tetrazole-containing monomers into copolymers has expanded the areas of practical application of acrylic hydrogels. The use of copolymers based on acrylic acid (AC) salts and 2-methyl-5-vinyltetrazole is possible as a medium for growing plants at high temperatures of surrounding environment (Kabakova et al., 2003). Strongly swollen acrylic copolymers, along with a high water-holding capacity, have the presence of nitrogen and potassium elements in their composition, contribute to increasing crop yields and their resistance to adverse environmental factors (Bortolin al, 2011). It should be noted that at the initial stages of wheat development, the lack of nitrogen leads to a decrease in the natural weight of the grain, and in the later stages of ontogenesis - to a decrease in its quality: the protein content (Bairwa et al., 2013b).

The properties of acrylic hydrogels resemble those of biological tissues and are due to their ability to retain and release water to plants as needed (Zohuriaan-Mehr & Kabiri, 2008). The degree of swelling in distilled water and in saline solution of acrylic hydrogel composites can reach: 700 g g^{-1} and 75 g g^{-1} (Baidakova et al., 2019b). The water absorption of hybrid hydrogels obtained by free radical polymerization in an aqueous medium from acrylamide, acrylic acid and corn starch was 400–700 g g^{-1} in distilled water and 100–150 g g^{-1} in NaCl solution at a temperature of 20–30 °C (Long et al., 2003).

From a wide range of commercially available moisture-retaining sorbents, it can be noted: ‘Soiltex L7’, ‘Agrosoke’ (Great Britain), ‘Sumikagel’ (Japan), ‘Arasorb’ (Japan), ‘Matrigel’ (Germany), ‘Juviderm’ (France), ‘Hydrat sol P’ (France), etc. A moisture-absorbing agent based on hydrolyzed acrylonitrile and cellulose waste ‘RAPG’, had a degree of swelling up to 750 g g^{-1} (Gundyrin et al., 2016). The application doses of moisture-retaining polymer sorbents are minimal (0.3–0.5% of the soil weight), and depend on the type of soil and climate zone, the growing season of plants, the type of agricultural crop, etc. (Baran et al., 2015).

Soil conditioners can be an additional source of ammonium nitrogen for soil bacteria (Dabhi et al., 2013). In particular, the addition of wood flour to polyacrylamide hydrogel was an additional source of nutrition for soil bacteria (Entrya et al., 2002).

Acrylic hydrogels do not cause a negative impact on the environment, since they are introduced in small quantities, and decompose by microorganisms within 1–3 years, depending on their composition and production methods. At the same time, they are most advantageous economically compared to materials obtained on the basis of biopolymers in the price -properties ratio.

The inclusion of various fillers in the copolymers composition significantly expands the potential for the use of acrylic super moisture-absorbing agents by improving the physical and chemical properties of materials (Uspenskaya et al., 2005).

The use of the hydrogel matrix as a carrier of the nutrients necessary for the plant during the growing season is quite an urgent issue (Zhong et al., 2013). As nutrients for plant growth can be used secondary raw materials of meat processing secondary raw materials of meat processing for plant growth (Kremenevskaya et al., 2017). The combined use of acrylic hydrogels and hydrolyzed protein waste as fillers leads to regulated plant growth (Baidakova et al., 2019b). The use of amino acids of secondary biological raw materials makes it possible to obtain prerarations with growth-stimulating properties that can compete with expensive plant growth regulators. The cost of the biopreparation, obtained by us from the cattle hides production waste is about 1.7 euros. Thus, the development of polymer hydrogels filled with the protein growth stimulant obtained from collagen-containing animal tissue waste is a very relevant and promising direction for improving the soil structure, increasing its moisture capacity and optimizing the acid-alkaline balance (Yanez-Chavez et al., 2014; Baran et al., 2015; Mellelo et al., 2019).

The purpose of this work is to study the effectiveness of a polymer hydrogel based on potassium acrylate and the protein growth stimulant, including when they are used together in the soft wheat cultivation. Materials and Methods sections should include full description of all the materials, chemicals, instrumentation, and methodologies that were used in the work.

MATERIALS AND METHODS

Experimental studies were carried out in the experimental field of the Federal Research Center N.I. Vavilov All Russian Institute of Plant Genetic Resourses (VIR). The plant material for the study included the cultivars of soft wheat and triticale: Trizo, k-64981(Russia, Leningrad region) and Dua, k-828 (Australia). These samples were provided for study by the Department of Wheat Genetic Resources of the VIR.

The study object was a moisture–absorbing polymer hydrogel composition based on potassium acrylate and N, N’ - methylenebisacrylamide as a crosslinking agent (Baidakova et al., 2019a). Divinylbenzene is used as crosslinking agent in the creation of various moisture super absorbents in concentrations of 0.01–0.001 wt.% of the entire material weight. Based on the monomers reactivity and toxicity, methylene bisacrylamide was chosen as a crosslinking agent in the work. The polymer hydrogel (Fig. 1) based on potassium acrylate was obtained using an unique technology at the International Research Institute of Bioengineering at ITMO University.

The technological scheme of the composite superlagoabsorbent synthesis process included: preparation of the reaction mixture; polymerization; washing of the resulting hydrogel from monomers (the sol-fraction removal); drying of the resulting acrylic hydrogel composite at a temperature of no more than 40 °C; crushing. The auxiliary stage - the purification of the initial monomers and reagents: ammonium persulfate (PSA), which was previously recrystallized according to the standard method for removing impurities (Rabinovich & Khavin, 1991), acrylic acid (AA) was previously distilled under vacuum to remove the polymerization inhibitor. Next, preparation an 8N aqueous solution of potassium hydroxide. The KOH concentration was determined by titration of 0.1 N hydrochloric acid solution in the presence of phenolphthalein. As a redox system, PSA and tetramethylethylenediamine were used. Preparation of a 2%

aqueous solution of ammonium persulfate PSA. Preparation of a 1% aqueous solution of TMED (Baidakova et al., 2019a).

The protein hydrolysate (Fig. 2) was developed using an unique technology at the mega Faculty of Food Biotechnologies and Low-Temperature Systems of ITMO University from the processed products of slaughtered animals (RF Patent No. 2662782. 31.07.2018).

Figure 1. The polymer hydrogel composition in the dried state.

Figure 2. The protein growth stimulant (protein hydrolysate).

The protein hydrolysate composition includes various combinations of polypeptides with different molecular weights and amino acids that affect the yield of agricultural crops and increase their resistance to unfavorable environmental factors. The main active component in the protein hydrolysate is the amino acid - glycine, the content of which in the protein filler used is one third of the total weight of all the amino acids present in it.

The experiments were arranged on a randomized complete block designed with three replicates. For one variant of the experiment, plot area was 1.0 m^2, treatments for plots in replicates were arranged systematically. The experiment samples were sown manually on plots in an ordinary way of sowing with the distance between rows by 15 cm and the distance between seeds in a row by 1–2 cm. The seeding depth was 5–6 cm. The seeding rate was 300 grains per 1 m^2. These activities were carried out in accordance with the generally accepted recommendations and methods of the VIR.

The scheme of the experiment when applying a polymer hydrogel and a protein growth stimulant to the soil when sowing soft wheat and triticale was as follows:

‘K ‘– Control (without applying biopreparations to the soil);

‘0.5 G’ – Hydrogel (based on the ability to bind 200 mL of water);

‘1G’ – Hydrogel (based on the ability to bind 400 mL of water);

‘0.5 G:1S’ – Hydrogel + Protein stimulant (based on the ability to bind 200 mL of water);

‘1G:2S’ – Hydrogel + Protein stimulant (based on the ability to bind 400 mL of water).

Polymer granules of hydrogel envelop the roots of wheat, forming a protective cover and prevent them from drying out (Fig. 3), and a protein stimulant improves plant nutrition.

Wheat productivity was described by 19 indicators that characterize the morphological features of plants and the structure of wheat yield in the earing-flowering and maturation phases (Kolesnikov, Popova et al., 2019). In particular, the total and productive bushiness of plants, the ontogenesis phases, the flag and pre-flag leaves area (cm^2), the plant vegetative part weight (g), etc. have been measured. The yield structure have been studied by the spikelets number per spike, pcs.; the spike length, cm; the spike weight, g; the grains number per spike, pcs.; the grains weight; the 1,000 grains weight. In addition, the samples' field germination was marked. The amount of sampling for each variant of the experiment was 20 plants.

Figure 3. The polymer granules on the roots of soft wheat.

The potential (biological) yield of a single wheat plant was calculated according to the data about the productive bushiness and the grains weight of spike per one plant (g $plant^{-1}$). In relation to the area of sowing, the potential yield (Yp) of wheat cultivars (t ha^{-1}) was measured by the productive bushiness, the grains weight per spike and the number of plants sown per 1 m^2:

$$Yp = Mk \cdot Kp \cdot Pp \cdot 10{,}000 \qquad (1)$$

where are: Mk – the grains weight of spike per one plant (t); Kp – productive bushiness of the sample; Pp – crop density (number of plants per 1 m^2), calculated using field germination data.

The intensity of wheat affection by diseases was determined using both generally accepted criteria (the disease development, the reaction type) and additional criteria (in particular, the pustules number per leaf, the pustule area for - rust fungi, the number of spots with plaque, the area of spots with plaque - for powdery mildew, etc.). The pathogenesis parameters were characterized by the results of wheat leaves measurements in the laboratory using the MBS-9 binocular and the Micromed trinocular (Kolesnikov, Novikova et al., 2018). The use of this set of pathogenesis indicators allowed to expand the range of methods of statistical data analysis applicable to the study, and to increase the accuracy of the experiment.

Figure 4. The conidia of the helminthosporous root rot (*Bipolaris sorokiniana (Sacc.) Shoes.).*

The degree of plant damage caused by *Bipolaris sorokiana* (Sacc.) Shoem - helminthosporous root rot was evaluated in the laboratory. (Fig. 4) in the phases of wheat tillering (the stage of finished tillering) and earing-flowering in accordance with the generally accepted method (Popov, 2011).

The affection intensity of wheat flag and pre-flag leaves by powdery mildew - *Blumeria graminis Speer.* (Fig. 5) was measured in accordance with the graphical scale of the conditional degree of plant damage

(Geshele, 1978), the number and area of spots with plaque were taken into account (Kolesnikov, Kremenevskaya et al., 2020).

The intensity of wheat damage caused by the yellow rust pathogen - *Puccinia striiformis* West. syn. R. *glumarum* Eriks. et Henn. (Fig. 6) was evaluated according to the generally accepted Manners scale, and, in addition, the total number of pustules per leaf, the number of strips with pustules, the length of the strips with pustules, the area of the pustule and their number in the strip were studied.

Figure 5. Symptoms of the wheat powdery mildew development.

The values of the rust species' pustules area and powdery mildew' spots were calculated on the assumption of their elliptical shape (Kolesnikov, Kremenevskaya et al., 2020; Kolesnikov, Novikova et al., 2020).

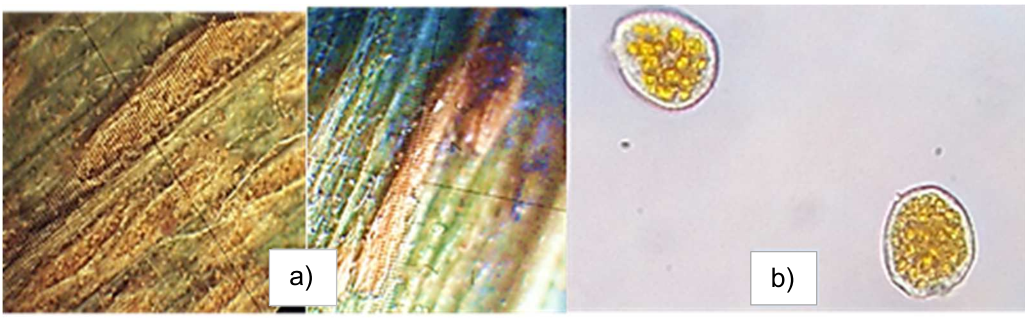

Figure 6. The symptoms of wheat yellow rust: uredopustules (a) and urediniospores (b).

Intensity of samples' damage, caused by septoria (*Stagonospora nodorum* (Berk.) Castellani & E.G. Germano), was determined in the phases of milk and wax ripeness of grain by the disease conditional development on the flag and pre-flag leaf surface in accordance with the James scale (James, 1971). The algorithm for statistical processing of field experience data was based on the creation of an electronic database, first in Microsoft Excel spreadsheets, then in the IBM SPSS Statistics software platform. The methods of parametric statistics based on the calculation of standard errors of the mean ± *SEM*, 95% confidence intervals and the Student's *t*-test were used in the calculations. Methods of nonparametric statistics included Cohen's test (Cohen, 1988), multiple comparisons (Scheffe's method).

RESULTS AND DISCUSSION

The polymer hydrogel, based on potassium acrylate and the protein growth stimulant, effect features on the soft wheat yield and triticale, including when used together, are shown on Fig. 7.

The maximum and statistically significant yield increase by 2.8 t ha^{-1} (Trizo, k-64981) and by 2.3 t ha^{-1} (Dua, k-828) was observed in the '1G:2S' experimental variant - when using the polymer hydrogel and protein growth stimulant combined.

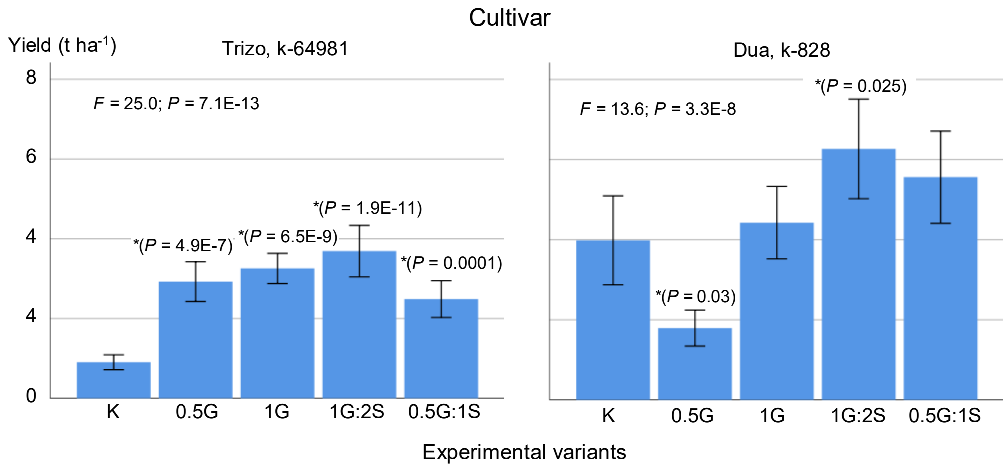

Figure 7. The soft wheat yield (t ha^{-1}) when using the polymer hydrogel and the protein growth stimulant, including their combined application. K-control; 0.5 G–hydrogel based on the ability to bind 200 mL of water; 1G–hydrogel (based on the ability to bind 400 mL of water); 0.5 G:1S–hydrogel + protein stimulant (based on the ability to bind 200 mL of water); 1G:2S–hydrogel + protein stimulant (based on of the ability to bind 400 mL of water). Vertical line – standard error of mean; * – significant values of the indicator, different from the control, according to the Scheffe criterion at a certain significance level; *F* – Fisher criterion according to the single-factor analysis of variance.

Subsequently, the effect size was estimated based on the calculation of Cohen's d values. Based on Cohen's test, a large effect was detected when the polymer hydrogel and the protein growth stimulant were used combined in the experiment variant 0.5 G:1S compared to the control (Trizo cultivar, k-64981: d = 2.5; Dua cultivar, k-828: d = 0.8) and an average medium effect - in the 1G variant:2S (Trizo grade, k-64981: d = 0.7; Dua grade, k-828: d = 0.5).

The change in the soft wheat and triticale potential yield per one plant (g plant), with the data about productive bushiness, is shown in Fig. 8. It is noted that the highest yield increase by 4.5–4.6 g was detected in the Trizo cultivar, k-64981 in the experimental variants, where the polymer hydrogel was used in the ratios of 0.5 G and 1G (0.5G – Cohen's d = 1.0 and 1G – Cohen's d = 1.1). The protein growth stimulant addition to the polymer hydrogel led to an increase in wheat yield by 18.1%.

The maximum value of B_p when B_p significantly increased by 26.4% (Trizo, k-64981) and by 35.8% (Dua, k-828) was registered in the experimental variant: protein growth stimulant + polymer hydrogel (1G:2S).

The highest biopreparations influence on the total and productive bushiness was registered on the Trizo cultivar, k-64981. The maximum increase in productive bushiness by 49.0–49.2% compared to the control was noted in the variants: 1G and 1G:2S (Fig. 9).

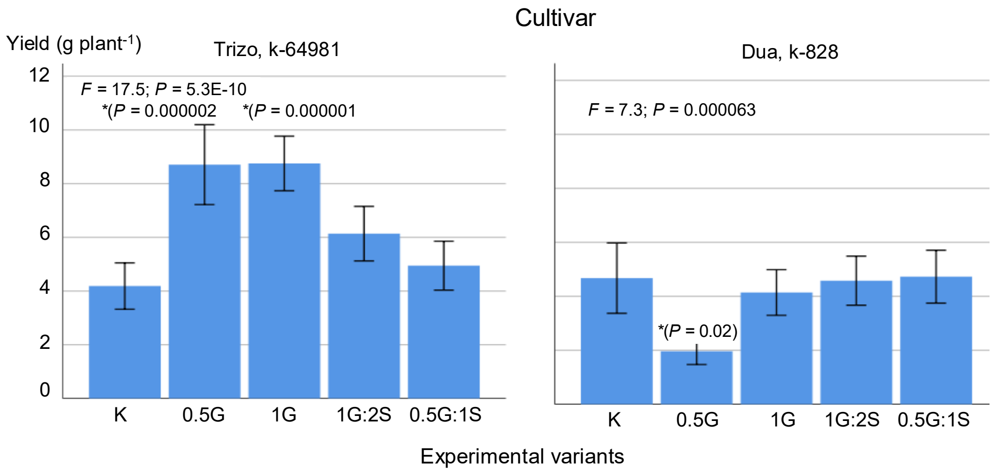

Figure 8. The changes in the potential yield of soft wheat (g plant^{-1}) when using the polymer hydrogel and the protein growth stimulant, including their combined application. K-control; 0.5 G–hydrogel based on the ability to bind 200 mL of water; 1G–hydrogel (based on the ability to bind 400 mL of water); 0.5 G:1S–hydrogel + protein stimulant (based on the ability to bind 200 mL of water); 1G:2S–hydrogel + protein stimulant (based on of the ability to bind 400 mL of water).Vertical line – standard error of mean; * – significant values of the indicator, different from the control, according to the Scheffe criterion at a certain significance level; *F* – Fisher criterion according to the single-factor analysis of variance.

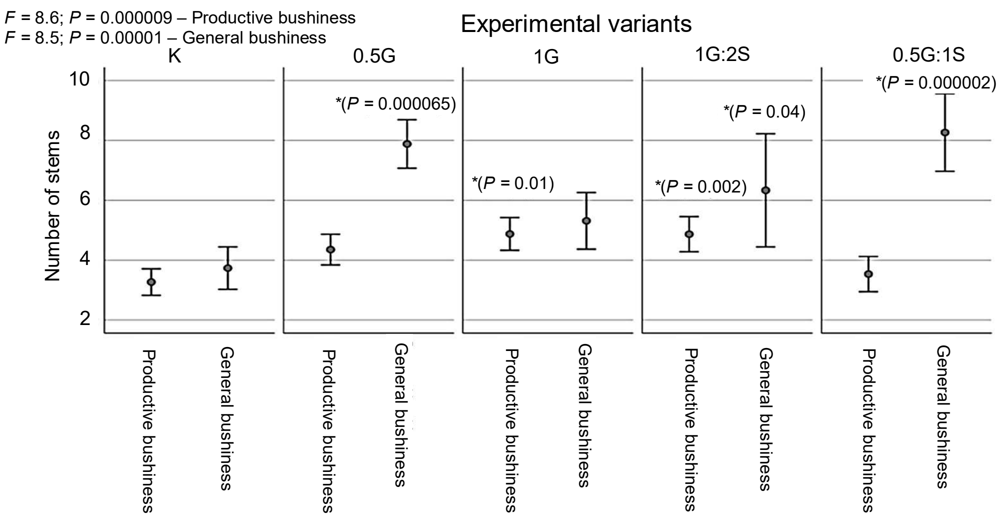

Figure 9. The productive and general bushiness of the Trizo soft wheat cultivar (k-64981) when using the polymer hydrogel and the protein growth stimulant, including their combined application. K-control; 0.5 G–hydrogel based on the ability to bind 200 mL of water; 1G–hydrogel (based on the ability to bind 400 mL of water); 0.5 G:1S–hydrogel + protein stimulant (based on the ability to bind 200 mL of water); 1G:2S–hydrogel + protein stimulant (based on of the ability to bind 400 mL of water).Vertical line – standard error of mean; * – significant values of the indicator, different from the control, according to the Scheffe criterion at a certain significance level; *F* – Fisher criterion according to the single-factor analysis of variance.

Based on Cohen's test of the wheat total bushiness, a large effect of the indicator changes was revealed in the variant: 0.5G (cultivar Trizo, k-64981: $d = 0.9$) and 0.5 G:1S (cultivar Trizo, k-64981: $d = 2.4$).

The change in the plants vegetative weight calculated on average for these wheat cultivars, depending on the experiment variant, is shown in Fig. 10. The largest increase in the plants vegetative weight (by 29.3%), compared with the control, was recorded in the 0.5G:1S variant. On the Trizo cultivar, k-64981 in the 1G variant, compared with the control, a significant increase by 72.4% of the nodal roots number and by 45.9% of the vegetative weight, while in the 0.5G variant - by 39.2% of the nodal roots length and by 27.4% of the vegetative mass was revealed. When the polymer hydrogel was used combined with the protein growth stimulant 0.5G:1S, the vegetative weight of plants increased by 35.6% compared to the control. However, there was no statistically significant effect of biopreparations on these parameters on Dua (k-828) triticale cultivar. Based on Cohen's test of the wheat vegetative weight in the 0.5G:1S variant, a large effect of the indicator changes was revealed in the cultivars Trizo, k-6498 ($d = 1.0$) and Dua, k-828 ($d = 0.8$).

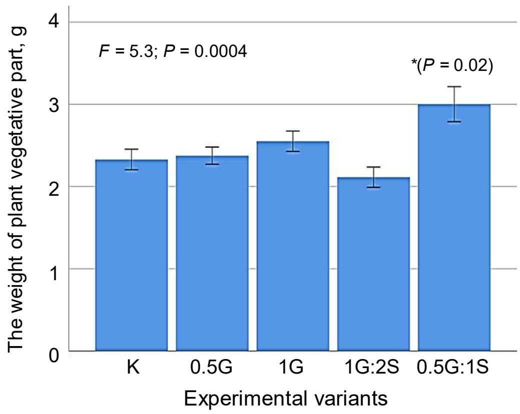

Figure 10. The weight of soft wheat vegetative part when using the polymer hydrogel and the protein growth stimulant, including their combined application. Vertical line – standard error of mean; * – significant values of the indicator, different from the control, according to the Scheffe criterion at a certain significance level; F – Fisher criterion according to the single-factor analysis of variance.

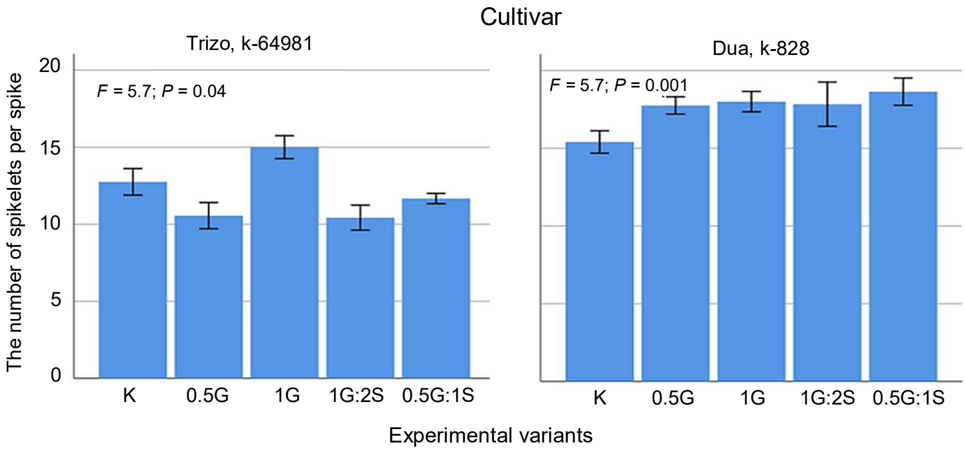

Figure 11. Changes in the number of spikelets per spike on Trizo, k-64981 and Duo, k-828 cultivars when using the polymer hydrogel and the protein growth stimulant, including their combined application. Vertical line – standard error of mean. F – Fisher criterion according to the single-factor analysis of variance.

The highest values of the spikelets number per spike (Fig. 11) and the grains number per spike (Fig. 12) in the variant 1G were registered (Trizo, k-64981 - Cohen's *d* = 0.5 and 0.9; Dua, k-828 - Cohen's *d* = 0.8 and 0.7, accordingly). The maximum effect size for the spikelets number per spike *d* = 1.3 was registered on the Dua, k-828 cultivar in the 0.5G:1S variant. On the Trizo, k-64981 cultivar, the use of polymer hydrogel led to an increase in the number of spikelets per spike by 9.0% and in the number of grains per spike by 24.2%, while on the Dua, k-828 cultivar - by 7.0% and 22.4%, respectively.

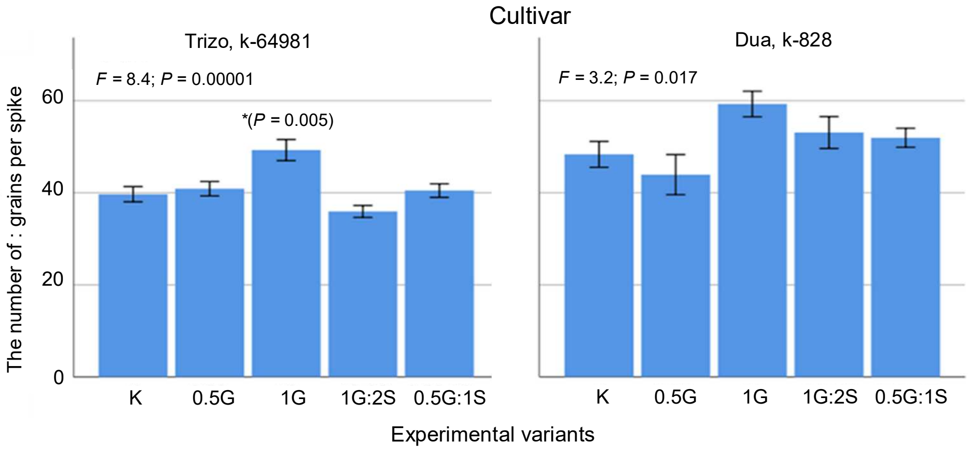

Figure 12. Changes in the number of grains per spike on Trizo, k-64981 and Duo, k-828 cultivars when using the polymer hydrogel and the protein growth stimulant, including their combined application. Vertical line – standard error of mean; * – significant values of the indicator, different from the control, according to the Scheffe criterion at a certain significance level; *F* – Fisher criterion according to the single-factor analysis of variance.

It is known that wheat diseases greatly reduce the crop yield. In particular, as shown in Fig. 13 the yield of wheat cultivar Trizo, k-64981 decreased depending on the intensity of the powdery mildew development. In addition, an inverse correlation was revealed between the pustules number (r = - 0.61), the number of pustules in the strip (r = -0.62), the length of the strip with yellow rust pustules (r = -0.65) and the area of the wheat flag leaf. The development of septoria (wheat leaf blotch) caused a decrease in the grains weight per spike (r = - 0.61).

Soft wheat (Trizo, k-64981) was affected in the most by the root rot pathogen (R_g = 20%) compared to triticale - (Duo, k-828) (R_g = 9.5%). In this regard, the biopreparations effectiveness was studied on the Trizo cultivar, k-64981. In the 0.5G experimental variant the root rot development had not detected. At the same time, only in this variant of the experiment, symptoms of powdery mildew development were revealed (R_m = 12.5 ± 2.5%; number of spots with a plaque of $N_{p.m.}$ = 12.0 ± 4.0; area of spots with a plaque of S_m = 5.9 ± 3.0 mm^2). The decrease in the root rot development by 9% compared to the control was noted in the 0.5G:1S experimental variant. When using only the polymer hydrogel in the 1G variant, a decrease in the root rot development by 6.7% was revealed. However, when the polymer hydrogel and the protein growth stimulant were used together at the highest concentrations in 1G:2S variant, the degree of plant damage by root rot increased by 2.2%.

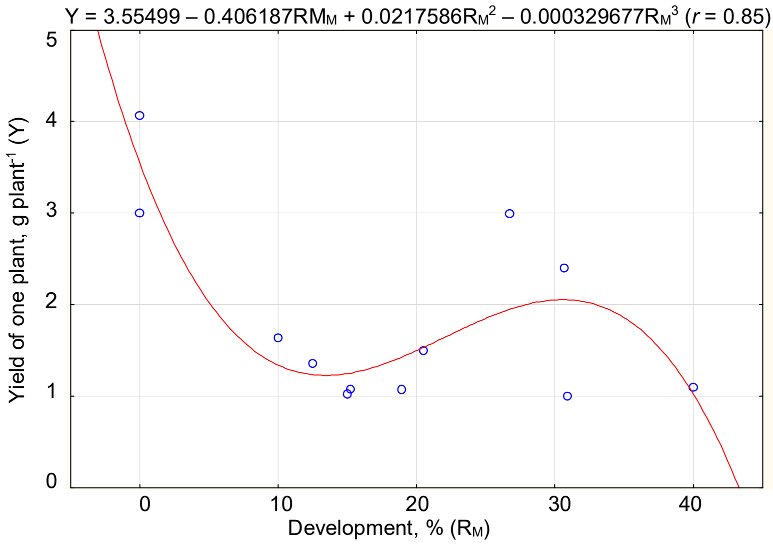

Figure 13. Dependence of the soft wheat (Trizo, k-64981) yield on the intensity of powdery mildew development

In accordance with Cohen's test values of root rot development on average on cultivars Trizo, k-64981 and Duo, k-828 in the 0.5G:1S variant, the greatest decrease in the disease development (by 11%) was revealed compared with the control, and the maximum scope of the effect $d = 0.9$ was marked. In this experimental variant, field germination increased by 30.2% ($d = 1.4$).

The development of wheat leaf blotch on the Trizo, k-64981 cultivar when using the polymer hydrogel in the 1G variant was the same as in the control. However, in the 0.5G experimental variant, when using the polymer hydrogel at lower concentrations and in the 1G:2S variant, when it used combined with the protein growth stimulant, the degree of wheat leaf damage by the disease decreased by 12.5% compared to the control (Cohen's test: $d = 5.3$ and $d = 6.1$, accordingly).

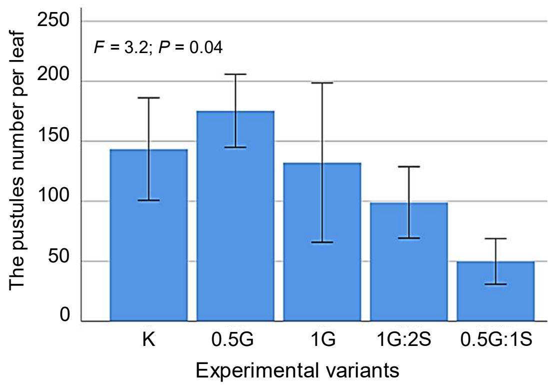

Figure 14. Change in the number of pustules of the yellow rust pathogen on the flag leaves of the Triso cultivar, k-64981, when using the polymer hydrogel and the protein growth stimulant, including their combined application. Vertical line – standard error of mean; *F* – Fisher criterion according to the single-factor analysis of variance.

The features of the yellow rust development, characterized by the number of pustules on the wheat flag leaf on the Trizo cultivar, k-64981 when using the polymer hydrogel and the protein growth stimulant, including their combined application, are shown in Fig. 14. In the experimental variant 0.5G:1S the smallest number of the pathogen pustules was registered (by 65.3% less than in the control, Cohen's test: $d = 0.7$).

In addition to the diseases development, in spring wheat and triticale sowings, for the first time in 2020, symptoms of deviation from normal plant growth and development - deformities of unknown etiology were revealed (Fig. 15). The most notable phenotypic changes were in the curvature of the spikes and spiral twisting of the leaves in the ear formation stage. During the subsequent ontogenesis phases, the symptoms remained unchanged until the harvest.

These deviations did not cause a significant decrease in yield, but their cause was not identified. Perhaps the changes were caused by some side effect during the period of action of the systemic herbicide StarTerr, BP, adverse weather conditions, as well as plant damage by phytoplasmas. Plant infestation with wheat nematode was excluded based on the results of plant material microscopy. In 2021, in the case of a return of such symptoms in cereals, we plan to study this phenomenon in detail through laboratory diagnostic methods.

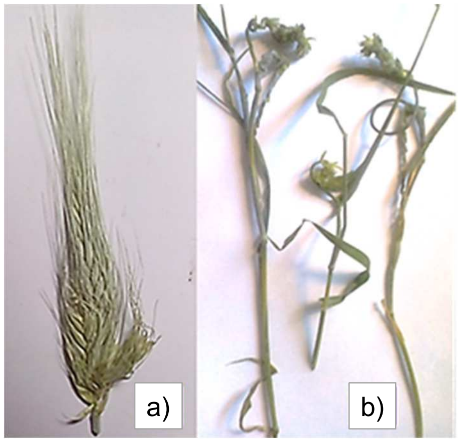

Figure 15. Symptoms of the plants' normal growth and development deviations of unknown etiology: a – deformation of triticale spikes (Dua cultivar, k-828), b –deformation of soft wheat plants (Trizo cultivar, k-64981).

The biopreparations use had an impact on the prevalence of symptoms of deviations from plants normal growth and development of unknown etiology. The greatest effectiveness in relation to the wheat deformation was revealed in the experimental variants 1G (Cohen's test: d = 1.1) and 1G:2S (Cohen's test: d = 1.3), where a decrease in the occurrence proportion of plants with deviations symptoms by 16.7% compared to the control was noted.

When evaluating the revealed values of effect size (Cohen's d) for 19 wheat productivity indicators in the above-mentioned experimental variants, the strongest effect on plants was registered for the protein growth stimulant and the polymer hydrogel combined application in the 0.5G:1S variant. A strong scope of the effect was noted for the growth of field germination, the increase in root length, the flag leaf area, the spike length, the spikelets number per spike, the spike weight, the potential yield. In this experimental variant, large effect size was revealed for reducing of the root rot development, and medium effect size - for indicators of the yellow rust development.

It should be noted that triticale has a greater adaptive potential to environmental factors than wheat. In this regard, we have identified a greater number of changes in photometric and phytopathological parameters in soft wheat in the experimental variants when using the polymer hydrogel and protein growth stimulant, including their combined application.

CONCLUSIONS

The stimulating treatments caused the most impact on the Trizo wheat cultivar, k-64981. The use of polymer hydrogel in the ratios 0.5G1 and 1G resulted in a statistically significant increase in 12 of the 19 indicators of wheat productivity (63.2%). The protein growth stimulant addition to the polymer hydrogel in 0.5G:1S and 1G:2S variants caused an increase by 15.8% of the indicators. However, when the protein growth stimulant and the polymer hydrogel were applied together to the soil, it was marked the greatest increase in the plants field germination - the most important indicator determining the yield of wheat: in the 1G:2S variant - by 26.4% and in the 0.5G:1S - by 20.0%, compared to other experimental variants, as well as a significant increase in the productive and total bushiness of the samples. In the 1G:2S variant of the experiment, the productive bushiness increased by 49.0%, and the total bushiness - by 69.6%. The maximum number of productivity indicators (26.3%), characterized by an increase in values compared to the control, was revealed on the triticale Dua, k-828 cultivar with the combined use of the polymer hydrogel and the protein growth stimulant in the 0.5G:1S experiment variant. In the experimental variants 1G:2S and 0.5 G:1S, in particular, a significant increase in the plants field germination by 35.8% and by 22.6%, their faster growth by 16.3% and by 11.0% (in the phase of ontogenesis) was noted. In the 0.5G:1S variant, the area of the flag and pre-flag triticale leaves, which directly affect the spike weight, increased by 80.3% and 61.2%, respectively. The maximum and statistically significant yield increase by 2.8 t ha^{-1} (Trizo, k-64981) and by 2.3 t ha^{-1} (Dua, k-828) was observed in the 1G:2S variant, which was mainly due to the joint statistically significant effect of the polymer hydrogel and the protein growth stimulant on field germination, while in the Trizo, k-64981 cultivar - on the productive bushiness of samples. In relation to pathogens, biopreparations acted ambiguously. The maximum decrease in the development intensity of root rot on the Trizo, cultivar k-64981 was identified in the 0.5G variant – by 20%, and the combined use of the polymer hydrogel and the protein growth stimulant (0.5G:1S) resulted in the disease development reduction by 8.9%. In addition, in the 0.5G:1S experimental variant, the minimum development of yellow rust was detected (the pustules number per leaf was less than in the control by 65.3%). The greatest effectiveness against wheat deformation of unknown etiology was revealed in the 1G and 1G:2S experimental variants, where there was a decrease in the occurrence proportion of plants with symptoms of deviations by 16.7% compared to the control.

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