Original Research Article

Polygalacturonates of Biogenic Metals - Prospective Components of New Composite Preparations for Wheat

ABSTRACT

New bi- and polymetallic complexes of polygalacturonic acid with essential trace elements for pre-sowing treatment of winter wheat seeds were created.

Aims: The goal of the research was to create effective environmentally safe preparations of multifunctional action, with low cost rates for grain crops based on natural polymers of pectin nature and to determine the effectiveness of their use for pre-sowing treatment of winter wheat seeds.

Methodology: Methods of chemical synthesis of products, research of their structure by atomic force microscopy were used in the work. Laboratory and vegetative experiments were carried out. The substrate is quartz sand. Physiological and biochemical methods were used to determine the working absorbing surface of the roots and its absorbing activity, amylolytic activity, the content of photosynthesis pigments according to Welburn. The results were processed using the methods of mathematical statistics.

Results: The atomic force microscopy method made it possible to detect a mixture of individual polymer molecules and their aggregates in pectin fractions. Depending on the concentration of pectins in the solution, they form different structures. New bi- and polymetallic complexes of polygalacturonic acid with essential trace elements for pre-sowing treatment of winter wheat seeds were created. According to the results of laboratory and vegetation experiments, the growth-stimulating activity of polygalacturonates of copper, iron, calcium, and nickel, which were used for pre-sowing processing of ***Smuhlyanka variety winter soft wheat seeds*** was determined. Preparations contribute to the active development of the root system of plants, strengthening their physiological activity. The investigated compounds are effective promising components of complex compositional preparations for modern agrotechnologies of winter wheat cultivation.

Conclusion: The use of such metal complexes at an insignificant rate of expenditure should contribute to the increase of economic and ecological indicators of crop production — the reduction of the cost price of wheat grain due to the increase in yield and grain quality

Keywords: Winter wheat, polygalacturonates of biogenic metals

1. INTRODUCTION

The modern production of agricultural products takes place in conditions of global natural and man-made challenges. As a result of climate change, the formation of large arid zones, salinization of substrates, water scarcity, there is a decrease in land area for crops, a decrease in their resistance to adverse environmental factors, the formation of new pathogens and pests of cultivated plants, an increase in their aggressiveness. All this leads to a decrease in crop yields, and a deterioration in the quality of products, including seeds, the sowing fractions of which have low germination rates (or indicators), and therefore contribute to the growth of prices in the markets.

The growing requirements for the ecological purity of crop products and the environment require the development of new approaches to plant protection and stimulation of their growth and development in unstable weather conditions and systemic depletion of soils. Therefore, for modern crop production, it is very important to create and implement new domestic environmentally friendly, technological and inexpensive multi-vector drugs, which, due to the impact on plants, would ensure an increase in the efficiency of their use of nutrient elements of mineral fertilizers and soil, contributed to mitigating the negative impact of numerous stress factors of abiotic and biotic nature, preserving and improving the yields and quality of crop products.

The use of polyfunctional preparations and microfertilizers for pre-sowing treatment of seeds and foliar dressings in crop production in Ukraine is a necessary and effective technological measure. In particular, this should be done when growing grain crops, taking into account the significant positive impact of microelements on productivity (or yield), quality of products, and plant resistance against various stress factors, mineral nutrition deficiency. Moreover, large areas of arable land in Ukraine are characterized by a low content of biogenic microelements in an accessible form for plants: 18 million ha have a low content of soluble forms of zinc, 2.5 mln ha – copper, 8 mln ha – cobalt, 15 mln ha – molybdenum, 8 mln ha – boron. Every year in domestic crop production there is a negative balance of essential microelements, especially zinc, copper, manganese, boron, and cobalt. This leads to a decrease in crop yields, an increase in the defeat of crops with phytopathogens, empty grains in cereals, and, as a result, a decrease in the profitability of grain production [5].

Modern agrobionanotechnology allows the use of natural seed adaptation systems and biologically active substances and, thereby, create additional seed resistance against negative environmental factors.

A fundamentally new approach to the synthesis of nanoscale multifunctional metal-containing materials for crop production and the pharmaceutical industry based on a unique stabilizing polymer matrix - arabinogalactan (AG) has been created. The difference between existing and new composites is that in the newly created composites there is a synergism of the properties of the natural stabilizing polymer matrix (biocompatibility, membrane-tropicity concerning a living cell, immunomodulatory properties, prolongation of biological action) and material of the central nanoscale nucleus - nanoparticles of biogenic metal. Arabinogalactan is characterized by high membrane resistance, ligand properties, colloidal stabilizer, antioxidant, immunomodulator, etc. [6].

The method of synthesis of water-soluble metal-containing derivatives of AG with cobalt and nickel has been developed. Metal-containing preparations AG retain the structural organization, water solubility, and membrane-tropicity of natural polysaccharides; metal content does not exceed 6%, which allows you to dose drugs taking into account the low concentration requirement for microelements [7].

Other authors believe that the action of substances that contain polysaccharide dominant, including pectins, is based on the specificity of carbohydrate-carbohydrate and carbohydrate-protein interactions on the surface of cells. The peculiarity of the structure of pectins, unique biological functions, and a wide range of physiological activity attracts the attention of researchers [8 - 12]

Many years of research have shown that pectin polysaccharides of higher plants have growth-promoting activity concerning crops [13, 14].

In addition, they increase the resistance of plants to diseases of fungal, bacterial, and viral origin. At the same time, it was established that the biological and physiological activity of pectin polysaccharides is largely determined by the peculiarities of the fine structure of their macromolecules, that is, the mortar of polymerization, the composition, length, and level of branching of the lateral carbohydrate chains and the presence of modifying groups [15-19].

It is important to establish and study elements of a fine structure, including binding with a protein that is in the composition of pectin compounds. For example, potato pectin contains protein components and has emulsifying and emulsion stabilizing properties. The pectin part of potato pectin can be adsorbed on the surface of graphite even after alkaline processing. In addition, potato pectin can form mesh structures from self-organizing pectin fragments at the verge of separation and show increased resistance to competitive extrusion from the surface [20]. Unlike pectins of other origins, sugar beet pectin acts as an emulsifier, the properties of which correlate with its more hydrophobic nature and high protein content [21].

Adsorption of individual chains of such pectin on mica requires the addition of divalent cations, while a thin layer containing amorphous regions and rod-like chains is spontaneously formed on the Griffith. The interfacial film of such pectin is more resistant to surfactant displacement than the film of pure protein, possibly due to the formation of a bond between pectin chains [22]. Studies of the fine structure of pectins provide new insights into the nanoscale organization of polysaccharides and polysaccharide-protein mixtures on macroscopic surfaces [23,24]. Modern spectroscopic methods, especially atomic-force spectroscopy (AFM), are used for this purpose. [11, 23,25-30]. The method made it possible to detect mixtures of individual polymer molecules and their aggregates in pectin fractions. This indicates that pectin compounds exist in the form of multi-polymer complexes, the individual components in which are linked by intermolecular interactions. Depending on the concentration of pectins in the solution, they form different structures.

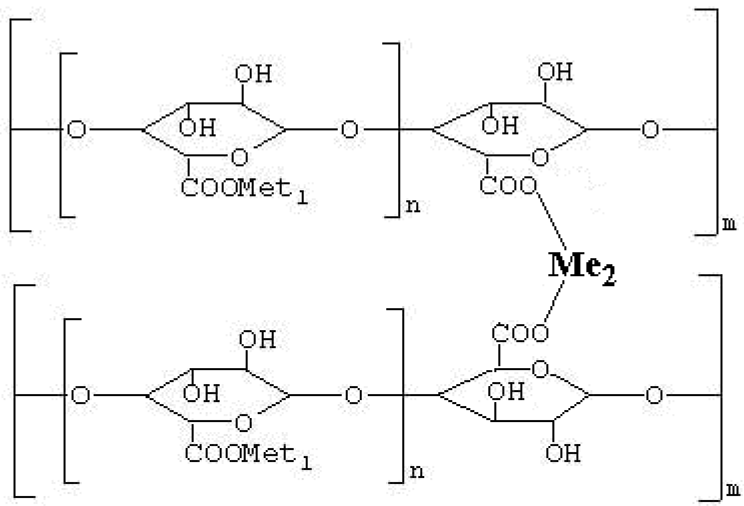
For example, at C> 10 µg / l these are aggregates of mesh structures, and at lower concentrations, they dissociate into individual components. There are separate rods, segment sticks, rings, and branched molecules at a concentration of C ~ 6.5 µg / l. We studied the morphology of the surface, which is formed by evaporation of solutions of apple and citrus pectins, using the AFM method. It has been established that changes in the environment affect the formation of surface morphology with different structures: from individual macromolecular tangles to various associates [31]. Thus, based on pectin and the corresponding microelements, it is possible to create complex compounds that combine the physiological activity of pectin with individual features of the action of microelements on plant development [9, 32, 33, 34]

The creation of new bi - and polymetallic complexes of polygalacturonic acid with essential elements will enhance their biological activity and provide new useful properties.

2. MATERIAL AND METHODS

We have synthesized bi - and polymetallic complexes of polygalacturonic acid for pre-sowing seed treatment.

The following is the general structural formula of the complex compound:



where Met_1 = Na, Me_2 = Cu^{II}, Co^{II}, Fe^{II}, Ca^{II}, Ni^{II}.

Metal complexes were obtained by appropriate treatment of citrus pectin TM "Cargill" (Germany). Unlike apple pectin, citrus pectin has carboxyl groups distributed unevenly (blocks). This increases the sensitivity to divalent ions. As a result of ionic interactions with divalent cations, molecular chains of citrus pectins acquire the ability to quickly interact with each other. Complex compounds were synthesized according to a two-stage scheme. In the first stage, Na pectate was obtained. For this purpose, a solution of NaOH was gradually added to a solution of pectin in water at the temperature of 50 - 55 °C until a pH of ~ 9.0 in the reaction mass was reached. In the second stage, the metal-containing polygalacturonates PG were obtained by the interaction of Na pectate with solutions of one or more salts. The reaction mass is concentrated, and an appropriate amount of ethyl alcohol is added to precipitate the complex compound and centrifuged. The resulting compound is dried at 40 - 50 °C to constant weight. The degree of substitution of Na for metals is from 23,45 to 26,45%. Metal complexes of pectins are water-soluble bi- and polymetallic compounds based on polygalacturonic acid. Metal complexes of this type are low-toxic. It can be used both in the solid-state and in the form of solutions.

Determination of the efficiency of the created polygalacturonates of biogenic metals was performed in laboratory and vegetation experiments. Experimental aqueous solutions of drugs were used for the pre-sowing treatment of winter wheat seeds. The effectiveness of the new drugs was determined according to the scheme of laboratory experiments with Smuhlyanka variety winter soft wheat seeds. To prevent infections, wheat seeds were treated with 60% ethyl alcohol for 15 minutes, then thoroughly washed with distilled water, dried, and treated with solutions of relevant test compounds by semi-wet etching at 20 liters of working solution per 1 ton of seeds. Treated wheat seeds were germinated for one day in a thermostat at 26 ºC in Petri dishes on wet filter paper for 50 pcs. per cup and were planted in vegetative three liters' vessels with 2.4 kg quartz-washed sand and humidity- 70% complete moisture capacity. The number of plants per vessel - was 15, the repetition - was 12 times, and the duration of the experiments - was 21 days. Nutrient medium - Hogland-Arnon [35]. Germination energy and laboratory germination of seeds were determined according to GOST 12038-84, and the mass fraction of dry matter in plant material was determined by the thermogravimetric method [36].

The total adsorbing and working absorption surfaces of the roots were determined by the method of Kolosov and Sabinin with methylene blue [36]. Methylene blue was used as an adsorbent, the absorption of which was determined colorimetrically by changing the concentration of the test solution. It was taken into account that 1 mg of methylene blue in monomolecular adsorption covers 1.05 m^2 of the adsorbent surface. The process was carried out in compliance with the following requirements: the concentration of the test solution of methylene blue - 112.1 mg per 1 liter, the duration of immersion of the roots in the solution - 1.5 minutes, the volume of the solution and the ratio of the root is 10:1. The total adsorbent surface of the roots (m^2) was determined by multiplying the coefficient of 1.05 by the number of milligrams of absorbed methylene blue for the first two immersions of the roots in the solution. The working absorption surface of the roots was calculated by determining the number of absorbed bruises at the third immersion. The working (active) absorbing surface of roots is considered to be that part of their surface that, absorbing methylene blue molecules from the surrounding solution, transfers them further to the vessels.

Morphological parameters of the root system were studied after pre-staining the roots with a 0.1% solution of magenta, followed by the determination of the number and length of germinal and secondary roots of one plant.

To characterize the absorbing activity of the root system of experimental plants, the acidifying activity of roots (RSAA) of 7-day shoots was determined. This indicator allows us to assess the operation of proton pumps and the ability of the root system of sprouts to emit hydrogen ions in exchange for monovalent cations contained in the nutrient medium [20]. PSAA indicates the functioning of the proton adenosine triphosphate (H+- ATPhase) pump on the plasmalemma of the roots and it is the most informative indicator of the absorption capacity of the root system [37]. The activity of proton H+-pumps was determined by the pH-metric method of the medium in which the roots of the studied sprouts were incubated. The measurements were performed five times. To achieve the desired indicators, the following was done: wheat seeds were germinated in a thermostat at 25 °C in Petri dishes, after which 7-day sprouts were kept for 1 day in a solution of 0.1 mM $CaSO_4$, a day later transferred to a solution of 1 mM KCl, activating activity of H^+ - pumps, and a day later the pH of KCl solutions were measured. The intensity of acidification was assessed by the pH changing of the medium (1 mM KCl) [38,39].

The method of determining amylase activity [40] is to determine the amount of soluble starch remaining in the incubation medium after hydrolysis by amylase. Enzyme extract was obtained by homogenizing 1 g of sprouts in a porcelain mortar with 10 ml of 0.5 n $CaCl_2$. The homogenate was centrifuged for 10 min at 2000 g. The supernatant was used as an enzyme preparation. The incubation mixture included: 3 ml of 0.1 M acetate buffer (pH 5.0), 1 ml of 0.5 M $CaCl_2$, 1 ml of enzyme preparation (drugs), 1 ml of 3% freshly prepared soluble starch. Incubation was performed for 30 minutes at 37 °C. Upon completion of incubation, the enzyme was inactivated by adding 0.5 ml of 1 n HCl to the incubation mixture. To determine the content of non-hydrolyzed starch by amylase during the incubation 1 ml of the incubation mixture in 50 ml volumetric flasks was mixed with 0.5 ml of 1 N HCl, added 0.1 ml of iodine solution (0.3% solution of I_2 in 3% solution of CI), brought to the mark with distilled water. The solution acquired a blue color, the optical density of which is proportional to the starch content. It was determined on a photoelectrocolorimeter KFK-2MP at a wavelength of 610 nm. Enzyme activity was calculated by the amount of hydrolyzed starch during incubation and expressed in mg of hydrolyzed starch per 1 g of raw weight per hour. The starch content was calculated according to the calibration schedule.

The content of chlorophylls a, b, and the total content of carotenoids in 21-day plants were determined according to the Welburn method [41].

Dimethyl sulfoxide (DMSO) was used as a solvent for pigments, which has several advantages over other solvents. Extraction of pigments was carried out for hours in a thermostat at temperatures of 67 °C. Spectrophotometric measurements of the optical density of solutions were performed at wavelengths of 665, 649 nm (red region of the spectrum), and 480 nm (violet region). DMSO served as a control.

Statistical processing of the obtained indicators was performed by the method of correlation and variance analysis according to the methods described by B.O Dospekhov [42] using computer programs.

3. RESULTS AND DISCUSSION

3.1. The effect of pre-sowing treatment with metal-containing polygalacturonates on the total activity of α- and ß-amylases

An important indicator of deep physiological and biochemical processes in germinating seeds is the activity of amylase, which breaks down starch granules to form dextrins and sugars. Under the influence of the amylolytic complex of enzymes, assimilation starch is hydrolyzed to monomers, which is a prerequisite for involving this spare non-structural polysaccharide in exchange [43]. According to the data in table 1, pre-sowing treatment of seeds with PG of biogenic metals in all variants of the experiment helps to increase the activity of amylase relative to the control variant. When using these compounds in the experiment for the treatment of winter wheat of the Smuhlyanka variety seeds, intensive hydrolysis of starch occurs during the day due to the high activity of these enzymes, which was higher than the control for the second day by 26-42%, on the 3rd day - by 23-43%, on the 4th day - by 9-22. Analyzing the activity of amylase in dynamics using PG of biogenic metals, it was found that their high activity in winter wheat occurs on 3 days and reaches a maximum in the variant of GHG iron, copper, calcium, which is 43% higher than the control in winter wheat of the Smuhlyanka variety. A further decrease in the activity of amylase occurs due to the active hydrolysis of starch during seed germination.

Table 1. The effect of pre-sowing treatment with metal-containing polygalacturonates PG on the total activity of α- and ß-amylases in *Smuhlyanka variety winter wheat seeds* during germination, *mg of hydrolyzed starch for 1 hour I g dry matter of the grain.*

№	Treatment	Concentration of the solution, %	24 hours	48 hours	72 hours
1	Water, control	0	39,82 ± 0,52	90,12 ± 0,10	201,6 ± 0,39
2	PG* copper	0,02	51,27 ± 0,44	121,32 ± 0,57	220,4 ± 0,52
3	PG iron	0,02	50,31 ± 0,51	123,38 ± 0,62	235,0 ± 0,32
4	PG calcium, nickel	0,02	55,60 ± 0,49	126,49 ±0,4 8	239,7 ± 0,49
5	PG iron, copper, calcium	0,02	56,10 ± 0,49	129,32 ± 0,54	241,0 ± 0,42
6	AG**	0,02	55,31 ± 0,51	127,22 ± 0,63	246,2±0,55

* PG – Polygalacturonates, ** AG - Arabinogalactane

3.2 Effect of pre-sowing treatment of Smuhlyanka variety winter wheat seeds metal-containing polygalacturonates on germination energy, laboratory seed germination, and morphometric parameters of 21-day plants.

In the vegetation experiment, the use of PGs of biogenic metals for pre-sowing treatment of Smuhlyanka variety winter soft wheat seeds caused significant positive changes in the morphological parameters of the root system of 21-day plants. The results of determining the effect of solutions of PG GHG metal complexes on germination energy, laboratory seed germination, and morphological parameters of 21-day sprouts are given in Table 2.

Table 2 - The effect of pre-sowing treatment of Smuhlyanka variety winter wheat seeds compounds on germination energy, laboratory seed germination, and morphometric parameters of 21-day plants.

Treatment	Concentration of the solution, %	Germination energy, %	Laboratory seed germination, %	Germinal roots, 1 plant		Length of the overground parts, cm	Mass of a.d.m. of 100 plants, g
				Number	Length of the basic root, cm		
Water, control	0	79	89	4,8	19,6 ± 1,4	20,3 ± 0,8	5,16 ±0,26
PG copper	0,02	90	99	5,2	23,7 ± 1,2	24,1 ± 1,4	5,72 ±0,27
PG iron	0,02	89	93	5,1	22,9 ± 1,4	24,7 ± 1,2	5,83 ± 0,33
PG calcium, nickel	0,02	94	93	5,2	24,4 ± 0,7	25,9 ± 1,4	5,98 ± 0,31
PG iron, copper, calcium	0,02	92	94	5,2	25,0 ± 1,3	26,2 ± 1,2	6,14 ± 0,33
AG	0,02	90	96	5,0	25,4± 1,3	22,3 ± 1,2	6,04 ± 0,33

The data in Table 2 show that the use of PG of biogenic metals for the treatment of winter wheat seeds leads to an increase in germination energy and laboratory germination, the indicators of which exceed the control unit by 11-19% and 5-11%, respectively. It should be noted that the treatment of seeds with PG solutions provides an increase in the number of some characteristic features of the plant under study relative to the control sample. Notably, the number of germ roots increased from 4.8 to 5.0-5.2 pcs. /plant, the total length of the germ roots increased from 43.0 cm to 47.6-50.8 cm, the number of lateral roots and their length increased by 8-37%, the length of the main root increased by 17-29%, the linear dimensions of the ground part increased by 10-29%. Such changes in the morphological parameters of the root system under the influence of drugs led to an increase in the area of its working absorbent surface from 248 cm^2 / plant up to 265-300 cm^2/plant (7-21%) (Figure 1).

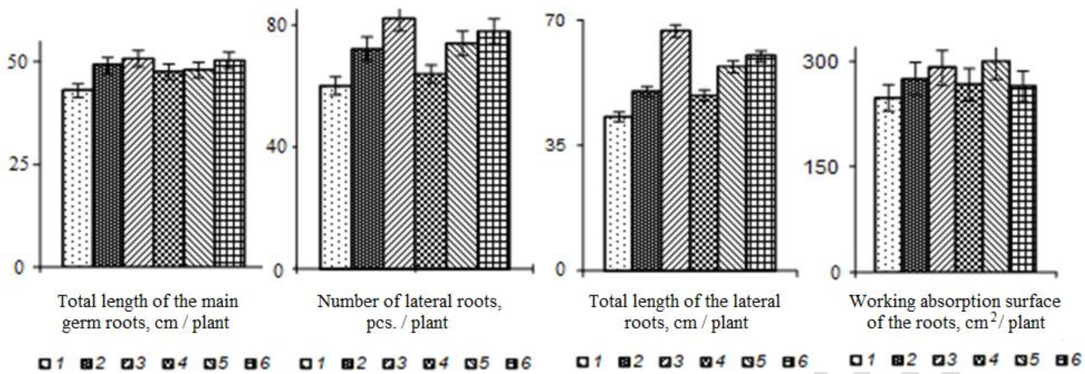


Fig. 1 - Influence of pre-sowing treatment of Smuhlyanka variety winter wheat seeds with solutions of polygalacturonates PG of biogenic metals on morphological parameters and absorption capacity of 21-days plants root system, vegetation experiment with sandy substrate

1 –Water, control sample; 2 – PG copper; 3 – PG iron; 4 – PG calcium, nickel; 5 – PG iron, copper, calcium; 6 – AG.

The stimulating effect of polygalacturonate metal complexes solutions on the formation of the root system of wheat plants in the early stages of their growth and development should further improve the root nutrition of plants, increase their resistance to adverse growing conditions and, consequently, increase yields.

All PG compounds used in the experiment for pre-sowing treatment of seeds caused a more intensive course of the processes of the biosynthesis of solids, as a result of which the mass of 21-day plants of these variants exceeded the mass of the control sample by 11-19% (Table 2). Calcium-nickel polygalacturonate has proven to be a more effective option for the pre-sowing treatment of winter wheat seeds concerning the effect on plant mass – there is a 19% increase in mass. Probably, the introduction of the essential element Ni into the PG helps to accelerate the translocation of nutrients in plants, which is consistent with the literature [44-46].

3.3 Effect of pre-sowing treatment of Smuhlyanka variety winter wheat seeds metal-containing polygalacturonates on the root system acidofication activity of 7-day sprouts.

It is noteworthy that all the studied compounds, in addition to a positive effect on the morphological parameters of the root system of plants (Table 3), contributed to a significant increase (13-51%) in its acidifying activity (RSAA) – proton H+- pumps work as the most important process, which largely determines the intensity of uptake of minerals by root cells.

Table 3. The effect of pre-sowing treatment of Smuhlyanka variety winter wheat seeds metal-containing PG on the root system acidofication activity of 7-day sprouts.

№	Treatment	Concentration of the solution, %	Root system acidofication activity, mcM H^+ / 1 plant / 24 h
1	Water, control	0	0,77 ± 0,05
2	PG copper	0,02	0,87 ± 0,04
3	PG iron	0,02	0,96± 0,04
4	PG calcium, nickel	0,02	1,16 ± 0,06
5	PG iron, copper, calcium	0,02	0,99 ± 0,04
6	AG	0,02	1,10 ± 0,05

Such an increase in Root system acidofication activity when using the studied compounds for the pre-sowing treatment of seeds should contribute to improving the mineral nutrition of plants in production conditions by activating proton pumps and strengthening the absorption processes of monovalent cations by the root system from a nutrient solution. This, according to experts [37-39], further affects the increase in grain productivity of plants.

3.4. Influence of pre-sowing treatment of Smuhlyanka variety winter wheat seeds metal-containing polygalacturonates on the content of chlorophyll and total carotenoids in the leaves of 21-day plants.

Photosynthesis is the key plant life function and the growth processes, adaptability and productivity depend on it. The plant photosynthesis apparatus characteristic, usable for research of the large plant samples, is the photosynthesis pigments levels content and the ratios between them.

According to Table 4 data, all compounds which were used for the pre-seed treatment of seeds (PSTS) contributed to an increase in the content of chlorophyll in the leaves, the number of chlorophylls, and the content of common carotenoids relative to control. This indicates that under the influence of metals polygalacturonates there is an intensification of photosynthetic processes and biosynthesis of exogenous antioxidants - carotenoids.

Iron-calcium-nickel polygalacturonates and AG turned out to be the most effective drugs. An increase in the content of chlorophylls in the leaves by 10-11% and total carotenoids by 25-23%, respectively, was recorded in these variants compared to the control.

An increase of endogenous antioxidants content - common carotenoids in the leaves of young plants can be considered as an indicator of the activation of the antioxidant system as an important system for protecting the photosynthetic apparatus of plants from the destructive effects of various stress factors and should contribute to increasing the resistance of plants against adverse growing conditions.

Table 4. Influence of pre-sowing treatment of Smuhlyanka variety winter wheat seeds metal-containing polygalacturonates on the content of chlorophyll and total carotenoids in the leaves of 21-day plants.

№	Treatment	Concentration of the solution, %	chlorophyll content, mg in a.d.m. of 100 plants			Content of total carotenoids, mg/100 plants
			a	b	a + b	
1	Water. control	0	47,0 ± 1,5	17,6 ± 0,5	64,6 ± 2,0	7,3 ± 0,3
2	PG copper	0,02	50,7 ± 1,6	18,2 ± 0,6	68,9 ± 2,2	8,3 ± 0,4
3	GHG iron	0,02	51,6 ± 1,6	17,1 ± 0,5	68,7 ± 2,1	8,9 ± 0,4
4	PG of calcium, nickel	0,02	49,7 ± 1,5	16,7 ± 0,5	66,4 ± 2,0	9,1 ± 0,3
5	GHG of iron, copper, calcium	0,02	52,1 ± 1,6	17,6 ± 0,5	69,7 ± 2,1	8,7 ± 0,4
6	AG	0,02	50,3 ± 1,6	17,0 ± 0,5	67,3 ± 2,1	9,0 ± 0,4

The results of the research indicate the effectiveness of aqueous solutions of PG for the pre-sowing treatment of winter wheat seeds.

Exogenous use of biogenic metal PG aqueous solutions for pre-sowing treatment of Smuglyanka winter wheat seeds reliably increases germination energy by 11-19%, laboratory germination of seeds by 5-11%, contributes to the formation of more germ and lateral roots (up to 10%), a significant increase in the acidifying activity of the root system of plants (by 13-51%). Iron-copper-calcium PG and calcium-nickel PG are not inferior to the action of arabinogalactan in foreign production by the positive effect on the stimulation of growth processes, photosynthetic activity in 21-day plants.

Exogenous application of aqueous solutions of PG biogenic metals for pre-sowing treatment of Smuglyanka winter wheat seeds reliably increases germination energy by 11-19%, laboratory seed germination by 5-11%, contributes to the formation of up to 10% more germinal and lateral roots, a significant increase by 13 —51% acidifying activity of the root system of plants. In terms of a positive effect on the stimulation of growth processes, photosynthetic activity in 21-day-old plants, PG iron-copper-calcium and PG calcium-nickel which are not at all inferior to the action of foreign-made arabinogalactan.

4. CONCLUSION

The positive effect of exogenous use of polygalacturonates of biogenic metals for the processing of winter wheat seeds is established. Pre-sowing treatment of PG seeds with biogenic trace elements enhances amylolytic activity, activates growth processes at the initial stage of ontogenesis, and enhances the physiological activity of the root system. According to the integrated assessment, among the studied solutions of polygalacturonates of biogenic metals, the most effective in influencing the morphological indicators and absorption capacity of the root system, and the intensity of biosynthesis of endogenous antioxidants was the iron-nickel-calcium polygalacturonate composite when using it for pre-sowing processing of *Smuhlyanka variety winter wheat seeds.*

Such compounds can be effective components of multi-vector composite preparations for exogenous use in modern agricultural technologies.

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APPENDIX