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ИСПЫТАНИЕ НАНОЧАСТИЦ МАКРО- И МИКРОЭЛЕМЕНТОВ НА ЗЕРНОВЫХ КУЛЬТУРАХ

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Исследования проведены в северной лесостепи Тюменской области. В лабораторных и полевых условиях испытаны различные формы и дозировки наночастиц макро- и микроэлементов и сопутствующих веществ при обработке семян и растений яровой тритикале и пшеницы. Препараты имели положительное влияние на прорастание семян, более высокие нормы снижали показатели энергии и всхожести. Энергия прорастания и всхожесть семян тритикале повышались на 4–10% при применении препаратов с содержанием наночастиц меди, марганца, молибдена, биогенного железа, Титана М. Обработка суточных проростков препаратами марганца, кальция, молибдена, Титана М, биогенного железа, бора, калия способствовала увеличению длины ростка на 7-е сутки на 7,8–25%, массы ростка на 6–8%. На применение калия реагировали только уже развивающиеся ростки. Отмечено, что применение биогенного железа вызывает снижение лабораторной всхожести семян на 4–10%, но способствует развитию главного корня. Его увеличение составило 9–12% по сравнению с контролем. Включение биогенного железа и кремния в смесь к химическому протравителю снижало эффективность против корневых гнилей от 18% в начале вегетации до 30% к периоду уборки. Применение биогенного железа способствовало повышению урожайности на 0,5–0,6 т/га, или 23%, в системе комплексной защиты культуры по сравнению с контролем и на 0,16–0,23 т/га – со стандартной схемой защиты культуры. Отмечено положительное влияние биогенного железа при обработке растений в фазу колошения как отдельного элемента технологии, так и в баковой смеси с фунгицидами.

Ключевые слова: наночастицы, макроэлементы, микроэлементы, зерновые культуры, урожайность, эффективность, болезни растений

TESTING OF MACRO- AND MICRONUTRIENT NANOPARTICLES ON GRAIN CROPS

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The studies were conducted in the northern forest-steppe of the Tyumen region. Under laboratory and field conditions, different forms and dosages of macro- and micronutrient nanoparticles and associated substances were tested in the treatment of seeds and plants of spring triticale and wheat. The preparations had a positive effect on seed germination, while higher rates reduced energy and germination. The germination energy and germination of triticale seeds increased by 4-10% with the application of preparations containing nanoparticles of copper, manganese, molybdenum, biogenic iron, Titan M. Treatment of daily seedlings with manganese, calcium, molybdenum, Titan M, biogenic iron, boron, potassium increased sprout length by 7.8-25% and sprout weight by 6-8% by day 7. Only already developing sprouts responded to the application of potassium. It was noted that the application of biogenic iron causes a 4-10% decrease in laboratory germination of seeds, but promotes the development of the main root. Its increase was 9-12% compared to the control. The inclusion of biogenic iron and silicon in the mixture to the chemical dressing reduced the effectiveness against root rot from 18% at the beginning of the growing season to 30% by the harvesting period. The application of biogenic iron increased the yield by 0,5-0,6 t/ha or 23% in the system of complex crop protection compared to the control and by 0,16-0,23 t/ha with the standard scheme of crop protection. A positive effect of biogenic iron in the treatment of plants during the earing phase as a separate element of the technology and in a tank mixture with fungicides was noted.

Keywords: nanoparticles, macroelements, microelements, grain crops, yield, efficiency, plant diseases

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INTRODUCTION

In the system of crop cultivation, seed dressing is the easiest way to improve the quality of seeds [1, 2]. Application of chemical plant protection agents has a regulatory effect both on pest objects, and on the crop itself, its growth and development. Their negative impact can be corrected by using in a complex of preparations to activate growth and reduce stress. The use of microfertilizers enhances seed germination and vegetative growth of plants in the first phases of ontogenesis[1] [3, 4]. Stimulation of growth processes can be expressed in a change in the effect on plant organs, which shows the differences in the direction of action of the preparations [5-7].

The use of foliar fertilizers with chelated iron compounds contributed to an increase in the indicators of yield structure [8, 9], the use of microfertilizers during the growing season in a mixture with nitrogen influenced the growth dynamics of spring wheat [10], fertilization with chelated zinc, copper and sulfur - on the grain quality [11]. A prolonged use of chelated forms of trace elements leads to inhibition of growth processes compared to only the seed treatment[2] [12, 13].

Reducing the volume of a substance or particle to nanoparticles to improve the conditions of penetration and delivery of necessary substances to plants should promote seed germination, accelerate plant growth, increase crop yields and protect plants from environmental influences [14, 15].

In the studies of Iranian scientists, the addition of nutrient media containing selenium particles was seen as a promising approach to

[1]Anikina L.M., Udalova O.R., Panova G.G. Influence of pre-sowing treatment of spring wheat seeds with silicon-containing chelate microfertilizers on the growth and development of its seedlings // Modern state, problems and prospects of agrarian science: proceedings of the Vth international scientific and practical conference: Simferopol: IT "Arial", 2020. Pp. 13-15.

[2]Chirko E.M., Timoshchenko V.G. Influence of growth regulators and microfertilizers on the germination of spring wheat seeds // Agriculture - problems and prospects: collection of scientific papers of Grodno: State Agrarian University, 2019. V. 45: Agronomy. Pp. 193-201.

altering plant growth, morphology, metabolism and anatomy, but there was an understanding of the phytotoxicity of such use, which definitely introduces significant epigenetic variations in DNA. Such results are also true for other nanomaterials: genetic damage to wheat, toxic effects on primary plant development, environmental instability, and cytotoxic effects on plants are evident. This necessitates a clear elaboration of safe norms for the application of nanomaterials on biological objects[3] [16, 17]. Ready-made macro- and microelement compositions are proposed for use in the main phases of plant ontogenesis in combination with pesticides, as well as a separate element of technology aimed at increasing the qualitative characteristics or productivity of agricultural plants by accumulating biomass and increasing the assimilative surface[4].

The purpose of the study was to determine the effect of preparative forms containing nanoparticles of macro- and microelements for the treatment of seeds and vegetative plants of cereal crops.

MATERIAL AND METHODS

The studies were conducted under laboratory and field conditions at the Research Institute of Agriculture of the Northern Trans-Ural Region, a branch of the Tyumen Scientific Center of the Siberian Branch of the Russian Academy of Sciences, northern forest-steppe zone. The measurements and observations were carried out according to the standard methodological guidelines adopted in the State Crop Testing Committee, crop production, and plant protection. Under laboratory conditions, a comparative assessment and selection of macro- and microelement solutions (nitrogen, phosphorus, potassium, calcium, manganese, magnesium, molybdenum, boron, zinc, copper, biogenic iron, Titan M and their mixtures) with the most positive effect on energy, germination and growth functions were performed. The content of the main active ingredient was 10-40 mg/ml, the accompanying substances in the form of silver - 1 mg/ml, stabilizers nanodispersity polyvinylpyrrolidone - 20%, collagen hydrolyzate - 15%. There are at least six variations for each element. Of these, the variants with the most positive effect were selected and studied in the second stage of research.

Seeds were treated before sowing with an hour exposure. Preparation of the working solution was calculated per 100 g of seeds, application rates from 1 to 100 ml/t or per 1 ha depending on the type of the experiment. Determination of the effects of the preparations during treatment of seeds and daily seedlings was carried out in Petri dishes and in wet rolls. Phyto-examination of seeds, assessment of seed infestation by various pathogens were performed on the 7th day. Then we sowed seeds with daily germination after treatment with preparations, 20 pieces per cup in five replications. The samples were planted according to GOST 12038-84[5]. Sprout length, root length, weight of vegetative organs, reduction of fungi on seeds were taken into account. Seeds of spring triticale were used in the experiment. Biogenic iron hydroxide (ferrihydrite) produced by the Krasnoyarsk Research Center was evaluated under field conditions in the protection system of spring wheat.

Biogenic iron was applied in appropriate phases of development to determine its effect on wheat plant development, diseases, and yield. The soil of the experimental plot is dark gray forest heavy loam. The field experiment was set up under standard agrotechnical conditions in a shallow plot area of 20 m^2 with fourfold repetition. During the growing season the lesion of root rot and leaf-rolling diseases was determined.

[3]Nanocides may become an alternative to conventional insecticides: [Electronic resource]. URL: https://glavagronom.ru/news/nanopesticidy-mogut-stat-alternativoy-obychnym-insekticidam, https://www.azonano.com.

[4]V. Popova, N.V. Goman, M.A. Kireeva Influence of foliar feeding with zinc and copper chelates on the quality of spring wheat grain when growing on meadow-chernozemic soil // Environmental readings - 2020: materials of the 11th National Scientific and Practical Conference with international participation. Omsk, 2020. Pp. 459-464.

[5]GOST 12038-84 Seeds of crops. Methods of analysis. Moscow: Publishing house of standards, 2004. 47 p.

The yield was counted by selection of sheaf material, mechanical threshing of plots. Analysis of seeds for quality parameters was carried out according to the relevant GOSTs[6]. Statistical data processing was performed using Excel program.

RESULTS AND DISCUSSION

In laboratory studies the results of different effects of the application of preparations containing nanoparticles of macro- and microelements were obtained. A comparative evaluation was carried out with more than 20 preparations with different rates of application. The positive effect of the preparations or its absence was noted. Mixtures consisting of 3-5 substances showed a neutral or negative effect when the elements and application rates were increased.

Preparations containing copper, zinc, boron, calcium and ready-mixed P + K with stabilizer PVP (polyvinylpyrrolidone) + Ag-C modifier, N + P + PVP + Ag-C at the solution rate of 5 ml/t had a positive effect on germination. Higher rates reduced energy and germination.

Triticale seeds germination energy increased with the application of preparations containing copper, manganese, molybdenum, biogenic iron, Titan M. The increase in growth energy was 4-10%. Superiority was in the preparations Titan M at 500 ml/t (+7%), molybdenum at 10-50 ml/t (+10, +7%). As a result, out of 58 variations, positive effect was found in five preparations with certain norms (see Table 1).

Seed germination in some variants was at the level of the initial germination energy or had an increase depending on the applied element. Significant increase in germination was noted for calcium, manganese preparations at the rate of 5 ml/t (+4, +5%), Titan M - 500 and molybdenum - 10-50 ml/t (+6, +10%).

The study of manganese nanoparticles (sulfate monohydrate) in most variations had a stimulating effect on the growth processes of spring triticale, but the use of collagen hydrolysate (HC) as a stabilizer of nanodispersity reduced the positive effect of the preparation in seed treatment. Manganese as normal up to 20 mg/g in the studied combinations in combination with the stabilizer (PVP) contributed to an increase of energy, germination, growth of vegetative organs, which assumes its use as a stimulating agent in seed treatment.

In variants with magnesium, variations with positive effect on germination were determined: Mg 10-20 mg + PVP with the rate of 1-5 ml/t, Mg 10 mg + HA with the rate of 1 ml/t. A greater effect on root development was observed with Mg 10 mg + Ag (silver) 1 ml + PVP at the rate of 1 ml/t. All variations of magnesium had a positive effect (at the rate of 1 ml/t) on the sprout development with an increase in its length by 1.1-2.1 cm and limitation of coleoptile growth by 0.5-1.2 cm. Treatment of daily sprouts with Mg 20 mg + PVP; Mg 10 mg + Ag 1 ml + HA contributed to an increase of sprout length by 2,7-2,9 cm and weight by 1,0-1,3 g at the rate of 5 ml.

The use of the same preparation in the treatment of seeds and already developing plants can have a different effect on their initial growth. Two criteria were compared: the total length of all sprouts (on average 9-15 cm) and the length of sprouts with normal healthy development (13,0-15,0 cm). It was noted that in some variants the sprout development was normal, without lagging, in others the effect of the preparation on growth inhibition was established. The increase in sprout length was observed for the preparations Mn (10 ml/t), Ca (10), Mo (50), Titan M (50), biogenic Fe (5 ml/t), B (5 mg/g + HA (10%), 1 ml/t), K (1000 ml/t). Of these, B 5 mg/g + HA (10%), 1 ml/t, K 1000 ml/t had a significant effect. The increase of sprout length was 1,0-3,2 cm, or 7,8-25%, of sprout crude weight 0,5-1,4 g, or 6-8%. Treatment of seeds with potassium had no effect on their germination activity, but treatment of the germinating seed had a positive effect on the growth functions of the young plant. Growth inhibition of triticale plants was observed in the following variants: Fe3O4, 5 + SiO, 2 + N, 5 + K, 10 ml/t;

[6]GOST 1386.5-93, GOST 30483-97, GOST 12042-80, GOST 10840-64, GOST 13586.1-68.

Табл. 1. Энергия и всхожесть семян при обработке препаратами, %
Tabl. 1. Energy and germination of seeds when treated with preparations, %

№ i/n	Option	Energy	Germination
1	K, 10 ml + N, 5 ml + SiO, 1 ml + Ca, 5 ml/t	86–88 (+1)	88–91 (+2)
2	Cu 2, 5 ml (> reduces energy and germination)	89–91 (+4)	89–91 (+3)
3	Mn 3, 5 ml/t (>at the control level))	89–91 (+4)	91-92 (+4)
4	Ca 5, 5 ml/t (>reduces energy and germination)	86–91 (+2)	90–94 (+5)
5	Biogenic iron, 5 ml/t	88–91 (+4)	87–92 (+3)
6	Titan M, 50 ml/t	88–92 (+4)	87–93 (+3)
7	Titan M, 500 ml/t	92–94 (+7)	91-95 (+6)
8	Mo 2, 5 ml/t	87–90 (+3)	89–91 (+3)
9	Mo 2, 10 ml/t	95–97 (+10)	96–98 (+10)
10	Mo 2, 50 ml/t	91–94 (+7)	92–94 (+6)
11	Zn 2000 ppm, 10 ml/t	82–85 (–2)	82–87 (–2)
12	Mg, 20 mg/ml + PVP particles < 10 nm, 1–5 ml/t	84–88 (–)	87–91 (+2)
13	4 B 5 mg/g + GA (10 %), 1 ml/t	83–87 (–1)	84–88 (–1)
14	P + K 10–12 mg/g + PVP 15% + Ag-C 0,5 mg/g, 500 ml/t	83–88 (-)	83–88 (-1)
15	P + K 10–12 mg/g + PVP 15% + Ag-C 0,5 mg/g, 1000 ml/t	85–87 (-)	87–89 (+1)
16	N + P 4-9 mg/g + PVP 15% + Ag-C 0,5 mg/g, 10 ml/t	79–83 (–5)	82–86 (–3)
17	5 K, 10 ml/t	78–80 (–7)	88–90 (+2)
18	5 K, 50 ml/t	85–90 (+2)	88–90 (+2)
19	5 K, 100 ml/t	86–90 (+2)	87–91 (+2)
20	7 N, 100 ml/t (от 5–50 ml/t influences positevely)	81–85 (–3)	88–92 (+3)
21	Control (water)	84–88 (– 2,95)	86–88 (–)
	LSD_{05}		2,99

Note. 1, 11–15, 18, 19 – neutral influence; 16, 17, 20 – negative; 3, 7, 9, 10 – positive.

Fe3o4, 100 ml/t; Zn 2000 ppm, 10 ml/t; N + P4-9 mg/g + PVP15% + Ag-C, 10 ml/t. The shoot length lag was 1-3.5 cm, weight - up to 4 g. Neutral effect (drug dosage was insufficient or its effect was weak) was observed in variants: Cu (2, 50 ml/t); Mn (3, 10 ml/t); Mo (2, 10 ml/t); Mg, (20 mg/ml) + PVP < 10 nm, 1 ml/t); K (500 ml/t); N (10 ml/t). The effect of some preparations when comparing the total sprout length showed a lag or was at the control level, but when comparing normally developed sprouts, their values increased, which is also confirmed by the crude weight of plants (see Table 2).

In the field study of biogenic iron we treated seeds and plants during the growing season in the main phases of protection agents application. Seed germination after treatment with tested means compared to control varied within 60-79%. The effect of biogenic iron on reduction of germination or inhibition of seed germination processes was noted. According to some authors, oxidative stress and reduction of seed germination can be caused by nanoparticles of many metals (silver, gold, iron), ferrites, as well as oxides of zinc, nickel, copper, iron, titanium, silicon [18-20]. Seed germination rate decreased by 4-10% during treatment with biogenic iron. It is probably necessary to limit the use of iron for their treatment, because it inhibits the emergence of sprouts and growth in the first phases of plant development. Bio-

Табл. 2. Рост растений яровой тритикале при обработке суточных проростков
Tabl. 2. The growth of spring triticale plants when processing day old seedlings

№ i/n	Option	Normally developed plants, %	Sprout length total / normally developed plants, cm	Sprout mass per 100 plants, g
1	Fe_3O_4, 5 + SiO, 2 + N, 5 + K, 10 ml/t	85	11,71/12,61	9,05
2	Cu 2, 50 ml/t	85	12,70	9,47
3	Fe3o4, 100 ml/t	90	11,65/12,64	9,10
4	Mn 3, 10 ml/t	90	12,27/13,31	9,73
5	Ca 5, 10 ml/t	80	13,59	10,43
6	Ca 5, 50 ml/t	80	13,00	9,81
7	Biogenic Fe, 5 ml/t	90	13,58	9,88
8	Титан M, 50 ml/t	95	12,5/13,38	9,63
9	Mo 2, 10 ml/t	95	12,81	9,15
10	Mo 2, 50 ml/t	95	13,00/13,64	9,00
11	Zn 2000 ppm, 10 ml/t	90	9,25/9,88	5,85
12	Mg, 20 mg/ml + PVP <10 nm, 1 ml/t	90	12,60	8,94
13	B 5 mg/g + GA (10%), 1 ml/t	90	13,74–14,11	9,55
14	P + K 10–12mg/g + ПВП15% + Ag-C, 10 ml/t	90	13,11	9,00
15	N + P 4–9 mg/g + ПВП15% + Ag-C, 10 ml/t	95	11,42	7,52
16	K, 500 ml/t	100	12,9	8,8
17	K, 1000 ml/t	95	14,33/15,96	9,62
18	N, 10 ml/t	90	12,69	8,61
19	Control (water)	95	12,74	9,0
	LSD_{05}	4,5	0,62	0,49

genic iron had a positive effect when treating plants during the growing season, especially during the active growth of the green parts of the plant. Treatment with biogenic iron had the same effect on the development of root system: the growth of the main root increased by 1,2-1,8 cm, or 9-12%, its weight increased by 0,6-0,9 g (see Table 3).

Application of chemical dressing reduced the length of coleoptile, and none of the preparations had a positive effect on its response. Sprout length had a significant increase of 1.7 cm only in the variant where liquid fertilizer was used, in the variant with biogenic iron there was a decrease in length by 2.2 cm and sprout weight by 0.9 g.

The efficiency of reducing infection on seeds with infection by fungi of the genus Alternaria - 10-12%, Fusarium - 2-7%, Bipolaris sorokiniana - 0-2% when treated with a chemical dresser was 100%; when adding biogenic iron and silicon to the mixture, the reduction was 90-95%.

The occurrence of root rot in the initial period of vegetation has a great impact on further growth, development and yield of the crop. In the tillering phase the disease development without treatment with a chemical dressing was 1.4%, spreading - 5.6%. During the growing season lesion increased 3-fold. Chemical dressing protected plants from root rot up to the phase of the beginning of tubing by 100%. Dur-

Табл. 3. Всхожесть и развитие зародышевых органов на 7-е сутки после обработки
Tabl. 3. Germination and development of germinal organs on the 7th day after treatment

Dressing option	Germination, %	Root length, cm	Root mass, g	Coleoptile length, cm	Sprout length, cm	Sprout mass, g
Disinfectant + insecticide + fertilizer	(72–82) 77	12,99	1,84	4,75	11,37	3,62
		+0,49	+0,13	–2,0	+1,72	–0,08
Control (without treatment)	(73–86) 78	12,5	1,71	6,75	9,65	3,70
		–	–	–	–	–
Disinfectant + Biogenic Fe, 1 ml	(66–76) 61	14,1	2,67	4,1	7,4	2,73
		+1,6	+0,96	–2,65	–2,25	–0,97
Disinfectant + SiO_2, 1 ml	(74–84) 79	14,3	2,54	4,75	9,3	3,39
		+1,8	+0,83	–2,0	–0,35	–0,31
Disinfectant + SiO2, 1 ml + Biogenic Fe,1 ml	(72–84) 78	13,7	2,34	5,0	9,7	3,56
		+1,2	+0,63	–1,75	+0,05	–0,14
LSD_{05}		1,08	0,54	1,72	1,6	0,36

ing the growing season, the decrease in protective function against disease development occurred to 78-84 and 71-79% against its spread. The inclusion of biogenic iron and silicon in the mixture to the chemical dressing reduced the effectiveness against root rot by 18-22% in the initial vegetation period, by the harvesting period of the crop - by 30-40%. When treated with a standard mixture (fungicidal disinfectant + insecticidal disinfectant + fertilizer) the effectiveness was higher by 8-17% in relation to the application of disinfectant in the mixture with iron, silicon (see Table 4).

The crop yield in conditions of average weediness before treatment with herbicides and weak manifestation of leaf-rolling diseases during the growing season was 2.4 t/ha in the control. The application of a complex of plant protection products increased by 0.4 t/ha, the double application of biogenic iron at seed dressing and at the earing phase - by 0.56 t/ha, when applying biogenic iron at tillering and earing phases in combination with silicon - by 0.63 t/ha. LSD_{05} was 0.2, which significantly exceeds the value of the standard scheme of protection (fungicide + insecticidal protector +

Табл. 4. Эффективность обработки против корневых гнилей, %
Tabl. 4. Treatment efficacy against root rot, %

Dressing option	Tillering phase			Before harvesting		
	Development	Spread	Effectiveness	Development	Spread	Effectiveness
Disinfectant + insecticide + fertilizer	0	0	100	0,72–1,01	2,90–4,05	84,42–78,2
Control (without treatment)	1,4	5,62	–	4,65	13,95	–
Disinfectant + Biogenic Fe, 1 ml	0,25	0,99	82,38	1,35	4,59	70,96
Disinfectant + SiO2, 1 ml	0,25	1,01	82,02	1,76	5,04	62,15
Disinfectant + SiO2, 1 ml + Biogenic Fe,1 ml	0,3	0,96	78,5	1,42	4,66	69,46
LSD_{05}	0,22	0,92	6	0,32	1,2	8

fertilizer). Application of silicon alone was at the level of standard protection. When assessing the use of biogenic iron, its positive effect was noted in the phases of tillering and earing and with greater efficiency in the phase of the beginning of earing in combination with fungicides or without them.

CONCLUSIONS

1. A positive effect on the germination energy (by 4-10%) and germination rate of spring triticale seeds was produced by using preparations containing copper, manganese, molybdenum, biogenic iron, Titan M. Of these, the preparations Titan M and molybdenum had a clear advantage (+7, +10%).

2. The effectiveness of micronutrient nanoparticles is enhanced by the inclusion of stabilizers that increase or decrease the effect of the elements.

3. The effect of micronutrients in the treatment of daily seedlings on the sprout length was observed in preparations of manganese, calcium, molybdenum, Titan M, biogenic iron, boron, potassium; the increase in sprout length was 7.8-25%, its weight - 6-8%.

4. Application of biogenic iron in seed pretreatment together with a chemical dressing promoted root growth by 12%; germination of seeds when treated with biogenic iron decreased by 4-10%.

5. Application of macro- and microelements in combination with chemical dressing reduced the effectiveness against root rot during the growing season by 16-30%.

6. The application of biogenic iron helped to increase the yield by 0,5-0,6 t/ha, or 23%, in the system of complex crop protection in comparison with the control and by 0,16-0,23 t/ha - with the standard scheme of crop protection. The positive effect of biogenic iron in the treatment of plants in the phase of earing as a separate element of technology, and in a tank mixture with fungicides was noted.

7. The application of macro- and micronutrient nanoparticles described in this study is possible both for seed pre-sowing treatment and during the growing season to stimulate growth.

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