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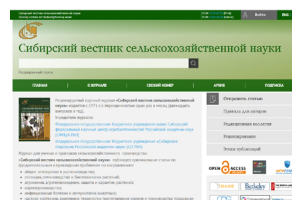
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СОДЕРЖАНИЕ

CONTENTS

ЗЕМЛЕДЕЛИЕ
И ХИМИЗАЦИЯ

AGRICULTURE
AND CHEMICALIZATION

Васильева Е.А., Рабинович Г.Ю. Получение и апробация биопрепарата для растениеводства на основе куриного помета

5 Vasilyeva E.A., Rabinovich G.Yu. Production and testing of a biopreparation for plant growing based on chicken manure

Балабанова Н.Ф., Воронкова Н.А., Волкова В.А. Сортовая специфика минерального питания новых сортов яровой твердой пшеницы

14 Balabanova N.F., Voronkova N.A., Volkova V.A. Varietal specificity of mineral nutrition of the new varieties of spring durum wheat

РАСТЕНИЕВОДСТВО И СЕЛЕКЦИЯ

PLANT GROWING AND BREEDING

Самбыла Ч.Н., Ходаева В.П., Позднякова И.В. Влияние биопрепаратов на продуктивность и качество мини-клубней картофеля в условиях лесостепи Кузнецкой котловины

24 Sambyla Ch.N., Khodaeva V.P., Pozdnyakova I.V. Influence of biopreparations on the productivity and quality of potato mini tubers in the forest-steppe conditions of the Kuznetsk Basin

Эрст А.А., Томошевич М.А. Содержание салидрозида в культивируемых клоновых растениях *Rhodiola rosea* L.

35 Erst A.A., Tomoshevich M.A. Salidroside content in cultivated clonal plants of *Rhodiola rosea* L.

Сотник А.Я., Крылова О.С., Григорьев Ю.Н. Влияние погодных условий Приобской лесостепи на урожайность ячменя ярового

42 Sotnik A.Ya., Krylova O.S., Grigoriev Yu.N. Influence of weather conditions in the Ob forest-steppe region on spring barley yield

ЗАЩИТА РАСТЕНИЙ

PLANT PROTECTION

Малюга А.А., Батов А.С., Гуреева Ю.А. Влияние средств интенсификации на поражение сортов картофеля сибирской селекции ризоктониозом

51 Malyuga A.A., Batov A.S., Gureeva Yu.A. Influence of the intensification agents on the infestation of Siberian potato varieties by rhizoctoniose

Плужникова И.И., Криушин Н.В., Бакулова И.В. Эффективность способов защиты агроценоза технической конопли от сорных растений

68 Pluzhnikova I.I., Kriushin N.V., Bakulova I.V. The effectiveness of the methods for protecting industrial hemp agrocenosis from weeds

ЗООТЕХНИКА И ВЕТЕРИНАРИЯ

ZOOTECHNICS AND VETERINARY MEDICINE

Пономарев С.В., Турчанинов Е.А., Левина О.А., Ахмеджанова А.Б., Федоровых Ю.В., Терганова Н.В. Оценка продуктивных качеств комбикорма производства ООО «БИФФ» для гибрида «РуКал» осетровых рыб

80 Ponomarev S.V., Turchaninov E.A., Levina O.A., Akhmedzhanova A.B., Fedorovykh Yu.V., Terganova N.V. Evaluation of the productive qualities of compound feed produced by the ООО "BIFF" for the "RuKal" hybrid sturgeon fish

Алтухова В.В., Востроилов А.В., Сафонов В.А. Влияние генотипа каппа-казеина на компонентный состав молока у высокопродуктивных коров-первотелок голштинской породы

90 Altukhova V.V., Vostroilov A.V., Safonov V.A. Influence of kappa-casein genotype on the milk component composition in high-yielding first-calf heifers of the Holstein breed

- Хромова О.Л., Абрамова Н.И., Селимян М.О., Зенкова Н.В.** Эффективность отбора быков-производителей в популяции голштинизированного скота **100** **Khromova O.L., Abramova N.I., Selimyan M.O., Zenkova N.V.** The effectiveness of stud bull selection in the Holstein cattle population

*МЕХАНИЗАЦИЯ, АВТОМАТИЗАЦИЯ,
МОДЕЛИРОВАНИЕ
И ИНФОРМАЦИОННОЕ ОБЕСПЕЧЕНИЕ*

*MECHANISATION, AUTOMATION,
MODELLING
AND DATAWARE*

- Петров С.М., Подгорнова Н.М., Сапалёв В.И.** Роботизированное внесение нанооксида цинка при листовой подкормке сахарной свеклы **109** **Petrov S.M., Podgornova N.M., Sapalev V.I.** Robotic application of nanozinc oxide for foliar application to sugar beet

- Назаров Н.Н., Некрасова И.В.** Качество распределения жидких минеральных удобрений при их поверхностном внесении **118** **Nazarov N.N., Nekrasova I.V.** Quality of the distribution of liquid mineral fertilizers in case of surface application



Получение и апробация биопрепарата для растениеводства на основе куриного помета

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Статья посвящена проблеме переработки птичьего помета. Рассмотрены биотехнологические приемы получения жидкого биопрепарата для растений на основе куриного помета. Исследования проведены на базе Всероссийского научно-исследовательского института мелиорированных земель (Тверская область). По итогам экспериментов подобраны оптимальные параметры процесса получения биопрепарата с использованием приема мягкой экстракции. Так как многие соединения присутствуют в курином помете в водорастворимой форме, при экстракции большая их часть переходит в раствор. При использовании жидких подкормок растения получают питание в виде концентрированного раствора, и такую их стимуляцию при необходимости можно осуществлять на протяжении всего вегетационного сезона. Экстрагировали подстилочный куриный помет годичной давности при температуре 70 °С водным раствором хлористого натрия в разных концентрациях (3, 5 и 7%) и при разной продолжительности воздействия (2, 4 и 6 ч). Исследовав полученные вытяжки, определили оптимальный режим экстракции: соотношение исходного сырья и экстрагента – 1 : 10, концентрация раствора хлористого натрия – 5%, время экспозиции – 6 ч. При соблюдении указанных параметров в полученном биопрепарате наблюдалась высокая ферментативная активность: у каталазы она составила 2,45 Е/мл, у целлюлазы – 0,28 мкг глюкозы/0,2 г/сут, у инвертазы – 168 мг глюкозы/г/сут. Также зафиксировано наибольшее содержание углеводов: редуцирующие сахара – 0,20%, глюкоза – 0,10, фруктоза – 0,23%. Определялся благоприятный консорциум микрофлоры: количество смешанных микроорганизмов – $4,0 \times 10^7$ КОЕ/мл, молочнокислых бактерий – $2,6 \times 10^5$ КОЕ/мл. Эффективность биопрепарата определяли в лабораторном эксперименте по всхожести семян и развитию растений льна сорта Надежда. При обработке семян биопрепаратом достоверно увеличилась длина проростков (на 19,3% при дозе 5 мл/л, на 16,9% при дозе 10 мл/л, на 21,5% при дозе 15 мл/л), масса сухих проростков увеличилась более чем в 2–3 раза (во всех разведениях), что доказывает эффективность применения нового биопрепарата.

Ключевые слова: куриный помет, экстракция, биопрепарат, углеводы, ферментативная активность, микрофлора

Production and testing of a biopreparation for plant growing based on chicken manure

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The article focuses on the problem of poultry manure processing. Biotechnological methods for obtaining a liquid biopreparation for plants based on chicken manure are considered. All studies were conducted at the All-Russian Research Institute of Reclaimed Lands (Tver Region). Based on the results of the experiments, optimal parameters for the process of obtaining a biopreparation using

a soft extraction technique were selected. Since many compounds are present in chicken manure in water-soluble form, most of them go into solution during extraction. When using liquid fertilizers, plants receive nutrition in the form of a concentrated solution and such stimulation can be carried out, if necessary, throughout the entire growing season. Chicken manure from a year ago was extracted at a temperature of 70 °C with an aqueous solution of sodium chloride in different concentrations (3, 5 and 7%) and for different durations of exposure (2, 4 и 6 hours). Having studied the obtained extracts, the optimal extraction mode was determined: the ratio of the initial raw material and extractant is 1:10, the concentration of the sodium chloride solution is 5%, the exposure time is 6 hours. When the specified parameters were met, high enzymatic activity was observed in the resulting biopreparation: catalase (2.45 U/ml), cellulase (0.28 µg glucose/0.2 g/day) and invertase (168 mg glucose/g/day). The highest carbohydrate content was also recorded: reducing sugars (0.20%), glucose (0.10%) and fructose (0.23%). A favorable microflora consortium was identified: the number of mixed microorganisms was 4.0×10^7 CFU/ml, lactic acid microorganisms – 2.6×10^5 CFU/ml. The biopreparation effectiveness was determined in a laboratory experiment on seed germination and development of flax plants of the Nadezhda variety. When the flax seeds were treated with the biopreparation, the length of the sprouts reliably increased (by 19.3% at a dose of 5 ml/l, by 16.9% at a dose of 10 ml/l), and by 21.5% at a dose of 15 ml/l), the mass of dry sprouts increased more than 2–3 times (in all dilutions), which proves the effectiveness of the new biopreparation.

Keywords: chicken manure, extraction, biopreparation, carbohydrates, enzymatic activity, microflora

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Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Being a by-product of the poultry industry and widely used as fertilizer, chicken manure has a rich composition: total nitrogen – 3.0%, calcium – 6.5%, phosphorus – 2.0%, potassium – 2.0%, magnesium – 0.6%, lysine – 0.22%, aspartic acid – 0.48%, threonine – 0.17%, serine – 0.19%, glutamic acid – 0.69%, glycine – 0.23%, alanine – 0.30%, leucine – 0.21%, tryptophan – 0.84% (relative to air-dry matter). In addition, the following trace elements were found in chicken manure: copper – 0.008%, manganese – 0.004%, zinc – 0.0026%, cobalt – 0.08%, sulfur – 0.14%, boron – 0.005% [1, 2].

It's important that it contains humic substances, which can specifically affect plant growth

because they have a hormone-like effect similar to auxin. In terms of how it affects crop productivity, manure is close to mineral fertilizers. However, most of the nitrogen and phosphorus in it is in organic form. The phosphorus in chicken manure hardly binds in the soil as insoluble phosphates, so when it mineralizes, plants use it much more efficiently than phosphorus from mineral fertilizers¹ [3, 4].

According to M.V. Semenov and co-authors [5], using chicken manure as compost helps improve the porosity and aeration of the soil, reduce its density, and increases the pH on average by 0.2–0.4 units. Using compost made from chicken manure helps boost biological activity, microbial diversity, increases carbon content in microbial biomass (by 25–75%), and also boosts

¹Schmidt A.G. Using chicken manure to optimize the nutrition of agricultural crops in the southern forest-steppe of Western Siberia: Extended abstract of a candidate's thesis in agricultural sciences. Omsk, 2020, 24 p.

soil enzyme activity (phosphatases and catalases by 5–7 times, ureases by 3–5 times).

Since all minerals, including most macro- and microelements, are present in manure in a water-soluble form, and therefore easily accessible to plants, it's clear that a significant portion of them goes into the solution during extraction. In addition, it is known that liquid fertilizers are often preferable, since using them allows plants to get nutrients in the form of a concentrated solution of macro- and micronutrients, and they can be fed throughout the growing season.

Some researchers who developed methods for producing liquid fertilizers and preparations using biotechnological techniques extracted biologically active substances from bird droppings specifically in liquid form²⁻⁴. At the same time, the specifics of the methods for extracting them vary. For example, A.A. Sboev and others suggest obtaining a solution of biologically active substances through hydrolysis in the presence of an alkaline solution and subsequent mesophilic anaerobic fermentation (see footnote 4). This solution, containing humic acids and biologically active substances, is recommended for use not only in crop production but also in animal husbandry. The product has been tested both as a seed germination activator and as a biologically active supplement for broiler chicks. At the same time, this method of producing the bioproduct is quite complex and labor-intensive, which leads to its higher cost. The study by M.S. Yesenamanova and co-authors deserves attention [6], as part of which, by extracting nutrients into a water solution from poultry manure, they obtained not only a complete biofertilizer but also biogas.

Research results from various authors confirm that liquid biopreparations and biofertilizers made from chicken manure contain a complex

of valuable organic compounds, macro- and microelements necessary for the normal life processes of plants and help stimulate their growth. At the same time, the most important factors are the accessibility and low cost of biotechnological processes related to extraction. These are exactly the factors we considered when carrying out a series of experiments in this area.

The purpose of the study is to find the best parameters for producing a bioproduct from chicken manure using a gentle extraction method to increase the amount of biologically active and physiologically beneficial substances that can be obtained.

MATERIAL AND METHODS

They used bedding chicken manure (bedding – sawdust) that was a year old from a dump near the 'Verkhnevolzhskaya' poultry farm in the Tver region for the extraction. This raw material had basically undergone natural composting and fermentation. The extraction of the initial litter was done using an aqueous solution of sodium chloride (NaCl) at different concentrations (3, 5, and 7%), with the optimal concentration determined experimentally.

To choose the most optimal extraction mode, the effect of the interaction duration between chicken manure and the extractant was studied. Extracts obtained after 2, 4, and 6 hours of extraction were examined. The temperature regime was the same in all cases and was 70 °C. The extraction of biologically active substances from chicken manure was done at a raw material to extractant ratio of 1:10 based on absolutely dry matter. In the resulting extracts, they determined: the acidity of the medium (pH), carbohydrate content (the Issekutz method), enzyme activity (catalase – according to Bach and Opa-

²Patent 2523839 Russian Federation, IPC C05F3/00. A method for preparing liquid organic fertilizer / Kovalev F.M.; applicant and patent holder the ООО "Voronezh Environmental Company"; applied 16.12.11; published 27.07.14, Bulletin No. 21. 1 p.

³Patent 2051591 Russian Federation, IPC A23K 1/00, C05F 3/00. A method for preparing feed or fertilizer from bird droppings / Malofeev V.I.; applied 11.10.90; published 10.01.96, Bulletin No. 1. 5 p.

⁴Patent 2687452 C1 Russian Federation, IPC C05F 3/00. A method for obtaining a solution of biologically active substances from bird droppings / Sboev A.A., Shuvero V.M., Doctor B.U.; applicant and patent holder ООО "Plaza-City"; applied 09.28.18; published 05.13.19, Bulletin No. 13. 7 p.

rin, cellulase and invertase – by the colorimetric method), total microbial count, and the number of lactic acid bacteria (the Koch method).

The effectiveness of the biopreparation was studied in a lab experiment on the germination of seeds and the growth of flax plants of the Nadezhda variety. The doses of the preparation were: 0.5; 1.0; 3.0; 5.0; 7.0; 10.0; 15.0; 20.0 ml per liter of water. The control used only water. For each test, 25 flax seeds were taken. The experiment was done in triplicate. They measured germination energy, as well as the length and mass of the test plant seedlings.

RESULTS AND DISCUSSION

Aqueous sodium chloride solution was chosen as the extractant because of its stabilizing properties for most microorganisms, since it is known that bird droppings are highly populated with various microflora [7]. At the same time, it was necessary to preserve most of the native microflora and inhibit the rapid growth of unwanted microorganisms during extraction to reduce nutrient loss.

The pH in the tested extracts didn't depend on the duration of the extractant exposure (see Table 1). There was a tendency for the pH to slightly decrease as the NaCl concentration increased up to 7%. The alkaline reaction of the biopreparation suggests that it contains humic acid, which is soluble in water at neutral and alkaline pH, and fulvic acid, which is soluble in water regardless of the pH level [8].

As the exposure time increased, catalase activity went up. The highest catalase activity was observed across all exposure durations (2, 4, 6 hours) at a 5% NaCl solution concentration. This finding aligns with the results of other studies, which show that catalase activity increases when a mild salt stress is present⁵. In our case, when the salt solution concentration increased to the highest value (7%), the process was suppressed and the enzyme activity decreased.

As the extraction time increased, cellulase activity went up: the highest value was recorded after a 6-hour exposure. It's known that cellulase is resistant to the effects of salts⁶. However, within the experiment we conducted, this statement was confirmed only with a 6-hour expo-

Табл. 1. Влияние концентрации раствора натрия хлорида и времени экспозиции на кислотность среды и активность ферментов

Table 1. Effect of sodium chloride solution concentration and the exposure time on the environment pH and enzyme activity

Exposure time, h	NaCl, Concentration, %	Variant number	pH	Catalase activity, U/ml	Cellulase activity, µg glucose/0.2 g/day	Invertase activity, mg glucose/g/day
2	3	1	8,4 ± 0,16	1,29 ± 0,66	0,21 ± 0,05	258 ± 1,15
	5	2	8,6 ± 0,14	1,67 ± 0,29	0,20 ± 0,03	214 ± 4,33
	7	3	8,5 ± 0,15	1,26 ± 0,46	0,17 ± 0,06	190 ± 7,32
4	3	4	8,6 ± 0,20	1,07 ± 0,32	0,23 ± 0,03	262 ± 1,15
	5	5	8,6 ± 0,14	1,77 ± 0,25	0,20 ± 0,05	187 ± 2,35
	7	6	8,5 ± 0,17	1,82 ± 0,37	0,16 ± 0,03	115 ± 2,87
6	3	7	8,5 ± 0,15	1,22 ± 0,30	0,24 ± 0,07	247 ± 3,05
	5	8	8,6 ± 0,20	2,45 ± 1,20	0,28 ± 0,05	168 ± 6,93
	7	9	8,3 ± 0,11	1,67 ± 0,44	0,29 ± 0,03	175 ± 8,66

⁵Alieva D.R., Babaev G.G., Azizov I.V. Effect of increasing NaCl concentration on photosynthesis and catalase activity of *Dunaliella salina* cells // Bulletin of Dnepropetrovsk University. Biology. Ecology, 2009, Issue 17, vol. 1, pp. 3–9.

⁶Asha B.M., Sakthivel N. Production, purification and characterization of a new cellulase from *Bacillus subtilis*, that exhibit halophilic, alkalophilic and solvent-tolerant properties // Annals of microbiology, 2014, vol. 64, pp. 1839–1848.

sure, while with 2- and 4-hour exposures there was a tendency for the activity of this enzyme to decrease. The difference could be related to the thermophilic nature of cellulase, which showed increased activity when chicken manure was exposed to heat for a longer period.

In all exposure scenarios, there was a clear decrease in invertase activity as the concentration of saline solution increased. The reason salinity negatively affects invertase is that it's an extracellular enzyme, so the destruction of some of the bacterial cells that produce invertase, under the influence of the pollutant (sodium chloride in this case), can lead to a drop in its production [9].

The presence of available forms of carbohydrates indicates the biological value of the preparation. It is known that monosaccharides stimulate the development of microflora, help transform humic substances, and catalyze seed germination and seedling growth⁷ [10].

In the bird droppings extract, reducing sugars (0.13–0.22%), glucose (0–0.12%), fructose (0.15–0.26%), and sucrose (0.06–0.26%) were found (see Table 2). There was no clear relation-

ship between sugar content and extraction time or salt solution concentration. Regarding glucose, it's worth noting that the amount increased in all exposure variations at a 7% sodium chloride concentration.

Looking at the extraction process from a microbiological point of view, you can see that increasing the exposure time from 2 to 4 hours led to a rise in the total amount of mixed microflora, but with further extraction (6 hours), it decreased. This can be explained by the prolonged effect of high temperature (70 °C) and, as a result, the suppression of the microflora (see Table 3). Lactic acid microorganisms reacted weakly to changes in extraction time, while increasing the salt solution concentration only positively affected their growth with a 2-hour exposure.

Considering the growth of microorganisms in the obtained extracts, the optimal options should be considered 3 and 7–9, since here, in the overall mix of microflora, the largest share was made up of lactic acid bacteria, which are more desirable and beneficial. Lactic acid bacteria show competitive and antagonistic activity against many pathogenic microorganisms and

Табл. 2. Влияние концентрации раствора натрия хлорида и времени экспозиции на содержание доступных углеводов

Table 2. Effect of sodium chloride solution concentration and the exposure time on the content of available carbohydrates

Exposure time, h	NaCl, concentration, %	Variant number	Content, %			
			glucose	fructose	sucrose	reducing sugars
2	3	1	Traces	0,26 ± 0,11	0,17 ± 0,08	0,22 ± 0,09
	5	2	»	0,17 ± 0,06	0,08 ± 0,03	0,14 ± 0,06
	7	3	0,12 ± 0,05	0,23 ± 0,08	0,11 ± 0,06	0,20 ± 0,07
4	3	4	0,03 ± 0,01	0,21 ± 0,09	0,26 ± 0,07	0,18 ± 0,08
	5	5	Traces	0,23 ± 0,06	Traces	0,19 ± 0,05
	7	6	0,05 ± 0,03	0,15 ± 0,05	0,16 ± 0,08	0,13 ± 0,04
6	3	7	Traces	0,22 ± 0,06	0,04 ± 0,03	0,19 ± 0,07
	5	8	0,10 ± 0,04	0,23 ± 0,08	0,06 ± 0,03	0,20 ± 0,07
	7	9	0,10 ± 0,06	0,25 ± 0,10	0,10 ± 0,05	0,22 ± 0,09

⁷Kireycheva L.V., Peregudov S.V., Shilova E.Yu. The use of a fertilizer-ameliorating mixture based on sugar production waste to improve the fertility of low-productivity soils // Agrochemical Herald. 2010, No. 1, pp. 22–24.

can produce antibiotics, proteins, acids (both organic and fatty), phenols, and other compounds. They can also colonize plant root systems, thereby preventing them from being infected by phytopathogens [11–13].

Based on the results obtained, the optimal extraction mode for chicken manure was chosen: exposure time – 6 hours, temperature – 70 °C, NaCl concentration – 5–7%. To determine its effectiveness under laboratory conditions, an experiment was conducted on seed germination and flax plant development. The study was carried out with different doses of the preparation (see Table 4, the figure).

According to the data in the figure, treating flax seeds with the tested preparation didn't affect their germination (no significant difference was found). At the same time, the length of the seedlings increased significantly: by 16.9% at a dose of 10 ml/l, by 19.3% at 5 ml/l, and by 21.5% at 15 ml/l (compared to the control). There was also an increase in the dry weight of the seedlings in all cases (more than 2–3 times), except at the 5 ml/l dose.

Табл. 3. Влияние концентрации раствора натрия хлорида и времени экспозиции на численность микроорганизмов

Table 3. Effect of sodium chloride solution concentration and the exposure time on the number of microorganisms

Exposure time, h	NaCl, concentration, %	Variant number	Total microbial count, CFU/ml	Lactic acid bacteria count, CFU/ml
2	3	1	$4,2 \times 10^8$	$7,5 \times 10^5$
	5	2	$1,75 \times 10^9$	$5,0 \times 10^5$
	7	3	$2,4 \times 10^8$	$1,15 \times 10^6$
4	3	4	$1,2 \times 10^9$	$3,08 \times 10^5$
	5	5	$4,8 \times 10^9$	$2,0 \times 10^5$
	7	6	$5,0 \times 10^8$	$1,82 \times 10^5$
6	3	7	$6,0 \times 10^7$	$1,8 \times 10^5$
	5	8	$4,0 \times 10^7$	$5,5 \times 10^5$
	7	9	$3,2 \times 10^7$	$2,6 \times 10^5$

CONCLUSION

In the study, a method of producing a plant biopreparation from chicken manure using gentle extraction was investigated. Based on a series of experiments, the most optimal extraction conditions were chosen: the raw material to extractant ratio (aqueous NaCl solution) – 1:10, temperature – 70 °C, salt solution concentration – 5%, exposure time – 6 hours. In this extraction mode, the extract showed high catalase activity (2.45 U/ml), cellulase (0.28 µg glucose/0.2 g/day) and invertase (168 mg glucose/g/day), the highest content of reducing sugars (0.20%), glucose (0.10%) and fructose (0.23%) with favorable microbial levels (total microbial count – 4.0×10^7 CFU/ml, lactic acid bacteria – 2.6×10^5 CFU/ml).

Treating flax plants with the obtained preparation showed its effectiveness: the length of the sprouts increased significantly (by 19.3, 16.9, and 21.5% at doses of 5, 10, and 15 ml/l respectively), and the dry weight of the sprouts also grew more than 2–3 times in almost all cases.

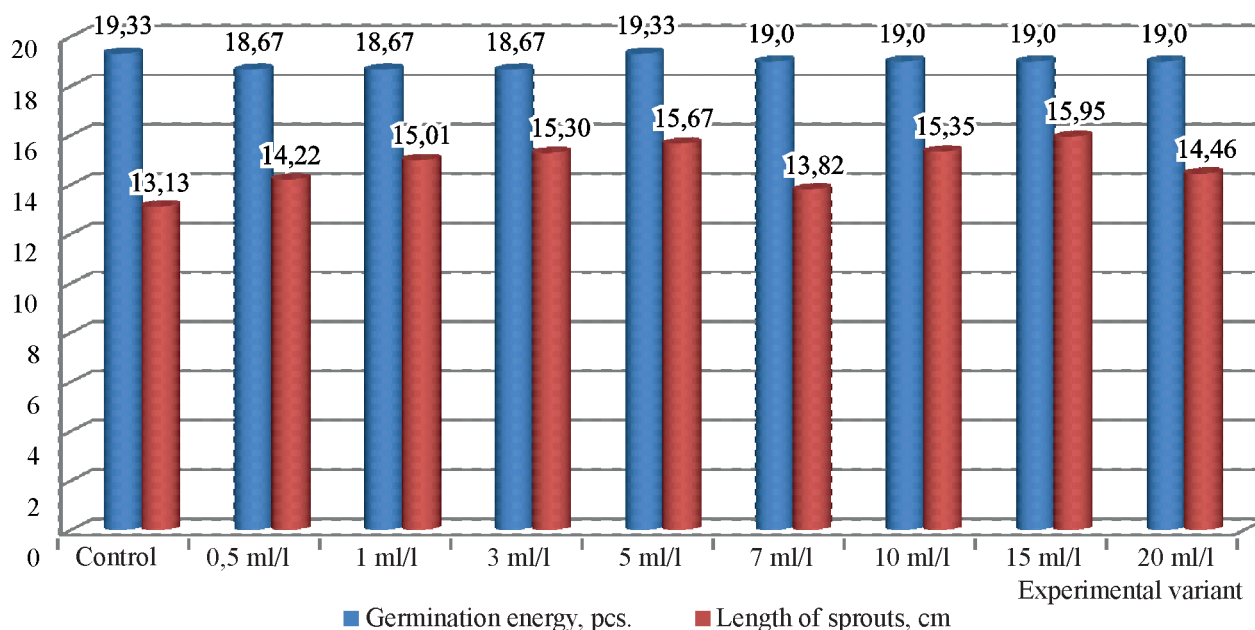
Табл. 4. Влияние препарата на всхожесть семян и развитие растений льна ($M \pm m$, $n = 3$)

Table 4. Effect of the preparation on seed germination and development of flax plants ($M \pm m$, $n = 3$)

Experiment option	Weight of sprouts, g	
	raw	dry
Water (control)	$0,92 \pm 0,03$	$0,10 \pm 0,01$
Preparation, ml/l:		
0,5	$0,78 \pm 0,07$	$0,23 \pm 0,04^*$
1,0	$0,89 \pm 0,02$	$0,22 \pm 0,01^{**}$
3,0	$1,03 \pm 0,08$	$0,32 \pm 0,03^{**}$
5,0	$0,96 \pm 0,03$	$0,09 \pm 0,02$
7,0	$0,88 \pm 0,07$	$0,21 \pm 0,03^{**}$
10,0	$1,00 \pm 0,11$	$0,29 \pm 0,03^{**}$
15,0	$0,94 \pm 0,18$	$0,27 \pm 0,01^{**}$
20,0	$0,98 \pm 0,26$	$0,27 \pm 0,02^{**}$

* $p \leq 0,10$.

** $p \leq 0,05$.



Влияние препарата на всхожесть и развитие льна

Effect of the preparation on the germination and development of flax

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Сортовая специфика минерального питания новых сортов яровой твердой пшеницы

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Изучена сортовая специфика яровой твердой пшеницы Омский топаз, Омский малахит на применение минеральных удобрений (0; P_{45} ; P_{45} + некорневая подкормка в фазу колошения N_{30} ; $N_{30}P_{45}$; P_{20} при посеве) в условиях Омского Прииртышья. Почва лугово-черноземная средне-мощная тяжелосуглинистая, содержание гумуса 6,3–6,5% (по Тюрину), подвижного фосфора и обменного калия – 101–120 и 350–420 мг/кг почвы (по Чирикову) соответственно, pH – 6,5–6,7. Установлено, что новые сорта Омский топаз, Омский малахит, заявленные как сорта с повышенным индексом глютена (более 50%), уступали по урожайности сорту-стандарту Жемчужина Сибири на неудобренном фоне на 19 и 11% соответственно. Максимальная прибавка зерна (0,35–0,37 т/га) у испытываемых сортов получена в варианте внесения минеральных удобрений в дозе $N_{30}P_{45}$ при агрономической окупаемости не более 5 кг зерном. У сорта-стандарта окупаемость составила 10,4 кг зерна. Выявлено, что содержание валовых форм азота, фосфора и калия в зерне и соломе пшеницы аналогично сорту-стандарту. Расход азота и калия у сортов Омский топаз и Омский малахит превышал расход этих элементов сорта-стандарта на 4,5–8,3 и 5,0–13,4 кг соответственно. Коэффициенты использования из почвы и удобрений (КИП и КИУ) NPK у новых сортов не отличались от стандарта, за исключением сорта Омский малахит: КИУ – 62%, на 11% абс. ед. ниже, чем у сорта-стандарта. Наибольшее содержание белка в зерне было у сорта Омский малахит – 16,4 (неудобренный фон), индекс глютена у сорта Омский топаз получен на уровне 76,1%, у сорта Омский малахит – 58,4%.

Ключевые слова: яровая твердая пшеница, сорт, минеральные удобрения, урожайность, качество зерна

Varietal specificity of mineral nutrition of the new varieties of spring durum wheat

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The varietal specificity of spring hard wheat Omsky Topaz, Omsky Malachite was studied in response to the use of mineral fertilizers (0; P_{45} ; P_{45} + foliar feeding in the heading phase N_{30} ; $N_{30}P_{45}$; P_{20} at sowing) in the conditions of the Omsk Irtysh region. The soil is meadow-chnozem, medium-deep, heavy loamy, with a humus content of 6.3–6.5% (according to Tyurin), mobile phosphorus and exchangeable potassium of 101–120 and 350–420 mg/kg of soil (according to Chirikov), respectively, and a pH of 6.5–6.7. It was found that the new varieties Omsky Topaz and Omsky Malachite, declared as the varieties with an increased gluten index (more than 50%), were inferior in yield to the Pearl of Siberia standard variety on an unfavorable background by 19 and 11%, respectively. The maximum increase (0.35–0.37 t/ha of grain) in yield in the tested varieties was obtained in the application of mineral fertilizers at a dose of $N_{30}P_{45}$, with an agronomic payback of no more than 5 kg of grain. In the standard variety, the payback was 10.4 kg of grain. It was revealed that the content of gross forms of nitrogen, phosphorus and potassium in wheat grain and straw is similar to the standard variety. The consumption of nitrogen and potassium in the Omsky Topaz and Omsky Malachite varieties exceeded the consumption of these elements of the standard variety by 4.5–8.3 kg; 5.0–13.4 kg, respectively. The coefficients of use of NPK from soil and fertilizers (CUN and CUF) of the new varieties did not differ from the standard, with the exception of the Omsky Malachite variety: CUF – 62%, 11% ab. units lower than that of the standard grade. The highest protein content in the grain was in the Omsky

Malachite variety –16.4 (unfertilized background), the gluten index in the Omsky Topaz variety was obtained at 76.1% and in the Omsky Malachite variety – 58.4%.

Keywords: spring durum wheat, variety, mineral fertilizers, yield, grain quality

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Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Among the many natural and agrotechnical factors that help improve fertilizer efficiency and increase crop productivity, the variety plays a big role¹ [1, 2]. An integral feature of the new variety is its high yield with improved quality parameters of crop products, making it popular among producers.

Studies on the genotypic responsiveness of agricultural plants have shown that the variety accounts for 25 to 67% of the yield². In this regard, it's really possible to fully unlock the crop's genetic production potential when it's grown taking into account the methods of varietal technology. These adaptive technologies, in addition to the set of standard technological practices, provide the plants with an optimally balanced level of mineral nutrition throughout the growing season.

There are quite a few studies showing that it's important to take a differentiated approach when choosing the level of mineral nutrition, depending on the crop variety. Researchers have found that the ability to significantly improve the use of nutrients from fertilizers, and thus their return in the yield, is linked to the variety's effect, with the specifics of root nutrition being genetically controlled³ [3, 4]. There are varieties that

can not only absorb significantly more nitrogen, phosphorus, and potassium from the soil and fertilizers, but also produce more organic matter per unit of absorbed element. Knowing the nutritional characteristics of a particular variety is an important way to increase the efficiency of the mineral fertilizers used for that crop. On the other hand, ignoring the traits of new varieties can lead to a situation where a large part of the fertilizers added to the soil ends up being useless for the plants, and the costs of applying them are not adequately compensated by increased yields. Therefore, when introducing new varieties, it makes sense to develop specific variety-focused farming practices for the particular soil and climate conditions.

The purpose of the study is to look at how new varieties of hard wheat respond to mineral nutrition conditions in the black soils of the Omsk Irtysh region.

The research objectives are:

- set the qualitative and quantitative parameters for the removal and consumption of the main nutrients;
- determine the responsiveness of spring durum wheat varieties to doses and methods of applying mineral fertilizers;
- to identify the impact of the studied factors on the formation of yield and grain quality.

¹Krivobochek V.G., Semina S.A., Ostroborodova N.I. The response of spring soft wheat Arkhat variety to the introduction of complex fertilizers // Volga Region Farmland, 2017, No. 2 (43). pp. 24–29.

²Voronkova, N.A. Biological resources and their importance in preserving soil fertility and increasing the productivity of agrocenoses of Western Siberia. Omsk: Omsk State Technical University, 2014 p.

³Gamzikova O.I. Studies on plant physiology, agrochemistry and genetics of mineral nutrition. Novosibirsk: Agros, 2008, 372 p.

The scientific novelty lies in the fact that for the first time, under the conditions of the Omsk Irtysh region on chernozem soils, the specifics of mineral nutrition of new spring durum wheat varieties with an increased gluten index have been studied.

MATERIAL AND METHODS

The subject of the study is spring durum wheat varieties Omsky Topaz, Omsky Malachite:

- Omsky Malachite: submitted for state variety testing in the Russian Federation in 2022. The variety was included in the State Register of Breeding Achievements of the Russian Federation in 2025. It combines high yield and grain quality (with a good gluten index);

- Omsky Topaz: submitted for state variety testing in the Russian Federation in 2023. It combines adaptability, high yield, and grain quality (with a good gluten index).

The research was conducted in 2021–2023 at the experimental plot of the agrochemistry laboratory of the Omsk Agricultural Science Center, located in the southern forest-steppe zone of the Omsk region.

Two-factor experiment design (3×5):

- factor A – variety: Pearl of Siberia (standard), Omsky Topaz, Omsky Malachite;

- factor B – mineral fertilizers: control (without applying mineral fertilizers); P_{45} (main application); P_{45} (main application) + foliar feeding NP N_{30} (heading stage); $N_{30}P_{45}$ (main application); P_{20} (pre-sowing application).

The experimental plot area was 20 m², with triple repetition, and systematic placement. The forecrop was complete fallow. The seeding rate was 5 million viable seeds per hectare. Mineral fertilizers (ammonium nitrate, ammophos) were applied manually during pre-sowing cultivation according to the research design, P_{20} applied locally at sowing. The sowing was done using a SS-11 seeder. Non-root nitrogen fertilization was carried out at the heading stage with urea, using 200 liters of working solution per hectare. During the tillering phase, the crops were treated with herbicide against weeds. Harvesting was done with a Wintersteiger Quantum Plus combine.

Laboratory and analytical studies of the soil and plant samples were carried out using the standard methods. Nitrate nitrogen content was determined using disulfo phenol acid according to Grandval–Lajoux, available phosphorus and exchangeable potassium – from a single extract according to Chirikov in the CINAO modification, GOST 26204–91, with the final determination of potassium by atomic absorption and phosphorus colorimetrically, staining – according to Deniges. Plant samples for total nitrogen, phosphorus, and potassium content were analyzed from a single sample (V.V. Pinevich, 1955), and the gluten index was determined according to GOST ISO 21415-2–2019. Data processing was done using analysis of variance (B.A. Dospekhov, 2014).

The soil of the experimental plot was medium-thick meadow-chernozem heavy loam, with a humus content of 6.3–6.5% (according to Tyurin), pH 6.5–6.7, and mobile phosphorus and exchangeable potassium of 101–120 and 350–420 mg/kg of soil (according to Chirikov), respectively.

The weather conditions during the years of research were characterized by not particularly high air temperatures and extremely uneven rainfall. The hydrothermal coefficient for May to August averaged 0.76–1.02.

RESULTS AND DISCUSSION

The responsiveness of new spring durum wheat varieties, whose grain gluten is characterized by a high gluten index, to the use of mineral fertilizers has been studied. The pasta production industry currently has special requirements for gluten quality, assessed by the gluten index (GI). Raw materials with a high index make it possible to use high-temperature drying technology for pasta, which helps increase productivity and efficiency in pasta production. On the global market, gluten quality is assessed by SDS-sedimentation values (>40.0 ml) and the gluten index (>65.0%) [5–7].

The productivity of a variety is one of the main indicators of how its genotype shows up when interacting with the environment. Testing varieties on different mineral nutrition backgrounds

allows you to determine the genotype's response norm to the level of nutrition. In this case, yield is the main indicator of how the variety responds to mineral nutrition conditions. Research results showed that the yield of the Omsky Topaz and Omsky Malachite varieties was 19% and 11% lower than the Pearl of Siberia standard, respectively, in the control version (see Table 1).

On average, for this factor, the yield of the Pearl of Siberia standard (3.15 t/ha) exceeded the yield of the tested varieties by 0.50–0.67 t/ha. It can be assumed that, while lagging behind the standard in productivity, the Omsky Topaz and Omsky Malachite varieties, declared as the varieties with improved grain quality characteristics, compensated for this decrease with enhanced technological traits. The Pearl of Siberia variety responded best to fertilizer application, with an additional yield of 0.36–0.78 t/ha depending on how it was applied. The yield of the new varieties on fertilized backgrounds did not exceed 0.37 t/ha. Yield analysis based on different fertilizer applications showed that applying a phosphorus fertilizer at a dose of P_{45} increased the yield of Pearl of Siberia by 0.43 t/ha, while the yield increase of the new varieties in this option was almost half as much, at 0.25–0.26 t/ha. With a binary combination of nutrients in the fertilizer ($N_{30}P_{45}$), the yield of the Pearl of Siberia variety was 3.49 t of grain/ha, which is 29% higher than in the unfertilized variant. Applying

N_{30} on a P_{45} background gave a grain increase of 0.35 t/ha. The response of the new varieties to the application of nitrogen-phosphorus fertilizers ($N_{30}P_{45}$) was lower than the standard. The yield of the Omsky Topaz and Omsky Malachite varieties in this case was at the level of applying phosphorus fertilizer (P_{45}), meaning the varieties responded very weakly to additional nitrogen feeding (N_{30}). Similarly, all three varieties behaved the same way when using foliar nitrogen feeding at a dose of N_{30} during the heading phase. No significant increase in yield was noted, which is quite natural since foliar feeding is mainly aimed at improving the quality traits of the grain [8, 9]. When applying phosphorus fertilizers (P_{20} in rows at sowing), the yield of the Pearl of Siberia variety was 0.62 t/ha higher compared to the control. For the new varieties, in the same setup, the additional grain obtained was almost 3 times less (0.21–0.24 t/ha).

When calculating the fertilizer response coefficient (FRC), it was found that the standard variety was the most sensitive (FRC – 129%) to improved mineral nutrition conditions (it can be classified as an intensive variety). For the new varieties, the FRC did not exceed 115%. It was found that only with a balanced nitrogen and phosphorus mineral nutrition (variant $N_{30}P_{45}$) did durum wheat plants demonstrate maximum response: from 114 to 115% for the new varieties and 129% for the standard. On average, the

Табл. 1. Влияние минеральных удобрений на урожайность сортов твердой пшеницы, т/га

Table 1. Effect of mineral fertilizers on the yield of durum wheat varieties, t/ha

Fertilizers applied, kg active ingredient/ha (B)	Variety (A)					
	Pearl of Siberia (standard)		Omsky Topaz		Omsky Malachite	
	Yield	FRC	Yield	FRC	Yield	FRC
Control (without fertilizers)	2,71	–	2,27	–	2,44	–
P_{45}	3,14	116	2,53	111	2,69	110
P_{45} + FA N_{30} in heading	3,07	113	2,51	111	2,64	108
$N_{30} P_{45}$	3,49	129	2,60	114	2,81	115
P_{20} in rows	3,33	123	2,48	109	2,68	110
On average by the variety factor	3,15	120	2,48	111	2,65	111

LSD₀₅ A = 0,24; LSD₀₅ B = 0,20; LSD₀₅ AB = 0,28

Note. FRC – fertilizer response coefficient.

FRC variety for Omsky Topaz and Omsky Malachite achieved 111% of this factor, 9% lower than the standard variety.

In order to establish standard parameters for the content, removal and consumption of nitrogen, phosphorus and potassium by wheat plants, plant samples of grain and straw were analyzed in full. The chemical composition of grain and straw did not differ significantly between the experimental variants, so only two variants are presented: without fertilizers and variant N₃₀P₄₅, which yielded the highest wheat grain yield (see Table 2).

It was found that the content of essential mineral nutrients in grain and straw was independent of crop genotypic characteristics and fertilizer application. The chemical composition of plant samples from the new varieties was virtually identical to that of the standard variety. For the nitrogen content in the grain of durum wheat varieties, the confidence interval was $2.67 \pm 0.14\%$, in the straw $-0.52 \pm 0.06\%$; phosphorus: in the grain $0.74 \pm 0.02\%$, in the straw $0.10 \pm 0.01\%$; potassium: in the grain $0.54 \pm 0.04\%$, in the straw $1.39 \pm 0.04\%$.

Nutrient removal depended largely on yield. In an unfertilized environment, the crop required 95.0–95.8 kg of nitrogen, 21.9–24.6 kg of phos-

phorus, and 79.2–88.3 kg of potassium to form a yield (see Table 3). In a fertilized environment, wheat yield exceeded the control variant (as noted previously). Removal is a calculated value, so the numerical data is naturally higher in the N₃₀P₄₅ variant.

We believe that the consumption of mineral nutrients to produce 1 ton of grain with the corresponding amount of by-products is an important agrochemical standard indicator. This information determines the correct calculation of mineral fertilizer rates for a given crop and the development of a fertilizer system within the overall crop rotation. While no significant differences were noted when analyzing the crop's nutrient content and removal, consumption should be examined in more detail. Nitrogen consumption for the standard variety was 35.3 kg/t of wheat grain in the control and 34.3 kg/t in the fertilized condition.

The Omsky Topaz and Omsky Malachite varieties differed from the standard variety in that they consumed 6.5 and 4.5 kg more nitrogen in the control and 8.3 and 6.9 kg more nitrogen in the fertilized variety, respectively. If converted to the Pearl of Siberia variety, these nitrogen consumption rates (4.5–8.3 kg) would have provided an additional grain yield of 0.13

Табл. 2. Влияние минеральных удобрений на содержание валовых форм NPK в основной и побочной продукции сортов твердой пшеницы, %

Table 2. Effect of mineral fertilizers on the content of gross NPK forms in the main products and by-products of durum wheat varieties, %

Fertilizers applied, kg active ingredient/ha (B)	Variety (A)					
	Pearl of Siberia (standard)		Omsky Topaz		Omsky Malachite	
	Grain	Straw	Grain	Straw	Grain	Straw
<i>Gross nitrogen content</i>						
Control (without fertilizers)	2,67	0,43	2,56	0,52	2,88	0,56
N ₃₀ P ₄₅	2,47	0,48	2,63	0,54	2,80	0,62
<i>Gross phosphorus content</i>						
Control (without fertilizers)	0,72	0,10	0,73	0,10	0,73	0,10
N ₃₀ P ₄₅	0,72	0,11	0,78	0,10	0,75	0,11
<i>Gross potassium content</i>						
Control (without fertilizers)	0,60	1,34	0,58	1,41	0,50	1,37
N ₃₀ P ₄₅	0,55	1,36	0,55	1,38	0,49	1,46

LSD₀₅ A = $F_T < F_\phi$; LSD₀₅ B = $F_T < F_\phi$; LSD₀₅ AB = $F_T < F_\phi$

Табл. 3. Влияние минеральных удобрений на вынос и расход валовых форм NPK основной и побочной продукцией сортами твердой пшеницы

Table 3. Effect of mineral fertilizers on the removal and consumption of the gross NPK forms of the main products and by-products of durum wheat varieties

Fertilizers applied, kg active ingredient/ha (B)	Variety (A)					
	Pearl of Siberia (standard)		Omsky Topaz		Omsky Malachite	
	Removal *	Consumption **	Removal	Consumption	Removal	Consumption
<i>Nitrogen</i>						
Control (without fertilizers)	95,8	35,3	95,0	41,8	97,2	39,8
N ₃₀ P ₄₅	120,0	34,3	111,0	42,6	116	41,2
<i>Phosphorus</i>						
Control (without fertilizers)	24,6	9,1	21,9	9,6	23,3	9,5
N ₃₀ P ₄₅	31,3	9,0	28,4	10,9	30,0	10,6
<i>Potassium</i>						
Control (without fertilizers)	88,3	32,5	85,3	37,5	79,2	29,4
N ₃₀ P ₄₅	97,6	29,3	106,0	42,7	87,3	31,0

*Removal, kg/ha.

**Consumption, kg/t of grain.

to 0.24 t/ha. Phosphorus consumption by durum wheat plants to produce 1 ton of grain with a corresponding amount of by-products varied from 9.0 to 10.9 kg/t, with no clear patterns depending on the factors studied. Potassium, like nitrogen, showed varietal differences: potassium consumption for the standard variety and Omsky Malachite was approximately the same – from 29.3 to 32.5 kg/t of grain. For the Omsky Topaz variety, this requirement ranged from 37.5 to 42.7 kg/t of grain, depending on the fertilization background. Compared to Pearl of Siberia, potassium consumption for this variety was 15% higher in the unfertilized state and 46% higher in the fertilized state. Established agrochemical characteristics in qualitative and quantitative parameters for each variety determine their individual fertilizer requirements.

Statistical processing of paired features of gluten index, protein content, grain unit and 1000 grain weight with the content of gross forms of nitrogen and phosphorus in grain showed their correlation from weak to strong positive ($r = 0,13-0,99$) (see Table 4). A correlation analysis revealed that for gluten-rich varieties, grain unit weight, gluten index, and 1,000-kernel

weight were more dependent on grain nitrogen content than for the Pearl of Siberia standard. Phosphorus was also important for these varieties: the correlation between grain unit weight, gluten index, and grain protein content with grain phosphorus concentration was moderate to high, with the standard's correlation being somewhat weaker than that of the Omsky Topaz and Omsky Malachite varieties.

New varieties of spring durum wheat utilize soil nutrients similarly to the standard variety (see Table 5). The utilization rate of soil nutrients was 65–68% for nitrogen, 6–7% for phosphorus, and 12–13% for potassium.

Varietal differences emerged in the utilization of nutrients from fertilizers. The Pearl of Siberia and Omsky Topaz varieties achieved nitrogen utilization rates of 73% and 76%, respectively, while Omsky Malachite achieved nitrogen utilization rates of 62%. The CUF of phosphorus in the varieties is 10–14% when applied together with nitrogen (N₃₀P₄₅), slightly lower when applying only phosphorus fertilizer (P₄₅) – 3–11%, the CUF 19–24% – when applying phosphorus in rows during sowing (P₂₀).

Protein content is an important quality indicator of grain. Our experiment yielded grain that met this criterion as first-class (see Table 6).

Табл. 4. Корреляционная связь отдельных элементов качества зерна и структуры урожая яровой твердой пшеницы с содержанием валовых форм азота и фосфора в зерне

Table 4. Correlation of individual elements of grain quality and yield structure of spring durum wheat with the content of gross forms of nitrogen and phosphorus in grain

Indicator	Variety (A)		
	Pearl of Siberia (standard)	Omsky Topaz	Omsky Malachite
<i>Total nitrogen content in grain, %</i>			
Gluten index	0,19	0,39	0,53
Protein	0,97	0,99	0,74
Grain unit	0,39	0,84	0,77
Weight of 1000 grains, g	0,53	0,79	0,66
<i>Total phosphorus content in grain, %</i>			
Gluten index	0,13	0,39	0,83
Protein	0,38	0,87	0,42
Grain unit	0,39	0,87	0,82
Weight of 1000 grains, g	0,83	0,58	0,51

Табл. 5. Коэффициенты использования питательных (КИП) элементов из почвы и удобрений (КИУ) сортами яровой твердой пшеницы в зависимости от применения удобрений, %

Table 5. Coefficients of utilization of nutrients from soil (CUN) and fertilizers (CUF) by the varieties of spring durum wheat depending on the application of fertilizers, %

Utilization coefficient (UC)	Option	Pearl of Siberia			Omsky Topaz			Omsky Malachite		
		Nitro-gen	Phos-phorus	Potassi-um	Nitro-gen	Phos-phorus	Potassi-um	Nitro-gen	Phos-phorus	Potassi-um
CUN	Without fertilizers	68	6	13	65	7	12	67	7	12
CUF	» »	–	–	–	–	–	–	–	–	–
	P ₄₅		11	–	–	5	–	–	3	–
	N ₃₀ P ₄₅	73	14	–	76	10	–	62	14	–
	P ₂₀ in rows		21	–	–	19	–	–	24	–

It was found that in unfertilized conditions, the leader in grain protein content was the Omsky Malachite variety (16.4%), while the Omsky Topaz variety had this indicator at the level of the standard variety – 14.5 and 15.2%, respectively. The variability of protein content in the grain of new durum wheat varieties depending on fertilizer use was insignificant. On average, by the variety factor, the protein yield for the standard variety was 0.46 t/ha, a similar result was obtained for the Omsky Malachite variety (0.43 t/ha). The lowest protein yield (0.37 t/ha) was for the Omsky Topaz variety.

The basis of vegetable gelatin is gluten, which is a complex of glutenin and gliadin [10,

11]. Determination of the gluten index in grain revealed clear varietal specificity (see Table 7).

The gluten index of Pearl of Siberia grain ranged from 19.2% to 23.4%, with the new varieties having a gluten index 2.3-3.6 times higher. The gluten index of Omsky Topaz ranged from 68.0% to 76.1%, while that of Omsky Malachite ranged from 50.2% to 58.4%. Modification of gluten content depending on fertilizers was observed in both new durum wheat varieties. The highest gluten content was observed in the variant with the primary nutrient application and the binary nutrient combination (N₃₀P₄₅) – 76.1% for the Omsky Topaz variety and 58.4% for the Omsky Malachite variety.

Табл. 6. Влияние минеральных удобрений на содержание (%) и сбор белка (т/га) новых сортов твердой пшеницы
Table 6. Effect of mineral fertilizers on the content (%) and protein yield (t/ha) of the new durum wheat varieties

Fertilizers applied, kg active ingredient/ha (B)	Variety (A)					
	Pearl of Siberia (standard)		Omsky Topaz		Omsky Malachite	
	Protein, %	Protein yield, t/ha	Protein, %	Protein yield, t/ha	Protein, %	Protein yield, t/ha
Control (without fertilizers)	15,2	0,41	14,5	0,32	16,4	0,40
P ₄₅	14,1	0,44	15,0	0,38	16,3	0,44
P ₄₅ + FA N ₃₀ in the heading phase	15,6	0,47	15,0	0,37	16,7	0,44
N ₃₀ P ₄₅	14,0	0,49	15,0	0,39	15,9	0,45
P ₂₀ in rows	14,5	0,48	15,6	0,38	16,3	0,44
On average by the variety factor	14,7	0,46	15,0	0,37	16,3	0,43

$LSD_{05} A = F_{\phi} < F_T$; $LSD_{05} B = F_{\phi} < F_T$; $LSD_{05} AB = F_{\phi} < F_T$

Табл. 7. Влияние минеральных удобрений на индекс глютена в зерне новых сортов твердой пшеницы, %
Table 7. Effect of mineral fertilizers on the gluten index in the grain of the new durum wheat varieties, %

Fertilizers applied, kg active ingredient/ha (B)	Variety (A)		
	Pearl of Siberia (standard)	Omsky Topaz	Omsky Malachite
Control (without fertilizers)	21,0	68,0	52,3
P ₄₅	23,4	74,0	55,6
P ₄₅ + FA N ₃₀ in the heading phase	21,8	71,7	50,2
N ₃₀ P ₄₅	20,6	76,1	58,4
P ₂₀ in rows	19,2	70,0	51,1

$LSD_{05} A = 12,2$; $LSD_{05} B = 15,8$; $LSD_{05} AB = 15,8$

CONCLUSION

Research examining the responsiveness of new spring durum wheat varieties to fertilizers on chernozem soils in the Omsk Irtysh region revealed that the tested varieties possess distinct genotypic characteristics. The new varieties were found to be inferior to the Pearl of Siberia standard in terms of yield and fertilizer responsiveness. In the unfertilized variant, the yield of the standard variety was 11% and 19% higher than that of the test varieties. The agronomic return on mineral fertilizer in the highest-yielding variant (N₃₀P₄₅) did not exceed 5 kg of grain. The NPK content of the grain and straw of the new varieties was similar to that of the standard variety. The nitrogen and potassium consump-

tion per ton of grain, with the corresponding amount of by-products, exceeded the standard. It was found that Omsky Topaz grain has a gluten index of 68–76%, while Omsky Malachite has a gluten index of 50–58%, which is 2.3–3.6 times higher than the standard variety.

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Влияние биопрепаратов на продуктивность и качество мини-клубней картофеля в условиях лесостепи Кузнецкой котловины

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В условиях лесостепи Кузнецкой котловины в 2023 и 2024 гг. изучено влияние биопрепаратов на продуктивные и качественные показатели картофеля. Материалами для исследований стали оздоровленные микро растения районированных сортов картофеля разных групп спелости: Любава (раннеспелый), Кемеровчанин и Невский (среднеранние), Тулеевский (среднеспелый), а также биопрепараты Фитоспорин-М, ПС (паста) и Фитоверм, КЭ (концентрат эмульсии). В качестве исходного материала из банка здоровых сортов картофеля взяты 768 микро растений по 192 растения каждого сорта и высажены в III декаде апреля на торфяной субстрат Агробалт-С в рассадные 64-ячеечные кассеты. Норму биопрепаратов для внекорневых обработок определяли согласно рекомендациям по их применению. Обработки проводили при выращивании рассадных растений картофеля (культура *in vivo*) в апреле – мае и в питомнике мини-клубней в июне – августе. Установлено, что биопрепараты способствовали увеличению высоты рассадных растений. По мере увеличения кратности внекорневых обработок доля выхода стандартной фракции мини-клубней у исследуемых сортов (кроме сорта Любава) повышается в среднем на 2–6% при двукратной обработке и на 1–4% при трехкратной. При этом количество нестандартной фракции снижается на 1–10%. Обработка растений биопрепаратами при выращивании рассады в культуре *in vivo* и при дальнейших обработках в питомнике размножения позволяет снизить развитие альтернариоза и ризактониоза на 3–8% и ограничить распространение фитофтороза. Полученные результаты позволяют считать влияние биопрепаратов на продуктивные и качественные показатели картофеля эффективным и перспективным.

Ключевые слова: картофель, сорт, мини-клубни, Фитоспорин-М, ПС, Фитоверм, КЭ, продуктивность, качество

Influence of biopreparations on the productivity and quality of potato mini tubers in the forest-steppe conditions of the Kuznetsk Basin

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In the forest-steppe conditions of the Kuznetsk Basin, the influence of biopreparations on the productivity and quality indicators of potatoes was studied in 2023 and 2024. The materials for the research were improved micro plants of the released potato varieties of different maturity groups: Lyubava (early-maturing), Kemerovochanin and Nevsky (middle-early), Tuleyevsky (medium-maturing), as well as the biopreparations Phitosporin-M, PS (paste) and Phytoverm, EC (emulsion concentrate). As a source material, 768 micro plants (192 plants of each variety) were taken from a bank of healthy potato varieties and planted in the

third ten-day period of April on Agrobalt-S peat substrate in 64-cell seedling cassettes. The dosage of biological preparations for foliar treatments was determined according to the recommendations for their use. Treatments were carried out during the cultivation of potato seedlings (*in vivo* culture) in April – May and in the mini-tuber nursery in June – August. It was established that biopreparations contributed to an increase in the height of seedling plants. As the frequency of foliar treatments increases, the share of the yield of the standard fraction of mini-tubers in the studied varieties (except for the Lyubava variety) increases by an average of 2–6% with two treatments and by 1–4% with three treatments. At the same time, the amount of non-standard fraction is reduced by 1–10%. Treatment of plants with biopreparations during *in vivo* seedling cultivation and subsequent treatments in the propagation nursery reduces the development of *Alternaria* and *Rhizactonia* blight by 3–8% and limits the spread of late blight. The results demonstrate that the impact of biopreparations on potato productivity and quality is effective and promising.

Keywords: potato, variety, mini tubers, Phytosporin-M, PS, Phytoverm, EC, productivity, quality

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Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Potatoes have long remained one of the most important crops, providing food security, economic growth, and job opportunities around the world [1]. Because of this, a lot of attention in the Russian Federation is being given to developing the potato-growing industry to reduce import dependence by increasing the productivity and quality of potatoes¹ [2, 3]. It's important to develop and implement scientifically based technologies for growing regional and newly created varieties, taking into account the variety-specific characteristics and optimizing their seed production [4–6]. In the end, the quality of seed potatoes should meet the standards, so there is often a need to carry out protective measures using chemical treatments [7, 8]. As an alternative to pesticides in seed production, biological products (bioproducts) are widely used² [9, 10]. Some authors note that biopreparations have a significant range of action, allowing for

increased productivity and resistance to adverse biotic and abiotic factors [11, 12], and limiting the spread and growth of fungal diseases [13]. However, there is very little research on the impact of biopreparations in original potato growing in Siberia. Therefore, studying the effects of biopreparations on the quantitative and qualitative indicators of potato seedlings is relevant and helps improve the methods for producing mini-tubers in original seed production.

The purpose of the work is to study the effect of biopreparations on the productivity and quality of seedling plants and mini-tubers of adapted potato varieties in the forest-steppe conditions of the Kuznetsk Basin in the Kemerovo region – Kuzbass.

MATERIAL AND METHODS

The research materials were improved micro plants of the released potato varieties of different maturity groups: Lyubava (early-

¹Subprogram of the comprehensive scientific research plan "Development of potato breeding and seed production in the Russian Federation" of the Federal Scientific and Technical Program for the Development of Agriculture for 2017–2025 (as amended by the RF Government Resolution No. 559 of 05.05.2018). URL: <https://files.stroyinf.ru/Data2/0/4294796/4294796031.pdf> (date of reference 23.11.2025).

²Chebotarev N.T., Tulinov A.G. Influence of biologically active substances on the productivity and quality of potato tubers in the Komi Republic // *Agrarian Bulletin of the Urals*, 2011, vol. 83, No. 4, pp. 76–78.

maturing), Kemerovochanin and Nevsky (middle-early), Tuleyevsky (medium-maturing); biopreparations Fitosporin-M, PS (paste) and Fitoverm, EC (emulsion concentrate).

The influence of biopreparations on the productivity and quality indicators of potato seedlings was studied in 2023 and 2024 in the Laboratory of potato breeding, biotechnology and agricultural engineering of the Kemerovo Research Institute of Agriculture – a branch of the Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences in accordance with potato seed production methods³.

Fitosporin-M, PS is a microbiological product with biofungicidal activity. The product is based on aerobic spore-forming bacteria *Bacillus subtilis* 26D (100 million/g), whose mechanism of action is to prevent the penetration of pathogens into plants and suppress their development. The product also helps increase resistance to adverse environmental factors. The biofungicide's protective action period is 10–15 days. Fitoverm, EC with the active ingredient aversectin C 1.0%, is a biological insecticide and acaricide with a protective action period of 7–20 days.

The application rates of biopreparations for foliar treatments were determined according to the recommendations for their use. Treatments were carried out during the cultivation of potato seedlings (*in vivo* culture) in April – May and in the mini-tubers nursery in June – August.

As a source material, 768 micro plants (192 plants of each variety) were taken from a bank of healthy potato varieties and planted in the third ten-day period of April on Agrobalt-S peat substrate in 64-cell seedling cassettes. The treatment of potato seedlings with preparations Fitosporin-M, PS and Fitoverm, EC in the *in*

vivo culture were carried out in three variants: 1 (control) – treatment with water; 2 – double treatment with biopreparations with a frequency of 15 days; 3 – triple treatment with biopreparations with a frequency of 10 days. The consumption of working fluid for 64 plants was: Fitosporin-M, PS – 10,5 ml, Fitoverm, EC – 6,5 ml.

Seedlings were planted in the mini-tuber propagation nursery in the second ten-day period of June. The experiment was conducted in three sets of two replicates, with systematic placement. Each replicate area was 4.8 m², for a total experimental area of 115.2 m². The treatment of seedlings with biopreparations was carried out in three variants: 1 (control) – treatment with water; 2 – double treatment with Fitosporin-M, PS during the period of budding and the beginning of flowering, Fitoverm, EC – the first treatment during the period of mass emergence of Colorado potato beetle larvae of the first and second instars, the next one – after 7 days; 3 – three-fold treatment with Fitosporin-M, PS during the period of the beginning of budding, the beginning of flowering, and full flowering, Fitoverm, EC – treatment during the period of mass emergence of Colorado potato beetle larvae, subsequent treatments after 7 and 14 days. Working fluid consumption – 300 l/ha. Harvesting mini-tubers is carried out in the third ten-day period of August.

Initial meteorological data for the growing season from May to August⁴ in the Kemerovo region – Kuzbass are presented separately for each study year. The hydrothermal coefficient (HTC) according to G.T. Selyaninov was used to estimate moisture availability during the growing season⁵. Counts and observations were carried out using the generally accepted methods: phenological observations⁶, diagnostics of plants for damage by hidden pathogens using

³Research methodology for potato cultivation. Moscow: Kolos, 1967, 263 p.

⁴The weather in Kemerovo by month in 2023 and 2024. URL: <https://world-weather.ru/pogoda/russia/kemerovo/2023/> (date of reference 05.07.2025).

⁵Selyaninov G.T. Origin and dynamics of droughts // Droughts in the USSR, their origin, recurrence and impact on harvest. L.: Gidrometeoizdat, 1958, pp. 5–30.

⁶Methods for evaluating improved varieties and meristem lines in elite potato seed production. Moscow, 1991, 39 p.

the ELISA method⁷, visual recording of fungal and viral diseases⁸, pests⁹, during the flowering period, the height of plants and the number of stems of seedlings were determined by variants and varieties; during the harvesting of mini-tubers, the number of tubers and the average weight of tubers per bush, the average weight of 1 tuber, and the fractional composition of the harvest were determined. The research results were processed using the analysis of variance method according to the method of B.V. Dospekhov¹⁰ and in the Snedekor computer application program¹¹.

The soil of the mini-tubers propagation nursery is leached chernozem with heavy loamy granulometric composition¹² [14, 15].

Agrochemical characteristics of the arable soil layer (0–30 cm): humus – 8–10%¹³,

phosphorus – 230–342 and potassium – 214–387 mg/kg of soil¹⁴, pH of salt – 4,9–5,0¹⁵. Data from weather stations showed that the average annual temperature ranged from +0,7 to +3,3 °C (–19,5 °C – January, +18,5 °C – July). Annual precipitation varies from 255 to 1700 mm, on average less than 400 mm¹⁶. The growing season during the study years was characterized by significant fluctuations in the air temperature and uneven precipitation (see Table 1).

In 2023, the average temperature during the growing season was 18.9 °C (18.5 °C in June, 20.4 °C in July, 17.7 °C in August), which is 1.8 °C lower than the long-term average (20.7 °C). HTC = 0,9. In 2024, the average temperature during the growing season was 20.6°C, which corresponds to the average long-term temperature, HTC = 1,5.

Табл. 1. Метеоусловия вегетационного периода в годы исследований по Кемеровской области – Кузбассу (2023 и 2024 гг.)

Table 1. Meteorological conditions of the growing season during the research years in the Kemerovo region – Kuzbass (2023 and 2024)

Indicator	Month, ten-day period										
	May		June			July			August		
	II	III	I	II	III	I	II	III	I	II	III
2023.											
Air temperature, °C	8,0	13,3	22,5	17,2	15,7	20,1	20,9	20,2	20,2	14,6	18,4
Precipitation, mm	1	2	3	9	11	14	29	44	6	50	4
2024											
Air temperature, °C	13,6	10,8	13,2	30,3	23,8	20,1	22,0	20,7	20,3	18,5	16,3
Precipitation, mm	17	33	73	1	12	40	15	14	16	25	30
Average long-term values											
Air temperature, °C	10,8	12,1	17,9	23,8	19,8	20,1	21,5	20,5	20,3	16,6	17,4
Precipitation, mm	9	18	38	5	12	27	22	29	11	38	17

⁷Instructions for the use of an enzyme-linked immunosorbent assay diagnostic kit for the detection of potato viruses. Korenevo, 2016, 8 p.

⁸GOST 59551–2021. Seed potatoes. Sampling and methods for diagnosing phytopathogens. Moscow, 2021. 20 p.

⁹GOST 33996–2016. Seed potatoes. Specifications and methods for determining quality. Moscow, 2017. 31 p.

¹⁰Dospekhov B.A. Methods of field experiment. Moscow: Agropromizdat, 1985, 351 p.

¹¹Sorokin O.D. Applied statistics on a computer. Novosibirsk, 2004, 162 p.

¹²Trofimov S.S. Soil ecology and soil resources of the Kemerovo region. Novosibirsk: Nauka (Siberian Branch), 1975, 299 p.

¹³GOST 26213–91. Soils. Methods for determining organic matter. Moscow, 1992, 8 p.

¹⁴GOST 26204–91. Soils. Determination of mobile phosphorus and potassium compounds using the Chirikov method as modified by the Central Information Scientific and Analytical Association. Moscow, 1992, 8 p.

¹⁵GOST 26483–85. Soils. Determination of pH of salt extract, exchangeable acidity, exchangeable cations, nitrate content, exchangeable ammonium, and mobile sulfur by the methods of the Central Information Scientific and Analytical Association. Moscow, 1985, 6 p.

¹⁶Climate. Kemerovo region. URL: <https://www.nbcrs.org/regions/kemerovskaya-oblast/klimat> (date of reference 05.07.2025).

RESULTS AND DISCUSSION

At the stage of planting mini-tubers in the nursery, the height of seedlings of the studied potato varieties varied between 10–15 cm. The survival rate of seedlings across the treatments was 77.6–81.4%. For the Lyubava and Kemerovchanin (control) varieties, the treatments with biopreparations showed an increase in survival rate by 1.2–4.1% (treatment 2) and 1.8–7.7% (treatment 3).

Observations of the growth and development of seedlings throughout the growing season showed, for all experimental variants, the stability of varietal characteristics in terms of morphological indicators of the bush, stem, leaf and flower in the studied potato varieties and the absence of significant differences between all plants during the planting-budding and planting-flowering periods.

At the full flowering stage, the height and number of potato stems were determined (see Table 2).

In the studies, three-fold treatment with biopreparations contributed to a significant increase in the height of plants of all studied potato varieties by an average of 2.9–4.6 cm (the smallest significant difference for the 5% significance level $LSD_{05} = 2,56$).

A reliable positive relationship was established between the treatment options with biological preparations and the height of seedlings ($R^2 = 0,98–0,99$). Share of influence of factors: variety – 69,1%, variant – 2,9%.

With the use of biopreparations, the number of stems per bush increased by an average of 0.1–0.7 (variant 2) and 0.1–0.6 (variant 3) compared to the control. However, a two-way analysis of variance revealed no effect of biopreparations on the number of stems in seedlings of the studied potato varieties. Consequently, the number of aboveground shoots was 58.3% determined by varietal characteristics.

Of interest are the data on seedling productivity and the dynamics of changes in these indicators depending on the use of biological products. The number of tubers per bush increases on average by 0.2–2.0 pieces/bush (variant 2) and 0.6–2.6 pieces/bush (variant 3) compared to the control ($LSD_{05} = 0,81$). A strong correlation was established between the frequency of application of preparations and the number of tubers per bush ($R^2 = 0,97–0,99$). Share of influence of factors: variety – 63,6%, variant – 15,2%.

Analysis of the change in the number of tubers by year showed an increase in 2023 by

Табл. 2. Влияние биопрепаратов на высоту и количество надземных побегов рассадных растений картофеля в питомнике размножения за 2023 и 2024 гг. (в среднем на один куст)

Table 2. The effect of biological preparations on the height and number of above-ground shoots of potato plants in a propagation nursery for 2023 and 2024 (on average per bush)

Copt	Option 1 (control)			Option 2			Option 3		
	A	B	average value	A	B	average value	A	B	average value
<i>Plant height, cm</i>									
Kemerovchanin (control)	71,7	60,7	66,2	74,3	58,3	66,3	75,3	65,0	70,2
Lyubava	60,7	60,5	60,6	58,3	61,6	60,0	65,0	62,0	63,5
Nevsky	56,0	60,3	58,2	58,0	61,0	59,5	58,7	64,0	61,4
Tuleevsky	78,0	76,0	77,0	78,6	78,8	78,7	84,0	79,1	81,6
LSD_{05} (share of influence): variety – 2,95 (69,1%); option – 2,56 (2,9%); year – 2,09 (2,7%)									
<i>Number of stems</i>									
Kemerovchanin (control)	7,3	7,0	7,2	8,3	6,8	7,6	7,7	7,1	7,4
Lyubava	6,0	7,3	6,7	6,3	7,0	6,7	7,0	7,3	7,2
Nevsky	6,7	6,2	6,5	6,3	6,2	6,3	7,3	6,4	6,9
Tuleevsky	8,3	8,3	8,3	8,7	8,0	8,4	9,7	7,9	8,8
LSD_{05} (share of influence): variety – 0,53 (58,3%); year – 0,37 (3,7%)									

0.1–3.4 pcs./bush (except for the Tuleevsky variety) and in 2024 by 1.0–2.3 pcs./bush, however, these differences are not significant (see Table 3).

The weight of tubers per bush was 504.0–666.0 g (variant 2) and 512.0–698.0 g (variant 3), which is 12–108 and 41–140 g more than the control at $LSD_{05} = 51,2$. The biological preparations had the greatest impact on the weight of tubers of the Nevsky variety, exceeding the control by 108.0 g (variant 2) and by 140.0 g (variant 3) ($LSD_{05} = 51,2$). The results obtained revealed a close relationship between the experimental variants and the average weight of tubers per bush: $R^2 = 0,95$ (variant 2), $R^2 = 0,99$ (variant 3). The influence of the variety on the weight of tubers per bush was 32.0% of the experimental variants – 16,6%.

The formation of the average weight of tubers per bush is also influenced by the year of the research, the share of influence – 6,0%. Thus,

the average weight of tubers per bush in 2023 is 12–229 g more, in 2024 – 51–106 g more (at $LSD_{05} = 41,8$).

Studies have not established the effect of biopreparations on the weight of a single tuber. A tendency toward a decrease in the weight of a single tuber by 1.6–8.3 g (variant 2) and by 4.0–4.7 g (variant 3, except for the Kemerovchanin (control) and Lyubava varieties) was observed. Varietal characteristics had the greatest influence on the average weight of a single tuber—34%.

Based on the conducted surveys and analysis of the structure of the tuber yield, it was revealed that the quantitative yield of tubers of the standard fraction (9–60 mm) was 57.0–73.0% (see Table 4).

Based on two-year studies, two- and three-fold treatments with biopreparations Fitosporin-M, PS and Fitoverm, EC increased the yield of standard mini-tubers in the Kemerovchanin variety (control) by 0.8–5.7%, Nevsky by 2.7–

Табл. 3. Влияние биопрепаратов на продуктивность рассадных растений картофеля в 2023 и 2024 гг. (в среднем)

Table 3. The impact of biological preparations on the productivity of potato seedlings in 2023 and 2024 (on average)

Variety	Option 1 (control)			Option 2			Option 3		
	A	Б	average value	A	Б	average value	A	Б	average value
<i>Number of tubers, pcs./bush</i>									
Kemerovchanin (control)	5,8	6,0	5,91	5,2	7,0	6,1	5,9	7,0	6,5
Lyubava	7,5	6,4	7,0	7,9	8,3	8,1	8,4	7,9	8,2
Nevsky	7,6	8,5	8,1	9,3	10,8	10,1	11,0	10,3	10,7
Tuleevsky	7,6	6,8	7,2	8,0	8,5	8,3	7,3	9,1	8,2
LSD_{05} (share of influence): сорт – 0,93 (63,6%), option – 0,81 (15,2%)									
<i>Tuber weight, g/bush</i>									
Kemerovchanin (control)	409	491	450	428	580	504	468	555	512
Lyubava	631	524	578	679	638	659	732	630	681
Nevsky	597	519	558	712	620	666	826	570	698
Tuleevsky	578	530	554	571	561	566	590	600	595
LSD_{05} (share of influence): variety – 59,1 (32,0%); option – 51,2 (16,6%); year – 41,8 (6,0%)									
<i>Tuber weight, g</i>									
Kemerovchanin (control)	70,5	81,8	76,2	82,3	82,9	82,6	79,3	79,3	79,3
Lyubava	84,0	81,9	83,0	85,9	76,9	81,4	87,1	79,7	83,4
Nevsky	78,6	61,1	69,9	76,6	57,4	67,0	75,1	55,3	65,2
Tuleevsky	76,0	77,9	77,0	71,4	66,0	68,7	80,8	65,9	73,0
LSD_{05} (share of influence): variety – 3,6 (34,0%); year – 2,57 (17,1%)									

Табл. 4. Влияние биопрепаратов на структуру урожая мини-клубней картофеля в 2023 и 2024 гг. (в среднем), %

Table 4. The effect of biological preparations on the crop structure of potato mini tubers in 2023 and 2024 (on average), %

Variety	Option 1 (control)			Option 2			Option 3		
	A	B	average value	A	B	average value	A	B	average value
<i>Fraction < 9 mm</i>									
Kemerovchanin (control)	27,6	19,8	23,7	15,4	12,1	13,8	19,5	20,5	20,0
Lyubava	16,1	14,6	15,4	22,4	13,9	18,2	27,8	11,5	19,7
Nevsky	22,8	21,7	22,3	19,0	23,4	21,2	16,4	24,2	20,3
Tuleevsky	11,4	11,9	11,7	10,8	13,6	12,2	11,9	14,0	13,0
LSD ₀₅ (share of influence): variety – 5,58 (30,8%); option – 4,83 (0%)									
<i>Fraction 9–60 mm</i>									
Kemerovchanin (control)	58,6	58,3	58,5	65,4	62,9	64,2	59,6	59,0	59,3
Lyubava	60,7	63,4	62,1	55,7	68,4	62,1	51,6	72,3	62,0
Nevsky	57,9	51,5	54,7	59,9	54,9	57,4	61,2	56,1	58,7
Tuleevsky	69,7	70,2	70,0	71,7	73,9	72,8	67,9	74,0	71,0
LSD ₀₅ (share of influence): variety – 4,22 (47,8%); вариант – 3,65 (1,2%)									
<i>Fraction > 60 mm</i>									
Kemerovchanin (control)	13,8	21,8	17,8	19,2	25,0	22,1	20,9	20,5	20,70
Lyubava	23,2	22,0	22,6	21,9	17,7	19,8	20,6	16,2	18,4
Nevsky	19,3	26,8	23,1	21,1	21,7	21,4	22,4	19,7	21,1
Tuleevsky	18,9	17,9	18,4	17,5	12,5	15,0	20,2	12,0	16,1

LSD₀₅ (share of influence): variety – 1,82 (19,7%); option – 1,57 (1,2%)

4.0% and Tuleyevsky by 1.0–2.8% (at LSD₀₅ = 3,65). Based on the results, it is clear that there is no consistent increase in the standard fraction due to the use of biological products or the frequency of treatments. Consequently, the analyzed indicator is by 47.8% determined by varietal characteristics.

The fractional composition of the yield shows some stability in the amount of fine (12.0–24.0%) and coarse fractions (15.0–23.0%), on average, of the total yield. In the variants with biopreparations, the amount of fine fraction decreases by 1.0–10.0% (variant 2) and 1.0–5.0% (variant 3) (LSD₀₅ = 4,83), large fraction - by 2.0–4.0% (variant 2) and 2.0–5.0% (variant 3) (LSD₀₅ = 1,57). In this context, the Lyubava and Tuleevsky (<9 mm) and Kemerovchanin (control) (>60 mm) varieties

were the exceptions. It was noted that the influence of varietal traits in the formation of the small fraction was significantly higher (30.8%) than in the large fraction (19.7%).

An important parameter that determines the quality of the obtained original seed material is the diagnosis and assessment of the presence of hidden infection by phytopathogens, since, according to V.N. Zeyruk, S.V. Zhevor and S.V. Vasiliev [4], the annual loss of potato crops due to pathogens, depending on the variety, annually ranges from 10 to 30%.

Leaf sampling during the potato flowering period revealed no viral or bacterial pathologies. Fungal disease monitoring during harvesting revealed alternaria leaf spot (*Alternaria solani* Sorauer.) in the form of isolated spots on the leaf surface of individual potato plants. The

exception was the Tuleevsky variety, which showed no signs of *Alternaria* blight in all experimental treatments. After three applications of the biopreparation, *Alternaria* leaf damage decreased by 5% in Lyubava plants. In the Kemerovchanin (control) and Nevsky varieties, *Alternaria* leaf damage remained at the control level in all experimental treatments, but no signs of disease spread were observed (see Table 5).

After applying the biopreparations, the incidence of rhizoctonia (*Thanatephorus cucumeris* (A.B.Frank) Donk.) in the Lyubava, Tuleevsky, and Nevsky varieties decreased by an average of 3–5%, while in the Kemerovchanin variety (control), it remained at 2% (variant 2). With increasing frequency of application of the biopreparations, the incidence of rhizoctonia in the Nevsky and Lyubava varieties decreased by 4% and 8%, respectively, while no incidence was detected in the remaining studied varieties (variant 3).

Visual monitoring during budding, flowering, and early harvest revealed no symptoms of

late blight (*Phytophthora infestans*) in all experimental treatments. The exception was the Nevsky variety, which showed a 1% incidence of late blight (variant 1); no symptoms were observed in the treatments treated with biological products. The effectiveness of Fitosporin-M, PS against late blight has also been established by other authors. According to I.N. Aminev and M.M. Khaibullin, the use of Fitosporin-M, PS reduced the incidence of potato plants affected by late blight by 13–14%¹⁷, increased resistance to late blight to 65.3–77.2% with a significant increase in yield by an average of 23.4%¹⁸.

During the seedling establishment period and the initial budding phase (second ten-day period of June – third ten-day period of July), no ingestion of Colorado potato beetle larvae was observed due to early treatment with Fitoverm, EC. After the emergence of first- and second-instar larvae, treatment with an insectoacaricide was applied. A slowdown in ingestion was observed within 3–4 days.

Табл. 5. Влияние биопрепаратов на поражение рассадных растений грибными болезнями за 2023 и 2024 гг., %

Table 5. The effect of biological preparations on the damage of seedling plants by fungal diseases in 2023 and 2024, %

Variety	Disease	Option 1 (control)			Option 2			Option 3		
		A	B	$x \pm$	A	B	$x \pm$	A	B	$x \pm$
Kemerovchanin (control)	Alternaria leaf spot	0	2	1 ± 1	0	2	1 ± 1	0	2	1 ± 1
	Rhizoctoniose	0	3	2 ± 1	0	3	2 ± 1	0	0	0 ± 0
	Late blight	0	0	0 ± 0	0	0	0 ± 0	0	0	0 ± 0
Lyubava	Alternaria leaf spot	13	9	11 ± 1	13	9	11 ± 1	7	6	6 ± 0
	Rhizoctoniose	20	13	16 ± 3	7	16	11 ± 3	7	9	8 ± 1
	Late blight	0	0	0 ± 0	0	0	0 ± 0	0	0	0 ± 0
Nevsky	Alternaria leaf spot	7	6	6 ± 0	7	6	6 ± 0	7	5	6 ± 0
	Rhizoctoniose	13	6	9 ± 3	7	6	6 ± 0	7	4	5 ± 1
	Late blight	0	2	1 ± 1	0	0	0 ± 0	0	0	0 ± 0
Tuleevsky	Alternaria leaf spot	0	0	0 ± 0	0	0	0 ± 0	0	0	0 ± 0
	Rhizoctoniose	7	2	4 ± 2	0	0	0 ± 0	0	0	0 ± 0
	Late blight	0	0	0 ± 0	0	0	0 ± 0	0	0	0 ± 0

¹⁷Aminev I.N., Khaibullin M.M. Influence of biological preparations on susceptibility, yield and quality of potatoes // Achievements of science and technology of the agro-industrial complex. 2011, No. 3, pp. 30–32.

¹⁸Uromova I.P., Sultanova L.R., Dedyura I.S. Biopreparations as a factor in increasing the yield and quality of potatoes // Advances in current natural sciences, 2016, No. 12, pp. 117–121.

Tuber analysis revealed no pest damage. Tuber tests for scab (*Streptomyces* spp.) in the experimental variants showed its absence in the Kemerovo and Nevsky potato varieties and a presence of up to 0.2 and 0.4% in the Tuleyevsky and Lyubava varieties, respectively. According to V.N. Zeyruk, S.V. Zhevoraya, and S.V. Vasilyeva [4], the presence of lesions of up to 0.4% is within the permissible limits.

CONCLUSION

The use of biopreparations in the original seed production of potatoes when growing mini-tubers increased the height of seedlings by 0.1–4.6 cm, the number of stems per bush by 0.1–0.5, the number of tubers per bush by 0.2–2.6, the weight of tubers per bush by 12–140 g, reduced the development of alternaria blight and rhizoctoniosis by 3–8%, limited the spread of late blight and ensured the yield of the standard fraction to 57.0–73.0%. Consequently, the use of biopreparations in the forest-steppe conditions of the Kuznetsk Basin limits the spread and development of fungal diseases and allows for an increase in the productivity and quality of the original potato material.

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ИНФОРМАЦИЯ ОБ АВТОРАХ

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Содержание салидрозида в культивируемых клоновых растениях *Rhodiola rosea* L.

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Салидрозид – гликозид тирозола, который преимущественно содержится в подземных частях растений рода *Rhodiola* L., включая родиолу розовую (*Rhodiola rosea* L.). Этот биологически активный компонент известен разнообразными полезными свойствами: противораковым, антиоксидантным, антивозрастным, противодиабетическим, антидепрессивным, антигиперлипидемическим, противовоспалительным и иммуномодулирующим эффектом. Проанализировано содержание салидрозида в корневищах и корнях *R. rosea* горноалтайского происхождения, выращиваемых в интродукции в лесостепной зоне Западной Сибири. Посадочный материал для эксперимента получен методом *in vitro*. Для биохимического анализа использованы клоновые растения возрастом от 2 до 6 лет, а также одно растение, выращенное в интродукции в течение 20 лет. Максимальное содержание салидрозида в корневище и корнях (2,33 и 1,04 мг/г соответственно), а также наибольший ежегодный прирост биомассы подземных органов (более чем в 3 раза) отмечены у клоновых образцов на 6-й год культивирования. С 2-го по 5-й год содержание салидрозида варьировало от 1,04 до 1,83 мг/г и не зависело от возраста растений. Растение, выращенное в интродукции в течение 20 лет, показало самое высокое содержание салидрозида в корневище – 12,25 мг/г, что соответствует показателям природных образцов из Горного Алтая или превышает их. Следует отметить, что лишь 20-летнее растение соответствует требованиям фармакопеи Российской Федерации по уровню накопления салидрозида. Сделан вывод, что 6-летний цикл культивирования при интродукции в лесостепной зоне Западной Сибири недостаточен для получения стандартного сырья *R. rosea*. В дальнейшем запланировано разработать агротехнические методы, которые позволят повысить содержание салидрозида и одновременно сократить время культивирования растений.

Ключевые слова: золотой корень, размножение *in vitro*, салидрозид, ВЭЖХ, интродукция

Salidroside content in cultivated clonal plants of *Rhodiola rosea* L.

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Salidroside is a glycoside of tyrosol, which is mainly found in the underground parts of plants of the genus *Rhodiola* L., including *Rhodiola rosea* L. This biologically active component is known for its various beneficial properties: anticancer, antioxidant, anti-aging, antidiabetic, antidepressant, antihyperlipidemic, anti-inflammatory and immunomodulatory effects. In this work, the content of salidroside in the rhizomes and roots of *Rhodiola rosea* of Altai Mountains origin, grown in introduction in the forest-steppe zone of Western Siberia, is analyzed. Planting material for the experiment was obtained by the *in vitro* method. Clonal plants aged 2 to 6 years, as well as one plant grown in introduction for 20 years, were used for biochemical analysis. The maximum salidroside content in the rhizome and roots (2.33 and 1.04 mg/g, respectively), as well as the highest annual increase in the biomass of underground organs (more than 3 times) were observed in clonal samples in the 6th year of cultivation. The maximum salidroside content in the rhizome and roots (2.33 and 1.04 mg/g, respectively), as well as the highest annual increase in the biomass of underground organs (more than 3 times) were observed in clonal samples in the 6th year of cultivation. In the period from the 2nd to

the 5th year, the salidroside content varied from 1.04 to 1.83 mg/g and did not depend on the age of the plants. The plant grown in an introduction for 20 years showed the highest salidroside content in the rhizome – 12.25 mg/g, which corresponds to or exceeds the indicators of natural samples from the Altai Mountains. It is important to note that only the 20-year-old plant meets the requirements of the Russian Pharmacopoeia for the level of salidroside accumulation. It was concluded that a 6-year cultivation cycle during introduction in the forest-steppe zone of Western Siberia is insufficient to obtain standard *Rhodiola rosea* raw materials. In the future, it is planned to develop agricultural methods that will increase the content of salidroside and simultaneously reduce the time of plant cultivation.

Keywords: golden root, *in vitro* propagation, salidroside, HPLC, introduction

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Конфликт интересов

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Conflict of interest

The authors declare no conflict of interest.

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INTRODUCTION

Salidroside is a phenylpropanoid glycoside, the main active component of plants of the genus *Rhodiola* L. Modern research confirms that salidroside is a promising drug with low toxicity and minimal side effects [1]. It has a wide range of pharmacological effects: it improves the condition of the cardiovascular and central nervous systems, has antihypoxic, tonic, rejuvenating, anti-cancer, anti-inflammatory, antioxidant, antiviral, immunostimulating, antidiabetic and an-

ti-osteoporotic effects¹ [2–8]. The main sources of salidroside are representatives of the genus *Rhodiola* – *R. rosea*, *R. crenulata*, *R. sachalinensis* and *R. kirilowii* [4]. Phytochemical studies show that salidroside content varies depending on plant part, sex and age [2, 9]. The collection period and the geographical origin of the plant are also important^{2–4}, as well as the soil composition⁵. Modern research shows that wild-harvested *R. rosea* plants tend to contain higher levels of salidroside than the farm-grown ones⁶.

¹Chiang H.M., Chen H.C., Wu C.S., Wu P.Y., Wen K.C. *Rhodiola* plants: chemistry and biological activity// J Food Drug Anal., 2015, vol. 23, pp. 359–369. DOI: 10.1016/j.jfda.2015.04.007.

²Węglarz Z., Przybył J., Gęszprych A. Roseroot (*Rhodiola rosea* L.): effect of internal and external factors on accumulation of biologically active compounds. In: Ramawat KG, Merillon JM (eds) *Bioactive molecules and medicinal plants*. Berlin, 2008, vol. 16, pp. 297–315.

³Buchwald W., Mścisz A., Krajewska-Patan A., Furmanowa M., Mielcarek S., Mrozikiewicz P.M. Content of biologically active compounds in *Rhodiola rosea* roots during the vegetation period // *Herba Pol.*, 2006, vol. 52, pp. 39–43.

⁴Altantsetseg K., Przybył J., Węglarz Z., Gęszprych A. Content of biologically active compounds in roseroot (*Rhodiola* spp.) raw material of different derivation // *Herba Pol.*, 2007, vol. 53 (4), pp. 20–26.

⁵Yan X., Wu S., Wang Y., Shang X., Dai S. Soil nutrient factors related to salidroside production of *Rhodiola sachalinensis* distributed in Chang Bai Mountain // *Environmental and Experimental Botany*, 2004, vol. 52 (3), pp. 267–276. DOI: 10.1016/j.envexpbot.2004.02.005.

⁶Grech-Baran M., Sykłowska-Baranek K., Pietrosiuk A. Biotechnological approaches to enhance salidroside, rosin and its derivatives production in selected *Rhodiola* spp. *in vitro* cultures // *Phytochem. Rev.*, 2015, vol. 14, pp. 657–674. DOI: 10.1007/s11101-014-9368-y.

Salidroside is currently widely used in pharmaceuticals, but its content in *R. rosea* is relatively low – 0.8–1.0%. Furthermore, reserves of natural raw materials are limited due to the difficulty of propagation, specific growing conditions, and large-scale illegal harvesting of plants. Due to the depletion of natural resources of *R. rosea*, the development of technologies for *in vitro* cultivation of promising clones, assessment of their biosynthetic potential (including salidroside content), and study of biological productivity during introduction are particularly relevant.

The purpose of the study is to determine the dynamics of salidroside accumulation in clonal plants of *R. rosea* cultivated in the forest-steppe zone of Western Siberia.

MATERIAL AND METHODS

The starting material for this study was *R. rosea* seeds from the Altai Republic, which grows on the southern slopes of the Iolgo Range (Karakol Lakes). The altitude is 1800–2000 m above sea level. *In vitro* cultivation of *R. rosea* and its adaptation to *ex vitro* conditions were carried out using a previously developed method [10].

After adaptation to *ex vitro* conditions, the plants were transplanted into 7 x 7 x 9 cm containers in a soil mixture consisting of a peat nutrient substrate (pH 5.5–6.5) and sand in a ratio of 4:1 and grown for two years in a nursery in containers.

Next, two-year-old plants were planted in the introduction area in ridges with a distance of 20–25 cm between plants. To protect against weeds, the soil was covered with black plastic film.

The introduction site is located on the territory of the Central Siberian Botanical Garden (CSBG) of the Siberian Branch of the Russian Academy of Sciences, located on the right bank of the Novosibirsk Reservoir, 25 km from the center of Novosibirsk. Geomorphologically, the territory of the Central Siberian Botanical Garden occupies the second and third floodplain terraces of the Ob River, composed of ancient alluvial sandy and sandy loam deposits. The terraces average 150–200 m above sea level. The

soils are sod-podzolic, with a pH ranging from 5.5 to 6.9.

The harvest was collected at the end of the growing season: late September – early October in 2019–2023, during years 2 (nursery) and 3–6 (introduction site) of cultivation. The experiment also analyzed the *R. rosea* plant imported from Gorny Altai and cultivated for 20 years at the Central Siberian Botanical Garden. The rhizomes and roots were shaken free of soil and washed. The roots were then separated from the rhizomes, and the plant parts were cut into slices. The fresh and dry weights of the roots and rhizomes were recorded for each plant before and after drying using warm air ventilation in a thermostat at 45°C (LIOP, Russia) for 5 days. The dried samples were stored in paper bags in dark, dry conditions at a temperature of 22°C.

Extracts from 1 g of rhizomes and roots were obtained by triple extraction with a 70% ethanol solution in an ultrasonic bath for 30 min at room temperature, followed by concentration to 2 ml using an “IKA HB 10 digital” rotary evaporator (Germany).

HPLC analysis was performed using an Agilent 1200 system with a diode array detector and an autosampler, with ChemStation data processing software (Agilent Technologies, Santa Clara, CA, USA). The chromatography column was Perfect Sil Target ODS-3; 4.6 × 250 mm. The mobile phase was methanol: water = 40:60. The elution rate was 1 ml/min. The injection volume was 5 µL. The analytical wavelength was $\lambda_{\max} = 254$ nm. Chromatographic analysis was performed in 3–5 replicates. Salidroside standard samples were purchased from Sigma-Aldrich (St. Louis, MO, USA).

Statistical processing and analysis of the results were performed using Microsoft Excel 7.0 and Statistica 6.0 (Duncan's test, factorial ANOVA, $p \leq 0.05$). Data are presented as mean values and standard deviations. A total of 10 plants from each cultivation year and one 20-year-old plant were analyzed. Data are presented in milligrams per gram of air-dried raw material (mg/g).

RESULTS AND DISCUSSION

Rhodiola rosea, when introduced into the forest-steppe zone of Western Siberia, demonstrated high resistance: it is not susceptible to diseases and pests, and annually produces mature and viable seeds (see the figure). The dynamics of the biomass growth of underground organs (rhizomes and roots) are presented in the table. The annual growth varied in different years, with the maximum values observed in the 4th and 6th years of cultivation, increasing by 3.6 and 3.2 times, respectively.

Salidroside content in rhizomes was significantly higher than in roots: in clonal plants, the difference ranged from 1.7 to 5.4 times, and in the 20-year-old sample, it was up to 7.1 times (see table). The 20-year-old sample had the highest biomass and salidroside concentrations in underground organs—up to 12.25 mg/g (see the figure). The maximum salidroside content among clonal plants was recorded in the sixth year of cultivation: 2.33 mg/g in rhizomes and 1.04 mg/g in roots. During this same period, a significant annual increase in the biomass of

underground organs was also observed—more than threefold.

Previously published data demonstrate significant variations in phenylethanoid content in *Rhodiola rosea* depending on its geographical origin and growing conditions. In samples collected in two mountainous regions of Austria, salidroside content ranged from 0.9 to 1.4 mg/g⁷; in the samples from different regions of China, the concentrations of salidroside and tyrosol were 1.3–11.1 and 0.3–2.2 mg/g, respectively⁸; In natural samples from Bulgaria, the salidroside content was 0.81–1.65% [11]. In the rhizomes of *Rhodiola rosea* from the Altai Mountains, the salidroside content was in the range of 0.98–3.53 mg/g, and tyrosol – from 0.10 to 0.70 mg/g [12]. In addition, a high coefficient of variability of salidroside content in *R. Rosea* plants upon introduction was shown – 61.85% [13].

The highest salidroside content, 51.0 mg/g, was found in a 16-year-old cultivated sample from Norway⁹.

According to our data, the 20-year-old introduced *R. rosea* plant has a high content of



Клоновые 6-летние растения (а) и корневище 20-летнего растения *R. rosea* (б), культивируемые в ЦСБС
Clonal 6-year-old plants (a) and rhizome of a 20-year-old *R. rosea* plant (b), cultivated in the Central Siberian Botanical Garden

⁷Alperth F., Turek I., Weiss S., Vogt D., Bucar F. Qualitative and quantitative analysis of different *Rhodiola rosea* rhizome extracts by UHPLC-DAD-ESI-MSn // Sci. Pharm., 2019, vol. 87, pp. 8. DOI: 10.3390/scipharm87020008.

⁸Linh P.T., Kim Y.H., Hong S.P., Jian J.J., Kang J.S. Quantitative determination of salidroside and tyrosol from the underground part of *Rhodiola rosea* by high performance liquid chromatography // Arch Pharm. Res., 2000, vol. 23, pp. 349–352. DOI: 10.1007/BF02975446.

⁹Elameen A., Kosman V.M., Thomsen M., Pozharitskaya O.N., Shikov A.N. Variability of major phenyletanes and phenylpropanoids in 16-year-old *Rhodiola rosea* L. clones in Norway // Molecules, 2020, vol. 25, p. 3463. DOI: 10.3390/molecules25153463.

Прирост биомассы и содержание салидрозидов в подземных органах 2–6-летних клоновых и 20-летнего растения *R. rosea*, культивируемых в ЦСБС

Biomass growth and salidroside content in underground organs of 2-6 year old clonal and 20 year old *R. rosea* plants cultivated in the Central Siberian Botanical Garden

Year of cultivation	Dry mass of underground organs, g	Salidroside content, mg/g	
		rhizome	root
2	2,93 ± 0,35f	1,61 ± 0,11d	0,63 ± 0,04d
3	4,21 ± 0,46e	1,04 ± 0,07e	0,61 ± 0,04d
4	15,22 ± 1,37d	1,83 ± 0,13c	0,34 ± 0,02e
5	22,74 ± 2,86c	1,54 ± 0,10d	0,82 ± 0,06c
6	71,56 ± 6,49b	2,33 ± 0,16b	1,04 ± 0,07b
20	110,35a	12,25 ± 0,61a	1,73 ± 0,12a

Note. Values followed by the same letter(s) in columns are not significantly different at $p \leq 0.05$ according to the Duncan's test.

salidroside in the rhizome, comparable to or exceeding the content in natural samples from the Altai Mountains. According to Zibareva et al. [14], the underground organs of cultivated *Rhodiola rosea* plants contained higher levels of salidroside compared to plants grown in natural conditions. Elameen et al. (see footnote 9) noted that long-term cultivation promotes the accumulation of rosavins and salidroside in *R. rosea*.

The highest salidroside content in the rhizome and root of clonal material is achieved in the sixth year of cultivation – 2.33 and 1.04 mg/g, respectively. Moreover, from the second to fifth years, salidroside content varied from 1.04 to 1.83 mg/g and was independent of the plant age. E.F. Kim¹⁰ also showed that in seedlings under cultivation conditions, salidroside content is low during the first three years, remaining at 0.4–0.6%.

CONCLUSION

According to the State Pharmacopoeia of the Russian Federation¹¹, the content of salidroside should be at least 0.8%. Ajdert et al. [15] pro-

pose to consider a minimum limit of 0.3% for the content of salidroside as a quality standard. We have shown that when growing clonal plants in the forest-steppe zone of Western Siberia, a 6-year cultivation cycle is not sufficient to obtain standard *R. rosea* raw materials. Among the studied samples, only the 20-year-old introduced plant meets the pharmacopoeia's salidroside accumulation standards. Previously, soil composition has been shown to significantly influence salidroside accumulation in another species (*R. sachalinensis*). It has been noted that rich organic matter, low pH, and high levels of exchangeable and total nitrogen in the soil ensure high salidroside productivity (see footnote 5). To economically viable cultivate *Rhodiola rosea* using the plantation method, it is necessary to shorten the cultivation period. Developing agronomic practices aimed at increasing the yield and productivity of *R. rosea* is becoming a priority.

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Влияние погодных условий Приобской лесостепи на урожайность ячменя ярового

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Представлены данные исследований о влиянии гидротермических факторов на уровень урожайности ячменя разных групп спелости в контрастных условиях среды. Проанализированы зависимости урожайности ячменя от количества атмосферных осадков, среднесуточной температуры воздуха и гидротермического коэффициента в условиях Приобской лесостепи. Исследования проводили в 2014–2023 гг. в СибНИИРС – филиале ФИЦ ИЦиГ СО РАН. Материал исследования – 51 сорт ячменя, созданный в селекционных центрах Сибири и включенный в Государственный реестр селекционных достижений, допущенных к использованию. Определено, что стабильность формирования урожайности по группам составила: «ранние» – 0,82%, «среднеранние» – 0,79% и «среднеспелые» – 0,80%, что указывает на синхронную реакцию сортов разных групп спелости на контрастные условия среды. При этом между группами спелости установлена биологически обусловленная закономерность: чем короче вегетационный период, тем ниже потенциал продуктивности. Установлено, что в условиях Приобской лесостепи уровень урожайности ячменя зависит от суммы осадков за май – июль ($r = 0,37–0,44$ – для неблагоприятных условий и $r = 0,63–0,68$ – для благоприятных) и показателя гидротермического коэффициента ($r = 0,45–0,58$ – для неблагоприятных условий и $r = 0,62–0,64$ – для благоприятных). Также установлена достоверная высокая корреляция между урожайностью и температурой воздуха в июне для всех групп спелости за 10-летний период ($r = 0,70; 0,72; 0,69$). Корреляционная связь урожайности ячменя с климатическими факторами различалась по тесноте в зависимости от фактора (влажность, температура) и от контрастности условий.

Ключевые слова: корреляционные связи, осадки, среднесуточная температура воздуха, гидротермический коэффициент

Influence of weather conditions in the Ob forest-steppe region on spring barley yield

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The paper presents research data on the influence of hydrothermal factors on the yield level of barley of different maturity groups under contrasting environmental conditions. The dependence of barley yield on the amount of precipitation, average daily air temperature and hydrothermal coefficient in the conditions of the Ob forest-steppe were analyzed. The research was conducted from 2014 to 2023 at the Siberian Research Institute of Plant Production and Breeding (SibNIIRS) – Branch of the Scientific Research Institute of Cytology and Genetics of the Siberian Branch of the Russian Academy of Sciences. The study material included 51 varieties of barley included in the State Register of the Varieties and Hybrids of Agricultural Plants Approved for Use in the West Siberian and East Siberian

Regions. It was determined that the stability of the yield formation by groups was as follows: "early" – 0.82%, "middle-early" – 0.79% and "medium-maturing" – 0.80%, which indicates a synchronous response of the varieties of different maturity groups to contrasting environmental conditions. It has been established that in the conditions of the Ob forest-steppe, the level of barley yield depends on the amount of precipitation for the period May – July ($r = 0.37$ – 0.44 for unfavorable conditions and $r = 0.63$ – 0.68 for favorable conditions) and the hydrothermal coefficient ($r = 0.45$ – 0.58 for unfavorable conditions and $r = 0.62$ – 0.64 for favorable conditions). A reliable high correlation has also been established between the yield and air temperature in June for all maturity groups over a 10-year period ($r = 0.70$; 0.72 ; 0.69).

Keywords: correlation links, precipitation, average daily air temperature, hydrothermal coefficient

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Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

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INTRODUCTION

Climate change could negatively impact global agricultural yields. A report by the Organization for Economic Cooperation and Development and the Food and Agriculture Organization of the United Nations predicts that 79% of the global agricultural yield will be achieved through increased crop yields¹. Changes in crop yields by year and zone depend on prevailing meteorological factors: the amount of precipitation and the nature of its distribution, the type of drought [1, 2]. The priority issue is to reduce the negative impact of these factors in order to increase the stable yield of grain products per unit area [3]. The yield of a variety, formed under the influence of contrasting environmental conditions, characterizes the degree of its adaptability to changing weather conditions [4]. To determine the dependence of crop yield on environmental factors, methods of mathematical modeling and mathematical statistics are used,

with the help of which a connection between crop yield and growing conditions is established, which increases the probability of predicted crop yield [5].

The purpose of the study is to investigate the influence of hydrothermal factors (precipitation, air temperature) on the yield of spring barley under contrasting conditions.

MATERIAL AND METHODS

The research was conducted from 2014 to 2023 at the SibNIIRS (Siberian Research Institute of Plant Cultivation and Breeding), a branch of the Federal Research Center Institute of Cytology and Genetics of the Siberian Branch of the Russian Academy of Sciences. Agricultural practices: plot area – 1 m², sowing time – early second ten-day period of May, sowing was carried out with an SSFK-7 seeder, seeding rate – 550 viable seeds per 1 m², preceded by complete fallow.

¹OECD-FAO Agricultural Outlook 2023-2032, OECD Publishing, Paris, <https://doi.org/10.1787/08801ab7-en>.

The research material used was 51 varieties of spring barley, developed in the breeding centers of Siberia². The varieties were sown in a demonstration nursery without replication according to the VIR methodology³. The experiments were conducted at a test site located in the Novosibirsk District of the Novosibirsk Region, in the forest-steppe soil-climatic zone. The primary soil type is leached, medium-deep, medium-humus chernozem⁴.

Meteorological conditions varied significantly during the years of research (see Table 1)⁵. The hydrothermal coefficient (HTC) varied over the years from low to excess moisture supply (0.61–1.75) according to the gradation of E.K. Zoidze [6].

Statistical and correlation analysis was performed in the Google Colab⁶ environment using standard Python libraries⁷. To interpret the strength of the connection, we used the Chaddock scale as presented by A.A. Orlov and A.I. Orlov [7].

RESULTS AND DISCUSSION

During the study period, the average daily air temperature for each month exceeded the long-term average by 1.0–1.6 °C (see Table 1), which is consistent with the trend of increasing air temperature noted in other studies conducted in different regions of the Russian Federation [8–10]. The 10-year average precipitation in May and July exceeded the long-term average by 10%,

Табл. 1. Метеорологические показатели и ГТК за май – июль, 2014–2023 гг.

Table 1. Meteorological indicators and the HTC for May – July, 2014–2023

Year	Average daily air temperature, °C				Amount of precipitation, mm				HTC			
	May	June	July	May – July	May	June	July	May – July	May	June	July	May – July
2014	10,0	17,4	20,2	15,9	50,5	17,4	76,9	144,8	2,99	0,37	1,23	1,15
2015	12,9	19,2	19,6	17,2	71,7	31,9	112,7	216,3	2,06	0,55	1,86	1,41
2016	10,5	19,7	20,2	16,8	31,6	37,7	76,7	146,0	1,28	0,66	1,22	1,01
2017	12,6	19,3	18,5	16,8	33,9	71,9	99,5	205,3	1,01	1,24	1,73	1,38
2018	7,0	19,1	18,5	14,9	80,5	70,2	64,6	215,3	0,47	1,23	1,13	1,75
2019	10,9	16,4	19,2	15,5	43,2	25,2	97,6	166,0	1,60	0,51	1,64	1,23
2020	15,5	16,6	19,7	17,3	53,7	23,8	84,9	162,4	1,19	0,50	1,39	1,06
2021	14,3	16,2	19,7	16,7	25,1	73,1	22,4	120,6	0,60	1,51	0,37	0,79
2022	15,4	17,3	18,9	17,2	2,5	58,8	47,8	109,1	0,06	1,22	0,81	0,73
2023	11,8	19,0	21,6	17,5	5,5	26,1	62,3	93,9	0,18	0,46	0,93	0,61
Average	12,1	18,0	19,6	16,6	39,8	43,6	74,5	157,9	1,16	0,87	1,23	1,11
Average long-term	10,5	17,0	19,4	15,6	37,0	45,0	61,0	143,0	1,05	0,94	1,14	1,05

²State Register of Breeding Achievements Approved for Use. Plant Varieties. (Official Publication). Moscow: Rosinformagrotekh, 2023, vol. 1, 634 p.

³Guidelines for the study and preservation of the world collection of barley and oats. St. Petersburg: State Scientific Institution VIR Russian Agricultural Academy, 2012. 63 p.

⁴Adaptive landscape farming systems of the Novosibirsk region / Russian Academy of Agricultural Sciences, Siberian Branch of the Siberian Research Institute of Plant Protection. Novosibirsk, 2002, 38 p.

⁵Pogodaiklimat.ru <http://www.pogodaiklimat.ru>

⁶<https://colab.research.google.com>

⁷<https://docs-python.ru/standart-library>

while in June, precipitation was 3% below the long-term average. Other studies have recorded a 25.6% reduction in summer precipitation [9]. Changes in average long-term indicators of average daily air temperatures and precipitation, as well as the nature of their distribution, pose the challenge for breeders to create varieties that are better adapted to environmental conditions.

The date of wax ripeness for varieties with the longest growing season (Signal, Aley and Buyan) was noted on August 1–6, except for 2018, when, due to heavy rainfall in the second ten-day period of May, sowing was carried out on May 21; accordingly, the ripening dates of the varieties were noted later. For the vast majority of varieties, the wax ripeness phase occurred before August 1, so the influence of environmental factors was examined for May–July. Plant moisture availability during this period was as follows: low in 2022 and 2023; insufficient in 2016 and 2021; sufficient in 2014, 2017, 2019, and 2020; increased in 2015; and excessive in 2018.

The highest yields among all barley varieties were recorded in 2019 and 2020 under optimal moisture conditions. The variety showed lower yields in 2021. This year there was significantly less precipitation, but it was distributed evenly throughout all ten days of June and the first ten days of July, which contributed to the formation of a high level of harvest compared to years with sufficient (optimal) moisture supply. In 2022, low moisture availability was observed during the barley plant development period (precipitation: May – 15%, June – 107%, July – 70%). However, thanks to the even distribution of precipitation across all ten-day periods of June and July, the yield in 2022 was above the 10-year average. A similarly even distribution of precipitation across the June and July ten-day periods was observed in 2023, with a deficit in June (47% in June, 92% in July). The 2023 crop yield was consistent with 2022 levels. In 2015, increased moisture availability was observed over the three months overall, but precipitation was distributed unevenly. At the beginning of May (before sowing), precipitation was almost twice the long-term average. In June, precipitation was

70% of the long-term average, with very high average daily temperatures. At the end of July, precipitation was 1.5 times higher than the long-term average, but this moisture was no longer used by the plants, as the leaves had dried out. As a result, in 2015 (with increased moisture availability in May–July), the varieties yielded below the 10-year average. In 2014 and 2018, precipitation in early May (before planting) contributed to a high hydrothermal coefficient over three months, but insufficient precipitation in June contributed to a decrease in yield. In 2017, a large amount of precipitation fell at the end of July, when the plants were no longer able to utilize it. Under 2016 conditions, insufficient moisture supply was due to a precipitation deficit in June (86%) coupled with high air temperatures in May and June (averaging 2.3°C above the long-term average), resulting in very low yields from the varieties.

Of the entire set of varieties, 12 belong to the “early” group (with the shortest period from germination to wax ripeness), 20 varieties are included in the “middle-early” group, and 19 belong to the “medium-maturing” group (see Table 2).

The difference between the varieties in terms of “minimum yield of a variety over 10 years” was 375 g/m² (75–450 g/m²), and in terms of “maximum yield of a variety over 10 years” – 537 g/m² (598–1135 g/m²). These values are due to varietal properties and indicate a significant influence of the genotype on yield variation, which is consistent with the opinion of other researchers [11]. The difference between the average minimum and average maximum yields for all varieties over 10 years, due to contrasting environmental conditions, was 733 g/m² (180–913 g/m²), significantly exceeding the range of variation due to genotype. This indicates the predominant influence of environmental factors in variability in spring barley yield.

A biologically determined pattern was established between the maturity groups: the shorter the growing season, the lower the productivity potential (“early” – 817, “middle-early” – 914 and “medium-maturing” – 971 g/m²). The dif-

Табл. 2. Урожайность сортов ячменя, 2014–2023 гг.

Table 2. Yield of barley varieties, 2014–2023

Variety, origin	Yield, g/m ²			Variety, origin	Yield, g/m ²		
	<i>X</i> *	min	max		<i>x</i> *	min	max
<i>Early (66–68 days)</i>							
Omsky 89, Omsk region	545	100	798	Kazminsky, Primorsky Territory	532	100	1053
Omsky 96, Omsk region	540	150	1043	Chervonets, Irkutsk region	609	350	839
Nevan, Irkutsk region	575	100	875	Bagan, Novosibirsk region	490	125	766
Zalarinets, Irkutsk region	456	125	634	Tanay, Novosibirsk region	602	212	839
Nepolegayushchy, Irkutsk region	477	100	736	Simon, Kemerovo region	594	175	929
Aykhal, Yakutia	385	100	598	Altan-Bulag, Buryatia	466	75	694
				Average (<i>n</i> = 12)	523	143	817
<i>Middle-early (69–71 days)</i>							
Ranny 1, Novosibirsk region	414	100	843	Zolotnik, Novosibirsk region	643	275	962
Biom, Novosibirsk region	599	200	1009	Talan, Novosibirsk region	658	225	979
Omsky 13709, Omsk region	543	150	844	Kolchan, Altai Territory	680	450	1077
Novo-Omsky, Omsk region	550	100	895	Omsky 80, Omsk region	568	300	886
Omsky 86, Omsk region	638	300	905	Omsky 88, Omsk region	644	100	942
Sasha, Omsk region	696	350	1053	Narymchanin, Tomsk region	559	125	1078
Agul 2, Krasnoyarsk Territory	550	100	835	Kedr, Krasnoyarsk Territory	591	100	853
Pallidum 394, Buryatia	602	250	774	Bakhus, Krasnoyarsk Territory	575	125	882
Monsoon, Primorsky Territory	518	100	831	Abalak, Krasnoyarsk Territory	664	325	938
Ача, Novosibirsk region	584	100	929	Primorsky 44, Primorsky Territory	518	100	775
				Average (<i>n</i> = 20)	590	189	914
<i>Medium-maturing (71–74 days)</i>							
Obskoi, Novosibirsk region	604	200	863	Sibirsky avangard, Omsk region + Krasnoyarsk Territory	682	150	1061
Omsky 85, Omsk region	698	100	1135	Vorsinsky, Altai Territory	726	375	957
Enisey, Krasnoyarsk Territory	574	125	826	Vorsinsky 2, Altai Territory	702	125	1108
Krasnoyarsky 80, Krasnoyarsk Territory	601	100	884	Omsky 95, Omsk region	692	400	958
Sobolek, Krasnoyarsk Territory	604	175	908	Barkhatny, Tomsk region	551	100	1052
Novosibirsky 80, Novosibirsk region	604	175	889	Krasnoyarsky 1, Krasnoyarsk Territory	614	250	806
Salair, Altai Territory	725	275	1097	Signal, Novosibirsk region	617	105	959
Nikita, Kemerovo region	590	100	969	Alei, Altai Territory	681	175	962
Omsky 87, Omsk region	654	250	990	Buyan, Krasnoyarsk Territory	570	125	989
Omsky 90, Omsk region	689	325	1039	Average (<i>n</i> = 19)	641	191	971
				Average (<i>n</i> = 51)	477	180	913

*X – 10-year average.

min – minimum yield of the variety over 10 years.

max – maximum yield of the variety in 10 years.

ference from the minimum to maximum yield by maturity group was: “early” – 674, “middle-early” – 725 and “medium-maturing” – 780 g/m². Absolute values showing the difference between limiting values for maturity groups cannot serve as a criterion for comparing the response of the varietal population of the group. Let us consider the stability of yield formation (range of

variation) by maturity groups as the ratio of the difference between the maximum and minimum values to its maximum value, proposed by V.A. Zykin et al. [12]. The stability of yield formation by groups was: “early” – 0.82%, “middle-early” – 0.79% and “medium-maturing” – 0.80%, which indicates a synchronous response of varieties of different maturity groups to contrasting

environmental conditions.

Crop yield is determined by the combination of many environmental factors affecting plants throughout their growth and development. Therefore, crop yield can be considered an indicator of favorable or unfavorable environmental conditions. Based on this, all years were divided into two scenarios (unfavorable and favorable). The “unfavorable years” category (yields below the 10-year average) included 2014–2018, while the “favorable years” category (yields above the 10-year average) included 2019–2023.

The correlation between barley yield and climatic factors varied in strength depending on the factor (moisture, temperature) and the contrast of conditions (see Table 3).

A significant correlation was found between yield and air temperature in June for a 10-year sample for all maturity groups ($r = 0.70$; 0.72 ; 0.69), which is consistent with the results obtained by R.D. Kamaleev et al. [13] in the cen-

tral zone of the Orenburg region. Other studies have obtained opposite results. Thus, in the experiments of I.V. Lyskova et al. [8] in the Kirov region, strong inverse correlations were noted between the yield of grain crops and the air temperature in June. These differences between the experiments are explained by the fact that the increase in yield is influenced by all environmental factors in combination and throughout the entire period of plant growth and development.

In contrasting conditions with a 5-year sample, the correlation between the variables under consideration is expressed weaker, since the variation of characteristics over 5 years (of one category) is manifested to a lesser extent. The relationship between air temperature for the entire period (May – July) and crop yield is moderate in both unfavorable ($r = 0.25$; 0.31 ; 0.43) and favorable conditions ($r = 0.48$; 0.42 ; 0.45), while no significant differences were noted between maturity groups. In a 10-year sample, a weak

Табл. 3. Коэффициенты корреляции урожайности с климатическими факторами в контрастных условиях

Table 3. Correlation coefficients of crop yield with climatic factors in contrasting conditions

Period	10-year average			Unfavorable years			Favorable years		
	t, °C	Precipitation	HTC	t, °C	Precipitation	HTC	t, °C	Precipitation	HTC
<i>Early (n = 12; 5 % threshold of significance $r = 0,58$)</i>									
May	0,30	0,04	0,10	0,01	0,47	0,26	0,13	0,62*	0,65*
June	0,70*	0,14	0,05	0,50	0,01	0,02	0,51	0,20	0,17
July	0,08	0,05	0,04	0,28	0,17	0,22	0,28	0,37	0,40
May – July	0,09	0,08	0,08	0,25	0,37	0,45	0,48	0,63*	0,62*
<i>Middle-early (n = 20; 5 % threshold of significance $r = 0,44$)</i>									
May	0,35	0,01	0,11	0,09	0,56*	0,36	0,07	0,73*	0,70*
June	0,72*	0,12	0,02	0,41	0,06	0,08	0,54*	0,23	0,20
July	0,03	0,14	0,12	0,33	0,13	0,18	0,21	0,36	0,38
May – July	0,04	0,14	0,15	0,31	0,44*	0,53*	0,42	0,68*	0,64*
<i>Medium-maturing (n = 19; 5 % threshold of significance $r = 0,46$)</i>									
May	0,27	0,01	0,06	0,18	0,51	0,43	0,20	0,66*	0,68*
June	0,69*	0,11	0,02	0,46*	0,17	0,20	0,43	0,33	0,30
July	0,06	0,13	0,11	0,43	0,02	0,10	0,16	0,45	0,47*
May – July	0,11	0,13	0,11	0,43	0,43	0,58*	0,45	0,64*	0,63*

*Significant at $p = 0,05$.

relationship was observed between temperature increase and yield increase ($r = 0.04\text{--}0.11$). This is explained by the fact that very high air temperature affects both the acceleration of development phases and a decrease in productivity, which is consistent with the results of A. A. Bisharev et al. [14], who, under the conditions of the Middle Volga region, recorded a negative effect of average air temperature on barley yield during the vegetative and generative periods of plant development.

The impact of precipitation on crop yield growth varied by month and depending on the contrasting conditions (see Table 3). In a 10-year sample, the relationship between May precipitation and crop yield was weak, but in contrasting conditions, it was noticeable due to crowding. Thus, for all maturity groups, a noticeable relationship was noted between the amount of May precipitation and yield both in favorable ($r = 0.62\text{--}0.73$) and unfavorable conditions ($r = 0.47\text{--}0.56$). These indicators are determined by the moisture reserves in the soil due to precipitation before sowing and atmospheric moisture after sowing, which ultimately ensures the survival of emerging plants and ear productivity. Similar results on the importance of May precipitation for the formation of spring barley productivity were obtained by R. D. Kamaleev et al. [13] in the central zone of the Orenburg region.

June and July precipitation did not correlate with yield. Thus, over a 10-year period, the correlation between yield and precipitation in June and July was weak across all varietal groups and equally strong across all maturity groups ($r = 0.11\text{--}0.14$ for June, $r = 0.05\text{--}0.14$ for July). Under favorable conditions, the correlation between July precipitation and crop yield is moderate ($r = 0.36; 0.37; 0.45$).

The highest correlation values were observed between the amount of precipitation for May – July and crop yield in the variant with favorable conditions ($r = 0.63; 0.68; 0.64$), and in unfavorable conditions, the connection is moderate ($r = 0.37; 0.44; 0.43$). The relationship between precipitation during the growing season of plants and crop yields is consistent with the results

obtained by A. P. Solodovnikov et al. [15] in the conditions of the Trans-Volga region.

The HTC indicator reflects the combined effects of precipitation and average daily air temperature. The highest correlation values were observed between the HTC for May and crop yield in the "favorable years" scenario ($r = 0.65\text{--}0.70$). A similarly strong correlation was observed between the HTC for May–July and the yield in the "favorable years" variant ($r = 0.62\text{--}0.64$), and in the "unfavorable years" variant – from moderate to noticeable ($r = 0.45\text{--}0.58$). The relationship between these indicators in the 10-year period is weak ($r = 0.08\text{--}0.15$). These differences in the strength of the relationship over a 10-year period, as in the case of precipitation, are explained by the asynchronous variation of the indicators under consideration, since the variation in yield also depends on other environmental factors.

Thus, the most significant influence on the formation of barley grain yield in the conditions of the Ob forest-steppe is exerted by the air temperature in June, the amount of precipitation and the HTC index for May – July. The established dependence of barley yield on the growing conditions will allow us to calculate, for specific conditions, predicted yield values based on empirical and calculated values of precipitation and air temperature.

CONCLUSION

A reliable high correlation was established between yield and air temperature in June for all maturity groups over a 10-year period ($r = 0.70; 0.72; 0.69$). The yield of barley depends on the amount of precipitation for May – July ($r = 0.37\text{--}0.44$ – for unfavorable conditions and $r = 0.63\text{--}0.68$ – for the favorable ones), and the HTC values for May–July ($r = 0.45\text{--}0.58$ – for unfavorable conditions and $r = 0.62\text{--}0.64$ – for the favorable ones).

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Влияние средств интенсификации на поражение сортов картофеля сибирской селекции ризоктониозом

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В статье представлены результаты оценки эффективности применения различных средств интенсификации при размножении исходного материала трех сортов картофеля сибирской селекции (Юна, Лина, Златка) в условиях лесостепи Новосибирского Приобья. Цель исследования заключалась в определении оптимальных сочетаний доз протравителя, гуминовых препаратов и минерального удобрения для снижения развития ризоктониоза на стеблях картофеля. В опытах использовали протравитель Селест Топ (норма расхода 0,2 и 0,4 л/т), гуминовые препараты Берес-8 (норма расхода по клубням 0,2 л/т, по вегетации – 0,2 л/га) и Реликт (норма расхода по клубням 0,01 л/т, по вегетации – 0,2 л/га) на двух уровнях минерального питания ($N_{40}P_{40}K_{80}$ и естественное плодородие). Изучение влияния комплексного применения минерального удобрения, протравителя и экологически безопасных препаратов на основе гуматов на фитосанитарную ситуацию в посадках картофеля показало, что внесение при посадке минерального удобрения в дозе $N_{40}P_{40}K_{80}$ способствует снижению поражения растений ризоктониозом на 5,0–7,6%. Ранжирование комплекса полученных показателей выявило, что наименьшее поражение растений картофеля ризоктониозом у всех сортов обеспечило возделывание культуры с использованием минерального удобрения в сочетании с протравливанием посадочного материала Селест Топом с нормой расхода 0,4 л/т для сорта Юна; обработкой семенных клубней смесью Селест Топ, 0,4 л/т + Реликт, 0,01 л/т и опрыскиванием растений в период вегетации препаратом Реликт с нормой расхода 0,2 л/га для сортов Лина и Златка.

Ключевые слова: картофель, группы спелости, протравитель, гуматы, удобрения, ризоктониоз

Influence of the intensification agents on the infestation of Siberian potato varieties by rhizoctoniose

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The article presents the results of assessing the effectiveness of using various means of intensification when propagating the source material of three potato varieties of Siberian selection (Yuna, Lina, Zlatka) in the forest-steppe conditions of the Novosibirsk Ob region. The purpose of the study was to determine the optimal combinations of the doses of disinfectant, humic preparations and mineral fertilizer to reduce the development of rhizoctoniose on potato stems. In the experiments, the disinfectant

Celest Top (consumption rate 0.2 and 0.4 l/t), humic preparations Beres-8 (consumption rate for tubers 0.2 l/t, during the growing season – 0.2 l/ha) and Relict (consumption rate for tubers 0.01 l/t, during the growing season – 0.2 l/ha) at two levels of mineral nutrition ($N_{40}P_{40}K_{80}$ and natural fertility) were used. Study of the effect of the combined use of mineral fertilizers, fungicides, and environmentally friendly humic-based preparations on the phytosanitary situation in potato crops showed that the application of mineral fertilizer at a dose of $N_{40}P_{40}K_{80}$ during planting helps reduce plant damage by rhizoctoniose by 5.0–7.6%. Ranking of the complex of obtained indicators revealed that the least damage to potato plants with rhizoctoniose in all varieties ensured the cultivation of crops using mineral fertilizers in combination with treatment of the planting material with Celest Top with a consumption rate of 0.4 l/t for the Yuna variety; treatment of the seed tubers with a mixture of Celest Top, 0.4 l/t + Relict, 0.01 l/t and spraying the plants during the growing season with Relict with a consumption rate of 0.2 l/ha for the Lina and Zlatka varieties.

Keywords: potato, maturity groups, seed dressing, humates, fertilizers, rhizoctoniose

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Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Currently, a necessary condition for intensifying the production of seed potatoes is the use of environmentally safe means and technologies that increase yield and reliably guarantee the production of the required volumes of seed material even under unfavorable weather conditions. The key tasks of original potato seed breeding are obtaining the initial material in the quantity required for elite seed production; improving its quality by reducing disease incidence; and ensuring the environmental safety of cultivation technologies.

One of the most common and harmful potato diseases in all regions where it is grown is rhizoctoniose (the causative agent – *Rhizoctonia solani* Kühn) [1–5]. In Western Siberia, with its sharply continental climate characterized by low temperatures and high humidity in the spring, as well as high temperatures and low humidity in the summer, there is a significant spread of this disease in potato crops. This is because the planting material used is infected with rhizocto-

niose sclerotia by at least 20%, soil infestation – at least 20 propagules per 100 g of soil (economic damage threshold – 0.2 propagules per 100 g of soil)¹ [1]. As a result, seedling emergence reaches 27%, and damage to sprouts and stems is 40% or more [1]. Crop losses in the region amount to 45–50% [6].

Rhizoctoniose poses a serious problem for potato seed growing too. Under favorable conditions, it can attack most of the sprouts even before they appear on the surface and later form a pathogen population on the surface of the new crop's tubers, which in the first case reduces the crop yield, and in the second – affects the seed quality of the tubers due to an increase in the sclerotial form of the disease and deeper spotting [7–9].

So, one of the main factors for successfully growing seed potatoes is having healthy planting material. Since it easily gets infected by various disease pathogens and, along with the soil, serves as a source and transmitter of the most harmful and dangerous plant diseases (30 to 60% of all

¹Malyuga A.A., Enina N.N., Scheglova O.V. Agrotechnical and chemical methods of combating rhizoctonia: recommendations. Novosibirsk, 2010, 24 p.

crop diseases are spread through seeds and soil), to increase the viability of seed tubers, reduce potato plants' rhizoctonia infection, lower the spread of this disease in the new crop tubers, and improve the quality of the harvested product, the seed tubers should be treated with fungicidal seed treatments and various biologically active substances² [5, 10–12].

For these purposes, both natural and synthetic physiologically active substances are used, whose mechanism of action is connected not only with adjusting the hormonal balance in cells but also with the ability to indirectly protect the plant by increasing its disease resistance³.

One of the substances that increase the yield of potato crops for any purpose and stimulate plant immunity are humates. Humic substances boost the stress-resistance of plants, enhancing their natural immunity to diseases. Currently, the most widely known are sodium humate and potassium humate, which help increase crop yields by speeding up plant growth and transferring nutrients to tubers earlier. The use of the above-mentioned drugs shortens the growing season, increases the yield of marketable tubers and their starch content (by 20–50%), boosts the potato's resistance to fungal diseases, and improves its storage life^{4,6} [13].

In addition, the development and spread of rhizoctoniosis on potatoes can be reduced by applying mineral fertilizers [14–16].

Thus, protective measures against diseases of this crop that are transmitted through soil and tubers, including rhizoctoniosis, should primarily aim at reducing the initial population of the pathogen to a level below the harmful threshold.

Achieving this goal is possible by implementing environmentally safe and cost-effective methods of phytosanitary improvement, among which one of the most important is the introduction of intensification tools (fungicides, growth stimulants, mineral fertilizers) into the cultivation process, which not only help fight diseases but also effectively improve the quality of the harvest.

In light of the above, the goal of the work was to determine the optimal combinations of seed treatment doses, humic preparations, and mineral fertilizer to reduce the development of rhizoctoniosis on the stems of Siberian breeding potato varieties.

MATERIAL AND METHODS

The study was carried out from 2022 to 2024 in the Novosibirsk region, in soil and climate conditions typical for the forest-steppe zone of Western Siberia. The objects of study were potato varieties of Siberian breeding: Yuna (early), Lina (middle-early), and Zlatka (medium-maturing).

The methodological basis was a system-alternative approach⁷, implemented in the form of a two-factor field experiment (factor A – level of mineral nutrition, factor B – plant protection).

The soil cover of the station is represented by drained leached chernozem of medium thickness. The depth of the humus horizon is about 40 cm. The agrochemical characteristics of the arable layer (0–30 cm) are as follows: humus content (according to Tyurin) – 5.0%, total nitrogen (according to Kjeldahl) – 0.34%, total phosphorus – 0.30%, available phosphorus and

²Malyuga A.A., Enina N.N., Burmistrova T.I. Application of peat-humic preparations and mineral fertilizers in potato cultivation: recommendations. Novosibirsk, 2009. 22 p.

³Agricultural Biotechnology: Textbook for Universities / V.S. Shevelukha, E.A. Kalashnikova, S.V. Degtyarev, et al.; edited by V.S. Shevelukha. Moscow, 1998, 415 p.

⁴Larina V.A. Coal-humic fertilizers in the soil and climatic conditions of Eastern Siberia // Humic fertilizers: theory and practice of their application: collection of articles. Kyiv, 1968, vol. 3, pp. 339–348.

⁵Nosova O.V. On stimulation of potato growth // Humic fertilizers: theory and practice of their application: collection of articles. Dnepropetrovsk, 1980, vol. 7, pp. 254–258.

⁶Zolotareva E.V., Fedotova O.V., Oshlakova Z.V., Anisimov M.M., Logachev V.V. Increasing the anti-stress activity of potatoes and tomatoes under the influence of phyto regulators // Actual problems of immunity, health improvement and protection of agricultural plants in the Russian Urals: collection of scientific papers of the Far Eastern Research Institute of Agriculture. Khabarovsk, 2000, pp. 79–89.

⁷Kiryushin V.I. Methodological concept of agricultural development in Siberia // Agriculture, 1989, No. 12, pp. 7–14.

potassium (according to Chirikov) – 29 and 13 mg/100 g of soil, respectively, pH = 6.7–6.8.

The growing season in 2022, in terms of temperature, was close to the long-term average. It's worth noting that the third ten-day period of May and the second ten-day period of June were slightly warmer than usual. Rainfall during this growing season was distributed very unevenly. In the third ten-day period of May, the first and second ten-day periods of July, and the first and third ten-day periods of August, there was insufficient moisture, with precipitation being 16.3, 2.6, 26.0, 6.5, and 4.0 times less than the long-term average. In other cases, the amount of rainfall was close to the climate norm (see Table 1).

The weather conditions during the 2023 growing season were marked by a lack of rainfall and higher air temperatures. May stood out in terms of dryness: in the third ten-day period of May, precipitation was 8.6 times lower than the long-term average. In the first ten-day period of June, the air temperature was 7.9 °C above the long-term average, and in the second and third ten-day periods, the amount of rainfall was 2.6 and 50 times below normal. Over the course of

the month, the amount of atmospheric moisture turned out to be 31.6 mm below the long-term average (2.2 times less). In the second ten days of July, temperatures were 4.1 °C above the norm, while in the first and third ten-day periods they were 1.9 °C above the long-term averages. Overall, during the month, the air temperature was 2.6 °C above the long-term average. The amount of precipitation that fell over the month was close to normal. In August, the temperature was almost in line with the long-term averages.

At the same time, in the first and second ten-day periods of August, the temperature was above normal by 2.9 and 4.2 °C respectively, while in the third period it was close to the long-term average. Overall, the month received 1.7 times more precipitation than normal. In the first ten-day period of August, the precipitation was 30 times below normal, while in the second and third periods it was 3.3 and 2 times higher, respectively.

The weather data for the 2024 growing season differed greatly from the long-term averages, especially in terms of moisture levels. There were heavy rains throughout the season, often

Табл. 1. Метеоусловия вегетационных периодов 2022–2024 гг. (агрометеостанция Огурцово, Новосибирская область)

Table 1. Meteorological conditions for the growing seasons of 2022–2024 (AMS Ogurtsovo, Novosibirsk region)

Indicator	Month, ten-day period									
	May	June			July			August		
	III	I	II	III	I	II	III	I	II	III
2022										
Air temperature, °C	19,0	12,0	19,5	20,2	18,5	18,1	20,0	18,8	15,2	15,7
Precipitation, mm	1,0	16,4	20,5	21,9	7,4	1,0	20,4	3,7	13,6	5,5
2023										
Air temperature, °C	15,2	23,3	17,7	16,0	21,0	23,0	20,8	20,8	14,8	17,7
Precipitation, mm	1,5	5,0	0,4	21,0	13,0	15,0	32,0	0,8	67,0	45,0
2024										
Air temperature, °C	10,3	14,3	19,3	24,6	20,3	22,1	22,3	20,6	18,6	16,1
Precipitation, mm	25,0	25,0	51,0	10,0	19,0	34,0	27,0	38,0	28,0	66,0
Average long-term values										
Air temperature, °C	13,2	15,4	16,7	18,1	19,1	18,9	18,9	17,9	16,0	13,5
Precipitation, mm	13,0	13,0	20,0	25,0	19,0	26,0	27,0	24,0	20,0	22,0

in the form of downpours. In May, June, and August, there was a significant excess of atmospheric moisture: 70 mm of rainfall fell in May, 113 mm in June, and 133 mm in August (which is 94.4%, 94.8%, and 201.5% above the norm, respectively). In July, their number was within the normal range. Heavy rains and high temperatures created stressful conditions for potato growth. The total precipitation for the growing season was 396 mm, which is 1.7 times higher than the long-term average. The 2024 growing season is considered moderately waterlogged. The average daily air temperature exceeded the long-term average from May to August by 1.1, 2.8, 2.6, and 2.6 °C, respectively.

The experiment was carried out on a natural infection background under a crop rotation of potato – green manure fallow (rapeseed) – potato. All technological operations in growing the crops, if they were not the subject of the study, were carried out according to the accepted recommendations⁸.

The repetition is double, the number of plants per repetition is 24. Planting density is 57.1 thousand plants/ha, with a spacing of 0.25 × 0.7 m. The experiment layout was designed according to B.A. Dospekhov's methodology⁹ (see Table 2).

Each of the three potato varieties was grown on natural fertile soil and on soil with mineral fertilizer (N₄₀P₄₀K₈₀). The effectiveness of protection was evaluated in several setups, including pre-plant treatment of seed tubers with the fungicide Celest Top, SC, and humate-based complexes (Beres-8 and Relict), as well as spraying plants with Beres-8 and Relict (the treatment was done once during the budding phase).

Табл. 2. Схема опыта

Table 2. Experimental design

Pre-planting treatment of tubers	Vegetative treatment
CT 0,4	–
CT 0,4 + B 0,2	B 0,2
CT 0,2 + B 0,2	»
CT 0,4 + R 0,01	R 0,2
CT 0,2 + R 0,01	»

Note. Here and further in the tables, the following symbols are used to indicate the treatment options: CT 0.4 – Celest Top (consumption rate 0.4 l/t); CT 0.4 + B 0.2 – Celest Top (consumption rate 0.4 l/t) + Beres-8 (consumption rate 0.2 l/t); CT 0.2 + B 0.2 – Celest Top (consumption rate 0.2 l/t) + Beres-8 (consumption rate 0.2 l/t); ST 0.4 + R 0.01 – Celest Top (application rate 0.4 l/t) + Relict (application rate 0.01 l/t); CT 0.2 + R 0.01 – Celest Top (application rate 0.2 l/t) + Relict (application rate 0.01 l/t); B 0.2 – Beres-8 (application rate 0.2 l/ha); R 0.2 – Relict (application rate 0.2 l/ha).

Taking care of the crops included pre-emergence harrowing, inter-row cultivation, and hilling. To fight weeds, they used the herbicides Boxer, EC (prosulfocarb, 800 g/l) at a rate of 3 l/ha and Fusilade Super, SC (fluazifop-P-butyl, 125 g/l)¹⁰. The tops were removed using mechanized mowing with a KIR-1.5 mower-chopper, and the experimental plots were harvested with a two-row KTN-2V mounted potato digger. To study the effect of intensification methods on stem and stolon infection by rhizoctoniosis, the plants were examined 4, 6, and 10 weeks after planting. Степень развития болезни определяли по методике J. Frank¹¹, количество поврежденных столонов – по общепринятой методике^{12, 13}.

⁸Vegetable crops and potatoes in Siberia: recommendations / compiled by G.K. Mashyanova, E.G. Grinberg, T.V. Steinert. Novosibirsk, 2010, pp. 496–507.

⁹Dospekhov B.A. Methodology of field experiment (with the basics of statistical processing of research results): textbook for universities. Moscow, 2012, 351 p.

¹⁰State catalog of pesticides and agrochemicals permitted for use in the Russian Federation (as of April 11, 2022) / Ministry of Agriculture of the Russian Federation. Moscow, 2022. URL: <https://mcx.gov.ru/search/?q=каталог+пестицидов++и+агрохимикатов&test=test>.

¹¹Frank J., Leach S.S., Webb R.E. Evaluation of potato clone reaction to Rhizoctonia solani // Plant disease reporter, 1976, vol. 60, N 11, pp. 910–912.

¹²Research Methodology for Potato Cultivation. Moscow, 1967, 264 p.

¹³Zhevora S.V., Fedotova L.S., Starovoytov V.I. et al. Methodology for conducting agrotechnical experiments, records, observations and analyses on potatoes: method. instructions. Moscow, 2019, 120 p.

The assessment of the degree of potato stem damage by rhizoctoniose was done using a five-point scale:

- 0 – signs of damage are absent;
- 1 – brown streaks or spots up to 25 mm long;
- 2 – a spot or ulcer up to 50 mm long;
- 3 – a 50 mm long spot that doesn't encircle the sprout (stem);
- 4 – large sores, almost encircling the sprout (stem), possible constriction;
- 5 – the sprout (stem) is completely ringed or has broken.

The intensity of rhizoctoniose development on the stems was calculated using the formula

$$R = \frac{\sum a \cdot b}{NK} \cdot 100\%,$$

where R – prevalence, %; a – prevalence score; b – number of sprouts (stems) with this score, pcs.; $\sum a \cdot b$ – the sum of the product of the number of diseased plants by points; N – total number of recorded stems, pcs.; K – the highest score on the scale.

At the same time, the number of affected and fallen stolons was counted.

The results were processed using the Snedecor software package¹⁴.

RESULTS AND DISCUSSION

Yuna variety

The study showed that, on average, the mineral nutrition factor has a significant effect on the development of rhizoctoniose. For example, applying mineral fertilizer during planting reduced stem infection by 7.6% (see Table 3). The most effective way to protect potato plants from rhizoctoniose was also the pre-plant treatment of tubers with the Celest Top composition, 0.2 l/t + Relict, 0.01 l/t, combined with spraying the plants with Relict at a rate of 0.2 l/ha. In this case, the disease development decreased by 2.5%.

Analysis of the averages for the factors of protection and mineral nutrition showed that all the studied options reduce the development of rhi-

zootoniose by 1.8–15.9% compared to the control. This indicator decreased significantly (by 9.2%) under natural fertility in the Celest Top 0.4 l/t + Relict 0.01 l/t (tuber treatment) + Relict 0.2 l/ha (plant spraying) option. When optimizing mineral nutrition with Celest Top at 0.4 L/t, as well as Celest Top at 0.4 l/t + Beres-8 at 0.2 l/t (treatment) + Beres-8 at 0.2 l/ha (spraying), rhizoctoniose infection decreased by 15.3–15.9%, while with Celest Top at 0.2 l/t + Relict at 0.01 l/t (treatment) + Relict at 0.2 l/ha (spraying), it decreased by 13.1%.

The least development of rhizoctoniose at the seedling stage was observed when seed tubers were treated with the fungicide Celest Top (0.4 l/t) and plants were grown using mineral fertilizers – significantly lower by 19.5% compared to the control. The studied indicator was also slightly lower (by 17.9% and 15.8% compared to the control) when optimizing mineral nutrition and treating tubers with a mix of Celest Top (0.4 l/t) with Beres-8 (0.2 l/t) or Relict (0.01 l/t).

At the budding stage, the least development of rhizoctoniose on the stems was observed with mineral fertilizer in the Celest Top option, 0.4 l/t, as well as in the options Celest Top, 0.4 and 0.2 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying). In these cases, disease infection was 15.3%, 14.1%, and 12.7% lower than the control.

By the ripening phase, in all the variants (except Celest Top, 0.2 l/t + Beres-8, 0.2 l/t (seed treatment) + Beres-8, 0.2 l/t (spraying) with optimized mineral nutrition), disease development was significantly lower than in the control. So, under natural fertility conditions, this indicator ranged from 40.2 to 47.5%, while with the application of mineral fertilizers to the crop, it ranged from 34.2 to 38.2%.

The use of mineral fertilizer helped reduce stolon damage from rhizoctoniose by 2.1%. The lowest damage was seen with two options: Celest Top, 0.4 l/t; and Celest Top, 0.4 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying). In these cases, the number of damaged sto-

¹⁴Sorokin O.D. Applied statistics on the computer. Novosibirsk, 2012, 282 p.

Табл. 3. Влияние средств интенсификации на пораженность картофеля сорта Юна ризоктониозом (2022–2024 гг.), %

Table 3. Influence of the intensification agents on the infestation of the Yuna potato variety with rhizoctoniose (2022–2024), %

Mineral nutri- tion level	Treatment option		Phase			Average by factors		
	tubers	plants	full sprouts	budding	ripening	protection + mineral nutri- tion level	protec- tion	mineral nutri- tion level
Progress of the disease								
Natural fer- tility	CT 0,4 (control)	–	24,0	32,0	51,3	35,7	27,7	31,1
	CT 0,4 + B 0,2	B 0,2	16,8	40,3	44,7	33,9	27,1	
	CT 0,2 + B 0,2	»	19,0	34,9	41,3	37,3	32,5	
	CT 0,4 + R 0,01	R 0,2	11,7	20,3	47,5	26,5	29,3	
	CT 0,2 + R 0,01	»	17,6	25,5	40,2	27,8	25,2	
N ₄₀ P ₄₀ K ₈₀	CT 0,4	–	4,5	16,7	38,1	19,8	–	23,5
	CT 0,4 + B 0,2	B 0,2	6,1	20,8	34,2	20,4		
	CT 0,2 + B 0,2	»	22,0	23,7	54,5	33,4		
	CT 0,4 + R 0,01	R 0,2	8,2	17,9	38,2	32,1		
	CT 0,2 + R 0,01	»	12,6	19,3	36,0	22,6		
LSD _{0,5} (for quotient averages)			1,6	2,3	1,7			
LSD _{0,5} (by factors)						8,0	5,6	3,6
Number of damaged stolons								
Natural fer- tility	CT 0,4 (control)	–	0	2,5	23,3	8,6	8,6	9,7
	CT 0,4 + B 0,2	B 0,2	2,2	8,0	14,5	8,2	8,2	
	CT 0,2 + B 0,2	»	3,0	4,0	36,4	14,5	14,5	
	CT 0,4 + R 0,01	R 0,2	0,6	3,2	15,1	6,3	6,3	
	CT 0,2 + R 0,01	»	2,1	16,0	14,4	10,8	10,8	
N ₄₀ P ₄₀ K ₈₀	CT 0,4	–	0	5,6	9,6	5,1	5,1	7,6
	CT 0,4 + B 0,2	B 0,2	1,4	4,5	14,9	6,9	6,9	
	CT 0,2 + B 0,2	»	0,5	8,3	23,0	10,6	10,6	
	CT 0,4 + R 0,01	R 0,2	0	2,6	19,9	7,5	7,5	
	CT 0,2 + R 0,01	»	1,7	3,0	18,6	7,8	7,8	

lons was 6.3–6.9%. The analysis of averages for the factors of protection and mineral nutrition showed that not all studied options reduce the level of stolon infection by the fungus *R. solani*. A decrease of 2.3% was noted under natural fertility with the Celest Top variant, 0.4 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying). In addition, rhizoctonia infection decreased by 1.7–3.5% when mineral nutrition was optimized in the Celest Top options at 0.4 l/t, as well as Celest Top 0.4 l/t + Beres-8 0.2 l/t (seed treatment) + Beres-8 0.2 l/ha (spraying). In the Celest Top 0.4 and 0.2 l/t + Relict 0.01 l/t (seed treatment) + Relict 0.2 l/ha (spraying) options, the indicator decreased by 0.8–1.1%. In other cases, the values were close to the control option.

A complete absence of damaged stolons by rhizoctoniose at the sprouting stage was observed on both mineral nutrition backgrounds when seed tubers were treated with Celest Top (0.4 l/t), as well as when the full-rate seed treat-

ment included the addition of Relict (0.01 l/t). Slight (0.5–0.6%) damage to the stolons was found with the Celest Top treatment, 0.4 l/t + Relict, 0.01 l/t (seed dressing) + Relict, 0.2 l/ha (spraying) under natural fertility, and with the Celest Top treatment, 0.2 l/t + Beres-8, 0.2 l/t (seed dressing) + Beres-8, 0.2 l/ha (spraying) with optimized mineral nutrition.

At the budding stage, the lowest levels of stolon damage by rhizoctoniose (2.5–3.2%) were observed: under natural fertility conditions with Celest Top at 0.4 l/t, as well as Celest Top 0.4 l/t + Relict 0.01 l/t (seed treatment) + Relict 0.2 l/ha (spraying); under mineral fertilizer conditions with Celest Top 0.4 and 0.2 l/t + Relict 0.01 l/t (seed treatment) + Relict 0.2 l/ha (spraying).

At the maturation stage, the least damage to stolons from rhizoctoniose was observed in the option where the seed tubers were treated with pure Celest Top (0.4 l/t) while optimizing mineral nutrition: the resulting value was 13.7% lower than the control. In the other cases, except for the Celest Top 0.2 l/t + Beres-8, 0.2 l/t (treatment) + Beres-8, 0.2 l/t (spraying) option in both backgrounds, the disease development was lower than in the control, ranging from 14.4 to 19.9%.

Ranking the obtained results showed that the least damage to Yuna potatoes from rhizoctoniose was achieved when the crop was grown using mineral fertilizer (N₄₀P₄₀K₈₀) and the seed material was treated with Celest Top at a rate of 0.4 l/t – in this case, the sum of ranks was the lowest among all the protection options (see Table 4).

In addition, the group of “best” objects against the background of mineral fertilizer included options that involved treating seed tubers with Celest Top (0.4 l/t) in a mix with humic preparations Beres-8 (0.2 l/t) and Relict (0.01 l/t), followed by spraying the plants with Beres-8 (0.2 l/ha) and Relict (0.2 l/ha), respectively.

Lina variety

According to the results obtained, on average, optimizing mineral nutrition reliably reduced stem infection of the Lina potato variety by rhizoctoniose by 5% (see Table 5). Also, the most effective option for protecting potatoes from this disease turned out to be Celest Top, 0.4 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying). In this case, the disease development decreased by 4.4%. Analysis of the averages for

Табл. 4. Ранжирование исследуемых признаков (развитие ризоктониоза, количество пораженных столонов) для картофеля сорта Юна (2022–2024 гг.)

Table 4. Ranking of the studied characteristics (development of rhizoctoniose, the number of affected stolons) for the Yuna potato variety (2022–2024)

Object's place	Mineral nutrition level	Treatment option		Sum of ranks
		tubers	plants	
“Best” objects				
1	N ₄₀ P ₄₀ K ₈₀	CT 0,4	–	18,0
2	»	CT 0,4 + R 0,01	R 0,2	23,0
3	»	CT 0,4 + B 0,2	B 0,2	28,0
“Average” objects				
4	N ₄₀ P ₄₀ K ₈₀	CT 0,2 + R 0,01	R 0,2	30,0
5	Natural fertility	CT 0,4 + R 0,01	»	34,0
6	» »	CT 0,2 + R 0,01	»	43,0
7	» »	CT 0,4 (control)	–	45,0
“Worst” objects				
8	Natural fertility	CT 0,4 + B 0,2	B 0,2	49,0
9	N ₄₀ P ₄₀ K ₈₀	CT 0,2 + B 0,2	»	52,0
10	Natural fertility	CT 0,2 + B 0,2	»	56,0

protection and mineral nutrition factors showed that for this variety, a significant (10.5%) reduction in rhizoctoniose infestation was achieved using the Celest Top variant, 0.4 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying) along with mineral fertilizer.

In the other cases, these values were at the control level. The exception was the Celest Top option, 0.2 l/t + Beres-8, 0.2 l/t (treatment) + Beres-8, 0.2 l/ha (spraying).

In the Lina variety, the minimum development of rhizoctoniose at the seedling stage was observed when seed tubers were treated with the

composition Celest Top, 0.4 l/t + Relict, 0.01 l/t and when the plants were grown using mineral fertilizers (significantly 19.2% less compared to the control). Treating potato tubers with a mix of Celest Top (0.4 and 0.2 l/t) and Relict (0.01 l/t) significantly reduced plant infection with rhizoctoniose under natural fertility, as did using Celest Top alone and Celest Top (0.4 and 0.2 l/t) with Beres-8 (0.2 l/t) when mineral nutrition was optimized. In the first case, rhizoctoniose infection was 5.4–10.7% lower compared to the control, and in the second case, it was 4.5–8.9% lower.

Табл. 5. Влияние средств интенсификации на пораженность картофеля сорта Лина ризоктониозом (2022–2024 гг.), %

Table 5. Influence of the intensification agents on the infestation of the Lina potato variety with rhizoctoniose (2022–2024), %

Mineral nutri- tion level	Treatment option		Phase			Averages by factor		
	tubers	plants	full sprouts	budding	ripening	protection + mineral nutrition level	pro- tection	mineral nutrition level
<i>Progress of the disease</i>								
Natural fer- tility	CT 0,4 (control)	–	23,2	38,9	40,4	34,2	33,0	36,8
	CT 0,4 + B 0,2	B 0,2	20,3	48,9	49,2	39,5	36,7	
	CT 0,2 + B 0,2	»	25,7	49,3	58,6	44,5	40,7	
	CT 0,4 + R 0,01	R 0,2	12,5	43,5	44,4	33,5	28,6	
	CT 0,2 + R 0,01	»	17,8	37,9	41,0	32,2	32,5	
N ₄₀ P ₄₀ K ₈₀	CT 0,4	–	14,3	38,4	42,5	31,7		31,8
	CT 0,4 + B 0,2	B 0,2	16,3	33,4	51,9	33,9		
	CT 0,2 + B 0,2	»	18,7	34,2	57,8	36,9		
	CT 0,4 + R 0,01	R 0,2	4,0	31,5	35,7	23,7	–	
	CT 0,2 + R 0,01	»	25,9	33,8	38,9	32,9		
LSD _{0,5} (for quotient averages)			3,8	2,2	2,5			
LSD _{0,5} (by factors)						7,6	5,4	3,4
<i>Number of damaged stolons</i>								
Natural fer- tility	CT 0,4 (control)	–	7,0	13,0	23,5	14,5	12,0	11,6
	CT 0,4 + B 0,2	B 0,2	0,1	11,0	23,5	11,5	11,4	
	CT 0,2 + B 0,2	»	2,2	13,7	26,2	14,0	16,0	
	CT 0,4 + R 0,01	R 0,2	2,3	9,2	19,7	10,4	8,4	
	CT 0,2 + R 0,01	»	0	12,9	15,2	9,4	8,5	
N ₄₀ P ₄₀ K ₈₀	CT 0,4	–	1,6	8,7	18,5	9,6		10,8
	CT 0,4 + B 0,2	B 0,2	0,4	8,8	24,9	11,4		
	CT 0,2 + B 0,2	»	5,8	9,6	38,9	18,1	–	
	CT 0,4 + R 0,01	R 0,2	0	3,4	15,7	6,4		
	CT 0,2 + R 0,01	»	0	6,5	16,7	7,7		

At the budding stage with mineral fertilizer, all studied combinations of seed treatment with humic complexes significantly reduced stem disease development by 4.7–7.4%. Under natural fertility, in all protection options (except Celest Top, 0.2 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying)), there was a significant increase in plant disease incidence by 3.1–10.4%.

A significant reduction in disease development by 4.7% was observed only at the ripening stage with the Celest Top option, 0.4 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying) on the background of mineral fertilizer. In other cases, either there was a notable increase in disease incidence (4.4–18.2%), or the figures were at the control level.

Applying mineral fertilizer slightly reduced the damage to stolons from rhizoctoniose. The lowest stolon infection (3.5–3.6%) was achieved with two options: Celest Top, 0.4 and 0.2 L/t + Relict, 0.01 L/t (seed treatment) + Relict, 0.2 l/ha (spraying).

Analysis of the averages by the factors of protection and mineral nutrition showed that all studied options (except Celest Top, 0.2 l/t + Beres-8, 0.2 l/t (seed treatment) + Beres-8, 0.2 l/ha (spraying)) on both mineral nutrition backgrounds reduce stolon damage by the fungus *R. solani* by 0.5–8.1%. The lowest values were noted when optimizing mineral nutrition in the Celest Top options, 0.2 and 0.4 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying). In these options, disease development was 6.8–8.1% lower than the control.

A complete absence of rhizoctonia-damaged stolons at the sprouting stage was observed when seed tubers were treated with Celest Top (0.4 l/t) in combination with Relict (0.01 l/t) under natural fertility conditions, as well as in the options of Celest Top, 0.4 and 0.2 l/t + Relict, 0.01 l/t when mineral nutrition was optimized. A small number of damaged stolons (0.1–0.4%) were found when the tubers were treated with the Celest Top mixture, 0.4 l/t + Beres-8, 0.2 l/t on both mineral nutrition backgrounds. In the

other options, the development of rhizoctoniose was 1.2–5.4% lower than the control.

At the budding stage, the lowest infection of stolons by rhizoctoniose (15.2% and 15.7%) was observed under natural fertility with Celest Top, 0.2 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying), as well as with mineral fertilizer using Celest Top, 0.4 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying). Against the backdrop of natural fertility, in the Celest Top option, 0.4 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying), the infestation of stolons was 3.8% lower than in the control. When applying mineral fertilizer in the version with treatment of tubers with pure Celest Top at the full application rate, as well as in the version Celest Top, 0.2 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying), the incidence of rhizoctoniose was 5.0% and 6.8% lower compared to the control. In other cases, this indicator was either at the control level or exceeded it.

Ranking the obtained data showed that the least damage to the Lina potato variety from rhizoctoniose was achieved by growing the crop using mineral fertilizer ($N_{40}P_{40}K_{80}$) in the Celest Top variant, 0.4 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying). The sum of ranks in this case was the lowest among all protection options (see table 6).

Also, the “best” group of treatments included the Celest Top option, 0.2 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying). In this case, the treated tubers were planted with the use of mineral fertilizer.

Zlatka variety

Studies have shown that, on average, optimizing mineral nutrition significantly reduced stem damage by rhizoctoniose in Zlatka potatoes by 6.3% (see Table 7). The most effective protection against this disease was provided by pre-plant treatment of the tubers with a mixture of Celest Top at 0.4 l/t + Beres-8 at 0.2 l/t, combined with spraying the plants with Beres-8 at 0.2 l/ha. In this case, the development of rhizoctoniose was 4.5% lower than the control. In the other variants, this figure was 1.4–2.9%.

Табл. 6. Ранжирование исследуемых признаков (развитие ризоктониоза, количество пораженных столонов) для картофеля сорта Лина (2022–2024 гг.)

Table 6. Ranking of the studied characteristics (development of rhizoctoniose, the number of affected stolons) for the Lina potato variety (2022–2024)

Object's place	Mineral nutrition level	Treatment option		Sum of ranks
		tubers	plants	
“Best” objects				
1	N ₄₀ P ₄₀ K ₈₀	CT 0,4 + R 0,01	R 0,2	8,0
2	»	CT 0,2 + R 0,01	»	24,0
“Average” objects				
3	Natural fertility	CT 0,2 + R 0,01	R 0,2	30,0
4	N ₄₀ P ₄₀ K ₈₀	CT 0,4	–	32,0
5	»	CT 0,4 + B 0,2	B 0,2	38,0
6	Natural fertility	CT 0,4 + R 0,01	R 0,2	41,0
7	» »	CT 0,4 (control)	–	42,5
“Worst” objects				
8	Natural fertility	CT 0,4 + B 0,2	B 0,2	48,5
9	N ₄₀ P ₄₀ K ₈₀	CT 0,2 + B 0,2	»	51,0
10	Natural fertility	CT 0,2 + B 0,2	»	68,0

Analysis of the averages for the protection and mineral nutrition factors showed that for this variety, the development of the disease is significantly reduced by all the studied combinations of seed treatment and humic preparations when the crop is grown using mineral fertilizers. The reduction in stem infection by rhizoctoniose in these variants ranged from 4.6–9.6% compared to the control. Under natural soil fertility, only treating the tubers with a mixture of Celest Top, 0.4 l/t + Beres-8, 0.2 l/t, combined with spraying the plants during the growing season with Beres-8 at a rate of 0.2 l/ha, made it possible to noticeably (by 6.2%) reduce the intensity of the disease. In the other variants, the values of this indicator were at the control level.

At the sprouting stage, minimal rhizoctonia development was noted against the background of natural fertility when seed tubers were treated with the Celest Top composition, 0.4 l/t + Beres-8, 0.2 l/t, as well as when mineral fertilizers were applied to the crop and planting material was treated with a mixture of Celest Top, 0.4 l/t + Relict, 0.01 l/t. In these options, the rhizoctoniose infection was significantly lower than the control by 11.8% and 11.9%, respectively.

In the other options, with both types of mineral nutrition, all studied combinations of seed treatment with humic preparations also significantly reduced the disease development (by 4.3–10.6% compared to the control).

At the budding stage, against the background of mineral fertilizer, all the studied combinations of seed treatment with humic complexes significantly reduced the development of rhizoctoniose on the stems by 4.8–8.1% compared to the control. The lowest observed value was in the Celest Top variant, 0.2 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying). Against the background of natural fertility, only the Celest Top option, 0.4 l/t + Beres-8, 0.2 l/t (seed treatment) + Beres-8, 0.2 l/ha (spraying) contributed to a significant (by 5.1%) reduction in disease incidence in Zlatka variety plants. In the other options, the values of this indicator were at the control level.

At the ripening stage, only in the case of the Celest Top variant, 0.4 l/t + Beres-8, 0.2 l/t (seed treatment) + Beres-8, 0.2 l/ha (spraying) against the background of natural fertility, a significant reduction in disease development was observed (by 1.7%). In other cases, against this nutrient

Табл. 7. Влияние средств интенсификации на пораженность картофеля сорта Златка ризоктониозом (2022–2024 гг.), %

Table 7. Influence of the intensification agents on the infestation of the Zlatka potato variety with rhizoctoniose, % (2022–2024)

Mineral nutrition level	Treatment option		Phase			Averages by factor		
	tubers	plants	full sprouts	budding	ripening	protection + mineral nutrition level	protection	mineral nutrition level
<i>Progress of the disease</i>								
Natural fertility	CT 0,4 (control)	–	13,9	16,4	25,2	18,5	16,2	17,2
	CT 0,4 + B 0,2	B 0,2	2,1	11,3	23,5	12,3	12,0	
	CT 0,2 + B 0,2	»	5,1	18,8	27,9	17,3	14,0	
	CT 0,4 + R 0,01	R 0,2	9,6	24,3	26,6	20,2	14,8	
	CT 0,2 + R 0,01	»	8,7	16,7	27,7	17,7	13,3	
N ₄₀ P ₄₀ K ₈₀	CT 0,4	–	3,3	15,6	22,8	13,9	–	10,9
	CT 0,4 + B 0,2	B 0,2	4,6	10,4	20,3	11,8		
	CT 0,2 + B 0,2	»	5,4	11,6	15,2	10,7		
	CT 0,4 + R 0,01	R 0,2	2,0	11,1	15,4	9,5		
	CT 0,2 + R 0,01	»	5,4	8,3	12,9	8,9		
LSD _{0,5} (for quotient averages)			0,6	1,2	1,5			
LSD _{0,5} (by factors)						6,2	4,4	2,8
<i>Number of damaged stolons</i>								
Natural fertility	CT 0,4 (control)	–	0,8	6,2	20,0	9,0	7,4	7,9
	CT 0,4 + B 0,2	B 0,2	0	4,2	12,6	5,6	5,7	
	CT 0,2 + B 0,2	»	1,2	4,6	20,3	8,7	6,8	
	CT 0,4 + R 0,01	R 0,2	0	3,6	17,3	7,0	5,5	
	CT 0,2 + R 0,01	»	0	11,1	17,0	9,4	7,4	
N ₄₀ P ₄₀ K ₈₀	CT 0,4	–	0	5,4	12,1	5,8	–	5,2
	CT 0,4 + B 0,2	B 0,2	0	0,9	16,9	5,9		
	CT 0,2 + B 0,2	»	0	3,2	11,6	4,9		
	CT 0,4 + R 0,01	R 0,2	0	1,5	10,9	4,1		
	CT 0,2 + R 0,01	»	0	0,8	15,3	5,4		

background, there was either a reliable increase in disease incidence (by 2.5–2.7%) or the indicators were at the level of the control values. Optimizing mineral nutrition made it possible to significantly (by 2.4–12.3%) reduce stem infections by rhizoctoniose. The lowest level was observed in the Celest Top variant, 0.2 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying).

Adding mineral fertilizer helped reduce stolon damage from rhizoctoniose by an average of 2.7%. The lowest stolon damage was seen with the following treatments: Celest Top, 0.4 l/t + Beres-8, 0.2 l/t (seed treatment) + Beres-8, 0.2 l/ha (spraying); Celest Top, 0.4 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spray-

ing). In these treatments, the percentage of damaged stolons was 5.5–5.7% (1.7–1.9% less than the control).

Analysis of the averages for protection and mineral nutrition factors showed that all the tested options (except Celest Top, 0.2 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying)) reduce stolon damage by the fungus *R. solani* under both mineral nutrition backgrounds by 0.3–4.9% compared to the control. When optimizing mineral nutrition, the lowest values were observed in the options Celest Top, 0.2 l/t + Beres-8, 0.2 l/t (seed treatment) + Beres-8, 0.2 l/ha (foliar application), as well as Celest Top, 0.4 l/t + Relict, 0.01 l/t (seed treatment) +

Relict, 0.2 l/ha (foliar application). In these options, disease development was 4.1–4.9% lower than the control.

At the sprouting stage, there were no stolons damaged by rhizoctoniose in any of the experimental options (except for the Celest Top 0.4 l/t options, as well as Celest Top 0.2 l/t + Beres-8 0.2 l/ha, where this figure was insignificant – only 0.8–1.2%).

During the budding phase, the least damage to stolons by rhizoctoniose (0.8–0.9%) was observed on the optimized mineral nutrition background in the Celest Top, 0.4 l/t + Beres-8, 0.2 l/t (seed treatment) + Beres-8, 0.2 l/ha (spraying) and Celest Top, 0.2 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying) options. In other cases, on both mineral nutrition backgrounds, there was a decrease in the number of damaged stolons by 0.8–4.7% (except for the Celest Top option, 0.2 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying) without using fertilizer, where there were 4.9% more damaged stolons than in the control).

At the ripening stage, the lowest number of stolons affected by rhizoctoniose (7.4% less than in the control) was observed under natural fertility with the Celest Top variant, 0.4 l/t + Beres-8, 0.2 l/t (seed treatment) + Beres-8, 0.2 l/ha (spraying); with optimized mineral nutrition, the lowest infection was seen in the variants Celest Top, 0.4 l/t; Celest Top, 0.2 l/t + Beres-8, 0.2 l/t (seed treatment) + Beres-8, 0.2 l/ha (spraying) and Celest Top, 0.4 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying). In these cases, the number of stolons affected by rhizoctoniose was 7.9, 8.4, and 9.1% lower compared to the control. In the other options, this figure was either at the control level or 2.7–3.1% lower.

Ranking the results showed that the potato variety Zlatka had the least damage from rhizoctoniose when grown using mineral fertilizer ($N_{40}P_{40}K_{80}$) in the Celest Top 0.4 l/t + Relict 0.01 l/t (seed treatment) + Relict 0.2 l/ha (spraying) variant. The sum of ranks in this case was the lowest among all the protection options (see Table 8).

In addition, the “best objects” group included options like Celest Top, 0.2 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying), as well as Celest Top, 0.4 and 0.2 l/t + Beres-8, 0.2 l/t (seed treatment) + Beres-8, 0.2 l/ha (spraying). In all these cases, the treated tubers were planted with the use of mineral fertilizers.

It is worth noting the effective reduction of the pathological process of rhizoctoniose when using half the recommended dose of Celest Top in combination with humates, which allows for a decrease in pesticide load on the potato agrocenosis of the Lina and Zlatka varieties.

CONCLUSION

For the Yuna potato variety, the least damage to stems and stolons from rhizoctoniose was observed when growing the crop using mineral fertilizer and treating the planting material with the insect-fungicide Celest Top at a rate of 0.4 l/t.

Applying mineral fertilizer at a rate of $N_{40}P_{40}K_{80}$ during planting reduced the infection of this variety by rhizoctoniose by 7.6% compared to the control. Under natural fertility conditions, the development of the disease was reduced by 9.2% with the Celest Top option, 0.4 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying). When optimizing mineral nutrition with tuber treatment using Celest Top (0.4 l/t) alone and in the version Celest Top, 0.4 l/t + Beres-8, 0.2 l/t (treatment) + Beres-8, 0.2 l/ha (spraying), plant infection with rhizoctoniose decreased by 15.3–15.9% compared to the control. In the same context, in the version Celest Top, 0.2 l/t + Relict, 0.01 l/t (treatment) + Relict, 0.2 l/ha (spraying), it was possible to reduce the rate by 13.1%.

Adding mineral fertilizer helped reduce stolon damage in the Yuna potatoes by 2.1%. The lowest stolon damage (6.3–6.9%) was achieved with two options – Celest Top, 0.4 l/t, and Celest Top, 0.4 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying).

For the Lina potato variety, the least damage to stems and stolons from rhizoctoniose was observed when the crop was grown using mineral fertilizer ($N_{40}P_{40}K_{80}$) combined with Celest Top,

Табл. 8. Ранжирование исследуемых признаков (развитие ризоктониоза, количество пораженных столонов) для картофеля сорта Златка (2022–2024 гг.)

Table 8. Ranking of the studied characteristics (development of rhizoctoniose, the number of affected stolons) for the Zlatka potato variety (2022–2024)

Object's place	Mineral nutrition level	Treatment option		Sum of ranks
		tubers	plants	
“Best” objects				
1	N ₄₀ P ₄₀ K ₈₀	CT 0,4 + R 0,01	R 0,2	16,5
2	»	CT 0,2 + R 0,01	»	20,0
3	»	CT 0,2 + B 0,2	B 0,2	21,0
4	»	CT 0,4 + B 0,2	»	23,5
“Average” objects				
5	Natural fertility	CT 0,4 + B 0,2	B 0,2	26,5
6	N ₄₀ P ₄₀ K ₈₀	CT 0,4	–	29,5
“Worst” objects				
7	Natural fertility	CT 0,4 + R 0,01	R 0,2	48,5
8	» »	CT 0,2 + R 0,01	»	52,5
9	» »	CT 0,4 (control)	–	57,0
10	» »	CT 0,2 + B 0,2	B 0,2	59,0

0.4 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying).

Optimizing mineral nutrition reliably reduced the infection of this variety of plants with rhizoctoniose by 5%. The most effective protection turned out to be the Celest Top option, 0.4 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying). In this case, disease development decreased by 4.4% compared to the control.

In potato plantings of the Lina variety, a significant (by 10.5%) reduction in disease development was observed with the Celest Top treatment, 0.4 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying) combined with mineral fertilizer.

The lowest stolon infection was achieved with two options – Celest Top, 0.4 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying) and Celest Top, 0.2 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying). The number of infected stolons in these options was 3.5–3.6%.

For the Zlatka variety potatoes, the lowest damage to stems and stolons from rhizoctoniose

was recorded when grown using mineral fertilizer (N₄₀P₄₀K₈₀) combined with Celest Top, 0.4 l/t + Relict, 0.01 l/t (seed treatment) + Relict, 0.2 l/ha (spraying).

For the Zlatka variety, optimizing mineral nutrition reliably reduced stem infection by rhizoctoniose by 6.3% compared to the control. The most effective option was Celest Top, 0.4 l/t + Beres-8, 0.2 l/t (treatment) + Beres-8, 0.2 l/ha (spraying). In this case, disease development decreased by 4.5%.

For this variety, all studied combinations of seed treatment and humic preparations significantly reduced disease development (by 4.6–9.6%) when the crop was grown using mineral fertilizer. Among them, the Celest Top option stood out: 0.4 l/t + Beres-8, 0.2 l/t (seed treatment) + Beres-8, 0.2 l/ha (spraying). In this case, rhizoctoniose infection decreased by 5.9%.

Adding mineral fertilizer helped reduce stolon damage in Zlatka potatoes by 2.7%. The lowest stolon infestation was achieved with two options – Celest Top, 0.4 l/t + Beres-8, 0.2 l/t (treatment) + Beres-8, 0.2 l/ha (spraying) and

Celest Top, 0.4 l/t + Relict, 0.01 l/t (treatment) + Relict, 0.2 l/ha (spraying). In these options, the number of affected stolons was 5.5–5.7%, which is 1.7–1.9% less than the control.

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Эффективность способов защиты агроценоза технической конопли от сорных растений

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В статье представлены результаты исследования по оценке влияния агрохимических средств, применяемых для защиты посевов конопли от сорняков, на засоренность и хозяйственно полезные признаки культурных растений. Эксперимент проводили на территории Пензенской области в 2021–2024 гг. на технической конопле среднерусского экотипа сорта Надежда. Биологическая эффективность защитных мероприятий при опрыскивании гербицидами Лонтрел Гранд и Миура составила 59–77 и 54–86%. При совокупном действии всех изучаемых факторов данный показатель находился в пределах 64–89 и 77–98% соответственно. Обработка семян веществами, обладающими ростостимулирующими свойствами, позволила увеличить полевую всхожесть на 5–7%. Агрохимические средства, применяемые в различных вариантах защиты от сорняков, обеспечили повышение сохранности растений конопли к уборке на 10–16%. Ослабление конкуренции между культурными и сорными растениями оказывало достоверное положительное влияние на морфометрические показатели. Протравливание семян способствовало увеличению длины соцветия на 6–10%, листовая подкормка – на 3,7%. При этом опрыскивание по листу препаратом Изагри Вита вызвало увеличение диаметра стебля на 2,4%. Формирование высокой прибавки урожая стеблей (1,47 и 1,50 т/га) произошло благодаря гербицидной прополке изучаемыми препаратами на фоне обработок семенного материала (Артафит, АгроВерм Экран) и вегетирующих растений (Изагри Вита). Представленная схема защиты, включающая обработку семян и подкормку жидким комплексным удобрением по листу в зависимости от типа гербицида (против дву- или однодольных сорняков), обеспечила прибавку урожая семян конопли на 0,33–0,40 и 0,29–0,41 т/га.

Ключевые слова: конопля техническая, засоренность посевов, способы защиты, морфометрические показатели, урожайность

The effectiveness of the methods for protecting industrial hemp agrocenosis from weeds

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The article presents the results of research on the effect of agrochemical agents used in the crop hemp agrocenosis to protect against weeds on the contamination and economically useful signs of cultivated plants. The experiments were conducted in the Penza region on technical hemp of the Central Russian ecotype of the Nadezhda variety in 2021–2024. The biological effectiveness of protective measures when sprayed with Lontrel Grand and Miura herbicides was 59–77 and 54–86%. With the combined effect of all the factors studied, this indicator was within the range of 64–89 and 77–98%, respectively. Treating seeds with the substances that have growth-stimulating properties allowed for an increase in field germination by 5–7%. Agrochemicals used in various weed control methods have increased the survival rate of hemp plants by 10–16% by harvest time. The weakening of competition between cultivated and weed plant had a significant positive effect on morphometric parameters. Seed treatment contributed to an increase in the length of the inflorescence by 6–10%, leaf top dressing – by 3.7%. Moreover, spraying the leaves with Izagri Vita caused an increase in stem diameter by 2.4%. The formation of a high increase in the yield of stems (1.47 and 1.50 t/ha) occurred due to herbicide weeding with the studied preparations against the background of treatments of seed material (Artafit, AgroVerm Ekran) and vegetative plants (Izagri Vita). The presented protection scheme, which

includes seed treatment and fertilization with a liquid complex fertilizer per leaf, depending on the type of herbicide (against dicotyledonous or monocotyledonous weeds), provided an increase in seed yield of 0.33–0.40 and 0.29–0.41 t/ha.

Keywords: industrial hemp, weed infestation, protection methods, morphometric parameters, yield

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Conflict of interest

The authors declare no conflict of interest.

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INTRODUCTION

One of the main factors negatively affecting crop yields is weeds, which cause about 10–15% of global crop losses each year¹. In Russia, due to significant crop contamination, an average of 20 to 30% of the potential harvest is systematically lost, and the technological and sowing parameters of agricultural products are significantly reduced [1].

In crop fields, they compete with weeds for light, water, and nutrients. During these processes, there are changes in the ontogeny of both cultivated and weed plants. At the same time, cultivated plants are more susceptible to the effects of unfavorable factors. Their competitive ability is mainly influenced by their genotype and growing conditions. Weeds are characterized by greater resistance to stress factors^{2, 3} [2–6].

Distinctive features of technical hemp devel-

opment include uneven growth and a weak root system (8–13% of the plant's mass). It is known that cultivated plants grow fairly slowly during the initial phases of vegetation. This period is herbocritical for hemp⁴. It has been experimentally proven that for industrial hemp, seed yield losses due to weediness in the crops can reach from 32 to 64%, and stem losses – 43%. In addition, weediness in hemp fields is a cause of soil depletion, which can lead to reduced yields of subsequent crop rotations^{5, 6}.

Weeds affect the growth of crops at the beginning of their development and, as a result, the biomorphometric indicators of plants. Controlling weeds in the agroecosystem should be done before the start of interspecies competition between crops and weeds (for crops, this is the stage when the second pair of leaves appears) [7].

¹Gupta P. Pesticide Exposure-Indian Scene // *Toxicology*, 2004, vol. 198, pp. 83–90.

²Dmitriev N.N., Solodun V.I., Sultanov F.S. Innovative technologies in agriculture and crop production in the Irkutsk region: scientific and practical recommendations. Irkutsk: Irkutsk State Agrarian University, 2021. 216 p.

³Wilson J., Steel J., Steel S.-L. Do plants ever compete for space? // *Folia Geobot*, 2007, N 42, pp. 431–436.

⁴Taranukho V.G., Kamasin S.S., Pugach A.A. Plant growing. Spinning crops: a teaching aid. Gorki: BGSKhA, 2020, 51 p.

⁵Galieva G.R., Korepanova E.V., Goreeva V.N. Weed infestation of Central Russian monoecious hemp crops at different seedling rates in fiber cultivation technology // Century-old plant growing: Proc. of the All-Russian scientific and practical conference dedicated to the 100th anniversary of the Department of Plant Growing. Perm: Udmurt State Agrarian University, 2023, pp. 45–50.

⁶Rostovtsev R.A., Ushchapovsky I.V., Novikov E.V. Actual problems of production and primary processing of industrial hemp // State and prospects of development of the agro-industrial complex: collection of scientific papers of the XII International scientific and practical conference within the framework of the XXII Agro-industrial Forum of the South of Russia and the Interagromash exhibition. Rostov on Don, 2019, pp. 421–424.

Using certain agricultural techniques helps reduce weediness in hemp crops. However, the most effective way to protect against weeds is still using herbicides⁷ [8–10].

Improving the competitiveness of crops against weeds is made possible by enhancing plant growth and development through the use of stimulative agents and chelated fertilizers.

So, over the past decade, the use of various types of growth biostimulants has increased significantly, which can boost crop productivity, improve harvest quality, and increase resistance to biotic and abiotic stresses⁸ [11–14].

Using special types of agrochemicals as seed treatments and foliar fertilizers allows you to fully tap into the potential of modern crop varieties. Thanks to their content of macro- and microelements combined with amino acids, these products positively affect plant development throughout the entire growth period, increasing their yield and the quality of agricultural produce⁹ [15].

So, to improve the effectiveness of technological methods for protecting hemp crops from weeds, it's relevant to study the impact of biostimulants (as foliar feeding) and agrochemicals (for seed treatment) on hemp plants and their competitiveness against weeds when herbicides are used.

The goal of the study is to justify the effectiveness of using herbicides combined with modern farming techniques involving various types of growth-stimulating drugs and agrochemicals, as well as to assess their impact on crop weediness, morphometric indicators, and the yield of industrial hemp.

MATERIAL AND METHODS

The study was conducted from 2021 to 2024 at the Penza Research Institute of Agriculture on

crops of industrial hemp of the Central Russian ecotype, Nadezhda variety. The experiment, designed as a three-factor experiment, included assessing crop weediness, the biological effectiveness of protective measures, as well as analyzing seed germination, plant survival up to harvest, and their morphometric traits depending on the factors studied. For seed treatment, they used products that stimulate growth processes and increase plant resistance to adverse environmental factors: Artafit, AgroVerm Ekran, Lignogumat (factor A). Herbicide protection was provided by Lontrel Grand and Miura (factor B). Foliar feeding was done using the liquid complex fertilizer Izagri Vita (factor C) (see Table 1).

The experimental design included two controls: 1 – seed treatment with water; 2 – plants without treatment with agrochemicals and herbicides. The data were compared with the control for the factor being analyzed and with the control without any agrochemicals or herbicides (absolute control).

The working fluid rate when treating seeds was 10 liters per ton, and when spraying the test plots – 200 liters per hectare.

The agrochemical composition of the soil is represented by heavy loamy medium-thick leached chernozem ($\text{pH}_{\text{salt}} = 5,4$). The humus content in the soil is 5.6% (according to Tyurin), easily hydrolyzable nitrogen – 130.0 mg/kg of soil, available phosphorus – 172.0 mg/kg, exchangeable potassium – 201.4 mg/kg.

The setup of the field experiment and record-keeping were carried out according to the methodological guidelines for conducting field and vegetation experiments with hemp, conducting registration tests of herbicides, and based on

⁷Kulikova N.A., Lebedeva G.F. Herbicides and environmental aspects of their use: a textbook for university students. Moscow, 2010, 152 p.

⁸Nikolaev A.V., Apaeva N.N. The effect of herbicide mixed with growth stimulants on weed infestation of barley crops // Current issues of improving the technology of production and processing of agricultural products: materials of the international. scientific and practical. conf., Yoshkar-Ola, 2023, vol. 25, pp. 14–18.

⁹Sazhina K.A. General aspects of choosing the type of fertilizer for cultivating industrial hemp // Achievements and prospects of scientific and innovative development of the agro-industrial complex: collection of articles based on the materials of the V All-Russian (national) scientific and practical conference. Kurgan, 2024, pp. 21–24.

Табл. 1. Применявшиеся препараты

Table 1. The preparations used

Brand name, dosage form, manufacturer	Consumption rate	Active ingredients
Artafit, WSC (water-soluble concentrate), ООО NPIC BioGradis, Russia	0,15 kg/t	Polydiallyldimethylammonium chloride (100 g/l)
AgroVerm Ekran, AS (aqueous suspension), BioEraGroup, Russia	1,0 l/t	Live cells, spores and metabolite complex of <i>Bacillus subtilis</i> (2×10^9 CFU/ml)
Lignogumat, A (powder), ООО "NPO "Implementation of Environmental Technologies", Russia	0,12 kg/t	Fulvic (29%) and humic (58%) acids
Lontrel Grand, WDG (water-dispersible granules), Dow AgroSciences, Austria	0,08 kg/ha	Clopyralid (750 g/kg)
Miura, EC (emulsion concentrate), August JSC, Russia	0,8 l/ha	Chisalofof-P-ethyl (125 g/l)
Izagri Vita, concentrated solution, IZAGRI, Russia	1,0 l/ha	A complex of amino acids, macro- and microelements

B.A. Dospekhov's field experiment methodology^{10, 11}.

The weather conditions during the growing periods while the experiment was conducted were not favorable for crop growth. The hydrothermal coefficient (HTC) for the entire hemp development period corresponded either to insufficient moisture (2021 – 0.97; 2023 – 0.85; 2024 – 0.76) or weak moisture (2022 – 0.39).

The treatment of plots with herbicides at the three-leaf stage in 2021 and 2023 was done under dry conditions (HTC for the period between sprouting and the appearance of three leaf pairs was 0.13 and 0.26, respectively), in 2024 – with insufficient moisture (HTC = 0.50). More favorable conditions for hemp plant growth occurred in 2022 (HTC = 0.80).

The interphase period from the appearance of three pairs of leaves to budding in 2021–2023 was not wet enough for the crop to grow (HTC = 0.53–0.74). In 2024, the HTC was higher (0.79), but there was still a lack of moisture.

At the beginning of the interphase period from budding to flowering, we did a foliar feeding of the plants. During the years of the study, the moisture level at that time varied: in 2021 it

was optimal (HTC = 1.09), in 2022 and 2024 it was insufficient (HTC = 0.72 and 0.74), and in 2023 it was excessive (HTC = 2.44).

The interphase period of flowering to seed ripening in 2021 was characterized as optimally humid (HTC = 1.11), in 2022 – dry (HTC = 0.16), and in 2023 and 2024 – insufficiently humid (HTC = 0.55 and 0.80).

Weather conditions affected the species composition of weeds, the level of infestation in the agroценоз, the implementation of protective measures, and the morphogenesis of cultivated plants.

RESULTS AND DISCUSSION

During the survey of weed vegetation in experimental fields of industrial hemp, it was found that in terms of numbers, cereals are in the first place (35.9%), represented by yellow fox-tail (*Setaria glauca* (L.) Beauv.) and barnyard grass (*Echinochloa crusgall* (L.) Beauv.) from the Poaceae family. Among the dicotyledonous weeds, species such as lamb's-quarters (*Chenopodium album* L.) and many-seeded goosefoot (*Chenopodium polyspermum* L.) from the Chenopodiaceae family (on average 13.8%), as well

¹⁰Bedak G.R. Methodological guidelines for conducting field and vegetation experiments with hemp. Moscow: VASKhNIL, 1980, 34 p.

¹¹Dospekhov B.A. Methodology of field experiment (with the basics of statistical processing of research results). Moscow: Alliance, 2014, 349 p.

as redroot amaranth (*Amaranthus retroflexus* L.) from the amaranth family (9,9%) predominated, which significantly exceeded the parameters of representatives of other families (see Fig. 1).

Among the weed community (the group of weed plants in a field of industrial hemp), the most dangerous was the Canada thistle (*Cirsium arvense* L.), field sow thistle (*Sonchus arvensis* L.), corn bindweed (*Convolvulus arvensis* L.), as well as wintering species – narrowleaf hawk's beard (*Crepis tectorum* L.), field pansy (*Viola arvensis* Murr.), field pennycress (*Thlaspi arvense* L.), German camomile (*Tripleurospermum inodorum* (L.) Sch. Bip.).

In the hemp agrocenosis, at different levels of weed infestation, the constant component was the pigweed species described above: red-root amaranth, wild buckwheat, curltop ladyfly, hedgenettle betony, drug fumitory. In the early growth stages of the crop, if the cultivation technology is disrupted, redroot amaranth and lamb's-quarters can significantly reduce the competitiveness of hemp plants.

During the weed assessment carried out 30 days after spraying with the herbicide Lontrel Grand, a fairly high effectiveness of the protective measure was observed – 76.5% (see Fig. 2). With herbicide protection in place, using growth stimulants Artafit, AgroVerm Ekran, Lignogumat as seed treatments, and the agrochemical

Izagri Vita for foliar feeding increased the biological effectiveness of protective measures to 82.3%, 88.5%, and 86.2%, respectively.

The effectiveness of protecting crops from grass weeds 30 days after applying the herbicide Miura was 86.3%, and when this product was combined with growth stimulants and agrochemicals, it increased to 91–98%. At the same time, the biological efficiency of weed suppression by the end of the growing season in these cases ranged from 93.9–95.0%, compared to 54.1% when only the grass herbicide was used.

The analysis of field germination and the survival of hemp plants showed that the weather conditions and the chemicals used affected the indicators in question (see Fig. 3).

Over the years of the experiment, using drugs that stimulate growth processes allowed field seed germination to increase from 4.9% (Artafit) to 6.5% (Lignogumat). The greatest effect (78.8%) was achieved when using the Lignogumat seed treatment combined with spraying plants with the herbicide Lontrel Grand and the liquid fertilizer Izagri Vita.

Before harvesting, an increase in plant survival was noted in the treatments using herbicides by 2.1% and 4.4% compared to the control.

Reducing the weediness of the agrocenosis helped create better conditions for the growth and development of hemp. The highest plant

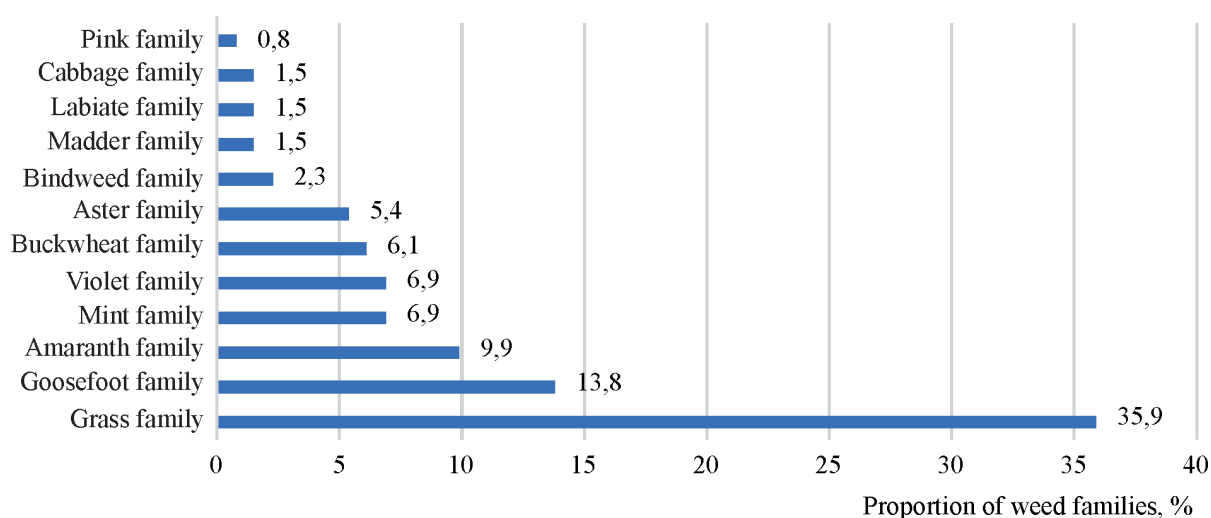


Рис. 1. Сорный компонент посевов конопли (2021–2024 гг.)

Fig. 1. Weed component of hemp crops (2021–2024)

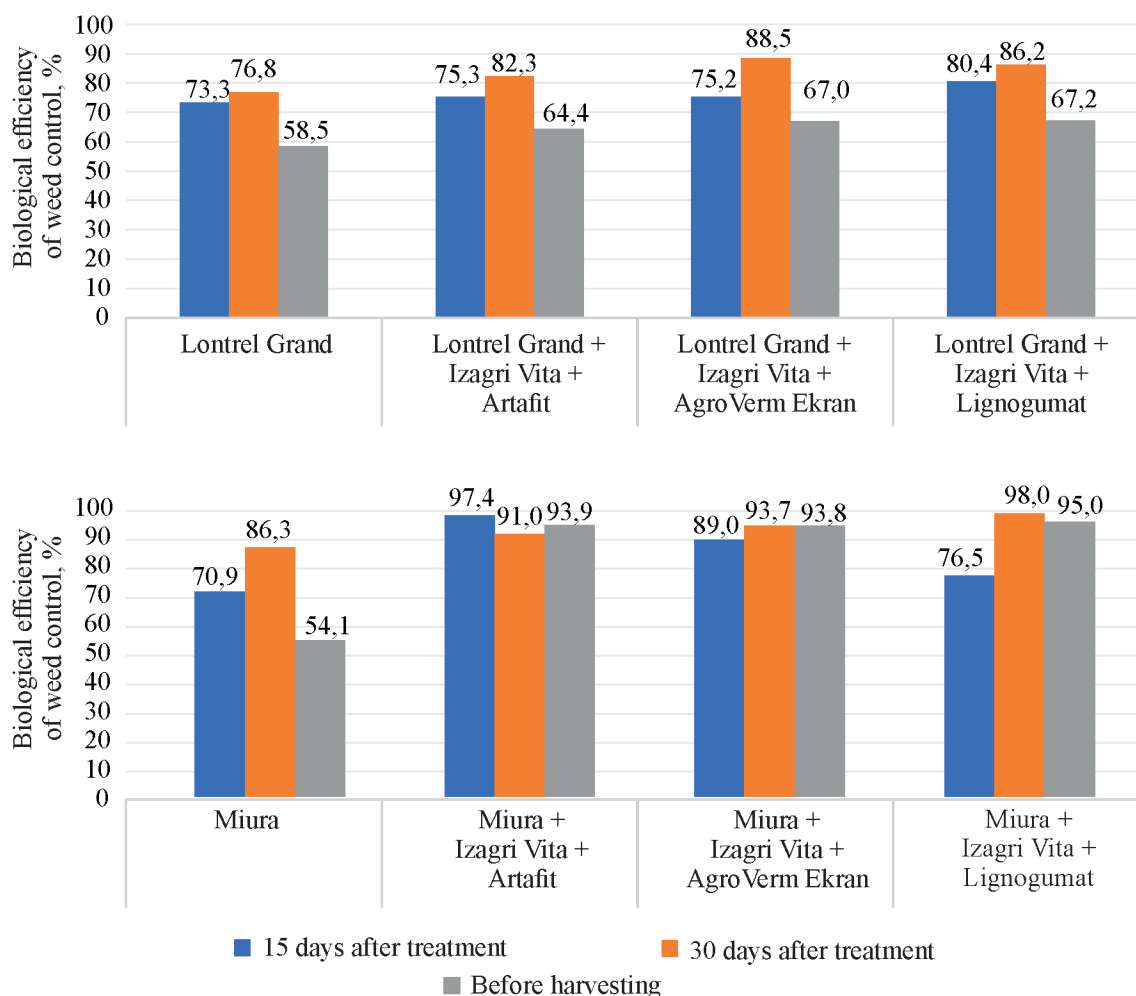


Рис. 2. Влияние агрохимических средств на засоренность посевов конопли (2021–2024 гг.)

Fig. 2. The effect of agrochemicals on the contamination of hemp crops (2021–2024)

survival until harvesting was promoted by treatment with Lignogumat and the herbicide Miura (90.6%).

Using herbicides together with various types of stimulating substances when treating seeds, as well as using the agrochemical as a feed during vegetation, affected the quantitative characteristics of cannabis plants, except for the number of internodes (see Table 2).

Seed treatment contributed to an increase compared to the control in overall plant height by 3.2% (Artafit), inflorescence length by 10.3% (Artafit), 5.5% (AgroVerm Ekran), and 8.3% (Lignogumat), and internode length by 1.7% (Artafit). Herbicide treatment increased the technical stem length by 1.1% (Miura), while foliar feeding stimulated growth of the technical length by 1.4%, inflorescence length by 3.7%,

and stem diameter by 2.4%. The best option for boosting the morphometric parameters of hemp plants was a protection method that included the combined use of Artafit, Lontrel Grand, and Izagri Vita.

The factors we studied had less effect on the plants' morphometric traits than on their yield.

As a result of the correlation analysis, moderate negative correlations were found between the protection variants 30 days after treatment with the herbicide Lontrel Grand and both crop weediness and seed and stem yields (-0.554 ± 0.18 and -0.621 ± 0.17 , respectively), as well as a negative correlation between crop weediness after treatment with the herbicide Miura and seed yield (-0.568 ± 0.18).

In the control version, stem yield was 5.64 t/ha (see Fig. 4). The increase in stem yield com-

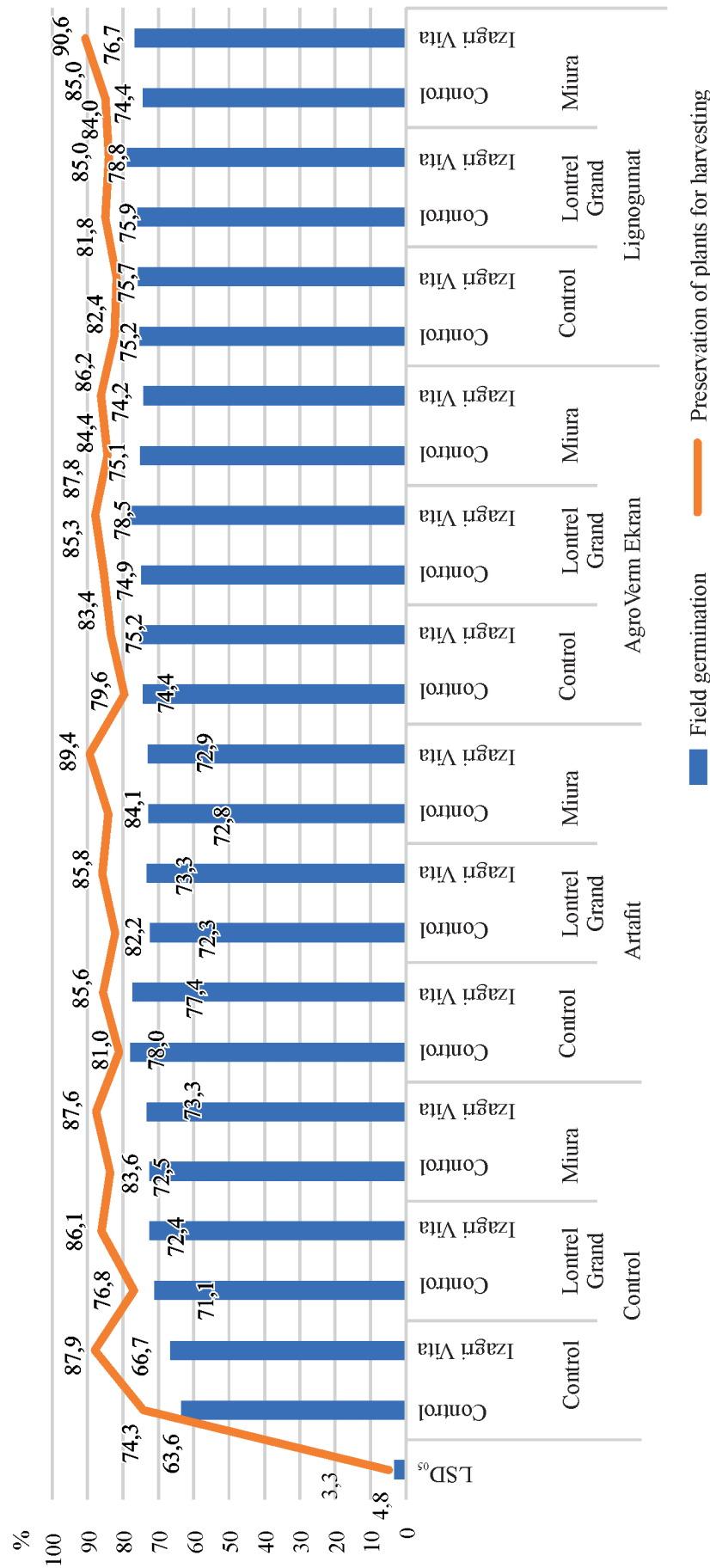


Рис. 3. Влияние способов защиты на полевую всхожесть и сохранность растений конопли (2021–2024 гг.)
Fig. 3. The influence of protection methods on field germination and survival of hemp plants (2021–2024)

Табл. 2. Влияние способов защиты на морфометрические показатели растений конопля (2021–2024 гг.)
Table 2. The influence of protection methods on the morphometric parameters of hemp plants (2021–2024)

Option			Plant height, cm	Technical length of stem, cm	Inflorescence length, cm	Stem diameter, mm	Internode length, cm	Number of internodes, pcs.
Factor A	Factor B	Factor C						
Control	Control	Control	219,5	173,3	54,3	7,9	16,7	10
		Treatment	222,3	183,8	57,1	8,2	17,2	11
	Lontrel Grand	Control	223,6	178,3	51,9	8,0	17,1	11
		Treatment	232,1	186,0	55,0	8,3	17,4	11
	Miura	Control	229,2	186,0	52,2	8,3	17,7	10
		Treatment	228,0	186,8	56,7	8,3	17,6	10
Artafit	Control	Control	234,3	181,3	54,5	8,3	17,5	10
		Treatment	235,3	182,8	63,0	8,7	17,3	10
	Lontrel Grand	Control	229,4	187,0	55,7	8,3	17,8	10
		Treatment	238,3	187,8	63,1	8,9	17,8	10
	Miura	Control	232,9	178,0	61,6	8,6	17,5	10
		Treatment	228,5	180,0	62,6	8,6	17,5	10
AgroVerm Ekran	Control	Control	235,4	185,3	59,6	8,6	17,3	10
		Treatment	230,4	184,3	56,6	8,5	17,4	10
	Lontrel Grand	Control	229,8	183,8	59,5	8,4	17,2	10
		Treatment	230,0	186,0	57,9	8,6	17,4	10
	Miura	Control	226,9	182,3	53,9	8,1	17,0	10
		Treatment	224,4	180,0	56,9	8,1	17,7	10
Lignogumat	Control	Control	225,7	181,3	58,5	8,0	16,9	11
		Treatment	227,8	185,8	55,3	8,1	17,6	10
	Lontrel Grand	Control	226,2	181,0	60,7	8,2	17,5	10
		Treatment	227,1	183,8	60,0	8,5	17,0	11
	Miura	Control	223,0	177,8	57,9	8,1	17	10
		Treatment	231,3	178,8	61,4	8,4	17,4	10
LSD _{0,5} to compare the quatuents			9,4	5,5	5,7	0,29	0,55	NS*

*NS – the differences are insignificant at $p = 0,05$.

pared to the control was promoted by the action of all the factors studied: factor A – an increase of 4.1% (Artafit), 7.2% (AgroVerm Ekran), and 2.9% (Lignogumat); factor B – by 8.1% (Lontrel Grand) and 7.1% (Miura); factor C – by 3.9%. The formation of a high yield increase compared to the control without the use of agrochemical products was facilitated by herbicidal weeding with Lontrel Grand and Miura combined with seed treatment with Artafit and AgroVerm Ekran, respectively, and treatment of growing plants with Izagri Vita (1.47 and 1.50 t/ha, or 26.1% and 26.6%).

Seed yield was around 1.52 t/ha. The increase in this parameter compared to the control was achieved thanks to the effect of seed treatments (3.5–4.0%), herbicides (3.5 and 7.0%), and foliar feeding (5.8%). Over the years of research, high increases in seed yields compared to the control without the use of agrochemicals have been achieved by controlling the growth of broadleaf weeds with the herbicide Lontrel Grand (0.33–0.40 t/ha, or 21.7–26.3%) and grasses with the herbicide Miura (0.29–0.41 t/ha, or 19.1–27.0%) against the backdrop of using various stimulants as seed treatments and agrochemicals as foliar fertilizers.

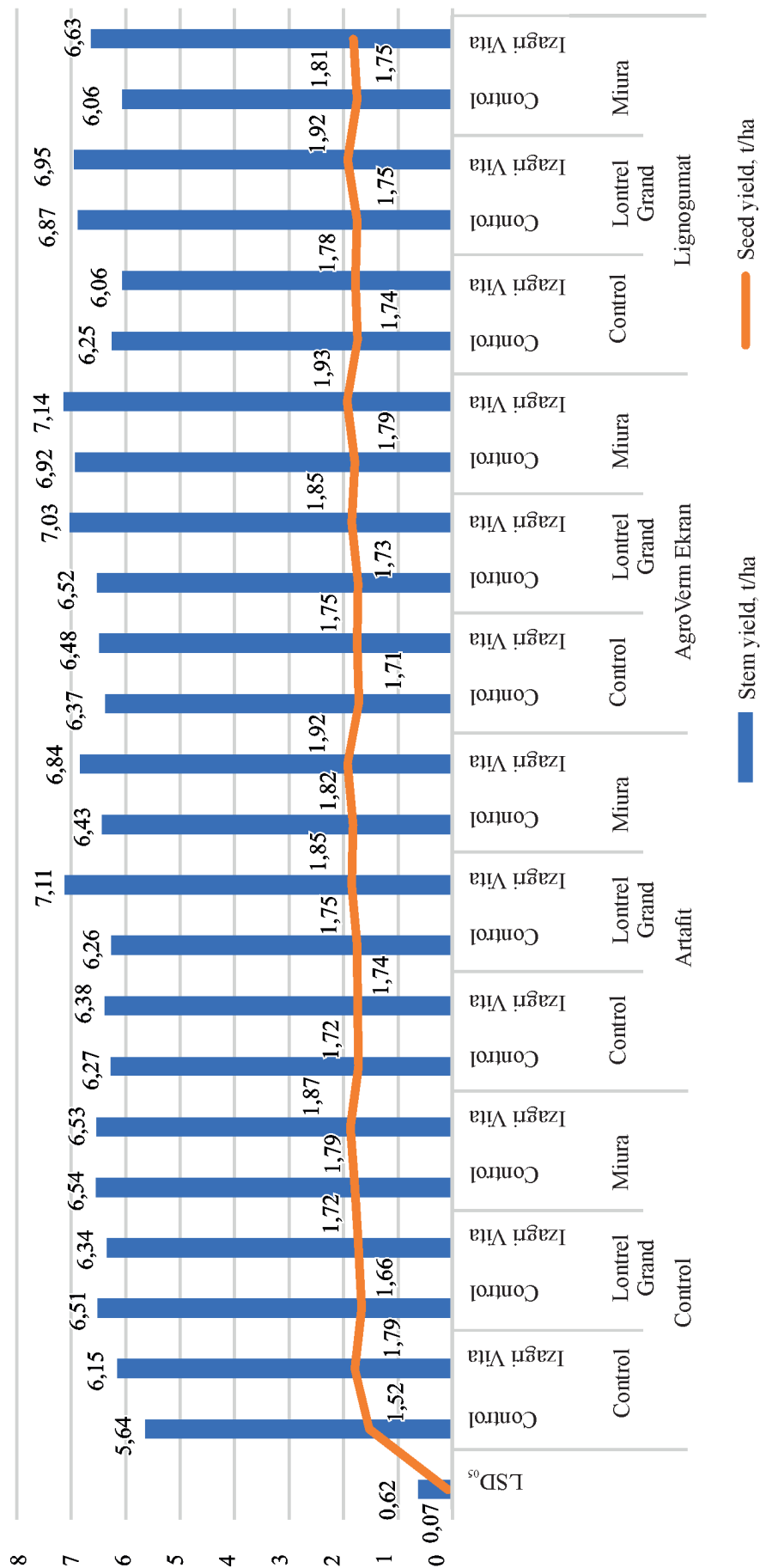


Рис. 4. Влияние способов защиты на урожайность конопли (2021–2024 гг.)
Fig. 4. The influence of protection methods on hemp yield (2021–2024)

CONCLUSIONS

1. Using herbicides in industrial hemp crops to suppress weeds, combined with modern agricultural techniques, the use of various types of stimulants, and agrochemicals, allows the crop to stay competitive against weeds.

2. The reduction in weediness of hemp crops compared to the control when spraying only with the herbicides Lontrel Grand and Miura was 59–77% and 54–86%, respectively, while with the combined effect of all studied factors, this figure decreased by 64–89% and 77–98%.

3. Reducing competition between hemp plants and weeds led to higher field emergence of seeds and better survival of crops until harvest, as well as positively affecting their morphological traits.

4. The protective measures carried out helped increase stem yields significantly with herbicide weedings using Lontrel Grand and Miura in combination with seed treatments using Artafit and AgroVerm Ekran, and for growing plants – with Izagri Vita (+1.47 and 1.50 t/ha). The preserved seed yield in the Lontrel Grand herbicide variants combined with seed treatments and agrochemical was 0.33–0.40 t/ha, while in the Miura herbicide variants with the mentioned agro-technical measures, it was 0.29–0.41 t/ha.

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Оценка продуктивных качеств комбикорма производства ООО «БИФФ» для гибрида «РуКал» осетровых рыб

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В статье представлены результаты комплексной оценки влияния экспериментального комбикорма производства ООО «БИФФ» на продуктивные качества и физиолого-биохимический статус перспективного объекта аквакультуры – гибрида русского осетра (*Acipenser gueldenstaedtii*) и ленского осетра (*Acipenser baerii*), известного как «РуКал». Исследование проводили в контролируемых условиях установки замкнутого водоснабжения в течение 56 сут. Цель работы – проанализировать эффективность влияния опытного корма на ростовые показатели, выживаемость и ключевые параметры крови, отражающие общее физиологическое состояние рыб. Результаты эксперимента продемонстрировали высокую продуктивность и отличную адаптацию гибрида к предлагаемому рациону. Абсолютный прирост массы за период опыта составил 106,17 г, а среднесуточный прирост достиг 1,90 г/сут. Зафиксирована 100%-я выживаемость, коэффициент упитанности по Фультону достоверно увеличился. Гематологический анализ выявил положительную динамику: уровень гемоглобина повысился на 9,7%, что указывает на усиление кислородтранспортной функции крови, а концентрация общего белка в сыворотке возросла до 28,15 г/л, что свидетельствует об активизации пластического обмена. При этом показатели углеводного и липидного обмена (глюкоза и холестерин) оставались стабильными и соответствовали физиологической норме для осетровых рыб. Таким образом, комбикорм ООО «БИФФ» показал высокую эффективность, обеспечивая интенсивный рост, высокую выживаемость и формирование оптимального физиолого-биохимического статуса у гибрида «РуКал» в условиях установки замкнутого водоснабжения. Полученные данные обосновывают перспективность применения данного корма в практике товарного осетроводства для повышения его экономической эффективности.

Ключевые слова: кормление, осетровые, гибрид, комбикорм, продуктивность, рост, физиолого-биохимические показатели крови, установка замкнутого водоснабжения

Evaluation of the productive qualities of compound feed produced by the OOO "BIFF" for the "RuKal" hybrid sturgeon fish

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The article presents the results of a comprehensive assessment of the impact of experimental compound feed produced by OOO "BIFF" on the productive qualities and physiological and biochemical status of a promising aquaculture facility – Russian sturgeon hybrid (*Acipenser gueldenstaedtii*) and

Lena sturgeon (*Acipenser baerii*), known as "RuKal". The study was conducted under controlled conditions of a recirculating aquaculture system for 56 days. The purpose of the work was to analyze the effectiveness of the experimental feed on growth rates, survival, and key blood parameters reflecting the general physiological state of the fish. The results of the experiment demonstrated high productivity and excellent adaptation of the hybrid to the proposed diet. The absolute weight gain during the experiment period was 106.17 g, and the average daily gain reached 1.90 g/day. A 100% survival rate was recorded, and the Fulton fatness ratio increased significantly. Hematological analysis revealed positive dynamics: hemoglobin level increased by 9.7%, which indicates an increase in the oxygen transport function of the blood, and the concentration of total protein in the serum increased to 28.15 g/l, which indicates the activation of plastic metabolism. At the same time, the parameters of carbohydrate and lipid metabolism (glucose and cholesterol) remained stable and corresponded to the physiological norm for sturgeon fish. Thus, the ООО "BIF" compound feed has shown high efficiency, providing intensive growth, high survival rate and the formation of optimal physiological and biochemical status in the "RuKal" hybrid in the conditions of ultrasound. The data obtained substantiate the prospects of using this feed in the practice of commercial sturgeon breeding to increase its economic efficiency.

Keywords: feeding, sturgeon, hybrid, compound feed, productivity, growth, physiological and biochemical parameters of blood, installation of a closed water supply

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Conflict of interest

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INTRODUCTION

Fish products remain one of the main sources of complete protein and biologically active substances in the human diet [1–3]. The sturgeon family (Acipenseridae), which includes species like beluga, Russian sturgeon, Siberian sturgeon, kaluga, and others, has traditionally been valued for the high taste quality of their meat and caviar. However, natural populations of most sturgeon species are in a sorry state, making the development of their commercial cultivation in aquaculture an important task [4, 5].

The dynamic growth of global aquaculture requires the adoption of intensive technologies, among which year-round industrial fish farming

in recirculating systems plays a leading role [6, 7]. Another promising direction is interspecies hybridization, which allows combining valuable commercial traits of the parent forms (growth rate, disease resistance, and adaptive potential) [8–10]. The key factor in the economic efficiency of aquaculture is optimizing feeding [11–13]. Developing and implementing new feed formulations that ensure high productivity while reducing costs is a relevant scientific and practical challenge [14–17].

The aim of the study is to examine the effect of the experimental compound feed produced by the ООО "BIF" on the growth, survival, and physiological condition of the Russian sturgeon

(*Acipenser gueldenstaedtii*) × Siberian sturgeon (*Acipenser baerii*) hybrid ("RuKal"), as well as to analyze the efficiency of commercial cultivation of the hybrid under recirculating water system conditions.

MATERIAL AND METHODS

The experimental work was carried out at the Innovation Center "BioAquapark – Aquaculture R&D Center" and in the research laboratory "Sturgeon breeding and promising aquaculture facilities" at the Astrakhan State Technical University. The study focused on the "RuKal" yearlings (see Fig. 1).

During the experiment, fish were kept in ICA-1 fiberglass tanks with rounded edges, measuring 1×1×0.8 m, with a constant flow, forced aeration, and filtration (see Fig. 2).

Throughout the entire research period, the main hydrochemical indicators, as well as the water temperature and flow rate, were kept at the levels optimal for fish life. The fish were raised at a constant water temperature of 20–22 °C. The dissolved oxygen content was maintained at 8–10 mg/l (80–90% saturation). The hydrochemical conditions complied with OST 15.372-871¹.

The feed was provided by the OOO "BIFF" for evaluating its quality and safety. The young fish were raised at the same stocking density and according to the species' biological characteris-

tics, following daily norms and feed tables [9].

Fish farming and biological indicators were evaluated based on a set of indicators (taking into account I.F. Pravdin's recommendations) and were determined using the following formulas^{2, 3}:

absolute gain ($P_{аб}$) = $m_k - m_0$;

Fulton's condition factor

$$(Q_{\phi}) = (W \times 100) / L^3;$$

mass accumulation coefficient

$$(K_M) = ((m_k^{1/3} - m_0^{1/3}) \times 3) / t;$$

average daily gain

$$(P_{cp.cyr}) = (m_k - m_0) / t;$$

average daily growth rate

$$(A) = [(m_k / m_0)^{1/t} - 1] \times 100\%;$$

specific growth rate

$$\frac{\log(m_k) - \log(m_0)}{t} \times 100,$$

where m_k and m_0 – final and initial fish mass (g), L – absolute fish length (cm), t – research duration (days).

Fish survival was measured individually. A range of physiological and biochemical blood parameters was determined to compare feed efficiency. Heparin was used as an anticoagulant for hematological analysis. The concentration of hemoglobin in the blood was determined photometrically⁴ using a reagent kit from Agat-Med (Russia), the erythrocyte sedimentation rate

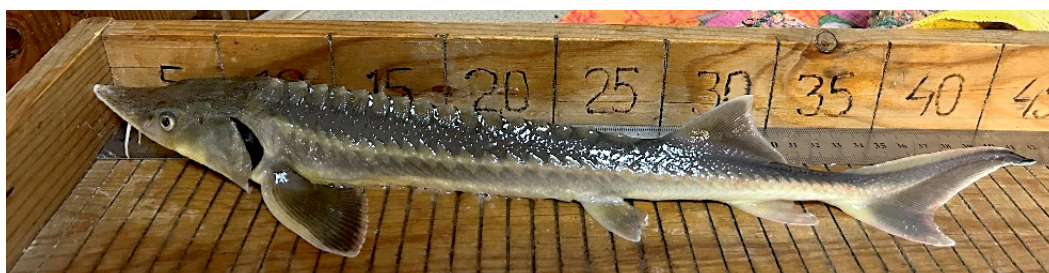


Рис. 1. Объект исследования

Fig. 1. Object of research

¹Water for fishery reservoirs. General requirements and standards. – Introduced on 01.01.88. Moscow: USSR Ministry of Fisheries, 1987, 12 p.

²Vinberg G.G. Metabolic intensity and food needs of fish. Minsk: Belarusian University, 1956, 253 p.

³Kupinsky S.V. Rainbow trout – preliminary parameters of the standard model of mass accumulation / S.V. Kupinsky, S.A. Baranov, V.F. Reznikov // Collection of scientific papers: Industrial fish farming in closed systems. Moscow: VNIIPRKh, 1985, Issue 46, pp. 109–115.

⁴Van Kampen E.J. Standardization of hemoglobinometry. The hemiglobincyanide method / E.J. Van Kampen, W.G. Zijlstra // Clin. Chim. Acta, 1961, pp. 538.

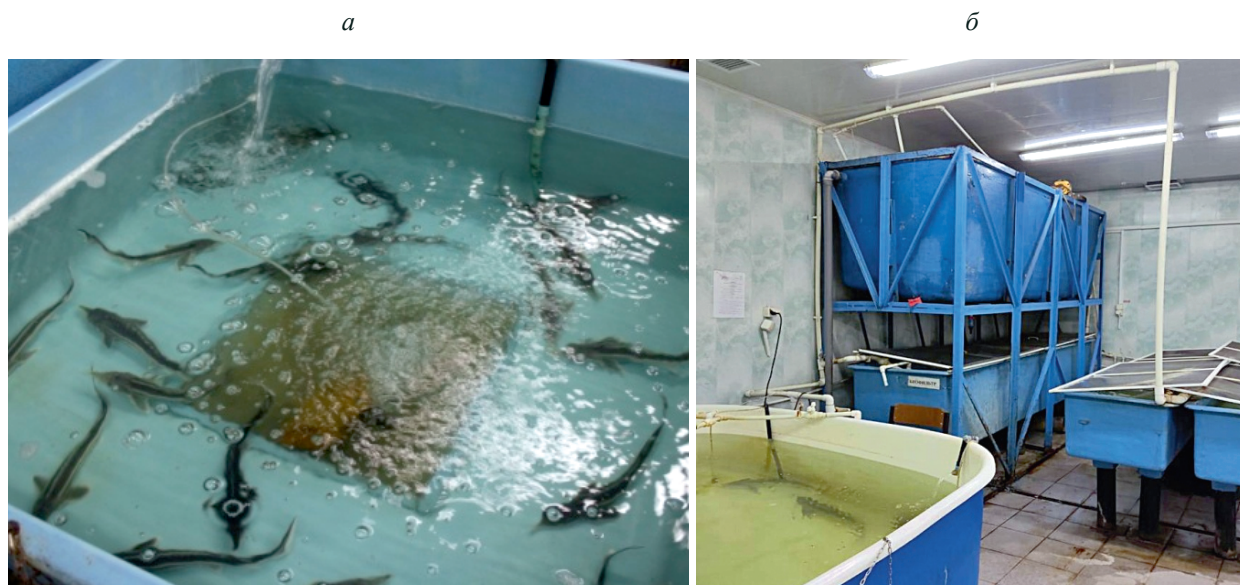


Рис. 2. ИЦ «Биоаквапарк – НТЦ аквакультуры»:

а) бассейн (1×1 м) для подращивания молоди; б) установка замкнутого водоснабжения

Fig. 2. IC "Bioaquapark – RDC of aquaculture":

а) swimming pool (1×1 m) for rearing juveniles; б) recirculating aquaculture system

(ESR) was determined using the method of G.I. Panchenkov⁵.

Blood samples were collected in heparin-free tubes and allowed to coagulate to obtain serum. Serum protein levels were determined in the laboratory using the biuret method⁶ using reagents from the company "Agat-med".

The level of cholesterol, which plays an important role in the immune system and is involved in plastic and energy metabolism, was determined by an enzymatic method⁷. Glucose levels were determined using an enzymatic colorimetric method⁸ without deproteinization. In both cases, reagents from the company "Olvex Diagnosticum" were used.

To determine the concentration of solutions during physiological and biochemical blood analysis, a UNICO 2100 spectrophotometer was used.

The obtained data were statistically processed using the Excel software package, including calculation of the mean, error of the mean, and assessment of the level of significance of differences using Student's *t*-test.

RESULTS AND DISCUSSION

A pilot batch of feed from the ООО "БИФФ" demonstrated high protein and fat content. The composition met the physiological needs of sturgeon and the requirements of nutritional standards and other technological parameters (see Fig. 3). The fish were noted to consume the feed well.

The fish's condition was monitored visually throughout the entire rearing period. No signs of hyperemia were recorded.

A fish-farming and biological assessment of the "RuKal" hybrid at two consecutive stages of

⁵Limansky V.V. Instructions for physiological and biochemical analysis of fish / V.V. Limansky, A.A. Yarzhombek, E.N. Bekina, S.B. Andronnikov. Moscow: VNIIPRKh, 1984, 59 p.

⁶Filippovich Yu.B. Practical training in general biochemistry / Yu.B. Filippovich, T.A. Egorova, G.A. Sevast'yanova. Moscow: Prosveshchenie, 1975, 318 p.

⁷Fishbach F. A manual of laboratory diagnostic tests 7th ed / F. Fishbach, M. Dunning. – Lippincott Williams & Wilkins, 2004, 1291 p.

⁸Trinder P. Determination of glucose in blood using glucose oxidase with an alternative oxygen acceptor / P. Trinder // Ann ClinBiochem., 1969, pp. 24–25.

cultivation (28 days each) with 100% survival revealed positive dynamics of key growth and development indicators (see Table 1).

By the end of stage II, a statistically significant ($p \leq 0.05$) increase in average body weight by 19.3% was recorded – from 303.69 ± 25.28 to 362.19 ± 20.89 g.

Absolute body length also tended to increase (from 44.01 ± 1.07 to 44.88 ± 1.41 cm), but the differences did not reach statistical significance. A significant increase in growth and body condition indicators was noted. The parameters reflecting the growth rate in relative terms (average daily growth rate, specific growth rate, mass accumulation coefficient) remained consistently high and did not show significant changes between stages, being in the range of 0.26–0.63%.

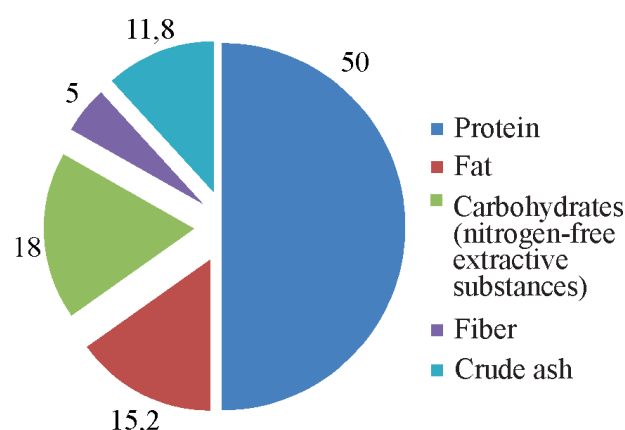


Рис. 3. Состав корма по основным питательным веществам, %

Fig. 3. Feed composition by main nutrients, %

Fulton's condition factor significantly increased from 0.35 ± 0.03 to 0.42 ± 0.03 units, which indicates an improvement in the general physiological state and accumulation of energy reserves. Weight gain indicators also demonstrated reliable positive dynamics: absolute gain increased from 47.67 to 58.50 g, and average daily gain from 1.70 to 2.09 g.

Thus, over the 56-day observation period, the "RuKal" hybrid demonstrated high viability (100% survival rate), stable linear growth and reliable intensive weight gain, accompanied by a significant increase in the Fulton's condition factor. The functional state of cultured fish was assessed based on the analysis of the metabolic function of the blood according to the data of hematological and biochemical studies (see Table 2).

A positive dynamic of hemoglobin level was observed from 50.97 ± 2.77 g/l at the start of the experiment to 55.96 ± 2.83 g/l by the end of stage II, while the difference between the initial and final values is statistically significant ($p \leq 0.05$).

A significant increase was also noted for the erythrocyte sedimentation rate (ESR), the value of which increased from 0.77 ± 0.11 to 1.15 ± 0.11 mm/h at stage II ($p \leq 0.05$).

Total plasma protein concentrations also showed a steady upward trend. By the end of the study, this indicator reached 28.15 ± 2.63 g/l,

Табл. 1. Рыбоводно-биологические показатели гибрида «РуКал» ($n = 25$)

Table 1. Fish-breeding and biological parameters of the "RuKal" hybrid ($n = 25$)

Indicator	I stage	II stage
Weight, g	$303,69 \pm 25,28$	$362,19 \pm 20,89^*$
Absolute length, cm	$44,01 \pm 1,07$	$44,88 \pm 1,41$
Fulton's condition factor, units	$0,35 \pm 0,03$	$0,42 \pm 0,03^*$
Absolute gain, g	47,67	58,50*
Average daily gain, g	1,70	2,09*
Average daily growth rate, %	0,61	0,63
Specific growth rate, %	0,26	0,27
Mass accumulation coefficient, units	0,04	0,04
Survival rate, %	100,00	100,00
Duration, days	28	28

Note. *At $p \leq 0.05$ the differences are significant.

Табл. 2. Динамика физиолого-биохимических показателей крови гибрида «РуКал» ($n = 25$)

Table 2. Dynamics of physiological and biochemical parameters of blood of the hybrid "RuKal" ($n = 25$)

Indicator	The start of the research	I stage	II stage
Hemoglobin, g/l	$50,97 \pm 2,77$	$54,90 \pm 4,62$	$55,96 \pm 2,83^*$
ESR, mm/h	$0,77 \pm 0,11$	$0,89 \pm 0,20$	$1,15 \pm 0,11^*$
Total protein, g/l	$22,06 \pm 18,65$	$25,70 \pm 1,10$	$28,15 \pm 2,63^*$
Cholesterol, mmol/l	$2,62 \pm 0,23$	$2,84 \pm 0,39$	$2,07 \pm 0,41$
Glucose, mmol/l	$3,85 \pm 0,14$	$3,14 \pm 0,31$	$3,56 \pm 0,27$

Note. $^*At p \leq 0,05$ the differences are significant; n the number of individuals in each group.

significantly exceeding the baseline level of 22.06 ± 18.65 g/l ($p \leq 0,05$).

Plasma cholesterol and glucose levels did not undergo significant changes during the experiment ($p > 0,05$). The concentration of cholesterol fluctuated in the range of 2.07–2.84 mmol/l, glucose – 3.14–3.85 mmol/l, remaining within the physiological norms for sturgeon fish.

Thus, during the growing period, the hybrid "RuKal" showed a significant increase in the content of hemoglobin, total protein and ESR with stable indicators of lipid and carbohydrate metabolism.

Growth rates of cultured fish in the first stage of the study were good. In the second stage of cultivation, growth rates increased by 22.0% for absolute and average daily growth, and by 3.2–3.8% for average daily and specific growth rates. The mass accumulation coefficient remained unchanged. The survival rate was 100% throughout the entire study period.

A marker of the state of the fish body is the dynamics of biochemical blood parameters, which characterize the quality and quantity of nutrition, stocking density, adaptive abilities of fish, and the intensity of the impact of anthropogenic factors [8, 10].

An important diagnostic indicator of changes in oxygen content in the blood is hemoglobin. During the study period, an increase in this indicator by 9.9% was noted, which indicates an increase in the oxygen transport capacity of the blood, necessary to maintain increased metabolism with intensive growth. This is a classic adaptive response that ensures adequate oxygen supply to tissues.

The erythrocyte sedimentation rate was below normal levels. However, over the study period, the rate changed by 49.3%. An increase in ESR in fish is often interpreted as a nonspecific indicator of changes in plasma protein composition (particularly an increase in fibrinogen or globulin levels) and may also be related to changes in blood flow properties and red blood cell size during growth. The observed increase in ESR, along with the rise in total protein, probably reflects physiological shifts in the plasma protein spectrum related to developmental growth and metabolic activity, rather than a pathological process, given the high survival rate and positive growth trends.

A reliable increase in the concentration of total protein in blood plasma by stage II is an overall indicator of intensified biosynthesis processes, which directly correlates with the recorded significant increase in body mass and condition factor. The level of total serum protein was within the range described for this species under similar rearing conditions, but below the standard values. However, when using the feed being studied, at Stage I, this indicator increased by 16.5% (coefficient of variation of the trait = 18.0%), and at Stage II, it increased by another 9.5% (coefficient of variation of the trait = 20.0%). The increase in protein concentration reflects a positive trend in anabolic metabolism, which aligns with the results of the calculation of fish farming biological indicators.

Cholesterol levels were within the reference range. The decrease in this indicator was 20.9% over the entire study period.

Since an increase in blood cholesterol affects its viscosity and disrupts active metabolism in the body, it can be assumed that the dynamics of lipid metabolism in fish mainly supported the normal process of energy resource accumulation. This is confirmed by the favorable conditions for keeping the fish, as blood cholesterol levels are primarily influenced by the living conditions and feeding technology.

One of the informative biochemical indicators of the physiological state of living organisms is the glucose content in the blood. This important measure of carbohydrate metabolism directly depends on the activity level of fish, and a sharp increase in glucose levels can indicate stress [11]. The glucose level in the farmed fish remained within the physiological norm throughout the study. The observed trend (a slight dip followed by a return to the original level) isn't statistically significant. This suggests that the experimental conditions or stages of the study didn't have a major stressful or negative effect on the carbohydrate metabolism of this group of fish. The lack of pronounced hyperglycemia is a good sign, indicating that the sturgeon hybrid was relatively well during the experiment.

The lack of statistically significant changes in glucose and cholesterol levels points to a steady balance of energy and lipid metabolism throughout the experiment. The stability of cholesterol levels reflects a well-balanced process of its synthesis, transport, and use in the growing body [4, 8, 11].

Thus, the combination of the obtained data (weight gain, fattening, increased levels of total protein and hemoglobin with stable glucose levels and high survival rates) allows us to conclude that the "RuKal" hybrid has adapted well to the conditions of recirculating water systems and feeding with the experimental feed from the OOO "BIFF". The observed hematological changes are compensatory and adaptive in nature, aimed at meeting the metabolic needs of a actively growing body. This physiological and biochemical profile confirms the potential of this hybrid form for aquaculture.

CONCLUSIONS

1. The "RuKal" hybrid shows high growth potential and excellent viability in a recirculating water system. Over a 56-day observation period with 100% survival, there was positive weight gain: both the absolute and daily average gain increased by 22%, and the mass and Fulton's condition factor went up significantly. This indicates effective adaptation and favorable growing conditions.

2. The observed changes in the hematological profile are adaptive and compensatory in nature and correlate with rapid growth. The significant increase in hemoglobin concentration (by 9.9%) reflects an enhanced oxygen-transport function of the blood to support the increased metabolism. The rise in total serum protein levels (by 27.6% by the end of the experiment) serves as an overall marker of boosted biosynthesis processes, which is directly linked to the increase in body mass.

3. The dynamics of biochemical indicators suggest a balanced metabolism and no chronic stress. Stable glucose and cholesterol levels, which are within the physiological norms for sturgeon, indicate steady energy and lipid metabolism. The absence of statistically significant hyperglycemia rules out prolonged stress from the experimental conditions. A 20.9% decrease in cholesterol may indicate its active use in growth and energy processes.

4. The change in ESR is not pathological. Although the ESR value remained below the normal range for sturgeons, its significant increase (49.3%), along with higher total protein and excellent aquaculture characteristics, most likely reflects physiological shifts in plasma protein composition related to growth and development, rather than an inflammatory process.

5. The collected data confirm the successful adaptation of the "RuKal" hybrid to the conditions of experimental cultivation in recirculating water systems using feed from the OOO "Biff". The observed physiological and biochemical changes are a natural response of a actively growing organism and indicate favorable conditions for care and feeding. The results support

the promising potential of using this hybrid form in commercial sturgeon farming.

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Влияние генотипа каппа-казеина на компонентный состав молока у высокопродуктивных коров-первотелок голштинской породы

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Понимание физиологических стратегий, лежащих в основе высокой молочной продуктивности, требует детального анализа не только средних показателей по группе, но и вариабельности внутри генетически однородных животных. Особенно актуально изучение взаимосвязей между количеством синтезируемых компонентов молока и уровнем продуктивности в зависимости от генотипа по ключевым генам молочного белка. Целью данной работы стало выявление генотип-специфических особенностей взаимосвязи между выходом молочного жира и синтезом других компонентов молока у коров-первотелок голштинской породы с различными генотипами по каппа-казеину (*CSN3*) на основе метода процентильной стратификации. Научно-хозяйственный опыт выполняли в 2023–2025 гг. на базе сельскохозяйственного предприятия в Воронежской области. Объектом исследования стали коровы-первотелки голштинской породы ($n = 166$), генотипированные по локусу *CSN3*. Внутри каждого генотипа (*AA*, *AB*, *BB*) методом процентильной стратификации по показателю «выход молочного жира за 305 дней лактации» были сформированы три страты (нижняя, средняя, верхняя). Проведен анализ интегральных показателей за полную лактацию: удоя, выхода и массовой доли жира и белка, продолжительности лактации. Полученные данные важны для дифференцированного подхода в селекции и управлении кормлением в зависимости от генетического потенциала животных. Установлены генотип-специфические особенности реализации высокой молочной продуктивности. Показано, что увеличение выхода молочного жира преимущественно обеспечивается ростом удоя и сопровождается снижением массовой доли белка, что свидетельствует о наличии метаболического компромисса между количественными и качественными характеристиками молока. Полученные результаты имеют практическое значение для разработки дифференцированных селекционных и технологических подходов к управлению продуктивностью коров с различным генетическим потенциалом.

Ключевые слова: голштинская порода, каппа-казеин (*CSN3*), метаболический компромисс, процентильная стратификация, выход молочного жира, компонентный состав молока

Influence of kappa-casein genotype on the milk component composition in high-yielding first-calf heifers of the Holstein breed

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Understanding the physiological strategies underlying high milk productivity requires a detailed analysis not only of group averages but also of the variability within genetically homogeneous animals. It is especially important to study the relationship between the amount of synthesized milk components and the level of productivity depending on the genotype of key milk protein genes. The purpose of this work was to identify the genotype-specific features of the relationship between milk fat yield and the synthesis of other milk components in Holstein first-calf heifers with different kappa-casein (*CSN3*) genotypes using the percentile stratification method. The scientific and production

trial was conducted from 2023 to 2025 at the agricultural enterprise in the Voronezh region. The study subjects were Holstein first-calf heifers ($n=166$) genotyped for the *CSN3* locus. Within each genotype (*AA*, *AB*, *BB*), three strata (low, medium, high) were formed using the percentile stratification method based on the indicator "milk fat yield per 305-day lactation". Integral indicators for the complete lactation were analyzed: milk yield, yield and mass fraction of fat and protein, and lactation length. The obtained data are important for a differentiated approach to selection and feeding management depending on the genetic potential of animals. Genotype-specific features of the implementation of high milk productivity have been established. It has been shown that an increase in milk fat yield is mainly ensured by an increase in milk yield and is accompanied by a decrease in the mass fraction of protein, which indicates the presence of a metabolic compromise between the quantitative and qualitative characteristics of milk. The obtained results have practical significance for the development of differentiated selection and technological approaches to managing the productivity of cows with different genetic potential.

Keywords: Holstein breed, kappa-casein (*CSN3*), metabolic compromise, percentile stratification, milk fat yield, milk component composition

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Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Milk productivity in cattle is a classic example of a complex quantitative trait formed under the influence of many genetic and paratypic factors [1, 2]. Nowadays, the economic efficiency of dairy farming is determined not just by the amount of milk produced, but also largely by the quality of the milk itself, especially its fat and protein content [3]. These components directly affect the nutritional value, technological properties of milk during processing, and, as a result, the cost of the final product [4].

One of the key genetic markers used in breeding to improve milk protein content is the kappa-casein gene (*CSN3*) [5, 6]. The polymorphism of this gene (alleles *A* and *B*) is associated with amino acid changes in the protein, which affects the size of casein micelles and cheese yield. Numerous studies confirm the advantage of allele *B* and the *BB* homozygous genotype in milk protein content [7, 8]. However, the phenotypic expression of a genotype often shows a lot of variation between individuals, even within

genetically uniform groups. The traditional approach of comparing average values between genotypes doesn't reveal the range of physiological strategies that individual animals use to achieve high values in complex selection traits.

Productivity is a dynamic process. The lactation curve, which shows the change in average monthly milk yield from calving to drying off, is an overall indicator of the udder's functional state and the cow's metabolic adaptation. Analyzing the shape of the curve (peak height and timing, rate of decline) in groups of animals that have reached different productivity levels can provide important insights into energy efficiency and the stability of lactation across different genetic variants [9, 10].

Lactation curve parameters have moderate heritability and are genetically correlated with overall milk production, milk component content, and health indicators, which makes it possible to consider them as independent selection traits [10, 11]. Selective breeding based on lactation curve traits helps change the frequencies of

alleles associated with productivity and lactation resilience, which reflects the targeted microevolutionary changes in the dairy cattle population [11, 12].

The purpose of the study is to identify genotype-specific features of the relationship between milk fat yield, the component composition of milk, and the dynamics of the lactation curve in first-calf Holstein cows.

MATERIAL AND METHODS

The work was done in 2023–2025 at the agricultural enterprise OOO “Don” in the Khokholsky District, Voronezh Region. The study focused on first-calf Holstein cows ($n = 166$), kept under identical feeding and housing conditions. The animals were genotyped for the kappa-casein (*CSN3*) locus in an accredited laboratory. Based on the results, three genetic groups were formed: *AA* ($n = 59$), *AB* ($n = 79$), *BB* ($n = 29$).

For a detailed analysis within each genotype, a percentile stratification method was used based on the “milk fat yield over 305 days of lactation” indicator. Animals of each genotype were ranked by the value of this trait and then divided into three strata of approximately equal numbers. The lower stratum (1) included animals whose trait values corresponded to the lower percentile interval of the sample, the middle stratum (2) included animals with average trait values, and the upper stratum (3) included animals with the highest milk fat yield values. This approach allowed forming groups of comparable size within each genotype and conduct a reliable comparison of milk production indicators. Statistical processing was performed using standard software packages. The significance of differences between strata within a genotype was assessed using parametric and nonparametric criteria. The differences were considered significant at $p \leq 0.05$. The lactation curves were visualized based on the average monthly values.

RESULTS AND DISCUSSION

Percentile stratification based on milk fat yield over 305 days of lactation resulted in the formation of three differentiated production

groups (lower, middle, and upper strata) within each *CSN3* genotype. This allowed for a detailed comparison of milk production indicators and the monitoring of lactation dynamics within genetically homogeneous groups. When interpreting the obtained data, special attention was paid to the mass fraction of fat and protein as key indicators of the qualitative composition of milk, determining its technological value during processing.

It should be noted that the actual lactation duration in the studied herd exceeded the standard 305 days, averaging 349 days across the herd. This is due to the farm's production process, in which cows are started individually, taking into account the animals' physiological condition and productivity level. In this case, the indicator “milk fat yield for 305 days of lactation” was used as a standardized selection criterion for animal stratification, while the analysis of integral indicators was carried out based on data from a fully completed lactation.

When analyzing the productivity indicators for the entire lactation, a pronounced extensive strategy was noted in the animals during the transition from the lower to the upper stratum (see Table 1). A highly reliable increase in milk yield per lactation of 2740.7 kg was observed ($p \leq 0.001$), while the fat mass fraction remained statistically unchanged. Thus, the high fat yield (+116.6 kg, $p \leq 0.001$) was achieved due to the increased volume of milk produced. A critical consequence of this strategy was a significant decrease in protein mass fraction by 0.11% ($p \leq 0.01$). Variability in quantitative traits (milk yield, fat and protein yield) in the upper stratum did not decrease, and for some indicators, it increased (milk yield from 17.83 to 20.34%), indicating high heterogeneity in high-yielding animals with the *AA* genotype at the kappa-casein locus.

Heterozygous animals demonstrated a mixed (intensive-extensive) strategy (see Table 2). Fat yield in the upper stratum increased by 102.9 kg ($p \leq 0.001$). This increase was achieved not only due to an increase in milk yield (by 2291.6 kg, $p \leq 0.001$), but also due to a statistically sig-

Табл. 1. Показатели молочной продуктивности за всю лактацию у коров-первотелок с генотипом AA по каппа-казеину в различных стратах
Table 1. Milk productivity indicators for the entire lactation of first-calf heifers with the AA genotype for kappa-casein in different strata

Indicator	Lower stratum (1) (n = 19)		Middle stratum (2) (n = 19)		Upper stratum (3) (n = 20)		1-2	1-3	2-3
	M ± m	Cv, %	M ± m	Cv, %	M ± m	Cv, %			
Milk yield, kg	9838,3 ± 402,6	17,83	10918,7 ± 508,4	20,29	12579 ± 572,2	20,34	-1080,44	2740,74***	-1660,3*
Mass fraction of fat, %	4,08 ± 0,03	3,73	4,17 ± 0,04	4,57	4,13 ± 0,03	4,02	-0,09	-0,05	0,04
Milk fat yield, kg	401,82 ± 16,74	18,16	454,89 ± 19,9	19,07	518,37 ± 22,43	19,35	-53,07*	-116,55***	-63,48*
Protein mass fraction, %	3,54 ± 0,02	3,28	3,5 ± 0,03	3,92	3,43 ± 0,02	3,16	0,04	0,11**	0,07
Milk protein yield, kg	349,2 ± 15,72	19,62	382,46 ± 17,14	19,53	431,64 ± 19,85	20,57	-33,26	-82,44**	-49,18
Duration of lactation, days	343,89 ± 13,32	16,89	352,15 ± 18,05	22,35	358,25 ± 15,83	19,7	-8,26	-14,36	-6,10

Here and in table. 2, 3:
* $p \leq 0,05$.
** $p \leq 0,01$.
*** $p \leq 0,001$.

nificant increase in milk fat content by 0.09% ($p \leq 0.05$) compared to the lower stratum.

A metabolic trade-off with protein synthesis was also present (a decrease in protein content by 0.11%, $p \leq 0.01$), but it was expressed to a lesser extent than in the AA genotype. An important difference was the decreasing variability in the upper stratum: the coefficient of variation of milk yield decreased from 20.82 to 9.73%, fat yield – from 22.30 to 9.41%, indicating greater homogeneity of high-yielding animals with the AB genotype at the kappa-casein locus.

Animals with the homozygous B allele also implemented an extensive strategy of increasing fat yield at the expense of milk yield (an increase in milk yield of 3309.9 kg, $p \leq 0.001$) with stable fat content. However, the key feature of this genotype was the most pronounced decrease in milk protein content – by 0.2% ($p \leq 0.01$) upon transition to the upper stratum. Moreover, the variability of highly productive animals was minimal among all genotypes (coefficient of variation of milk yield 7.73%, milk fat yield 7.59%), which may indicate genetically determined stability and predictability of the productive response in carriers of the B allele.

Analysis of the lactation-wide performance indicators presented in Table 1 for first-calf heifers with the AA kappa-casein genotype, divided into strata based on milk fat yield, revealed the following key patterns. A statistically significant increase in milk productivity was found from the lower to the upper stratum. Milk yield per lactation in the upper stratum (12579.0 ± 572.2 kg) was significantly ($p \leq 0.001$) higher than that in the lower stratum by 2740.7 kg, and in the middle stratum by 1660.3 kg ($p \leq 0.05$). Similar positive dynamics were observed for milk fat yield, the value of which in group 3 (518.37 ± 22.43 kg) was significantly higher than in groups 1 and 2, by 116.55 kg ($p \leq 0.001$) and 63.48 kg ($p \leq 0.05$), respectively. Milk protein yield also improved, reaching 431.64 ± 19.85 kg in the upper stratum, which is 82.44 kg ($p \leq 0.01$) higher than in the lower stratum. At the same time, the fat content in milk remained statistically stable at 4.08–4.17% ($p \geq 0.05$), demonstrating the ab-

Табл. 2. Показатели молочной продуктивности за всю лактацию у коров-первотелок с генотипом *AB* по kappa-казеину в различных стратах
Table 2. Milk productivity indicators for the entire lactation of first-calf heifers with the *AB* genotype for kappa-casein in different strata

Indicator	Lower stratum (1) (<i>n</i> = 26)		Middle stratum (2) (<i>n</i> = 26)		Upper stratum (3) (<i>n</i> = 27)		1-2	1-3	2-3
	<i>M</i> ± <i>m</i>	<i>Cv</i> , %	<i>M</i> ± <i>m</i>	<i>Cv</i> , %	<i>M</i> ± <i>m</i>	<i>Cv</i> , %			
Milk yield, kg	9544 ± 389,82	20,82	10545,5 ± 307,39	14,86	11835,6 ± 221,63	9,73	-1001,5*	-2291,6***	1290,1**
Mass fraction of fat, %	4,08 ± 0,03	4,42	4,12 ± 0,03	4,06	4,17 ± 0,03	4,66	-0,04	-0,09	-0,05
Milk fat yield, kg	390,43 ± 17,07	22,3	434,96 ± 13,16	15,43	493,36 ± 8,94	9,42	-44,53*	-102,93***	-58,4***
Protein mass fraction, %	3,56 ± 0,02	4,14	3,51 ± 0,02	3,36	3,45 ± 0,02	4,38	0,05	0,11**	0,06
Milk protein yield, kg	340,76 ± 14,16	21,2	371,25 ± 11,49	15,79	408,48 ± 6,79	8,64	30,49	67,72***	37,23**
Duration of lactation, days	353,69 ± 13,07	18,84	342,11 ± 10,48	15,62	332,59 ± 6,46	10,1	11,58	21,10	9,52

sence of a direct relationship between milk yield and fat content in this genotype. Critical is the identified reliable decrease in the mass fraction of protein from 3.54% in the lower stratum to 3.43% in the upper stratum ($p \leq 0.01$), which indicates the possible existence of a metabolic compromise: an increase in quantitative indicators of productivity in the *AA* genotype is accompanied by a deterioration in the protein quality of milk. The coefficients of variation (*Cv*) for the main quantitative traits (milk yield, fat and protein yield) remained at a high level (17.8–20.6%) in all strata, and even increased in some, indicating significant individual variability and heterogeneity of highly productive animals of the *AA* genotype.

The duration of lactation tended to increase with increasing stratum (from 343.9 to 358.3 days), although inter-stratal differences did not reach the level of statistical significance ($p \geq 0.05$).

When analyzing the productive indicators for the entire lactation (see Table 2), in first-calf heifers with the heterozygous *AB* genotype for kappa-casein, a clear gradation of all quantitative traits was revealed depending on the stratum formed by the yield of milk fat. Thus, the milk yield in group 3 (11835.6 ± 221.63 kg) significantly exceeded the milk yield in group 1 by 2291.6 kg ($p \leq 0.001$), and in group 2 by 1290.1 kg ($p \leq 0.01$). A similar picture was noted for the yield of milk fat: the indicator of the upper stratum (493.36 ± 8.94 kg) was reliably higher than in the lower one, by 102.93 kg ($p \leq 0.001$), and in the middle one – by 58.4 kg ($p \leq 0.001$). The yield of milk protein also progressed, reaching 408.48 ± 6.79 kg in stratum 3, which is 67.72 kg ($p \leq 0.001$) and 37.23 kg ($p \leq 0.01$) more than in strata 1 and 2, respectively.

The qualitative composition of milk exhibited specific dynamics. Fat content showed positive dynamics, consistently increasing from 4.08% in the lower stratum to 4.17% in the upper stratum, but interstratal differences did not reach statistical significance ($p \geq 0.05$). This pattern of changes qualitatively distinguishes heterozygous animals from the *AA* genotype, which had

stable fat content, and may indicate the ability of *AB* cows to slightly increase fat content in response to increasing milk yield. Consistent with the general pattern, this genotype also showed a significant decrease in protein content by 0.11% ($p \leq 0.01$) when comparing the lower and upper strata.

The most significant distinguishing feature of the *AB* genotype is a sharp reduction in the phenotypic variability (*Cv*) of productive traits in high-yielding animals. The coefficient of variation for milk yield in the upper stratum is only 9.73% versus 20.82% in the lower stratum, and for fat yield, it is 9.42% versus 22.3%. This indicates possible genetic homogeneity, stability, and predictability of productive traits in high-yielding carriers of the *AB* genotype. The duration of lactation in this genotype showed an inverse, albeit statistically insignificant ($p > 0.05$), trend: a decrease from 353.7 days in the lower stratum to 332.6 days in the upper stratum.

Thus, within the *AB* genotype, the upper stratum demonstrates the highest productivity in all quantitative indicators (milk yield, fat and protein yield) compared to the lower and middle strata of the same genotype.

The results presented in Table 3 characterize the milk productivity of first-calf heifers with the homozygous *BB* genotype and reveal its controversial breeding potential. Quantitative indicators in animals of the upper stratum (milk yield $11,712.3 \pm 286.39$ kg, fat yield 492.37 ± 11.81 kg) significantly ($p \leq 0.001$) exceed those in the lower stratum by 3,309.9 and 140.22 kg, respectively. However, the increase in milk protein yield (by 94.84 kg) was less pronounced and did not reach significance when comparing the middle and upper strata. Qualitative indicators demonstrate dissociation: the mass fraction of fat remains consistently high (approximately 4.2%) and does not change significantly between strata ($p \geq 0.05$), while the mass fraction of protein undergoes the sharpest decrease among all genotypes – from 3.60% in the lower stratum to 3.38% in the upper stratum ($p \leq 0.01$). This 0.22% drop represents a potentially serious technological risk, as it significantly worsens the

Табл. 3. Показатели молочной продуктивности за всю лактацию у коров-первотелок с генотипом *BB* по каппа-казеину в различных стратах
Table 3. Milk productivity indicators for the entire lactation of first-calf heifers with the *BB* genotype for kappa-casein in different strata

Indicator	Lower stratum (1) ($n = 10$)		Middle stratum (2) ($n = 9$)		Upper stratum (3) ($n = 10$)		1-2	1-3	2-3
	$M \pm m$	<i>Cv</i> , %	$M \pm m$	<i>Cv</i> , %	$M \pm m$	<i>Cv</i> , %			
Milk yield, kg	$8402,4 \pm 544,77$	20,5	$10584,44 \pm 579,6$	16,42	$11712,3 \pm 286,39$	7,73	2182,04*	-3309,9***	1127,66
Mass fraction of fat, %	$4,2 \pm 0,03$	2,6	$4,13 \pm 0,03$	2,86	$4,2 \pm 0,06$	4,77	0,07	0	-0,07
Milk fat yield, kg	$352,15 \pm 21,9$	19,66	$436,64 \pm 22,97$	15,78	$492,37 \pm 11,81$	7,59	-84,49	-140,22	-55,73
Protein mass fraction, %	$3,6 \pm 0,053$	4,64	$3,61 \pm 0,04$	4,04	$3,38 \pm 0,03$	3,04	-0,01	0,22**	0,23**
Milk protein yield, kg	$302,2 \pm 18,79$	19,66	$381,71 \pm 20,21$	15,89	$397,04 \pm 11,48$	9,14	-79,51	-94,84	-15,33
Duration of lactation, days	$331,2 \pm 12,81$	12,23	$342,22 \pm 20,64$	18,1	$327,1 \pm 9,53$	9,21	-11,02	4,1	15,12

protein-fat balance of milk and its cheese-making properties. An important positive characteristic of the *BB* genotype, like that of the *AB*, is the high homogeneity of high-yielding animals, as evidenced by the lowest coefficient of variation among all groups for milk yield (7.73%) and fat yield (7.59%) in the upper stratum. This indicates consolidated genetic control of productivity traits. Lactation duration in the *BB* genotype showed no consistent relationship with stratum level, varying between 327 and 342 days without statistically significant differences ($p \geq 0.05$). Thus, the *BB* genotype has the greatest potential for increasing milk yield and fat yield with outstanding stability, but its key limiting factor is a significant decline in milk protein yield at high productivity levels.

The Russian scientific literature has accumulated significant data on the impact of kappa-casein on milk productivity. A study* on five domestic breeds demonstrated that the *B* allele of the *CSN3* gene correlates with economically useful milk productivity indicators, protein content, and milk yield. However, within-breed diversity at this locus is significantly higher than between-breed differences. These results are consistent with the conclusion that the *CSN3* genotype determines not so much the average level of productivity as the physiological strategy for achieving it.

In the study [13], it was found that milk from cows with the *CSN3BB* genotype contains more fat, protein, calcium, and phosphorus, which is consistent with the results of the analysis. However, our study showed a significant decrease in the mass fraction of protein with high milk yields, whereas the authors [13] associated the *BB* genotype with an increased protein content at a lower level of productivity.

When analyzing the results of the studies [14], it was found that the daughters of bulls with the *CSN3AB* genotype were significantly superior to cows from bulls with the *CSN3AA* genotype in milk yield by 10%, milk fat and protein yield by

12.4 and 9.8%, respectively, and milk fat content by 0.09%, which is consistent with the results of our studies, where the *AB* genotype demonstrates better balance and predictability.

The results support the idea of a metabolic trade-off between the quantity and quality of milk production. Increasing milk yield and fat content was often accompanied by a decrease in protein percentage, which might be due to the redistribution of the body's energy and building resources under high production demands. Similar trends have been noted before in the studies focused on the genetic control of milk composition in Holstein cows.

The results also show the differences in the level of phenotypic variation between the genotypes. The lowest variation coefficients in the high-producing animal genotypes *AB* and *BB* may point to a more consolidated genetic control of productivity traits and potentially a higher predictability of the breeding response.

CONCLUSIONS

1. The effectiveness of the percentile stratification method for forming genetically homogeneous groups (*AA*, *AB*, *BB*) within differentiated productivity strata (lower, middle, upper) has been confirmed. The method provided a clear and statistically significant separation of animals by productivity level, allowing for a detailed comparative analysis.

2. Genotype-specific patterns of achieving high productivity have been identified: genotype *AA* follows an extensive strategy, showing a sharp increase in milk yield (by 2740.7 kg, $p \leq 0.001$) and fat output at a stable fat content, but this comes with a significant decrease in protein content (-0.11% , $p \leq 0.01$) and maintaining high individual variability (milk yield $C_v \sim 20\%$).

3. Genotype *AB* shows a mixed (intensive-extensive) strategy: the increase in fat yield (+102.9 kg, $p < 0.001$) is driven by both higher milk yield and a trend towards higher fat content. The decrease in protein content (-0.11% ,

* Sulimova G.E., Akhiani Azari M., Rostamzadeh D., Mohammad Abadi M.R., Lazebny O.E. Allelic polymorphism of the kappa-casein gene (*CSN3*) in Russian cattle breeds and its informativeness as a genetic marker // *Genetics*, 2007, vol. 43, No. 1, pp. 88–95.

$p \leq 0.01$) is moderate. A critical difference is the sharp reduction in variability in highly productive animals (the coefficient of variation of milk yield decreases from 20.82 to 9.73%), which indicates genetic predictability and homogeneity.

4. The *BB* genotype also implements an extensive strategy with the highest milk yield increase (+3309.9 kg, $p \leq 0.001$). However, its key negative feature is the most pronounced decrease in protein content (-0.22%, $p \leq 0.01$), which represents a technological risk. At the same time, highly productive animals of this genotype are also distinguished by minimal variability of productive traits (milk yield *Cv* – 7.73%, milk fat yield – 7.59%).

5. Percentile stratification has proven its value as a tool for identifying hidden relationships and metabolic tradeoffs within genotypes. The data obtained indicate the priority of the heterozygous *AB* genotype in breeding for balanced, high productivity while maintaining milk quality and predictability. Selection of animals of the *BB* genotype must be carried out with caution due to the risk of deterioration of milk protein production, and the selection of *AA* animals requires additional criteria to reduce their high phenotypic heterogeneity.

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Эффективность отбора быков-производителей в популяции голштинизированного скота

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Генетическое улучшение популяций молочного скота основано в первую очередь на использовании лучших быков-производителей, устойчиво передающих свои качества потомству. Цель проведенного исследования – определить эффективность отбора лучших быков-производителей в популяции голштинизированного черно-пестрого скота Вологодской области на основе племенной ценности, рассчитанной разными методами. В исследовательскую базу включили данные по 8812 коровам первого отела и 171 быку, которые являются отцами этих коров. Племенную ценность быков определяли по показателям надоя, как основному селекционному признаку в молочном скотоводстве, на основе расчета генетического потенциала и его реализации и методом «дочери-сверстницы». По результатам расчета производителей отобрали в две группы по 40 гол. с лучшими показателями племенной ценности, определенной разными методами. Эффективность отбора по каждому из методов определяли на основе расчета селекционного дифференциала как разности продуктивности «дочь – мать». Положительный показатель селекционного дифференциала подтверждает эффективность использования производителя в популяции. В исследуемых группах у большинства производителей (36 из 40, или 90,0%) установлен положительный селекционный дифференциал по молочной продуктивности (от +218 до +2684 кг). Также в каждой группе быков выявлено по четыре производителя с отрицательным селекционным дифференциалом от –25 до –297 кг. Превосходство потомства этих быков над сверстницами обеспечено не только влиянием отцовской генетики, но и использованием высокопродуктивного маточного поголовья. В результате проведенного исследования установлено, что эффективность отбора быков-производителей повышается, если оценку при любом методе дополнить расчетом селекционного дифференциала. Комплексное использование предлагаемых методов будет способствовать повышению надежности оценки племенной ценности быков и эффективности отбора лучших производителей в популяции.

Ключевые слова: молочное скотоводство, отбор, быки-производители, эффективность, племенная ценность, генетический потенциал, селекционный дифференциал

The effectiveness of stud bull selection in the Holstein cattle population

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The genetic improvement of dairy cattle populations is based primarily on the use of the best stud bulls that sustainably transmit their qualities to their offspring. The purpose of the conducted study was to determine the effectiveness of the selection of the best stud bulls in the population of Holstein Black-and-White cattle of the Vologda region based on the breeding value calculated by different methods. The research database included data on 8812 cows of the 1st calving and 171 bulls, which are the fathers of these cows. The breeding value of bulls was determined by milk yield indicators, as the main selection trait in dairy cattle breeding, based on the calculation of genetic potential and its realization, and using the "daughter-peer" method. According to the calculation results, the stud bulls were chosen in groups of 40 heads with the best breeding value indicators determined by different methods. The effectiveness of selection for each of the methods was determined based on the calculation of the selection differential, as the difference in productivity "daughter-mother". The positive indicator of the selection differential confirms the effectiveness of using the stud bull in the population. In the studied groups, the majority of the stud bulls (36 out of 40 or 90.0%) have a positive selection

differential in milk productivity (from +218 to +2684 kg). Also, 4 stud bulls with a negative selection differential from –25 to –297 kg were identified in each group of the bulls. The superiority of the offspring of these bulls over their peers is ensured not only by the influence of paternal genetics, but also by the use of highly productive breeding stock. As a result of the conducted research, it was found that the effectiveness of the selection of stud bulls increases if the assessment with any method is supplemented by the calculation of the selection differential, and the integrated use of the proposed methods will help to increase the reliability of the assessment of the breeding value of bulls and the effectiveness of the selection of the best stud bulls in the population.

Keywords: dairy cattle breeding, selection, stud bulls, efficiency, breeding value, genetic potential, selection differential

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Conflict of interest

The authors declare no conflict of interest.

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INTRODUCTION

In dairy farming, selective breeding of pedigree populations is based on the targeted, systematic selection of the best animals and their rational use to increase the number of desirable genotypes. Timely identification of animals with high genetic potential and their optimal use are the keys to effective selective breeding [1–3].

G.V. Yeskin notes that with the introduction of artificial insemination in dairy cattle breeding, the role of breeding bulls in improving breed populations has increased significantly, since each of them can produce thousands of offspring annually¹.

According to scientists and practitioners, stud bulls are the primary genetic resource for further improvement of dairy cattle. Careful selection of stud bulls based on their ability to transmit desirable economically beneficial traits ensures posi-

tive dynamics in breeding and selection work in dairy breed populations [4–6].

The significant influence of stud bulls on the selection traits of offspring has been established by many researchers. For example, Ulyanovsk State Agricultural Academy scientists V.P. Gavrilenko and G.A. Bushova determined that the most significant genetic factor in dairy cattle selection is the "sire" factor, which had a significant effect ($p < 0.001$) on milk production and daughter fertility. The "genotype" and "line" factors had a lesser influence².

Scientists from the Oryol State Agricultural University, V.S. Buyarov and A.I. Shendakov, established a reliable influence of the "sire-bull" factor on the phenotypic variability of the live weight of heifers from birth to 18 months, on milk yield, and the fat and protein content in the milk of daughters³.

¹Eskin G.V., Plemtyashov K.V., Turbina I.S., Anistenok S.V. The state of the domestic gene pool of Ayrshire bulls // Dairy and meat cattle breeding, 2015, No. 5, pp. 5–8.

²Gavrilenko V.P., Bushova G.A. Genetic factors, their role in the selection of dairy cattle // Vestnik of Ulyanovsk state agricultural academy, 2010, No. 1, pp. 36–39.

³Buyarov V.S., Shendakov A.I., Shendakova T.A. Efficiency of dairy cattle selection // Animal Husbandry of Russia, 2011, No. 1, pp. 41–42.

Employees of the South Ural State Agrarian University have proven the significant superiority in lifetime productivity of daughters of individual stud bulls in a herd of Holsteinized Black-and-White cattle in the Chelyabinsk region [7].

The selection of sires begins with an assessment and selection based on ancestry. This is a predictive criterion that allows determining the likely breeding value of an animal, primarily its genetic potential based on the productivity of its female ancestors [8].

The Federal Law "On Breeding Livestock" states that the level of genetic potential and its influence on the economically useful traits of the offspring determine the breeding value of dairy cattle⁴.

The rate at which a sire's genetic potential is realized by his daughters indicates the degree to which the bull's genotype influences the traits of the offspring. The combination of genetic potential and its realization can serve as an estimate of the breeding value of bulls used in the population [9, 10].

Officially, domestic dairy farming practices use progeny quality assessment, based on a direct comparison of the productivity of the daughters of the tested bulls with their peers. O.G. Loretts, V.S. Mymrin, I.N. Yanchukov, and other scientists believe that progeny quality testing of stud bulls is the most objective method for assessing an animal's genetic value^{5, 6} [11].

According to R.V. Tamarova, this method remains a key link in breeding work and determines not only the breeding value of stud bulls, but also the effectiveness of their use in the population⁷.

Accurate evaluation of sires is important for selection and subsequent use to improve the breeding traits of the population. Many scientists believe that in today's large-scale breeding envi-

ronment, a comprehensive evaluation of sires is essential to identify the best ones and maximize the use of high-value bulls in the breeding process [12–15].

In this regard, research aimed at improving the efficiency of evaluation and selection of the best breeding bulls is relevant.

The purpose of the study is to determine the effectiveness of selecting the best stud bulls in the population of Holsteinized Black and White cattle based on the breeding value calculated by different methods.

The objectives of the study included:

- determination of the breeding value of stud bulls used in the population of Holsteinized Black and White cattle by two methods: by the level of genetic potential and its realization by daughters and by the difference between the productivity of the bull's daughters and their peers;
- selection of bulls into two groups of 40 heads each with the best breeding value indicators, calculated using different methods;
- identification of the selection efficiency for each of the methods based on the calculation of the selection differential for bulls that were included in the groups with the best breeding value indicators.

MATERIAL AND METHODS

The research database was compiled using the "Seleks. Dairy Cattle" information and analysis system. It included data on 8,812 first-calving cows and 171 sires of these cows, from the Vologda Oblast population of Holsteinized Black-and-White cattle. To ensure the reliability of the results, the database also included data on sires with at least five daughters.

The breeding value of bulls was determined based on milk yield indicators (as the main selection trait in dairy cattle breeding) based on

⁴Federal Law "On Breeding Livestock" of August 3, 1995 No. 23-FZ (as amended on March 23, 2024). URL: <https://legalacts.ru/doc/federalnyi-zakon-ot-03081995-n-123-fz-o/> (date of reference July 25, 2024).

⁵Loretts O.G., Likhodeevskaya O.E., Barashkin M.I., Mymrin V.S., Sevastyanov M.Yu. Evaluation of foreign and domestic breeding bulls used in breeding farms of the Sverdlovsk region // *Agrarian Bulletin of the Urals*, 2012, No. 4 (96), pp. 14–17.

⁶Yanchukov I., Ermilov A., Kharitonov S., Glushchenko M. The role of genomic assessment in dairy cattle breeding // *Dairy and meat cattle breeding*, 2013, No. 8, pp. 6–8.

⁷Tamarova R.V., Zyryanova S.V. Evaluation of the quality of the offspring of Mikhailovsky-type bulls of the Yaroslavl breed with different Holstein bloodlines // *Agrarian Journal of Upper Volga Region*, 2014, No. 4, pp. 93–97.

the calculation of genetic potential and its implementation and the “daughter-peer” method.

The genetic potential of breeding bulls was calculated using the formula

$$GP = \frac{M + MF}{2},$$

where GP – genetic potential; M and MF – indicators of productive traits for the highest lactation of the mother and mother of the bull's father.

The realization of the genetic potential of breeding bulls was determined as the ratio of the average productivity of the bull's daughters during the first lactation to his genetic potential, expressed as a percentage.

To compare the evaluation methods, two groups of 40 stud bulls with the best breeding values were formed. The breeding values were calculated using different methods: based on the level of genetic potential and its realization by daughters, and based on the difference between the productivity of a bull's daughters and their peers.

The selection efficiency was assessed by the selection differential, which was calculated as the difference between the average productivity of the bulls' daughters and their mothers during the first lactation.

Statistical, biometric and graphical data processing was performed using Microsoft Excel 2010.

RESULTS AND DISCUSSION

At the initial stage of the study, the genetic potential of the stud bulls was calculated based on the milk productivity of their maternal ancestors and the degree to which their daughters realized this potential during their first lactation. The calculations revealed a high level of productivity in their maternal ancestors. Genetic potential for milk yield ranged from 9,200 to 19,580 kg (see Fig. 1). Most bulls (77.6%) had a genetic potential for milk production exceeding 12,000 kg.

Calculation of the realization of the genetic potential of bulls by daughters during the first lactation revealed an inverse relationship between the level of genetic potential and its realization. The correlation coefficient between them was $r = -0.65$. For individual bulls, the realization of the genetic potential in milk yield ranged from 44.5% to 88.8%.

To determine the effectiveness of this selection using the rating method, 40 stud bulls with a genetic potential level of at least 12,000 kg of milk and its sale by daughters during the first

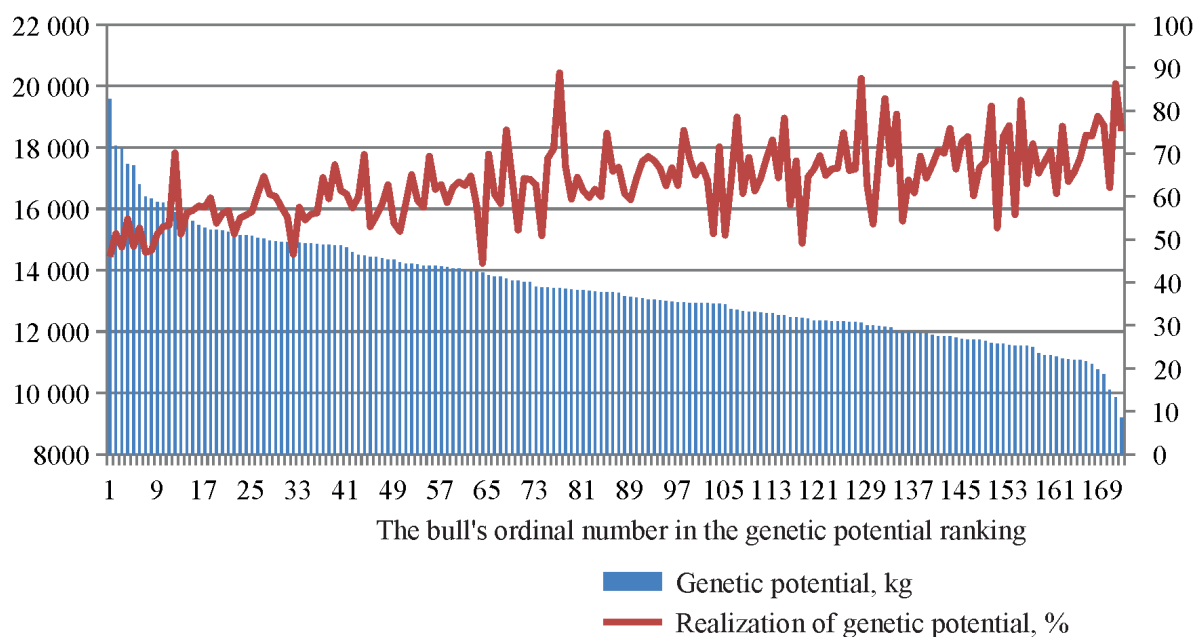


Рис. 1. Распределение быков по уровню генетического потенциала и степени его реализации
Fig. 1. The distribution of bulls by the level of genetic potential and the degree of its realization

lactation of at least 60% were selected as the best. The average genetic milk production potential of the maternal ancestors of the selected bulls was 13,811 kg, with a milk yield of 65.6%. The number of first-calving cows sired by the selected bulls totaled 3,313, or 37.6% of the total number of animals studied.

The average milk yield of first-calving cows—the daughters of the evaluated sires and their peers—was also calculated. Based on the data obtained, the deviation in the productivity traits of the bulls' daughters from that of their peers was determined and the significance of the difference was calculated.

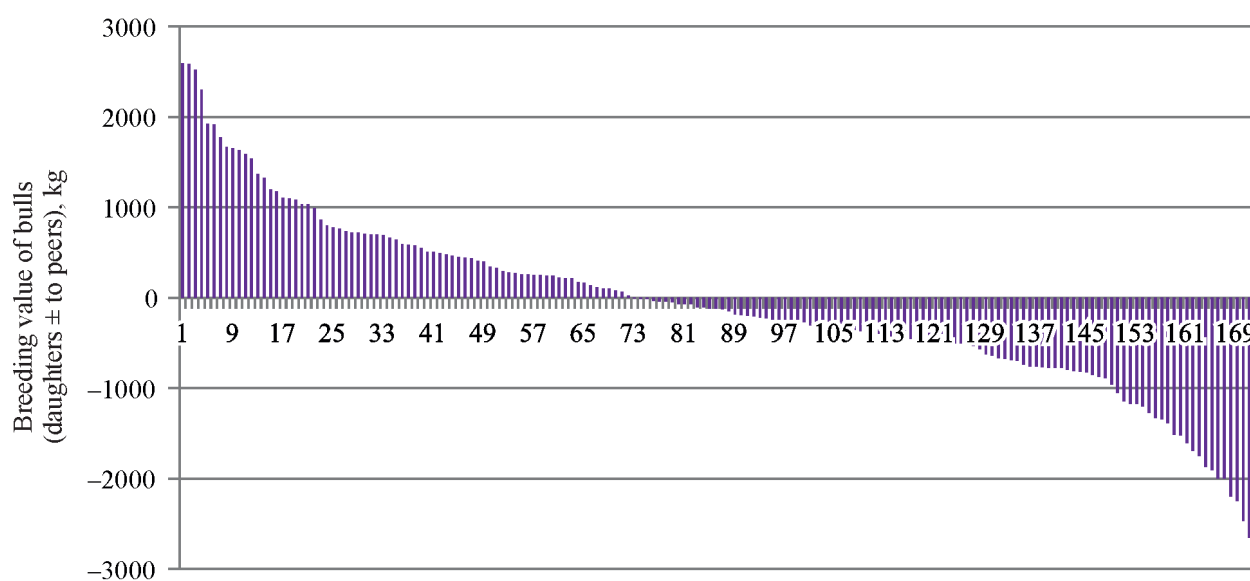
Based on the results of the evaluation of stud bulls using the “daughter-peer” method, it was found that the daughters of 79 stud bulls, or 46.1% of the number of the bulls included in the analysis, surpass their peers in milk yield from 37 to 2298 kg (see Fig. 2).

From these bulls, stud bulls whose daughters significantly ($p \leq 0.05$ – 0.001) outperformed their peers in milk yield were identified. To calculate the effectiveness of selection using this method, 40 sires with the highest daughter-to-peer milk yield were selected.

The total number of daughters of bulls amounted to 2,643 heads, or 30.0% of the total number of cows included in the study. The offspring of the selected sires significantly outperformed their peers in first-lactation milk yield, ranging from 273 to 2,298 kg.

A comparative analysis of the composition of the studied groups of sires revealed that 28 sires (70.0% of the 40 heads) were included in both groups selected for their genetic potential and its realization, and those selected using the “daughter-peer” method. Accordingly, the qualitative composition of the selected groups of bulls was largely similar.

The selection efficiency for each method was determined by calculating the selection differential as the difference in daughter-to-mother productivity. As a result, a high degree of variability in the selection differential was observed in the groups of bulls selected by different methods: from -297 to +2,296 kg in the first group, and from -297 to +2,684 kg in the second. The average value of the selection differential in bulls selected based on the level of genetic potential and its implementation was +930 kg, according to the results of the “daughter-peer” method of assessment +935 kg.



The bull's ordinal number in the breeding value ranking

Рис. 2. Распределение производителей по племенной ценности, рассчитанной методом «дочери-сверстницы»

Fig. 2. Distribution of stud bulls by breeding value, calculated by the “daughter – peer” method

In both groups, the majority of producers (36 out of 40, or 90.0%) showed a positive selection differential for milk productivity, which in the first group varied from +218 to +2296 kg, and in the second – from +117 to +2684 kg. This confirms the improving effect of bulls on the productivity of daughters.

Of the bulls with a positive selection differential, 25 sires were included in both the group selected for genetic potential and its realization, and the group selected for the difference in milk yield between daughters and their peers (see Table 1). Accordingly, these bulls have an accurate, reliable estimate of their improving effect on offspring productivity in the controlled population.

In each studied group of bulls, four sires with a negative selection differential were identified, three of which are included in both the first and

second groups (see Table 2). These are Zlatoy 834, Smirny 5477, and AltaSkaykrest 70541411. The bull Chadwick 11011994 is included in the first group, and Milord 417 is included in the second.

Daughters of these bulls yield between 25 and 297 kg of milk less than their mothers in their first lactation. Consequently, the realization of the genetic potential for milk production and the superiority of these bulls' offspring over their peers are due not so much to the influence of paternal genetics, but rather to the fact that the bulls were used on high-yielding breeding stock.

Thus, the average milk yield for 305 days of the first lactation of mothers of the offspring of the bulls with a negative selection differential was 10,040 kg for the bull Milord 417, 9419 for Smirny 5477, 9129 for Chadwick 11011994,

Табл. 1. Быки-производители, оказавшие достоверное положительное влияние на молочную продуктивность дочерей

Table 1. Stud bulls that had a significant positive effect on their daughters' milk production

Nickname	Inventory number	Herd of daughters	Genetic potential, kg	Realization of genetic potential, %	Breeding value $\pm$ relative to peers	Selection differential, kg
1	2	3	4	5	6	7
AltaAlpha	70346650	96	15041	60,8	701***	1306***
AltaLeiker	69990160	17	14967	60,5	604*	1075***
Blues	7774	16	14830	64,4	1104***	1540**
Monoserotis	56350339	12	14797	61,4	641*	1435**
AltaRoboto	71588445	17	14745	60,6	496*	470
Juror	7783	9	14469	69,8	1653***	856*
AltaShelby	70625905	68	14343	62,8	576***	1403***
AltaSuperior	66133538	37	14205	65,1	800***	1816***
Justin	4240504592	159	14147	61,7	293**	463**
Gusar	363	300	14124	62,8	440***	756***
AltaRazzle	70215869	46	14055	62,2	297*	219
Rabel	1958	71	14011	62,6	330**	1177***
Trubach	174	158	13966	64,8	611**	1092***
Morko	98114	19	13824	69,9	1254***	486
Mishret	106070030	26	13725	75,5	1917***	218
AltaDelcampo	880372082	118	13619	64,0	273***	919***
Versal	5442	62	13430	68,9	720***	560*
Kleik	11471420	15	13414	71,1	1100***	1315***
Lenok	3019	323	13398	67,0	550***	1773***
Suares	519550898	14	13289	74,7	1485**	687

Окончание табл. 1

1	2	3	4	5	6	7
Miksi	98117	177	13277	65,9	279***	1035***
Ralli	111	202	13035	69,3	593***	864***
Tor	69701703	51	13032	68,4	477**	2296***
Klad	3124	38	12947	75,4	1323***	196
AltaTsar	72189851	39	12937	68,8	456*	757**

* $p \leq 0,05$.

** $p \leq 0,01$.

*** $p \leq 0,001$.

Табл. 2. Племенная ценность быков-производителей с отрицательным селекционным дифференциалом

Table 2. Breeding value of stud bulls with a negative selection differential

Nickname	Inventory number	Herd of daughters	Genetic potential, kg	Realization of genetic potential, %	Breeding value $\pm$ relative to peers	Selection differential, kg
AltaSkycrest	70541411	12	14932	60,0	507*	–25
Smirny	5477	30	12902	71,6	753**	–224
Milord	417	30	12531	78,3	1370***	–230
Chadvik	11011994	21	13248	66,8	19	–280
Zlatoi	834	118	13664	63,9	283*	–297*

* $p \leq 0,05$.

** $p \leq 0,01$.

*** $p \leq 0,001$.

9022 for Zlaty 834, 8977 kg for AltaSkaykrest 70541411, with an average productivity of mothers for the studied herd of 7606 kg.

CONCLUSIONS

1. The study revealed a high level of genetic productivity potential in the maternal ancestors used in the bull population. 77.6% of the bulls had a genetic potential for milk production exceeding 12,000 kg.

2. Evaluation of stud bulls using the daughter-peer method showed that the daughters of 46.1% of bulls outperform their peers in milk yield from 37 to 2298 kg.

3. Selecting the best sires into groups based on genetic potential and its degree of realization, as well as the difference in milk yield between daughters and peers, revealed that the methods used were equally effective. This is evidenced by the 70.0% similarity in the qualitative composition of the bull groups and the similar aver-

age selection differentials in these groups—930 and 935 kg.

4. The efficiency of selection of stud bulls increases if the assessment using any method is supplemented by the calculation of the selection differential, reflecting the degree of improvement of the offspring in milk productivity in comparison with their mothers.

5. The integrated use of the proposed methods will contribute to increasing the reliability of assessing the breeding value of bulls and the efficiency of selecting the best stud bulls in the dairy cattle population.

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Роботизированное внесение наноксида цинка при листовой подкормке сахарной свеклы

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Сахарная свекла является одной из важнейших технических культур, урожайность которой часто снижается из-за дефицита цинка в почве. Традиционное почвенное внесение удобрений характеризуется низкой доступностью этого микроэлемента для растений. В статье обоснована перспективность применения роботизированного комплекса для прецизионной листовой подкормки сахарной свеклы наноразмерным оксидом цинка (nZnO). Определены преимущества наноформы оксида цинка по сравнению с традиционными формами, заключающиеся в повышенной способности к проникновению через устьичный аппарат листа и последующей транслокации по флоэме к корнеплоду. Показано, что аэрозольный способ внесения с электростатической зарядкой частиц позволяет минимизировать их агрегацию, обеспечивая доставку nZnO размером 30–50 нм и повышая эффективность поглощения цинка в 2,0–2,5 раза по сравнению с капельным опрыскиванием. Приведены экспериментальные данные, согласно которым листовая обработка nZnO в концентрации 200–300 ppm способствует увеличению урожайности корнеплодов на 10–17%, валового сбора сахара на 15–20%, содержания сахарозы на 1,0–1,5%. Представлена архитектура роботизированного комплекса, интегрирующего автономную платформу, гиперспектральную систему технического зрения для идентификации дефицита цинка по спектральным индексам и аэрозольный генератор для точечного внесения нано-микроудобрения. Технико-экономическое обоснование демонстрирует, что, несмотря на более высокие первоначальные затраты, рассматриваемая технология обеспечивает прибавку урожая до 8–12 т/га и чистый дополнительный доход 50–80 тыс. р./га за счет экономии препарата на 30–50% и значительного повышения выхода сахара (1,2–1,8 т/га). По результатам проведенного анализа можно сделать вывод об экологической безопасности, перспективности и потенциальной рентабельности изучаемой технологии.

Ключевые слова: сахарная свекла, листовая подкормка, наноксид цинка, роботизированный комплекс, аэрозольное внесение, урожайность, качество корнеплодов

Robotic application of nanozinc oxide for foliar application to sugar beet

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Sugar beet is one of the key industrial crops, the productivity of which is often limited by zinc deficiency in the soil. Traditional soil fertilization is characterized by low availability of this micronutrient to plants. The article substantiates the prospects of using a robotic complex for the

precision foliar fertilization of sugar beet with zinc oxide nanoparticles (nZnO). The advantages of the nanoform of zinc oxide compared to traditional forms have been determined, consisting in an increased ability to penetrate the stomatal apparatus of the leaf and subsequent translocation along the phloem to the root crop. It is shown that the aerosol application method with electrostatic charging of particles minimizes their aggregation, ensuring the delivery of nZnO sized 30–50 nm and increasing zinc absorption efficiency by 2.0–2.5 times compared to droplet spraying. Experimental data are presented, according to which foliar treatment with nZnO at a concentration of 200–300 ppm increases root yield by 10–17%, gross sugar yield by 15–20%, and sucrose content by 1.0–1.5%. The architecture of a robotic complex is presented, integrating an autonomous platform, a hyperspectral vision system for identifying zinc deficiency based on spectral indices, and an aerosol generator for targeted application of nano-microfertilizers. The technical and economic assessment demonstrates that, despite higher initial costs, the proposed technology provides a yield increase of up to 8–12 t/ha and a net additional income of 50–80 thousand rubles/ha due to a 30–50% saving in the preparation and a significant increase in sugar yield (1.2–1.8 t/ha). Based on the results of the analysis, a conclusion can be drawn about the environmental safety, prospects and potential profitability of the technology being studied.

Keywords: sugar beet, foliar fertilization, zinc nanooxide, robotic complex, aerosol application, yield, root quality

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Конфликт интересов

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Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Sugar beet (*Beta vulgaris* L.) is a key industrial crop in Russia's agro-industrial complex. Improving its productivity and root crop quality is a strategic objective. Traditional plant nutrition systems based on soil-applied fertilizers are often ineffective due to the low mobility and availability of their micronutrients (particularly zinc). Zinc deficiency negatively impacts plant metabolism, auxin synthesis, and, consequently, yield formation and sucrose accumulation.

Micronutrient deficiencies in the soil are the main limiting factor in beet production. The use of nanomicrofertilizers on various crops has promoted plant growth and development, increased yields and the quality of agricultural products, and has the potential to improve plant productivity and nutrition. Nanofertilizers can be used as an alternative to mineral fertilizers, as they help increase the efficiency of nutrient use by plants [1]. Foliar application of nanoforms of zinc, manganese, iron, and boron plays a significant

role in improving growth, yield, and quality of sugar beets. Nanoforms help gradually supply plants with essential nutrients. Nanofertilizers offer greater economic efficiency and are more environmentally friendly than chemical fertilizers [2–4].

Recently, foliar application technologies using nanoscale micronutrients have attracted the attention of researchers. Nanoparticles possess unique physicochemical properties: increased reactivity, increased specific surface area, and the ability to more effectively penetrate leaf cuticles and stomata. When combined with precision farming methods, such as autonomous robotic platforms, this technology opens up new possibilities for production process control [5, 6].

The results of the studies by H.H. Amin et al. [7] show that nano zinc oxide (nZnO) at concentrations of 50 and 100 ppm can be used for foliar spraying of sugar beet plants to reduce the harmful effects of powdery mildew caused by *Erysiphe betae* by inducing resistance to the pathogen.

In addition, nZnO reduces the impact of abiotic stressors [6]. J. Hong et al. [5] not only confirm that endocytosis is one of the mechanisms of nanoparticle uptake during foliar application, but also point out the role of this process in the subsequent transport of nanoparticles within the plant (entry into the phloem and movement to the roots).

The aim of this study is to substantiate the prospects of using a robotic complex for foliar aerosol fertilization of sugar beets with nanozinc oxide based on the analysis of modern scientific data and technical solutions.

Research objectives are:

- 1) to analyze the mechanisms of action of nano zinc oxide in foliar treatment;
- 2) to evaluate the effectiveness of the aerosol delivery method;
- 3) to propose the architecture of a robotic complex with a hyperspectral diagnostics system;
- 4) to carry out a feasibility study of the technology being studied.

SCIENTIFIC BACKGROUND TO THE EFFECTIVENESS OF ZINC NANO OXIDE

Experimental data obtained in various research centers convincingly demonstrate the advantages of zinc nanoforms compared to traditional salts and macro-sized oxides.

Domestic research in the field of robotic platforms for precision farming, in particular the work of V.K. Abrosimov and V.V. Eliseev [8], confirm the promise of using autonomous systems for the care of row crops. However, the issues of integrating such platforms with hyperspectral monitoring systems and aerosol application of nanofertilizers remain insufficiently studied, which determines the relevance of this study.

Increasing the yield and quality of root crops

Two-year field trials in Egypt demonstrated the high efficiency of foliar application of nZnO to sugar beet [9]. Treatment of plants with a 300 ppm nZnO solution, coupled with optimal nitrogen nutrition (100 kg/ha), significantly increased root weight by 12–17%, yield by 10–15%, gross sugar yield by 15–20%, and sucrose content by 1.0–1.5%. Moreover, the maximum effect in terms of quality indicators (juice purity, proportion of extracted sugar) was achieved with

a combination of nZnO in the amount of 200 ppm and a moderate dose of nitrogen (60 kg/ha), which indicates the possibility of optimizing resource consumption.

Mechanism of action

The high efficiency of nZnO is explained by its ability to more easily penetrate the leaf barrier. Studies on other agricultural crops have shown that nanoparticles smaller than 100 nm can penetrate the leaf primarily through the stomatal pathway and are then transported via the phloem to other plant organs, including the root system. For sugar beet, where the root is the productive organ, targeted delivery of zinc specifically to the sugar accumulation zone is critically important.

MECHANISM OF TARGETED AEROSOL DELIVERY OF NZNO TO FOLIAGE

Traditional spraying with aqueous suspensions has a significant drawback: the tendency of nanoparticles to aggregate, which increases their effective size and reduces their penetration. The solution is to use aerosol technology, in which sprayers are equipped with electrostatic charging systems. Special electrodes in the spray nozzles create a strong electric field that ionizes the air and transfers a negative charge to each aerosol particle during spraying. The use of electrostatics solves the problem of targeted nZnO spraying on beet tops and reduces losses due to attraction to the target and envelopment of the leaves.

Particle size control

E.R. Carmona et al. [10] demonstrated that an aerosol generator using the principle of collision dispersion allows the creation of particles of a given size (e.g., 30–50 nm for ZnO) while avoiding their aggregation. This ensures maximum bioavailability of the active substance.

Delivery efficiency

A comparison of the aerosol method with droplet application of the suspension showed that the proportion of zinc reaching the beet root system was 2.0–2.5 times higher in the former case. Small particles in aerosol form more easily penetrate the stomata along with the gas flow, unlike large droplets, which can be retained by the waxy cuticle layer [5, 10].

The results of the studies indicate that negatively charged particles are more effective for transport through plant vascular tissues.

The primary route of nanoparticle penetration is stomatal. The stomatal size (several micrometers) allows ZnO nanoparticles (~28–47 nm) to penetrate the leaf. Direct penetration through the cuticle is limited for particles larger than 5 nm [10].

Environmental safety

Point aerosol application (robotic patch sprayer) minimizes product loss and eliminates its direct entry into the soil, reducing the potential impact on soil biota [11].

MOVEMENT OF NZNO WITHIN THE PLANT TO THE ROOT CROP

1. Leaf entry. After penetrating through the stomata, nZnO enters the intercellular spaces and the apoplast.

2. Intracellular uptake (optional). Nanoparticles can be taken up by cells via endocytosis or through pores in the cell wall.

3. Further transport via the phloem. The main route of nZnO delivery to the root crop is phloem transport [5, 10]:

- once in the phloem sieve tubes, the nanoparticles move along with the flow of photosynthates (sugars, primarily sucrose) from the leaves to the root crop, where the sugars are stored;

- this process occurs due to the pressure difference (Munch's mass flow hypothesis).

4. Accumulation in the root. Nanozinc oxide accumulates in the root cells of sugar beets. Studies on other plants (watermelon) using the aerosol method confirm that metal nanoparticles can reach the roots [10]. A significant increase in the yield and quality of sugar beet roots with foliar treatment with nZnO is also indirectly confirmed by E.A. Teama et al. [9], indicating successful absorption and translocation of zinc.

CONCEPT OF A ROBOTIC COMPLEX FOR PRECISION FEEDING

The integration of aerosol technology into an autonomous robotic complex allows for the transition from continuous application of nZnO to precision application, taking into account the heterogeneity of the field (differences in soil, microrelief, uneven emergence and plant de-

velopment) and the phytosanitary condition of the crops [12–14]. This solution involves the creation of a digital control loop: sensors → algorithms → actuators. This transforms agricultural technology from an "art" into a controlled, high-precision engineering system that doesn't struggle with heterogeneity, but rather works with it, extracting maximum efficiency and savings from every section of the field.

Architecture of the complex

The complex includes:

1. An autonomous, electric-powered wheeled platform. This platform could be similar, for example, to robots with a variable track width, a multiple of 0.45 m (see Fig. 1, 2). The following devices based on standardized and unmanned approaches are also applicable in unstructured agricultural environments: the Robotics Plus autonomous spraying robot [15], the BoniRob robot [16], and the specialized SugaRob robot on a caterpillar track with a 1.8 m track width [8].

2. A vision system based on multi- and hyperspectral cameras for plant identification, assessment of their nitrogen status (NDVI, Normalized Difference Vegetation Index) and signs of micronutrient deficiency [17–19].

3. An aerosol generator with a high-precision nZnO dosing system, controlled by an onboard computer. The intelligent, selective precision spray system includes servo-driven nozzles, flow control systems, and ultrasonic sensors [20–23].

4. A navigation system (RTK-GPS, lidars) for navigation along a given trajectory and positioning. The Real-Time Kinematic (RTK) method enables centimeter-level positioning accuracy.

Operating algorithm

For early detection of zinc deficiency, the classic NDVI index is insufficient, as it only reflects overall photosynthetic activity. Hyperspectral sensing, which records reflectance in narrow spectral ranges sensitive to changes in trace element content, is more informative [17, 19]. Based on such data, specialized vegetation indices are calculated (for example, a normalized difference index correlating with zinc concentration in leaves). Several studies confirm the possibility of spectral differentiation of plants with different zinc contents, including its nanoform, which allows the use of hyperspectral cameras for early stress detection [9, 10].

The robotic system scans sugar beet crops in real time (agro-scouting). Upon detecting an area with signs of growth inhibition or changes in spectral characteristics indicating a potential zinc deficiency or nutritional imbalance, the system activates an aerosol generator. The nZnO is applied specifically to specific plants or groups of plants, rather than to the entire field. This reduces the application rate by 30–50% compared to traditional spraying.

Practical implementation for sugar beet

To assess zinc deficiency in sugar beet tops, one will need:

1. Calibration. This requires field studies: taking plant samples from different parts of the field, laboratory analysis of leaf tissue for zinc content, and simultaneously capturing their hyperspectral "signature."

2. Modeling. Using machine learning or regression analysis methods, a model should be built that links specific spectral characteristics (or combinations of indices) to the zinc concentration in the plant.

3. Monitoring. After calibrating the data obtained with a drone's hyperspectral camera, it's possible to create a potential zinc deficiency map rather than an NDVI map.

FEASIBILITY STUDY (FS)

An approximate estimate of the economic efficiency of the technology under consideration is given in the table.

Despite the high cost of nanozinc oxide and the depreciation costs of robotic equipment, as a result of a significant increase in yield [24] and savings in the preparation due to targeted application, the net economic efficiency of the technology under study is 2–3 times higher than that of the traditional approach.

CONCLUSIONS

Based on the analysis performed, the following conclusions can be formulated:

1. Foliar treatment of sugar beet with nanozinc oxide increases root crop yield by 10–17% and sucrose content by 1.0–1.5% due to more efficient penetration of nanoparticles through stomata and their transport along the phloem to the root crop [5, 9, 10].

2. Aerosol application with electrostatic charging allows for the delivery of particles 30–50 nm in size, minimizing their aggregation and increasing the efficiency of zinc absorption by 2.0–2.5 times compared to drip spraying [10].

3. The use of hyperspectral vision systems in



Рис. 1. Общая конструкция робота-опрыскивателя с форсунками, ориентированными для распыления перпендикулярно ряду растений [14]

Fig. 1. General design of a sprayer robot with nozzles oriented for spraying perpendicular to the plant row [14]



Рис. 2. Автономный робот Rippa, оснащенный интеллектуальным аппликатором для быстрой обработки растений и аэрозольного внесения нанудобрений (внекорневая подкормка) [13]

Fig. 2. Autonomous robot Rippa equipped with an intelligent applicator for rapid plant treatment and aerosol application of nanofertilizers (foliar application) [13]

combination with vegetation indices sensitive to trace element content makes it possible to detect zinc deficiency at early stages, which is confirmed by experimental data on the spectral differentiation of plants [9, 19].

4. The developed architecture of the robotic complex, including an autonomous platform, a hyperspectral diagnostic system, and an aerosol generator, ensures targeted application of the preparation, reducing its consumption by 30–50%, and increasing net additional income to 50–80 thousand rubles/ha.

5. For the successful implementation of this approach, further applied research is needed aimed at adapting the modes of aerosol application of nZnO specifically for sugar beet in various soil and climatic conditions, as well as the development and testing of prototypes of robotic systems. This direction, increasing the sustainability and productivity of sugar beet, appears to be extremely promising for investment and innovative development of the sugar beet sub-complex of the agro-industrial complex.

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Сравнительная оценка затрат и экономической эффективности подкормки сахарной свеклы
нанооксидом и сульфатом цинка (на 100 га)
Comparative assessment of costs and economic efficiency of feeding sugar beet with zinc nanooxide
and zinc sulfate (per 100 ha)

Indicator	Traditional spraying	Robotic complex
Preparation costs	150 rub. /ha (1 kg/ha of zinc sulfate)	600 rub../ha (0,2 kg/ha nZnO)
Working fluid consumption	200 l/ha (drip spraying)	5–10 l/ha (aerosol)
Application costs	500 rub. /ha (sprayer)	800 rub../ha (depreciation and maintenance of the robot)
Reducing the drug dosage	–	Up to 50% (through targeted application)
Expected increase in root crop yield	3–5 t/ha	8–12 t/ha
Expected increase in sugar yield	0,5–0,7 t/ha	1,2–1,8 t/ha
Additional income (at a sugar price of 50 rub/kg)	25–35 thous. rub./ha	60–90 thous. rub./ha
Net extra income	20–30 thous. rub./ha	50–80 thous. rub./ha

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Качество распределения жидких минеральных удобрений при их поверхностном внесении

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Представлены исследования по оценке и выбору распылителей при поверхностном внесении в почву жидких минеральных удобрений по критерию минимизации мощности на диспергирование единицы их объема и качеству распределения по подстилающей поверхности. Установлена целесообразность применения комбинированного гидропневмомеханического распылителя, сочетающего простоту и надежность в выполнении технологического процесса, присущие пневматическому способу диспергирования, низкие затраты мощности на этот процесс (не более 4 кВт/т), а также возможность использования сжатого воздуха для пневмомеханического распыливания. Обоснована перспективность использования для поверхностного внесения жидких минеральных удобрений вращающихся распылителей лепесткового и тарельчатого типов, обеспечивающих неравномерность распределения, не превышающую 8%, выраженную коэффициентом вариации. Определено, что независимо от типа распылителя при заданных оборотах (1700 мин^{-1}) зона устойчивого распределения распыленной жидкости (ширина факела распыла) определяется значением 2,2 м. Полученные характеристики качества распределения рабочей жидкости в факеле распыла позволяют сделать вывод о том, что при повышении давления в системе увеличивается расход рабочей жидкости, но сам характер ее осаждения на улавливающую поверхность подчинен закону нормального распределения. Установлено, что максимальное влияние на качественный показатель распределения рабочей жидкости оказывает диаметр распылителя и давление в системе, при этом значения данных факторов находятся на минимальном уровне. Поскольку значения коэффициентов при X_1 (нормированное значение давления жидкости в системе) и X_2 (нормированное значение диаметра отверстия распылителя) отрицательные, то их увеличение приводит к снижению неравномерности распределения рабочей жидкости на подстилающей поверхности. В этом случае минимальное значение неравномерности – 3,6% – достигается тогда, когда значения всех факторов находятся на максимальном уровне.

Ключевые слова: жидкие минеральные удобрения, поверхностное внесение, равномерность, вращающиеся распылители

Quality of the distribution of liquid mineral fertilizers in case of surface application

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The article presents research on the evaluation and selection of the sprayers for surface application of liquid mineral fertilizers to the soil based on the criterion of minimizing the power to disperse a unit of their volume and the quality of their distribution over the underlying surface. The expediency of using a combined hydro-pneumatic-mechanical sprayer has been established, which combines simplicity and reliability of the technological process execution inherent in the pneumatic method of dispersion, low power costs for this process (no more than 4 kW/t), as well as the possibility of using compressed air for pneumatic-mechanical spraying. The prospects of using rotating petal and plate-type sprayers for surface application of liquid mineral fertilizers, ensuring uneven distribution not exceeding 8%, expressed by the variation coefficient, have been substantiated. It has been determined that, regardless of the type of the atomizer, at a given speed (1700 мин^{-1}), the zone of stable distribution of the sprayed liquid (spray pattern width) is determined by the value of 2.2 m. The ob-

tained characteristics of the quality of the distribution of the working fluid in the spray pattern allow concluding that as the pressure in the system increases, the flow rate of the working fluid increases, but the pattern of its deposition on the collecting surface follows the law of normal distribution. It has been established that the diameter of the sprayer and the pressure in the system exert the maximum influence on the quality indicator of the distribution of the working fluid, while the values of these factors are at a minimum level. Since the values of the coefficients for X_1 (the normalized value of the liquid pressure in the system) and X_2 (the normalized value of the nozzle hole diameter) are negative, their increase leads to a decrease in the uneven distribution of the working liquid on the underlying surface. In this case, the minimum value of unevenness – 3.6% – is achieved when the values of all factors are at the maximum level.

Keywords: liquid mineral fertilizers, surface application, uniformity, rotating sprayers

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Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

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INTRODUCTION

The basis for the development of work on the application of liquid complex fertilizers (LCF) was the recommendations of V.M. Klechkovsky and A.V. Peterburgsky. These authors clearly state that "based on international experience, liquid complex fertilizers can be applied in the same ways as solid ones: by continuous distribution over the field surface before plowing or cultivation, local application during sowing, inter-row fertilization of row crops, or surface application of close-growing crops." Under such conditions, some farms may rely solely on liquid fertilizers and purchase a set of appropriate machines.¹ To date, a significant number of methods for spraying liquid media have been identified, but for surface application of liquid fertilizers, hydraulic dispersion is most in demand, including the use of deflector, slot, injector, cone, tangential and other types of sprayers, as well as mechanical dispersion, which ensures the dispersion of

liquid using rotating disks. All the above-mentioned types of sprayers can be recommended for surface application of liquid fertilizers, but it is necessary to select the most effective ones in terms of minimizing power consumption for dispersing a unit volume of liquid medium and to evaluate the possibility of using new types of sprayers for these purposes.

The purpose of the work is to evaluate the quality of distribution of liquid forms of mineral fertilizers during their surface application by sprayers of various types.

The objective of the work is to determine the influence of the main factors on the quality of distribution of liquid mineral fertilizers during their surface application using rotating hydro-pneumatic-mechanical sprayers.

MATERIAL AND METHODS

To justify the use of distribution devices for surface application of liquid complex fertilizers,

¹Agrochemistry / edited by V. M. Klechkovsky and A. V. Peterburgsky. 2nd edition, corrected and enlarged. Moscow: Kolos, 1967, 683 p.

a four-stage scientific research procedure was applied.

In the first stage, a promising method for dispersing the working fluid was identified, with the aim of minimizing the power consumption per ton of liquid medium (kW/t). A variety of sources were used to obtain the necessary information: catalogs, brochures, statistical data, reference books, recommendations, books, journal articles, the internet, and others. After analyzing and evaluating the information, the material is presented in the form of a logically justified diagram of power costs for dispersing 1 ton of liquid medium (kW/t) and a promising method is selected according to the specified criterion^{2,3}.

In the second stage, the fluid flow rate through nozzles with different hole diameters (l/min) was determined. The fluid flow rate was measured over 60 s and then converted to liters per hour (l/h). Nozzles with hole diameters of 1.5×10^{-3} ; 2.5×10^{-3} and 3.5×10^{-3} m were used for the study, and the system pressure was 0.02; 0.03 and 0.04 MPa.

Based on the research results, the range of possible use of sprayers with a given hole diameter for the implementation of the starting or main dose of liquid mineral fertilizers was determined [1–6].

In the third stage, the distribution of sprayed liquid within the work area by a single sprayer was examined. This determined the spray width and the distribution of the working fluid (WF) across the spray width (B , m) (see Fig. 1).

Based on the obtained data, the spray pattern spacing on the boom was determined using the spray pattern overlap method. It is taken into account that the spray pattern overlap of individual sprayers must be at least 30% of their width [7–9].

To conduct the research, two types of hydropneumatic mechanical sprayers using compressed air were adopted for implementation (see Fig. 2).

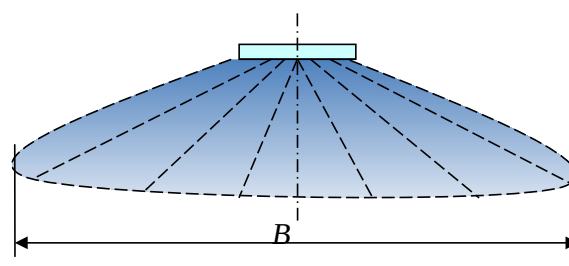


Рис. 1. К определению ширины факела распыла одиночным распылителем

Fig. 1. Determining the spray pattern width by a single sprayer

At the fourth stage of the research the quality of deposition of the sprayed preparation on the underlying surface by the sprayers was assessed. The following parameters were adopted: the number of disk revolutions per unit of time $n = 1700$; the spacing of the sprayers on the boom $B = 0.5$; 0.7 ; 0.9 m; the pressure in the system $P = 0.02$; 0.03 ; 0.04 MPa; the diameter of the sprayer hole 1.5×10^{-3} ; 2.5×10^{-3} and 3.5×10^{-3} m.

To assess the quality of deposition of the sprayed preparation onto the underlying sur-

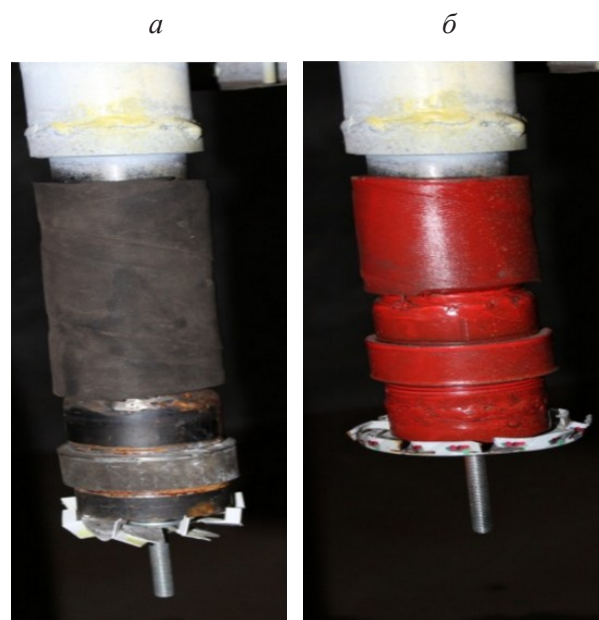


Рис. 2. Гидропневмомеханические распылители: а – лепестковый; б – тарельчатый

Fig. 2. Hydropneumatic-mechanical sprayers: а – leaf-type; б – disk

²Vasiliev A.G., Gretsov V.K. Methods of analysis of scientific and technical information. Moscow: IPKIR, 1989, 9 p.

³Guidelines for conducting patent research. Moscow: VNIPI, 1983, 193 p.

face, a factorial experiment was conducted with the specified factors varied at three levels. A three-level symmetrical composite design, No. 34, was chosen for the experiment^{4, 5} [10]. The output parameter is the uneven distribution of the working fluid on the underlying surface, expressed by the variation coefficient $\sqrt{v}$, %.

The studies were conducted on a specially designed laboratory setup (see Fig. 3). Each experiment was structured as follows:

The working fluid from the LCF tank, at the required pressure, regulated by a shut-off valve and displayed by a pressure gauge, is supplied through hoses to the pneumatic-mechanical sprayers for dispersion. Simultaneously, compressed air, forced by a fan, is supplied through

a central air duct via a distributor to the working fluid delivery area. Upon contact with the rotating surfaces of the sprayers, it disperses, is ejected into the air, and settles on the underlying surface, where it flows into measuring containers. A pressure gauge and shut-off and control equipment are used to control the pressure supply of the working fluid.

The experiment lasted 120 seconds. After the specified time, the incoming liquid was cut off. The liquid in the beakers was weighed on a VK-600 scale with an accuracy of 0.1 g, and the results were recorded in a log. After the experimental plan was implemented, the results were processed in accordance with the recommendations^{6, 7} and the influence of the indicated factors

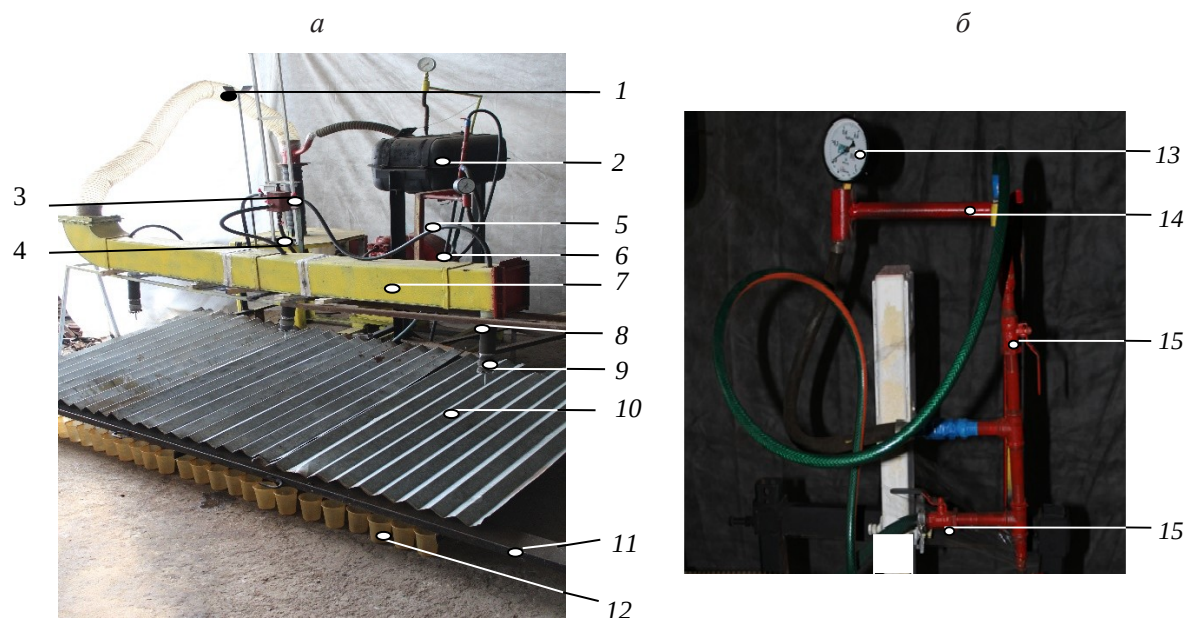


Рис. 3. Лабораторная установка для оценки качества распределения ЖКУ гидропневмомеханическими распылителями по подстилающей поверхности:

a – общий вид; *б* – система подвода и управления распределения рабочей жидкости:

1 – центральный воздуховод; 2 – бак для ЖКУ; 3 – распределитель ЖКУ; 4 – шланг подачи ЖКУ к распылителям; 5 – рама; 6 – вентилятор; 7 – распределитель сжатого воздуха; 8 – подставка для распределителя сжатого воздуха; 9 – пневмомеханический распылитель; 10 – подстилающая поверхность; 11 – отсечной механизм; 12 – мерные емкости; 13 – манометр; 14 – держатель манометра; 15 – запорные вентили

Fig. 3. Laboratory setup for assessing the quality of liquid complex fertilizer distribution by hydro-pneumatic mechanical sprayers on the underlying surface:

a – general view; *б* – a system for supplying and controlling the distribution of the working fluid:

1 – central air duct; 2 – tank for LCF; 3 – LCF distributor; 4 – LCF supply hose to the sprayers; 5 – frame; 6 – fan; 7 – compressed air distributor; 8 – stand for the compressed air distributor; 9 – pneumatic mechanical sprayer; 10 – underlying surface; 11 – cut-off mechanism; 12 – measuring containers; 13 – pressure gauge; 14 – pressure gauge holder; 15 – cutoff valves

⁴Tables of experimental plans for factorial and polynomial models: reference ed. / V.Z. Brodsky et al.; edited by V.V. Nalimov. Moscow: Metallurgy, 1982, 751 p.

⁵Patent No. 2790977 C1 Russian Federation, IPC A01C 23/02, A01C 23/04, B05B 7/24. Multi-flow liquid distributor / N.N. Nazarov, I.V. Nekrasova, I.V. Kopteva; No. 2022112099; applied 04.05.2022; published 01.03.2023.

on the qualitative indicators of the distribution of the working fluid across the width of the tool's grip was established.

RESULTS AND DISCUSSION

The process of atomization (dispersion) of a liquid jet is a complex physical phenomenon, which consists of breaking up a jet (or film) of liquid into a large number of droplets in space. Currently, many methods of liquid dispersion have been developed, each with its own advantages and disadvantages, determined by the quality of spraying, the cost of production of the equipment used, the power required to disperse a unit volume of liquid medium, operational reliability and other important indicators of the technological process under consideration [11, 12].

Analysis of the methods under consideration shows that hydraulic spraying is the most economical in terms of power consumption (2–4 kW) per ton of liquid dispersed. However, the resulting spray is rather coarse and non-uniform, yet this method is widely used for applying liquid fertilizers to the soil surface, as surface application involves large-droplet dispersion of the liquid medium. In mechanical atomization, where the working element is typically a rapidly rotating working element, a monodisperse spray is achieved by fragmenting the liquid as it is ejected from the atomizer by centrifugal force. The advantage of this method is that it allows for the atomization of highly viscous and contaminated liquids and the ability to regulate flow rates without significantly altering dispersion. Disadvantages include the high cost of sprayers and the relatively high power consumption of the dispersion process (approximately 15 kW per ton of liquid). Pneumatic dispersion of liquid fertilizers provides operational reliability and the ability to spray highly viscous liquids, but requires increased spray power (50–60 kW per ton of liquid).

From the analysis of the presented material it was established that in a comparative assessment of the values of the power expended for dispersing 1 ton of liquid medium, it is possible to use a combined hydropneumatic-mechanical sprayer, which combines simplicity, reliability in the implementation of the technological process, inherent in the pneumatic method of dispersion, and low power costs for this process, as well as the possibility of using compressed air for mechanical atomization. In this regard, the use of a hydropneumatic-mechanical method for dispersing liquid mineral fertilizers during their surface application can be considered quite acceptable in terms of power consumption for dispersing a unit volume of a liquid medium (see Fig. 4).

In accordance with the methodological approaches, the flow rate of liquid through nozzles with different hole diameters (l/min) was determined (see the table).

The given liquid consumption values allow to cover the required application rates of liquid mineral fertilizers when applied superficially as a starting dose.

In the third stage, the distribution of the sprayed liquid within the working area by a single atomizer was examined. The following spray pattern characteristics were determined: spray pattern width and the distribution of the working fluid across the spray pattern (b, mm).

It has been established that, regardless of the type of atomizer, at a given speed (1700 min^{-1}), the zone of stable distribution of the atomized liquid (spray width) is determined by the value of 2.2 m. The presented characteristics of the quality of distribution of the working fluid in the spray cone allow us to conclude that with an increase in pressure in the system, the consumption of the working fluid increases, but the nature of its distribution itself is subject to the law of normal distribution (see Fig. 5).

In the fourth stage, the quality of spray

⁶Mosteller F., Tukey D.W. Data Analysis and Regression; translated from English by Yu.N. Blagoveshchensky / edited and with a foreword by Yu.P. Adler. Moscow: Finance and Statistics, 1982, 239 p.

⁷Melnikov S.V., Aleshkin V.R., Roshchin P.M. Experimental Design in Agricultural Process Research; 2nd ed., revised and enlarged. Leningrad: Kolos, 1980, 168 p.

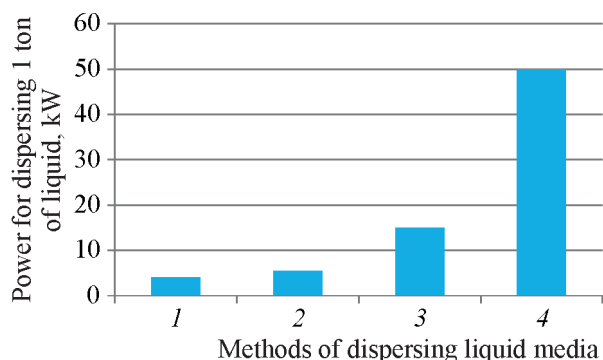


Рис. 4. Мощность, требуемая для диспергирования 1 т жидкой среды.

Способы диспергирования жидких сред: 1 – гидравлический; 2 – гидропневмомеханический; 3 – механический; 4 – пневматический

Fig. 4. Power required to disperse 1 t of liquid medium.

Methods of dispersion of liquid media: 1 – hydraulic; 2 – hydro-pneumatic-mechanical; 3 – mechanical; 4 – pneumatic

deposition onto the underlying surface was assessed using two types of pneumatic-mechanical atomizers—petal and disc. In both cases, a factorial experiment was adopted, varying the

Расход рабочей жидкости через жиклеры, л/мин (л/ч)
Flow rate of the working fluid through jets, l/min (l/h)

Диаметр отверстия жиклера, м	$P = 0,02$ МПа	$P = 0,03$ МПа	$P = 0,04$ МПа
$1,5 \cdot 10^{-3}$	0,3/18,0	0,36/21,6	0,4/24,0
$2,5 \cdot 10^{-3}$	2,0/120,0	2,5/150,0	2,8/168,0
$3,5 \cdot 10^{-3}$	4,15/249,0	4,34/260,4	4,56/273,6

above-mentioned factors at three levels. The output parameter was the unevenness of the working fluid distribution on the underlying surface, expressed as the variation coefficient $\sqrt{}$, %.

After implementing the experimental plan and processing its results, the regression coefficients were calculated taking into account their significance and a regression model of the process of dispersing the liquid over the collecting surface of a petal-type sprayer was obtained:

$$Y = 9,75 - 1,66 X_1^2 - 2,85 X_3^2 - 1,63 X_1 - 2,39 X_2 + 0,53 X_3 + 0,64 X_1 X_2, \quad (1)$$

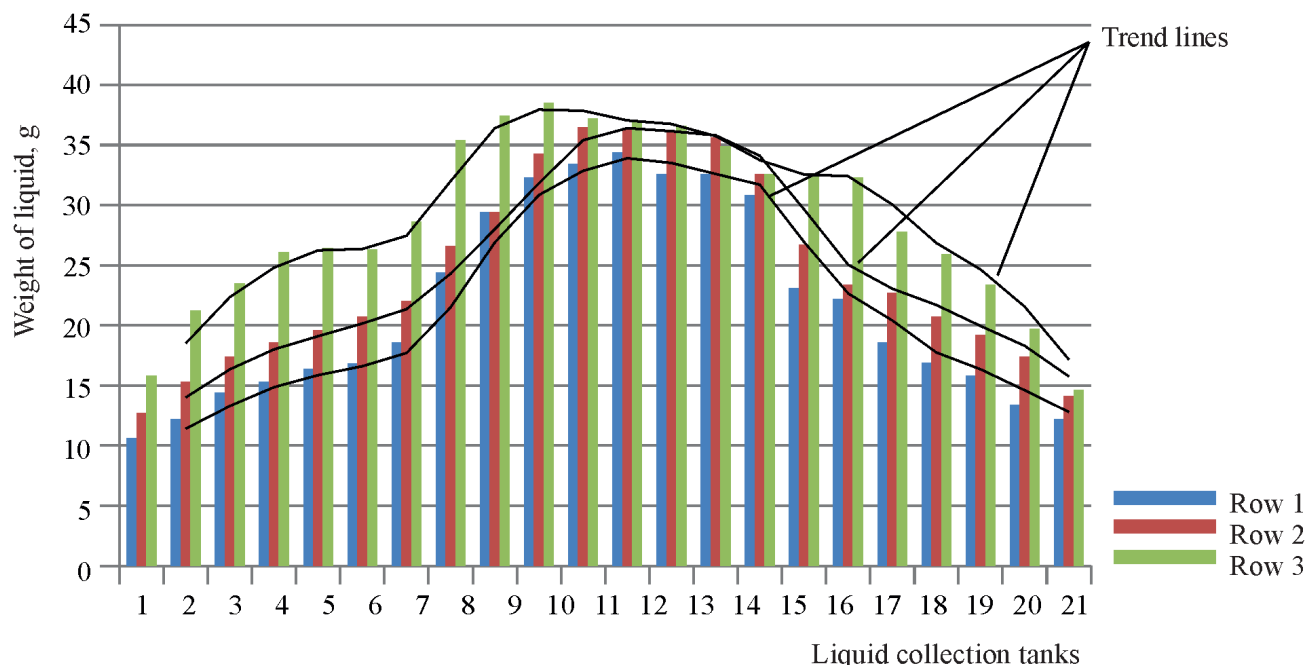


Рис. 5. Распределение рабочей жидкости по ширине факела распыла гидропневмомеханическим распылителем лепесткового типа:

ряд 1 – $P = 0,02$ МПа; ряд 2 – $P = 0,03$ МПа; ряд 3 – $P = 0,04$ МПа; $D = 2,5 \cdot 10^{-3}$ м

Fig. 5. Distribution of the working fluid along the width of the spray torch by a hydro-pneumatic mechanical sprayer of the petal type:

row 1 – $P = 0.02$ МПа; row 2 – $P = 0.03$ МПа; row 3 – $P = 0.04$ МПа; $D = 2.5 \cdot 10^{-3}$ m

where X_1 – normalized value of liquid pressure in the system ($X_H = -1$; $X_0 = 0$; $X_B = +1$) (P , MPa – 0,02; 0,03; 0,04); X_2 – standardized value of the nozzle orifice diameter ($X_H = -1$; $X_0 = 0$; $X_B = +1$) (D , m – $1,5 \cdot 10^{-3}$; $2,5 \cdot 10^{-3}$; $3,5 \cdot 10^{-3}$); X_3 – standardized value of the spacing of nozzles on the boom ($X_H = -1$; $X_0 = 0$; $X_B = +1$) (B , m – 0,5; 0,7; 0,9).

Analysis of the regression equation made it possible to establish the ambiguous influence of the studied factors on the quality of distribution of the working fluid over the underlying surface (see Fig. 6).

It was found that the nozzle diameter and system pressure have the greatest impact on the quality indicator, assessed by the uniformity of the working fluid distribution over the underlying surface, expressed by the variation coefficient, with the values of these factors being at a minimum. These factors are highly correlated, as they determine the flow rate of the working fluid supplied to the rotating nozzle.

Since the values of the coefficients for X_1 and

X_2 are negative, their increase leads to a decrease in the uneven distribution of the working fluid on the underlying surface. In this case, the maximum effect is achieved when X_1 and X_2 – max. It is important to note that the minimum value of unevenness – 3.6% – is achieved when the values of all factors are at the maximum level.

The influence of the mixed product of factors is also assessed by the significance and sign of the coefficient b_{ij} . Because $b_{ij} > 0$, then the minimum value of unevenness can be achieved if the designated factors are at the minimum and maximum levels.

In general, it is necessary to note the high quality of distribution of the working fluid by the petal distributor over the underlying surface: the average unevenness, estimated by the variation coefficient, does not exceed 8%.

Similarly, after implementing the experimental plan and processing its results, the regression coefficients were calculated taking into account their significance and a regression model of the process of dispersed liquid distribution over the

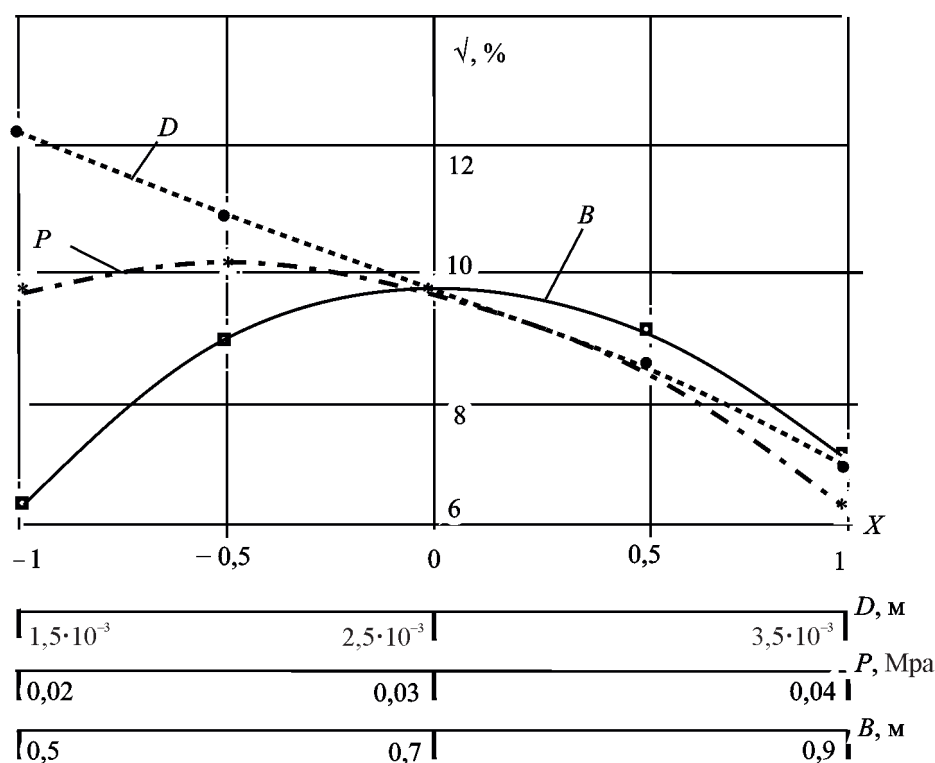


Рис. 6. Графическая интерпретация регрессионного уравнения (1)

Fig. 6. Graphical interpretation of the regression equation (1)

collecting surface of a plate-type sprayer was obtained:

$$Y = 7,2 + 1,09 X_1^2 + 1,11 X_2^2 - 0,76 X_1 - 1,85 X_2 + 1,14 X_3 + 1,65 X_1 X_2 + 0,85 X_1 X_3. \quad (2)$$

The normalized values of the factors are similar to those presented above.

Based on the analysis of the obtained regression equation, an ambiguous influence of factors on the quality of distribution of the working fluid over the underlying surface was also established (see Fig. 7).

As with the previous option, when using a plate-type sprayer, the sprayer diameter and system pressure have the greatest impact on the quality indicator, measured by the uniformity of the working fluid distribution over the underlying surface, expressed by the coefficient of variation. The values of these factors are also minimal.

To determine the influence of the coefficient values for X_1 and X_2 , the same reasoning applies as in the previous discussion. The coefficient values for X_1 and X_2 are negative, and increasing them leads to a decrease in the uneven distribution of the working fluid on the underlying surface. In this case, the maximum effect is achieved when X_1 and X_2 – max. The minimum value of unevenness – 4.1% – is achieved when the values of all factors are at the maximum level.

A distinctive feature from the previous scientific study is that there is a double interaction of factors: $X_1 X_2$ and $X_1 X_3$ (system pressure – nozzle diameter; system pressure – nozzle spacing). Because $b_{ij} > 0$, then the minimum value of unevenness can be achieved if the indicated factors are at the minimum and maximum levels.

It is worth noting the high quality of distribution of the working fluid by the disc distribu-

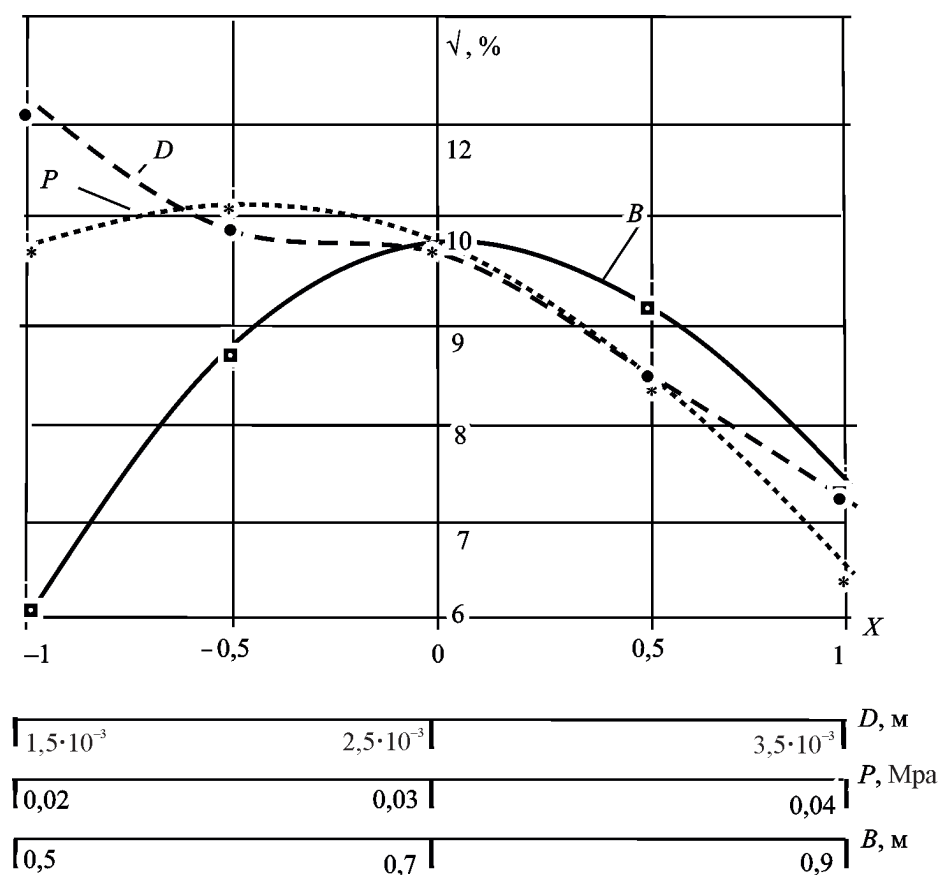


Рис. 7. Графическая интерпретация регрессионного уравнения (2)

Fig. 7. Graphical interpretation of the regression equation (2)

tor over the underlying surface: the average unevenness, estimated by the variation coefficient, is within 7%.

CONCLUSIONS

1. When comparing the values of power consumed to disperse 1 ton of liquid medium, the use of a hydropneumatic-mechanical method for dispersing liquid mineral fertilizers during their surface application can be considered promising (about 4 kW/t).

2. The feasibility of using rotating petal and plate type sprayers for surface application of liquid mineral fertilizers has been established, ensuring uneven distribution of no more than 8%, expressed by the variation coefficient.

3. It has been established that the maximum influence on the quality indicator, assessed by the uniformity of distribution of the working fluid over the underlying surface, expressed by the variation coefficient, is exerted by the diameter of the sprayer and the pressure in the system, while the values of these factors are at a minimum level, as well as when the values of all factors are at a maximum level.

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Periodical publication

Pakul A.L., Lapshinov N.A., Bozhanova G.V., Pakul V.N. Technological grain qualities of spring common wheat depending on the system of soil tillage // Siberian Herald of Agricultural Science. 2018. vol. 48. № 4. pp. 27-35. DOI: 10.26898/0370-8799-2018-4-4.

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In controversial cases, the editor may involve several specialists in the review process, as well as the Editor-in-Chief. If the reviewer’s opinion is positive, the article is submitted to the editor for preparation for publication.

In case a decision is made to have the manuscript revised, reviewer’s comments and remarks are passed to the author. The latter is given two months to make amendments. If, within this period, the author has not notified the editors about the actions planned, the article is removed from the publication waiting list.

In case there is a decision to reject the article, the notification with the editorial decision is sent to the author.

The designated author (contact author) is sent the final version of the manuscript accepted for publication, which he/she must check.

REVERSAL OF EDITOR/ REVIEWER’S DECISION

In case the author does not agree with the conclusions of the reviewer and/or editor, they can dispute the decision made. In order to do this, the author should:

- amend the manuscript in compliance with the comments substantiated by reviewers and editors;
- clearly outline their stance on the issue under question.

The editors facilitate the second submission of manuscripts that could potentially be accepted but were rejected due to the need of significant amendments or collection of the additional data, and are ready to clearly explain what must be rectified in the manuscript for it to be accepted for publication.

ACTIONS OF THE EDITORIAL BOARD IN CASE OF PLAGIARISM AND DATA FALSIFICATION DETECTION

The Editorial Board of the “Siberian Herald of Agricultural Science” follows the conventional ethical principles for scientific periodicals and guidelines of the “Publication Ethics Code” developed and approved of by the Committee on Publication Ethics (COPE) and demands that all those involved in the publishing process should obey these principles.

ERRORS RECTIFICATION AND ARTICLE WITHDRAWAL

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