



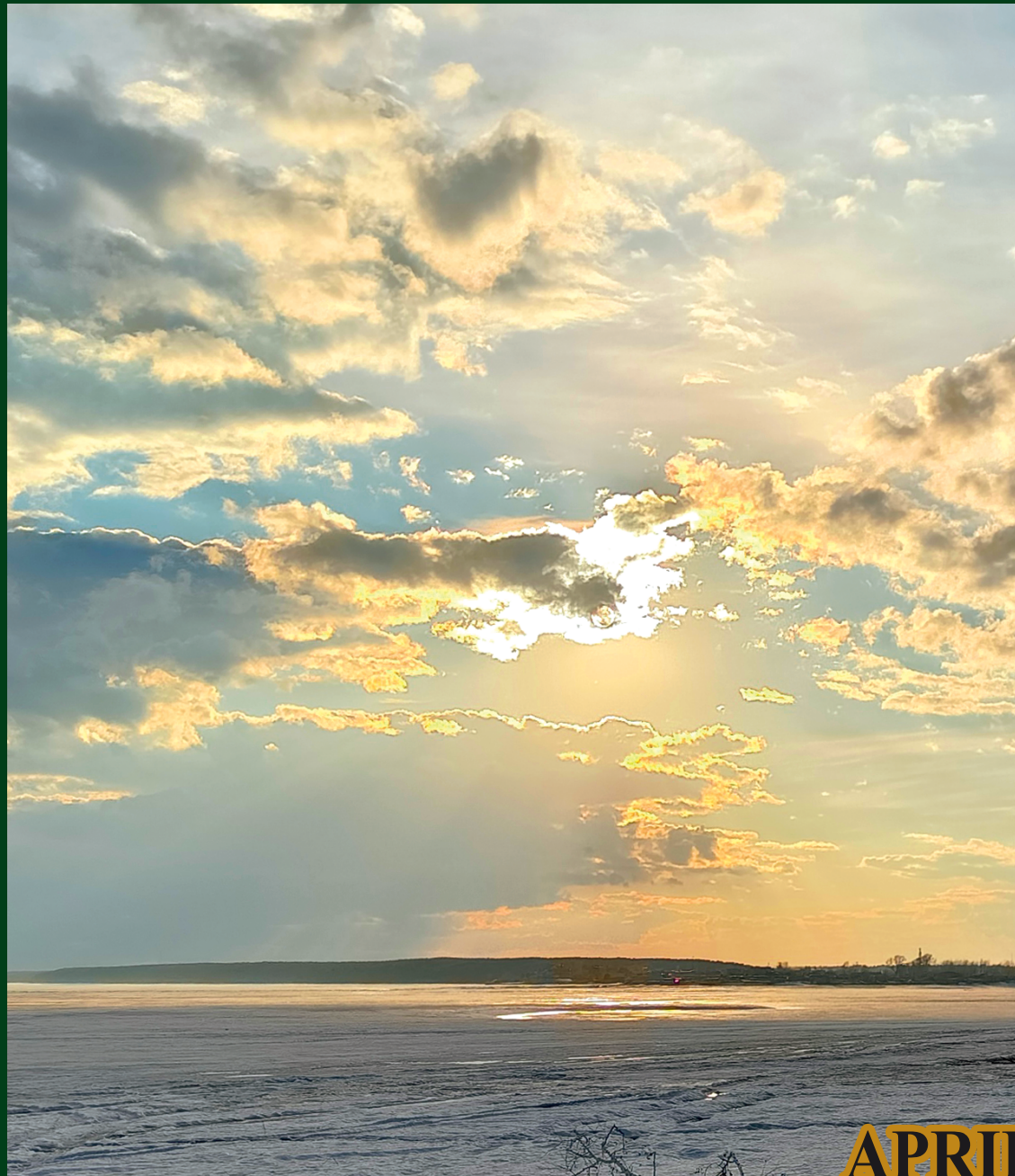
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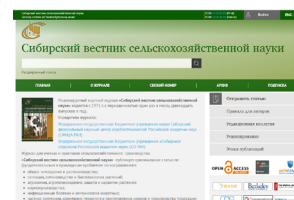
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Влияние технологий обработки почвы на ферментативную активность в ризосфере льна масличного

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Степной Крым характеризуется аридным климатом с высокими температурами и недостаточностью влаги, поэтому поддержание почв и повышение их плодородия становятся ключевыми задачами для обеспечения устойчивого развития сельского хозяйства. В статье представлены результаты экспериментального изучения воздействия различных технологий обработки почвы и применения микробиологического препарата Микробиоком-Агро на активность оксидоредуктаз в ризосфере льна масличного в условиях Крыма. Полевые исследования проводили в 2023, 2024 гг. на базе отдела полевых культур Научно-исследовательского института сельского хозяйства Крыма. В работе использовали сорт льна масличного Микс, который выращивали по двум технологиям: традиционной для региона вспашке на глубину 22–24 см и ресурсосберегающему прямому посеву без предварительной обработки почвы. Перед посевом применяли предпосевную бактериализацию семян Микробиоком-Агро, в контрольных вариантах использовали обработку водой. Результаты исследований показали, что в 2023 г. при традиционной системе земледелия и прямом посеве отмечено повышение термолabileй каталазной активности до 21,1–31,9 мл O_2 /мин/г абсолютно сухой почвы, что на 8,1–14,5% превышало показатели вариантов с применением биопрепарата. При этом обработка семян Микробиоком-Агро при традиционной технологии привела к снижению пероксидазной активности в 3 раза относительно контроля. В 2024 г. применение препарата в условиях прямого посева способствовало увеличению каталазной активности до 25,2 мл O_2 /мин/г абсолютно сухой почвы, что на 25,8% выше контрольных значений. В варианте с традиционной технологией обработки почвы биопрепарат сокращал пероксидазную активность в 6,6 раза по сравнению с контролем.

Ключевые слова: лен масличный, микробиологический препарат, ферментативная активность, ризосфера, обработка почвы

Influence of tillage technologies on the enzymatic activity in the rhizosphere of oilseed flax

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The steppe Crimea is characterized by an arid climate with high temperatures and a lack of moisture, so maintaining soils and increasing their fertility are becoming key tasks for ensuring the sustainable development of agriculture. The article presents the results of an experimental study on the impact of various soil treatment technologies and the use of the microbiological product Microbiocom-Agro on the activity of oxidoreductases in the rhizosphere of oilseed flax in the conditions of Crimea. The field studies were conducted in 2023–2024 based on the Department of Field Crops at the Research Institute of Agriculture of Crimea. The study used the Mix variety of oilseed flax, which was grown using two technologies: traditional ploughing to a depth of 22–24 cm, and resource-saving direct sowing

without pre-treatment of the soil. Before sowing, the seeds were pre-treated with Microbiocom-Agro and water was used in the control variants. The research results showed that in 2023, when using the traditional farming system and direct sowing, there was an increase in thermolabile catalase activity to 21.1–31.9 ml O₂/min/g of absolutely dry soil, which was 8.1–14.5% higher than in the variants using the biological product. However, when using the traditional technology, seed treatment with Microbiocom-Agro resulted in a 3-fold decrease in peroxidase activity compared to the control. In 2024, the use of the product under conditions of direct sowing contributed to an increase in catalase activity to 25.2 ml O₂/min/g of completely dry soil, which was 25.8% higher than the control values. In the variant with traditional soil treatment technology, the biopreparation caused a decrease in peroxidase activity by 6.6 times compared to the control.

Keywords: oilseed flax, microbiological preparation, enzymatic activity, rhizosphere, soil treatment

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Conflict of interest

The authors declare no conflict of interest.

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INTRODUCTION

Nowadays, a lot of different indicators are used to assess the biological state of soils, which is due to the many functions of soil microorganisms. Their life activities are based on the work of enzymes – biological catalysts that are responsible for biochemical reactions and are an integral part of the nutrient cycles in the soil, such as oxygen and nitrogen.

Enzymes form a natural reserve that gradually accumulates in the soil thanks to the activity of soil microorganisms, the work of land and underground animals, and also due to plant root secretions [1–3]. These enzymes keep their biological activity for a long time under optimal environmental conditions, like moisture, temperature, and soil acidity. Unlike the fluctuating

numbers of microorganisms, enzymatic activity is more stable [4–7]. Enzymes play a key role in breaking down organic matter, turning plant residues into nutrients and taking part in biochemical cycles.

The activity of soil enzymes in natural ecosystems is a sensitive indicator of the biochemical activity of soil microbial communities, as well as the rate of mineralization, humification, and accumulation of organic carbon in the soil. It can vary a lot depending on the type of crop grown, the method of soil treatment, and the level of fertilization [8, 9]. Long-term use of direct seeding, as well as the introduction of modern soil cultivation and sowing technologies on chernozems, does not lead to a decrease in soil enzymatic activity compared to traditional technologies [10, 11].

All the enzymes studied play an important role in the biodynamic processes of the soil ecosystem. Oxidoreductases (catalases, peroxidases, and polyphenol oxidases) are especially important in metabolism and energy exchange. These enzymes catalyze key redox reactions, regulating the biochemical transformations of organic and inorganic substances in the soil [12–15]. Studying enzyme activity in the plant rhizosphere helps determine the speed and nature of biochemical reactions in the soil. This kind of analysis is an important tool for objectively evaluating the biological effectiveness of modern farming technologies, including the use of microbial products and biological plant protection methods. The data gathered makes it possible to draw scientifically backed conclusions about how different agricultural practices affect soil communities and crop productivity.

The purpose of this work is to assess the effect of different soil treatments and seed bacterization with the microbiological preparation Microbiocom-Agro on enzyme activity in the rhizosphere of oil flax when grown in the steppe Crimea.

MATERIAL AND METHODS

Experimental studies in 2023 and 2024 were conducted on a test plot in the steppe zone of Crimea (Klepinino village, Krasnogvardeisky district) on oil flax of the Mix variety using two soil cultivation systems: traditional moldboard plowing (22–24 cm) and direct seeding without preliminary cultivation in combination with the use of the complex microbial preparation Microbiocom-Agro according to the following scheme: traditional technology – control (without treatment with Microbiocom-Agro), traditional technology – seed treatment with Microbiocom-Agro, direct seeding – control (without treatment with Microbiocom-Agro);

direct seeding – seed treatment with Microbiocom-Agro.

The soil cover of the experimental plot is southern chernozem with a low humus content. In the arable layer, the humus content is 2.4–2.6% (according to the Tyurin's method), mobile P_2O_5 is 1.0–2.5 mg/100 g of soil, and mobile K_2O is 18–28 mg/100 g of soil (according to the Machigin's method)¹.

The soil particle-size distribution is coarse silty-clayey, light loamy. Before sowing oil flax, the content of agronomically valuable aggregates (0.25–10.00 mm) in the 0–10 cm soil layer was 72.6–79.1% using traditional technology, and 73.0–82.1% using direct seeding.

The steppe area of the Crimean Peninsula has a continental dry climate, with sharp daily and seasonal temperature changes and uneven rainfall. According to long-term observations, the average annual temperature reaches +10.8 °C.

In 2023, the air temperature during the sowing and harvesting of oil flax was 1.4–2.5 °C above the average, and in 2024 it was 3.6–4.2 °C higher. The annual amount of precipitation averages 383–448 mm, but it falls unevenly². In 2023, 219.7 mm of precipitation fell, and in 2024 – 46.6 mm.

Pre-sowing seed preparation included treatment with the complex biological product Microbiocom-Agro, which contains a combination of beneficial microorganisms with various functional properties, including strains with nitrogen-fixing and phosphate-mobilizing activity, as well as microorganisms that produce growth substances and antagonize pathogenic microflora. To compare the effectiveness of the treatment, water-treated seeds were used as a control.

Soil samples were collected during the flowering phase. The activity of oxidation-reduction

¹Polovitsky I. Ya., Gusev P. G. Soils of the Crimea and the increase of their fertility. Simferopol: Tavria Publ., 1987, 152 p.

²Agro-climatic handbook of the Autonomous Republic of the Crimea (1986–2005): references / edited by A. I. Prudko and T. I. Adamenko. Simferopol: TsGM in ARC, 2011, 344 p.

enzymes (polyphenol oxidase and peroxidase) in the rhizosphere soil was determined using titration and photo-electro-colometry methods^{3,4}. The activity of catalase enzymes was measured using the Galstyan's gasometric method^{5,6}. Soil respiration was measured by the rate of CO₂ release over 24 hours of incubation at 27°C⁷.

For statistical processing of the data, Microsoft Excel 2007 and Statistica_10.0 programs were used, which made it possible to analyze the results with the calculation of mean values and standard errors⁸.

RESULTS AND DISCUSSION

According to the data of field experiments in 2023, a significant impact of pre-sowing seed inoculation and soil cultivation methods on the activity of oxidoreductase enzymes in the rhizosphere of oil flax was established.

As the results presented in Table 1 show, the use of traditional farming technology contrib-

uted to an increase in the total catalase activity by 1.7 ml O₂/min/g a.d.s. (absolutely dry soil), in the variant with direct seeding, an increase in thermolabile catalase by 4.6 ml O₂/min/g a.d.s. was observed, which is 8.1–14.5% more compared to the treatment with Microbiocom-Agro.

The analysis revealed a 65.1% reduction in polyphenol oxidase activity (20.3 ml KJO₃/100 g a.d.s.) with the traditional technology compared to the microbiological preparation. Furthermore, a trend toward decreased polyphenol oxidase activity was noted with direct seeding compared to the use of Microbiocom-Agro. In particular, the activity decreased by 8.8% (4.4 ml KJO₃/100 g a.d.s.), which may be due to extreme weather conditions that led to rapid depletion of available nutrients and oxygen in the soil.

Carbon dioxide emissions were found to depend on the farming technology and Microbiocom-Agro application. When using traditional tillage technology in combination with Micro-

Табл. 1. Влияние Микробиокома-Агро и технологий возделывания на ферментативную активность и выделение углекислого газа в ризосфере льна масличного в фазу цветения (полевой опыт, чернозем южный, 2023 г.)

Table 1. Influence of Microbiocom-Agro and cultivation technologies on enzymatic activity and carbon dioxide release in the rhizosphere of oilseed flax during the flowering phase (field experiment, southern chernozem, 2023)

Experiment option	Enzyme activity			CO ₂ emission, mg/ g a.d.s./days
	Total catalase, ml O ₂ /min/g a.d.s.	Thermolabile catalase, ml O ₂ /min/ g a.d.s	Polyphenol oxidase, ml KJO ₃ /100 g a.d.s	
Traditional technology	11,70 ± 0,90	21,10 ± 0,70	31,20 ± 8,40	0,46 ± 0,05
Traditional technology with Microbiocom-Agro	10,00 ± 0,40	19,40 ± 0,80	51,50 ± 3,70	0,46 ± 0,05
Direct sowing	12,20 ± 0,20	31,90 ± 4,30	49,80 ± 3,80	0,47 ± 0,001
Direct sowing with Microbiocom-Agro	12,50 ± 0,30	27,30 ± 0,90	54,20 ± 1,40	0,18 ± 0,02

³Khaziev F.Kh. System-ecological analysis of soil enzymatic activity), Moscow: Nauka, 1982, 204 p.

⁴Titova V. I. and Kozlov A. V., Methods for assessing the soil microbe cenosis functioning involved in the organic matter transformation: scientific and methodological manual (Nizhny Novgorod: The Nizhny Novgorod Agricultural Academy, 2012), p. 64.

⁵Galstyan A.Sh. Unification of the methods to study soil enzymatic activity// Eurasian Soil Science. 1978, N 2, pp. 107–113.

⁶Methods of soil microbiology and biochemistry. Ed. by D.G. Zvyagintsev. Moscow: Moscow State University Press, 1991, 304 p.

⁷Methodological guidelines for assessing the toxic effect of pesticides on soil microflora / under the general guidance of Yu.V. Kruglov. 1981. 43 p.

⁸Dospekhov B.A. Methodology of field experience (with the basics of statistical processing of research results). Moscow: Alliance, 2014, 351 p.

biocom-Agro, the rate of carbon dioxide emission increased by 0.28 mg/g a.d.s./day (60.9%) compared to direct seeding with Microbiocom-Agro. This indicates accelerated decomposition and oxidation of organic matter due to soil fauna.

According to the data presented in Fig. 1, the peroxidase activity during traditional soil treatment in the control variant was 1.22 μmol guaiacol/g, which is 1.6 times higher than the values for direct seeding technology. The use of Microbiocom-Agro in traditional cultivation technology reduced peroxidase activity by 3 times compared to the control. A decrease in the activity of this enzyme may indicate that the microbial preparation helps reduce stress caused by adverse factors such as drought and heat.

The results of biometric measurements of oil flax, carried out in 2023, showed the absence of reliable differences between the compared experimental variants (see Fig. 2).

During the 2024 research it was established that the use of traditional cultivation technology without treatment with a biopreparation contributed to an increase in the activity of total catalase in the rhizosphere of oil flax by 4.9 ml $\text{O}_2/\text{min/g}$ a.d.s. (15.0%) compared to the option using Microbiocom-Agro. Under direct seeding conditions using this preparation, an in-

crease in catalase activity by 6.0 ml $\text{O}_2/\text{min/g}$ a.d.s. (16.0%) was observed relative to control values. The study of thermolabile catalase revealed significant positive dynamics: with the traditional farming system with treatment with a biopreparation, the enzyme activity increased by 1.8 ml $\text{O}_2/\text{min/g}$ (9.8%), in the variant with direct sowing it was 6.5 ml $\text{O}_2/\text{min/g}$ (25.8%) compared to the untreated variants. The obtained data suggest that the microorganisms included in the preparation stimulate the antioxidant system of plants, which contributes to increasing their resistance to oxidative stress in unfavorable growing conditions.

Polyphenol oxidase activity was higher in the direct seeding and conventional technologies by 1.9 and 6.1 ml $\text{KJO}_3/100$ g a.d.s., respectively, which is 1.1 and 1.2 times higher than with Microbiocom-Agro. Analysis of 2024 data revealed no significant differences in the intensity of carbon dioxide emission in the rhizosphere of oil flax under different cultivation technologies.

Studies have shown that with traditional technology, peroxidase activity increased by 2.46 μmol guaiacol/g a.d.s. (6.6 times) compared to the traditional technology variant with Microbiocom-Agro. In direct sowing, bacterization with the preparation increased peroxidase activity by 2.21 μmol guaiacol/g a.d.s.

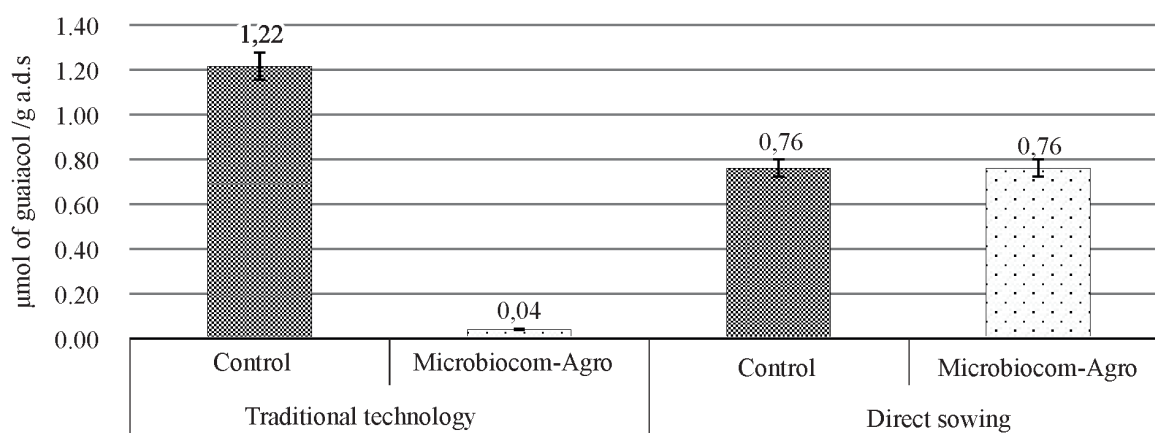


Рис. 1. Влияние Микробиокома-Агро и технологий возделывания на пероксидазную активность в ризосфере льна масличного в фазу цветения (полевой опыт, чернозем южный, 2023 г.)

Fig. 1. Influence of Microbiocom-Agro and cultivation technologies on peroxidase activity in the rhizosphere of oilseed flax during the flowering phase (field experiment, southern chernozem, 2023)

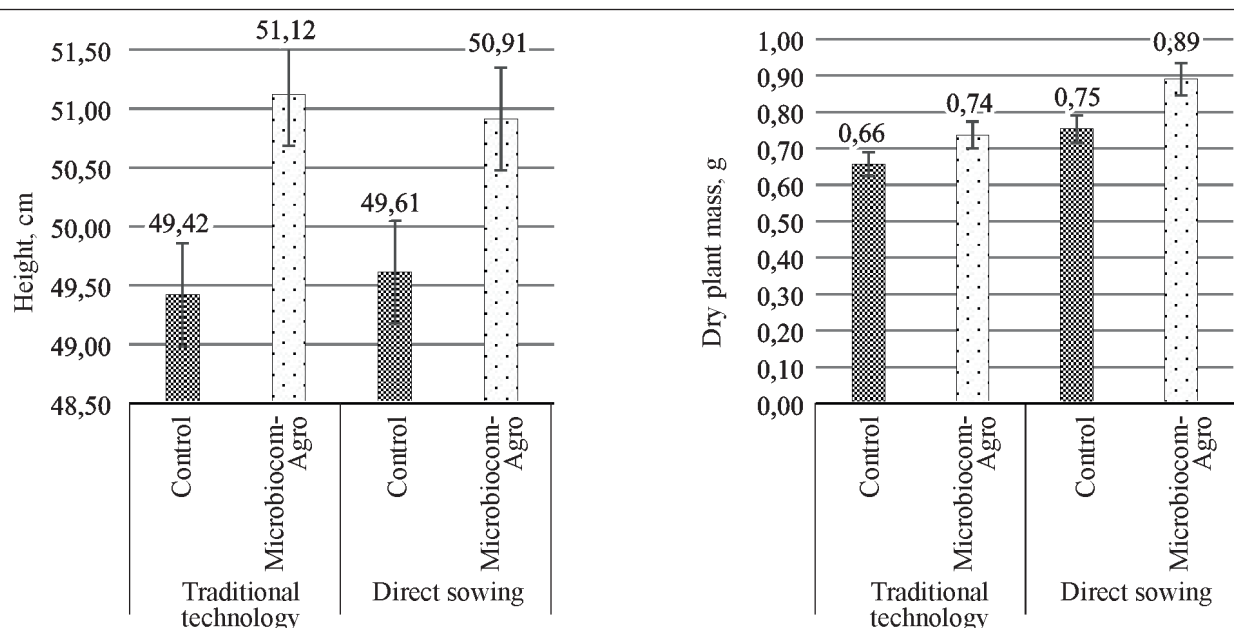


Рис. 2. Влияние Микробиокома-Агро и технологий возделывания на биометрические показатели растений льна масличного в фазу цветения (полевой опыт, чернозем южный, 2023 г.)

Fig. 2. Influence of Microbiocom-Agro and cultivation technologies on the biometric indicators of oilseed flax plants during the flowering phase (field experiment, southern chernozem, 2023)

(3.99 times) relative to the control (see Fig. 3).

In 2024, a trend of decreasing shoot length was established in the traditional technology variant with Microbiocom-Agro by 2.2 cm/plant, or 7.3%, and a trend of increasing in direct sowing with Microbiocom-Agro by 2.9 cm/plant, or 9.7%, compared to the control (see Fig. 4). A significant difference was noted in the dry mass of plants in traditional technology, which was 0.59 g/plant (107.3%) higher compared to direct sowing.

CONCLUSION

As a result of two years of observations, it was found that with traditional farming technology, catalase activity increased by an average of 14.9% (3.3 ml O₂/min/g a.d.s.) compared to the use of the biopreparation. When using direct seeding technology with the biological product Microbiocom-Agro, this indicator exceeded the control by 3.2 ml O₂/min/g a.d.s., which is 12.7%. This may indicate that the traditional

Табл. 2. Влияние Микробиокома-Агро и технологий возделывания на ферментативную активность и выделение углекислого газа в ризосфере льна масличного в фазу цветения (полевой опыт, чернозем южный, 2024 г.)

Table 2. Influence of Microbiocom-Agro and cultivation technologies on enzymatic activity and carbon dioxide release in the rhizosphere of oilseed flax during the flowering phase (field experiment, southern chernozem, 2024)

Experiment option	Enzyme activity			CO ₂ emission, mg/ g a.d.s./days
	Total catalase, ml O ₂ /min/ g a.d.s	Thermolabile catalase, ml O ₂ /min/ g a.d.s.	Polyphenol oxidase, ml KJO ₃ /100 g a.d.s	
Traditional technology	32,70 ± 0,30	16,40 ± 0,40	32,90 ± 1,90	0,14 ± 0,01
Traditional technology with Microbiocom-Agro	27,80 ± 0,60	18,20 ± 0,50	26,80 ± 1,60	0,16 ± 0,01
Direct sowing	37,40 ± 0,80	18,70 ± 0,80	26,60 ± 1,60	0,15 ± 0,02
Direct sowing with Microbiocom-Agro	43,40 ± 0,11	25,20 ± 2,50	24,70 ± 1,30	0,14 ± 0,02

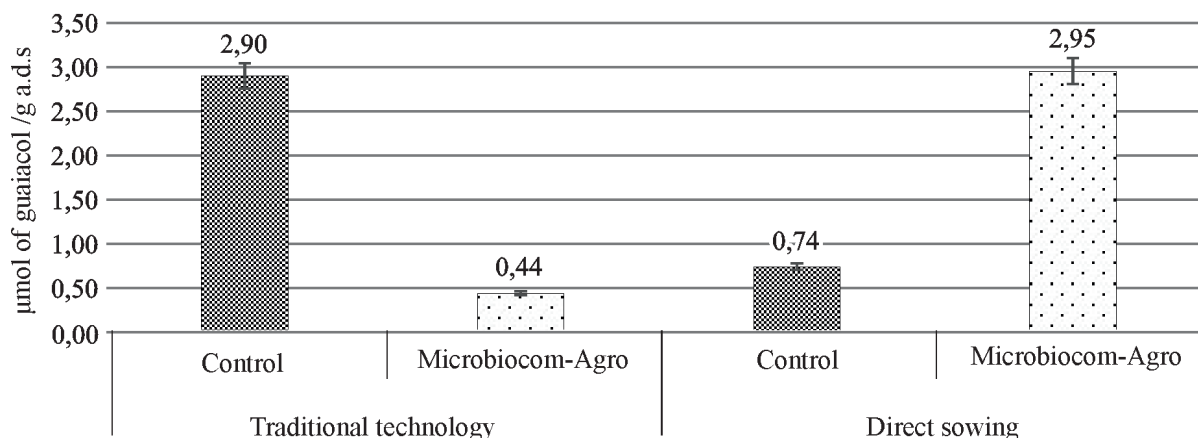


Рис. 3. Влияние Микробиокома-Агро и технологий возделывания на пероксидазную активность (полевой опыт, чернозем южный, 2024 г.)

Fig. 3. Influence of Microbiocom-Agro and cultivation technologies on peroxidase activity (field experience, southern chernozem, 2024)

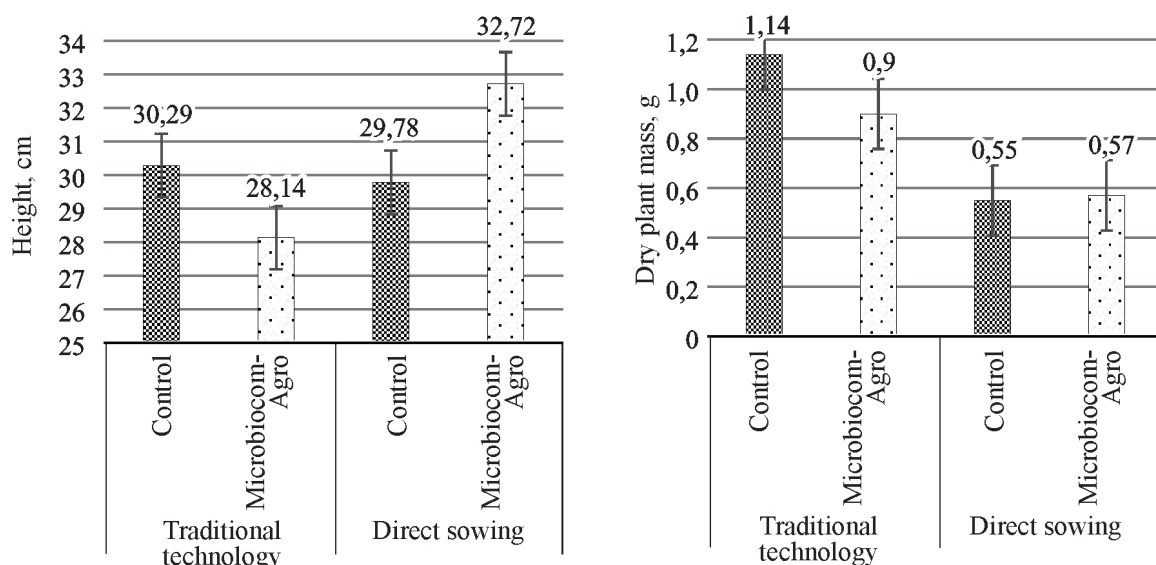


Рис. 4. Влияние Микробиокома-Агро и технологий возделывания на биометрические показатели (полевой опыт, чернозем южный, 2024 г.)

Fig. 4. Influence of Microbiocom-Agro and cultivation technologies on the biometric indicators (field experiment, southern chernozem, 2024)

technology creates stressful conditions for soil biota, causing increased activation of catalases. Direct seeding with the biological product creates a more stable and balanced environment.

It was found that with traditional soil cultivation, peroxidase activity increased by 4.9 times, while with the use of direct seeding technology with a biopreparation, this indicator increased by 2.5 times compared to the control. This circumstance may indicate that traditional treatment increases oxidative stress and disrupts

the soil structure, while the biological product Microbiocom-Agro reduces this load in direct sowing.

СПИСОК ЛИТЕРАТУРЫ

1. Белоусов А.А., Белоусова Е.Н. Оценка дифференциации ферментативной активности при применении безотвальных технологий обработки в слоях агрочернозема // Вестник КрасГАУ. 2024. № 12. С. 3–10. DOI: 10.36718/1819-4036-2024-12-3-10.
2. Мокриков Г.В., Федоренко А.Н., Собина А.С.,

- Казеев К.Ш., Кибалюк О.Л., Гринько А.В., Байбеков Р.Ф. Изменение биологических свойств чернозема обыкновенного при разной длительности применения нулевой технологии в условиях Ростовской области // *Земледелие*. 2024. № 7. С. 3–8. DOI: 10.24412/0044-3913-2024-7-3-8.
3. Чевердин Ю.И., Киценко В.П., Чевердин А.Ю. Микробиологическая активность чернозема в зависимости от характера использования и размера почвенных агрегатов // *Сибирский вестник сельскохозяйственной науки*. 2023. Т. 53. № 4. С. 5–12. DOI: 10.26898/0370-8799-2023-4-1.
 4. Дридигер В.К., Годунова Е.И., Гаджисумаров Р.Г., Волошенкова Т.В., Дидович С.В., Еговцева А.Ю., Смирнова И.И. Природоподобные технологии возделывания полевых культур в системе прямого посева // *Земледелие*. 2025. № 1. С. 3–9. DOI: 10.24412/0044-3913-2025-1-3-9.
 5. Белобров В.П., Шаповалов Д.А., Дридигер В.К., Юдин С.А., Ермолаев Н.Р. Почвозащитная роль прямого посева в земледелии // *Международный сельскохозяйственный журнал*. 2023. Т. 66. № 3 (393). С. 255–260. DOI: 10.55186/25876740_2023_66_3_255.
 6. Иванов А.Л., Белобров В.П., Дридигер В.К., Юдин С.А. Прямой посев – технология, восстанавливающая деградированные свойства черноземов // *Сельскохозяйственный журнал*. 2025. № 1 (18). С. 23–47. DOI: 10.48612/FARC/2687-1254/003.1.18.2025.
 7. Дридигер В.К., Волошенкова Т.В., Гаджисумаров Р.Г., Джандаров А.Н., Тимохина О.В., Дубилин А.И. Эффективность применения системы прямого посева на черноземе южном Волгоградской области // *Земледелие*. 2025. № 4. С. 17–23. DOI: 10.24412/0044-3913-2025-4-17-23.
 8. Горгулько Т.В., Дидович С.В., Алексеенко О.П., Шитик А.С. Влияние «Микробиоком-Агро» и различных технологий земледелия на микробиологическую активность ризосферы льна масличного // *Таврический вестник аграрной науки*. 2024. № 4 (40). С. 38–51. DOI: 10.5281/zenodo.14184314.
 9. Альсаед Н., Селицкая О.В., Поздняков Л.А., Аверткин И.А., Шубина Е.А. Оценка длительного воздействия бессменного выращивания различных сельскохозяйственных культур на микробные сообщества почвы // *Известия Тимирязевской сельскохозяйственной академии*. 2024. № 2. С. 5–24. DOI: 10.26897/0021-342X-2024-2-5-24.
 10. Гурьев Г.П., Донская М.В., Донской М.М., Якубовская А.И., Каменева И.А., Зубоченко А.А. Влияние микробиологических препаратов и предшественника на формирование симбиотического аппарата, урожайность и агрохимические показатели почвы при возделывании чечевицы, нута и чины // *Зернобобовые и крупяные культуры*. 2024. № 1 (49). С. 10–18. DOI: 10.24412/2309-348X-2024-1-10-18.
 11. Сорокина О.Ю. Влияние бактериальных удобрений в сочетании с минеральными и органоминеральными на продуктивность льна-долгунца // *Плодородие*. 2023. № 4 (133). С. 75–77. DOI: 10.25680/S19948603.2023.133.18.
 12. Гамзаева Р.С., Бекиш Л.П. Активность ферментов ризосферы тритикале при инокуляции микробными препаратами // *Сибирский вестник сельскохозяйственной науки*. 2024. Т. 54. № 11. С. 5–14. DOI: 10.26898/0370-8799-2024-11-1.
 13. Белоусова Е.Н., Белоусов А.А. Динамика активности ферментов углеродного цикла в условиях перехода на минимальные технологии обработки // *Вестник КрасГАУ*. 2024. № 5 (206). С. 19–26. DOI: 10.36718/1819-4036-2024-5-19-26.
 14. Шарков И.Н., Андроханов В.А., Самохвалова Л.М., Антипина П.В. Влияние минимизации обработки на баланс углерода в почве в лесостепи новосибирского Приобья // *Вестник НГАУ (Новосибирский государственный аграрный университет)*. 2023. № 1. С. 99–106. DOI: 10.31677/2072-6724-2023-66-1-99-106.
 15. Иванов А.В., Гетманский В.В., Тихончук П.В., Селихова О.А., Данилов А.В., Пилецкая О.А. Влияние технологии прямого посева на эмиссию CO₂ из черноземовидных почв Приамурья // *Почвоведение*. 2025. № 7. С. 932–942. DOI: 10.31857/S0032180X25070044.
- ## REFERENCES
1. Belousov A.A., Belousova E.N. Assessment of enzymatic activity differentiation when using waste-free processing technologies in agro-chernozem layers. *Vestnik KrasGAU = Bulletin of KrasSAU*, 2024, no. 12, pp. 3–10. (In Russian). DOI: 10.36718/1819-4036-2024-12-3-10.

2. Mokrikov G.V., Fedorenko A.N., Sobina A.S., Kazeev K.Sh., Kibaljuk O.L., Grin'ko A.V., Baybekov R.F. Changes in biological properties of ordinary chernozem with different duration of application of zero technology in the conditions of the Rostov Region. *Zemledelie = Zemledelie*, 2024, no. 7, pp. 3–8. (In Russian). DOI: 10.24412/0044-3913-2024-7-3-8.
3. Cheverdin Yu.I., Kitsenko V.P., Cheverdin A.Yu. Microbiological activity of chernozem depending on the use and size of soil aggregates. *Sibirskii vestnik sel'skokhozyajstvennoi nauki = Siberian Herald of Agricultural Science*, 2023, vol. 53, no. 4, pp. 5–12. (In Russian). DOI: 10.26898/0370-8799-2023-4-1.
4. Dridiger V.K., Godunova E.I., Gadzhiumarov R.G., Voloshenkova T.V., Didovich S.V., Yegovtseva A.Yu., Smirnova I.I. Nature-like technologies for cultivation of agricultural crops in the direct seeding system. *Zemledelie = Zemledelie*, 2025, no. 1, pp. 3–9. (In Russian). DOI: 10.24412/0044-3913-2025-1-3-9.
5. Belobrov V.P., Shapovalov D.A., Dridiger V.K., Yudin S.A., Ermolaev N.R. Soil-protection role of No-till in agriculture. *Mezhdunarodnyj sel'skokhozyajstvennyj zhurnal = International Agricultural Journal*, 2023, no. 3 (393), pp. 255–260. (In Russian). DOI: 10.55186/25876740_2023_66_3_255.
6. Ivanov A.L., Belobrov V.P., Dridiger V.K., Yudin S.A. Direct seeding – a technology that restores degraded properties of chernozems. *Sel'skokhozyajstvennyj zhurnal = Agricultural Journal*, 2025, no. 1 (18), pp. 23–47. (In Russian). DOI: 10.48612/FARC/2687-1254/003.1.18.2025.
7. Dridiger V.K., Voloshenkova T.V., Gadzhiumarov R.G., Dzhandarov A.N., Timokhina O.V., Dubilin A.I. Efficiency of using direct seeding system on southern chernozem of Volgograd region. *Zemledelie = Zemledelie*, 2025, no. 4, pp. 17–23. (In Russian). DOI: 10.24412/0044-3913-2025-4-17-23.
8. Gorgulko T.V., Didovich S.V., Alekseenko O.P., Shitik A.S. Influence of “Microbiocom-Agro” and various farming technologies on the microbiological activity of the rhizosphere of linum usitatissimum // *Tavricheskij vestnik agrarnoj nauki = Taurida Herald of the Agrarian Sciences*, 2024, no. 4 (40), pp. 38–51. (In Russian). DOI: 10.5281/zenodo.14184314.
9. Alsaed N., Selitskaya O.V., Pozdnyakov L.A., Avertkin I.A., Shubina E.A. Evaluation of the long-term effects of the permanent cropping on soil microbial communities. *Izvestiya Timiryazevskoj sel'skokhozyajstvennoj akademii = Izvestiya of Timiryazev Agricultural Academy*, 2024, no. 2, pp. 5–24. (In Russian). DOI: 10.26897/0021-342X-2024-2-5-24.
10. Guryev G.P., Donskaya M.V., Donskoy M.M., Yakubovskaya A.I., Kameneva I.A., Zubochenko A.A. Influence of microbiological preparations and forecrop on symbiotic apparatus formation, yield, and agrochemical soil parameters in cultivation of lentils, chickpeas, and grass pea. *Zernobobovye i krupyanye kul'tury = Legumes and Groat Crops*, 2024, no. 1 (49), pp. 10–18. (In Russian). DOI: 10.24412/2309-348X-2024-1-10-18.
11. Sorokina O.Yu. The effect of bacterial fertilizers in combination with mineral and organomineral fertilizers on the productivity of fiber flax // *Plodorodie = Plodorodie*, 2023, no. 4 (133), pp. 75–77. (In Russian). DOI: 10.25680/S19948603.2023.133.18.
12. Gamzaeva R.S., Bekish L.P. Activity of triticales rhizosphere enzymes during inoculation with microbial preparations. *Sibirskij vestnik sel'skokhozyajstvennoj nauki = Siberian Herald of Agricultural Science*, 2024, vol. 54, no. 11, pp. 5–14. (In Russian). DOI: 10.26898/0370-8799-2024-11-1.
13. Belousova E.N., Belousov A.A. Carbon cycle enzymes activity dynamics under conditions of transition to minimum processing technologies. *Vestnik KrasGAU = Bulletin of KrasSAU*, 2024, no. 5 (206), pp. 19–26. (In Russian). DOI: 10.36718/1819-4036-2024-5-19-26.
14. Sharkov I.N., Androkhonov V.A., Samokhvalova L.M., Antipina P.V. Effect of tillage minimization on the carbon balance in the soil in the forest-steppe of the Novosibirsk Ob region. *Bulletin of NSAU (Novosibirsk State Agrarian University)*, 2023, no. 1, pp. 99–106. (In Russian). DOI: 10.31677/2072-6724-2023-66-1-99-106.15.
15. Ivanov A.V., Getmansky V.V., Tikhonchuk P.V., Selikhova O.A., Danilov A.V., Piletskaya O.A. Influence of direct seeding technology on CO₂ emission by chernozem-like soils of the Amur region. *Pochvovedenie = Eurasian Soil Science*, 2025, no. 7, pp. 932–942. (In Russian). DOI: 10.31857/S0032180X25070044.

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Классификация засоренности посевов выюнком полевым с использованием нейросетевых архитектур ResNet

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Разработка эффективных методов автоматического мониторинга сорных растений – одна из ключевых задач для повышения устойчивости, продуктивности и рентабельности современного сельского хозяйства. Внедрение подобных технологий лежит в основе концепции точного земледелия, которое направлено на оптимизацию ресурсов и минимизацию антропогенного воздействия на агроэкосистемы. Ключевую роль в решении этой задачи играют технологии искусственного интеллекта, в частности методы глубокого обучения (Deep Learning). Настоящее исследование посвящено сравнительному анализу применимости сверточных нейронных сетей (CNN) архитектур ResNet-18, ResNet-34 и ResNet-50 для решения задачи классификации посевов пяти сельскохозяйственных культур (пшеницы, ячменя, гречихи, рапса и льна) по признаку засоренности выюнком полевым. Все протестированные архитектуры продемонстрировали высокую эффективность, достигнув точности (accuracy) более 91% и F1-меры в диапазоне 0,85–0,90, что свидетельствует о хорошем балансе между точностью и полнотой предсказаний. Выявлено, что наилучшие результаты показала не самая глубокая модель – ResNet-18, которая, несмотря на меньшую вычислительную сложность, превзошла более мощные аналоги ResNet-34 и ResNet-50 по стабильности и общей точности прогноза. Данный факт подтвержден анализом матриц ошибок, которые показали минимальное количество ложных срабатываний и пропусков цели у данной архитектуры. Полученные данные свидетельствуют о перспективности использования рассмотренных архитектур для задач мониторинга засоренности, однако для практического внедрения в мобильные или стационарные системы точного земледелия требуется дальнейшее исследование, включая сравнение со специализированными легковесными нейросетевыми архитектурами и оценку на расширенных наборах данных.

Ключевые слова: сверточные нейронные сети, ResNet, глубокое обучение, идентификатор, выюнок полевой, пшеница мягкая, ячмень обыкновенный, гречиха обыкновенная, рапс, лен обыкновенный

Classification of crop infestation with field bindweed using ResNet neural network architectures

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The development of effective methods for automatic weed monitoring is one of the key tasks for improving the sustainability, productivity, and profitability of modern agriculture. The introduction of such technologies underlies the concept of precision farming, which aims at optimizing resources and minimizing anthropogenic impact on agroecosystems. The key role in solving this problem is played by artificial intelligence technologies, in particular Deep Learning methods. The study is devoted to a comparative analysis of the applicability of convolutional neural networks (CNNs) with ResNet-18, ResNet-34, and ResNet-50 architectures for solving the problem of classifying crops of five agricultural species (wheat, barley, buckwheat, rapeseed, and flax) based on the sign of infestation with field bindweed. All the tested architectures demonstrated high efficiency, achieving accuracy of more than 91% and an F1-score in the range of 0.85–0.90, which indicates a good balance between the accuracy and completeness of predictions. It was found that the best results were achieved by not the deepest model – ResNet-18, which, despite having lower computational complexity, outperformed the more powerful counterparts ResNet-34 and ResNet-50 in stability and overall prediction accuracy. This fact

is confirmed by the analysis of error matrices, which showed the minimum number of false activations and target drop-outs for this architecture. The obtained data indicate the promising potential of using the considered architectures for weeding monitoring tasks; however, for practical implementation in mobile or stationary precision agriculture systems, further research is required, including comparison with specialized lightweight neural network architectures and evaluation on expanded datasets.

Keywords: convolutional neural networks, ResNet, deep learning, identifier, field bindweed, soft wheat, common barley, common buckwheat, rapeseed, common flax

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Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Nowadays, the need for larger and larger amounts of agricultural products is increasing every year. To ensure a yield increase of crops, new approaches to intensification are used. One of these approaches is the implementation of smart systems [1–3].

In Russia, various agricultural crops are grown. Grain crops like wheat, barley, and buckwheat are considered traditional food crops, while flax and rapeseed are technical crops. Depending on the region, the average yield for wheat is 33.7 c/ha, for barley – 32.7, and for buckwheat – 17.2 c/ha. In 2025, the average yield is 8.38 c/ha for flax and 21.1 c/ha for rapeseed¹.

Besides the impact of climate and soil factors, one of the serious problems in getting high yields is the heavy weed infestation of fields. Weeds are strong competitors for crops, taking away their nutrients, light, and moisture [4, 5].

Plant protection is necessary to minimize the

impact of harmful factors that hinder the growth of crops. To deal with weeds, a set of agricultural practices is used, as well as special chemical products. Agrotechnics includes a system of soil cultivation throughout the entire agricultural season, following crop rotation², optimal sowing times, sowing depth, as well as seeding rates and plant density [6]. Besides farming techniques, using herbicides – chemical plant protection products aimed at slowing down the growth and killing weeds – is also really important. Using herbicides makes it a lot easier to take care of crops³ and can also increase the yield of cultivated plants⁴.

To use herbicides effectively, one need to accurately identify the species of weeds, which requires a lot of human resources. Automated recognition can help reduce these costs. This will help reduce the time spent identifying weeds, speed up the use of herbicides in the early stages of their growth, ensure more precise treatment of the areas with the most weeds, allow for reducing the pesticide load on the agro-ecosystem,

¹Unified Interdepartmental Information and Statistical System (EMISS): indicator "Crop yield (per harvested area)."

²Kosenko T.G. Influence of agrotechnical practices on crop weediness // Innovative Technologies in the Agro-Industrial Complex: Proceedings of the International Scientific and Practical Conference (Michurinsk, November 21–23, 2018). Michurinsk: Michurinsk State Agrarian University, 2018, pp. 167–170.

³Bakaeva N. P. Effectiveness of herbicide application in spring wheat cultivation technology // Proceedings of the Samara State Agricultural Academy. 2018, N 4, pp. 16–21.

⁴Toloraya T.R., Laskin R.V., Patskan V.Yu. Effect of pre-sowing tillage systems on maize yield under different primary tillage methods and herbicide application regimes // *Zemledelie*, 2018, N 1, pp. 23–26.

and also cut down on the economic costs of agricultural production [7–10].

Artificial intelligence technologies, especially deep learning methods, play a key role in solving this problem. Among them, convolutional neural networks (CNNs) show the greatest effectiveness for analyzing visual data and are successfully used for plant classification and weed identification from digital images [15–17]. Many effective architectures have been developed for classification tasks, such as AlexNet⁵, GoogLeNet⁶ and ResNet⁷.

The ResNet architectural system is widely used for image processing. It works well for handling soil images [18] and vegetation cover. This architecture allows achieving acceptable results using a relatively small amount of training data, but it has the potential for more accurate detection when a larger number of images is used⁸ [19].

The goal of the study is to assess the applicability of the ResNet-18, ResNet-34, and ResNet-50 architectures and to carry out a comparative analysis of them for classifying crop images based on the level of contamination by field bindweed.

MATERIAL AND METHODS

As the source information for training convolutional neural networks (CNNs), a dataset was used, formed based on the results of phytosanitary diagnostics of crops of five agricultural plants: soft wheat (*Triticum aestivum*), common barley (*Hordeum vulgare*), common buckwheat (*Fagopyrum esculentum*), rapeseed (*Brassica napus*), common flax (*Linum usitatissimum*). The diagnostics were mostly carried out during the tillering phase of the crops on 74 monitoring

plots of 1 m² each, using a quantitative method for recording weed vegetation. On each plot, photos with a resolution of 3470 × 4640 pixels were taken using a mobile digital camera. For further work, we only selected images that showed the economic threshold of harm (ETH) being exceeded by field bindweed (*Convolvulus arvensis*), which means herbicide treatment is needed. Each type of planting was given a numerical label if there were weeds: Brassicanapus-conv – 0, Fagopyrumconv – 1, Hordeum-conv – 2, Linum-conv – 3, Triticum-conv – 4.

One of the successful algorithms for building such classifiers is convolutional neural networks. Nowadays, they play a key role in modern computer vision systems, especially in the field of recognizing spatial objects in images.

To identify field bindweed in an image and the intensity of weed infestation, we used one of the most popular convolutional neural network architectures – ResNet (or Residual Network), which is a neural network architecture that uses special blocks called residual blocks (see footnote 7).

To build the classifiers, we used convolutional neural network architectures ResNet-18, ResNet-34, and ResNet-50, implemented in the PyTorch library. As a starting point, we used models pretrained on the large-scale ImageNet dataset (over 1.2 million images, 1000 classes). This approach (transfer learning) lets you use previously learned general visual features (edges, textures, shapes) and fine-tune the model on the target task with a limited amount of data. During the fine-tuning stage, the classification heads of the original models (fully connected layers) were replaced with new ones corresponding to the five classes of the crops being

⁵Krizhevsky A.I., Sutskever I., Hinton, G. E. ImageNet classification with deep convolutional neural networks // Advances in Neural Information Processing Systems, 2012, Curran Associates.

⁶Szegedy C., Liu W., Jia Y., Sermanet P., Reed S., Anguelov D., Erhan D., Vanhoucke V., Rabinovich A. Going deeper with convolutions // IEEE Conference on Computer Vision and Pattern Recognition CVPR, 2015, pp. 1–9.

⁷He K., Zhang X., Ren S., Sun Proc J. Deep residual learning for image recognition // IEEE Conference on Computer Vision and Pattern Recognition CVPR, 2016, pp. 770–778. DOI: 10.1109/CVPR.2016.90.

⁸Suriyaga H. G., Rathnayake H. Weed detection in agriculture using end-to-end object detection with transformers in resnet-50 // International Research Conference on Smart Computing and Systems Engineering (SCSE). IEEE, 2024, vol. 7, pp. 1–6.

studied, which were affected by field bindweed. The training was carried out using the Adam optimizer with a learning rate set at 0.001; the weights of the pre-trained convolutional layers were adjusted during training (updated alongside the new layers).

A convenient wrapper called FastAi has been built for PyTorch, making it easy to work with the components of this framework [20]. In addition, FastAi has a technique for artificially increasing the volume and variety of the original data, called augmentation, which is especially useful when the amount of original data is limited.

The way the classifier based on ResNet models works is as follows. The original photo goes through alternating convolutional layers, activation functions, and pool layers. The ResNet output is represented as a 5-dimensional vector, where each component describes the probability estimate of a particular type of weed in the field crop. Weedness is predicted if its probability exceeds 50%.

RESULTS AND DISCUSSION

To improve the efficiency of training the neural network with a limited amount of original data, the original images were augmented in advance. It's assumed that there should be at least eight relevant images for each type of crop. Additional images were obtained using the Python Pillow library by applying various transformations: rotation, cropping, brightness and contrast adjustments. These operations created extra variations of the images that look different but retain the key feature – the presence of field bindweed contamination. As a result, the total size of the original dataset was expanded to 84 samples.

Next, the entire dataset was split into training and test sets in an 80 to 20% ratio, which is standard practice for evaluating a model's generalization ability. The test set is formed in such a way that it includes at least two samples of each type of crop.

Before starting the training, the key hyperparameters are set: number of epochs, batch size, and learning rate.

During training and testing, model parameters are chosen to minimize training errors, which represent measures of the difference between actual and predicted data attributes. Categorical cross-entropy is used as such a measure.

Various models – from the simplest ResNet-18 to the deeper ResNet-34 and ResNet-50By – were received by setting up different numbers of convolutional layers.

To further improve the model's reliability and stability during training, an augmentation procedure from the FastAi framework was used. This technique dynamically generated new variations of images, effectively increasing the diversity of the training and test sets by at least 5 times. As a result, the working size of the dataset used was at least 420 images.

After determining the initial model parameters, the training was resumed using the Adam optimizer, which is used to achieve better training results. The training was done for 100 epochs. One epoch means an iteration over all the images used, which are fed sequentially for training in batches of 16 images (see the table).

Train_loss describes the errors calculated on the training dataset and shows how well the model predicts on the training images. At the final stage, values between 0.01 and 0.20 are considered acceptable.

Valid_loss describes errors on test images that the model doesn't see during training, and it assesses the quality of predictions on the data that isn't used for training. Low valid_loss values just above the 0.01–0.20 range indicate the model has good generalization ability.

The overall final accuracy (multi accuracy) of the selected models describes the share of the images that are classified correctly almost equally, and is at least 91%.

The balanced measure – F1 – captures the trade-offs between precision and recall (their harmonic mean), and usually ends up between

0.85 and 0.90. Precision is the classifier's ability not to label a negative sample as positive, and recall is its ability to find all the positive samples.

The obtained results indicate that all classifiers are of fairly high quality and are suitable for use in deciding whether herbicide treatment of weeds is necessary. The best results are shown by the ResNet-18-based classifier.

The effective performance of the classifiers is shown in Fig. 1, which illustrates the successful recognition of field bindweed by the models on test images. The top label describes the sowing sample with the true types of weeds, while the label below shows the predicted weed labels for this sample according to the classifier.

Another tool for evaluating the quality of classification is the confusion matrix. In our case, considering the multi-class nature of the task, the matrix is built for each class using the 'one-vs-rest' approach, which allows us to pinpoint exactly which classes are the hardest to classify.

Результаты обучения нейросетей ResNet
по эпохам
Training results of ResNet neural networks
by epochs

Epoch	train_loss	valid_loss	accuracy_multi	F1
<i>ResNet-18</i>				
1	1,02	1,07	0,28	0,32
30	0,43	0,26	0,82	0,61
60	0,16	0,20	0,93	0,88
100	0,10	0,15	0,95	0,90
<i>ResNet-34</i>				
1	0,98	0,86	0,32	0,30
30	0,42	0,29	0,73	0,54
60	0,15	0,20	0,90	0,79
100	0,08	0,17	0,92	0,85
<i>ResNet-50</i>				
1	0,92	0,78	0,35	0,36
30	0,32	0,55	0,76	0,57
60	0,13	0,34	0,91	0,80
100	0,06	0,30	0,92	0,87

Figures 2–4 show the confusion matrices obtained for ResNet models based on data of weedy crops with the corresponding labels. Each 2×2 matrix corresponds to one class and is interpreted as follows: the rows represent the true labels, where Y stands for instances of the selected target class, and N for all other classes. The columns show the model's predictions: the Y column contains objects that the model classified as the target class, N – as other classes.

The elements on the main diagonal of the matrix (from left to right) correspond to correct predictions – true positives and true negatives. All the elements off the diagonal represent classification errors: false positives and false negatives. This approach clearly shows which classes the model most often confuses with each other.

The ResNet-18 model showed high efficiency in classifying most categories. Classes 0, 1, 2, and 3 were recognized with 100% accuracy, confirmed by 85 correct predictions, and only one mistake was recorded for class 4 (Triticum-conv) (see Fig. 2).

The ResNet-34 model, like ResNet-18, showed a similar classification: four classes (0, 1, 2, 3) were recognized with 100% accuracy, except for class 4 (Triticumconv) with one mistake (see Fig. 3).

The ResNet-50 model correctly classified only two classes (0 and 4) (see Fig. 4). The other three classes (1, 2, and 3) were classified with a minimal number of errors, indicating that the model performs really well, but not perfectly, on this dataset.

The study showed that deep learning-based classifiers like ResNet, especially ResNet-18, are very accurate and efficient at recognizing types of weed-infested crops.

Flexibility and adaptability make them appealing for tackling the task of detecting crop weediness and making decisions on herbicide treatment. Further work will focus on addressing these tasks with the aim of creating practically useful tools for resource-saving and environmentally oriented farming.

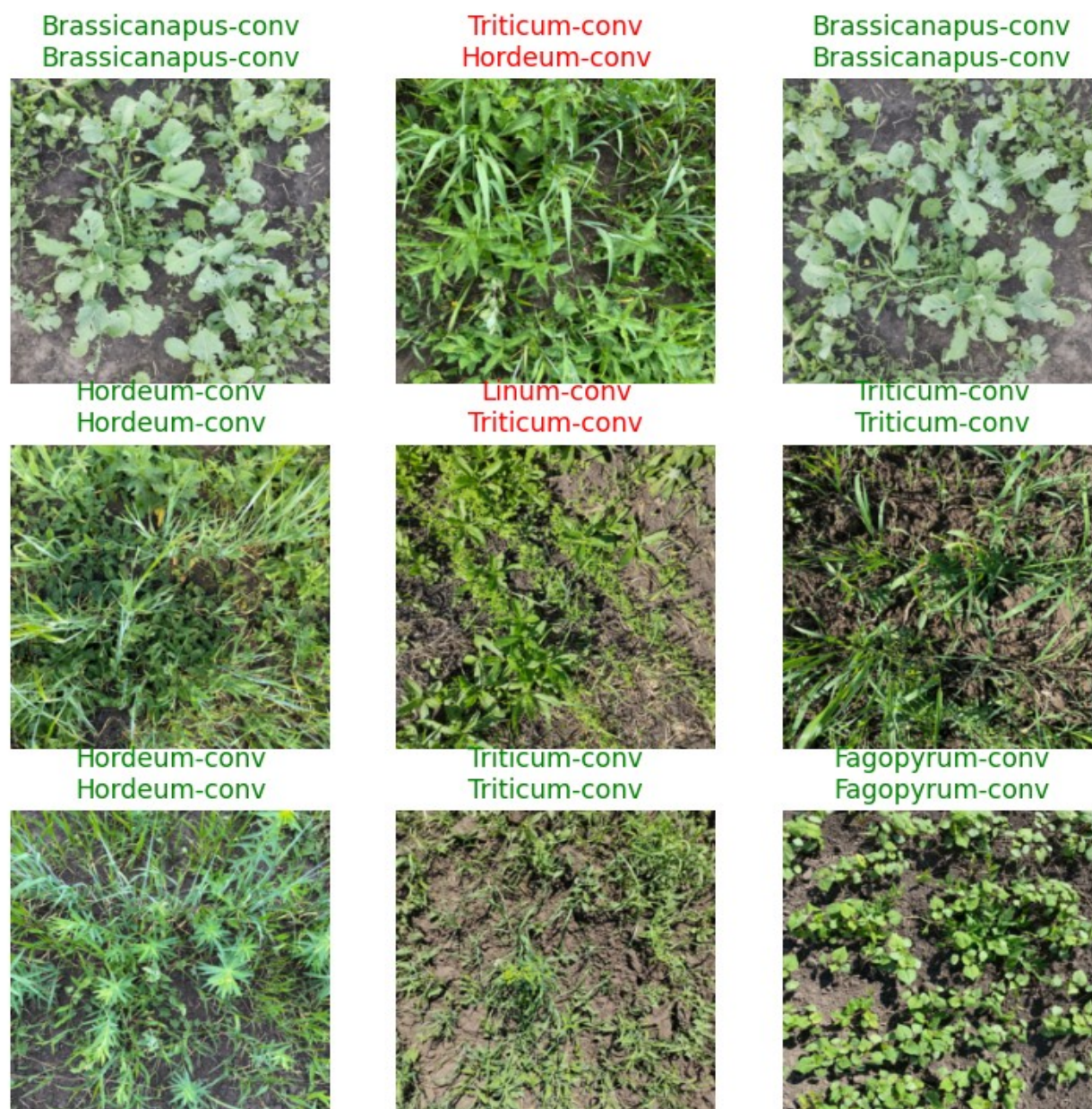


Рис. 1. Результат классификации девяти снимков по нейросети ResNet-18

Fig. 1. Classification results for nine images using the ResNet-18 neural network

CONCLUSIONS

1. Preliminary conclusions have been made about the applicability of ResNet convolutional neural networks for the task of classifying cereal crop plantings based on the presence of field bindweed. Using transfer learning and data augmentation methods allowed all tested architectures (ResNet-18, ResNet-34, ResNet-50) to achieve an accuracy of over 91% with an F1 score ranging from 0.85 to 0.91 on the available dataset.

2. In a comparative analysis, it was found that the ResNet-18 model, which has the lowest computational complexity, showed results comparable to deeper architectures, and slightly outperformed them in terms of stability and classification accuracy. This fact may suggest that a relatively shallow architecture is enough to solve the task on the current dataset, but confirming this conclusion requires additional validation on a larger and more diverse sample.

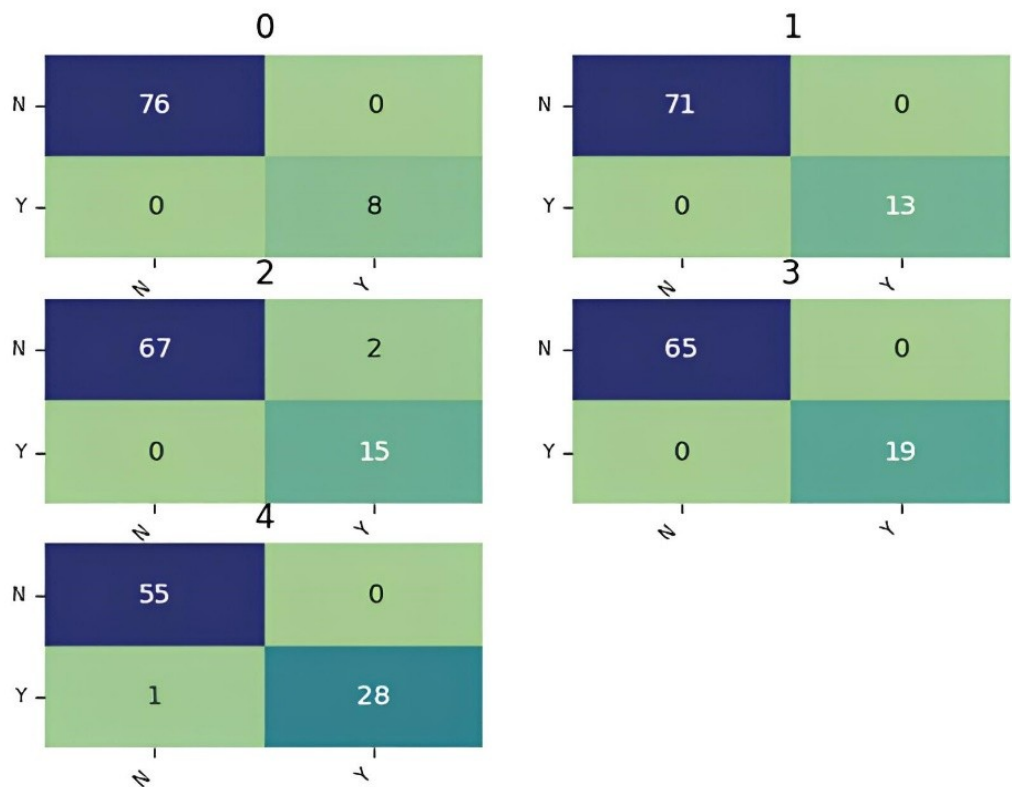


Рис. 2. Confusion matrix засоренных посевов для ResNet-18

Fig. 2. Confusion matrix of weedy crops for ResNet-18

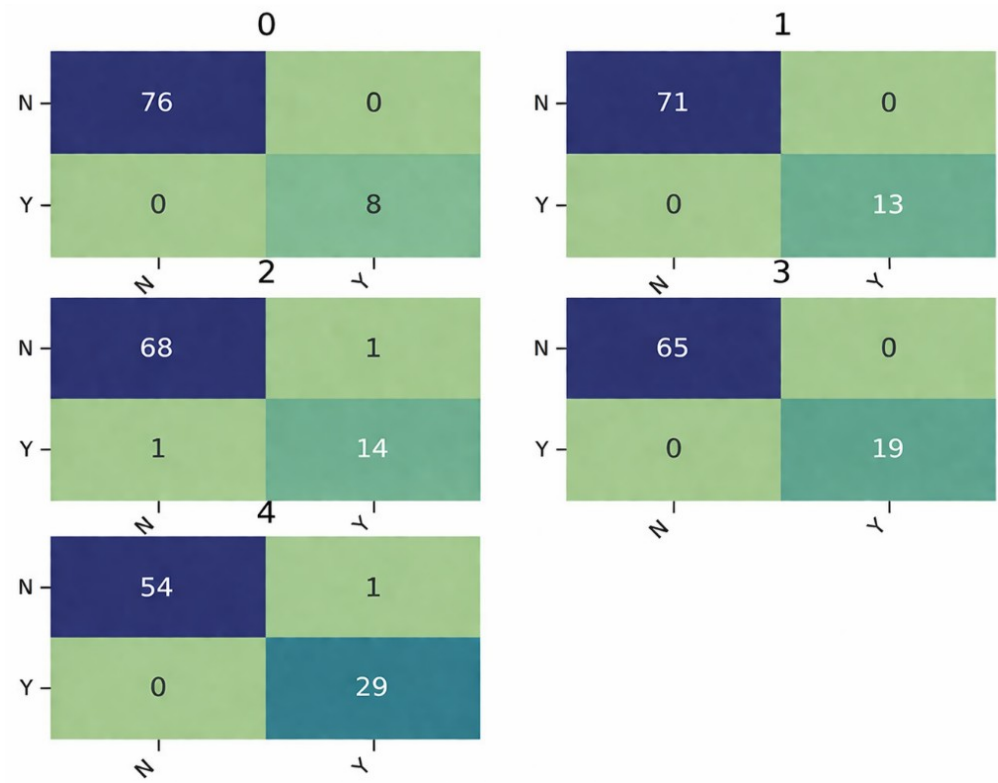


Рис. 3. Confusion matrix засоренных посевов для ResNet-34

Fig. 3. Confusion matrix of weedy crops for ResNet-34

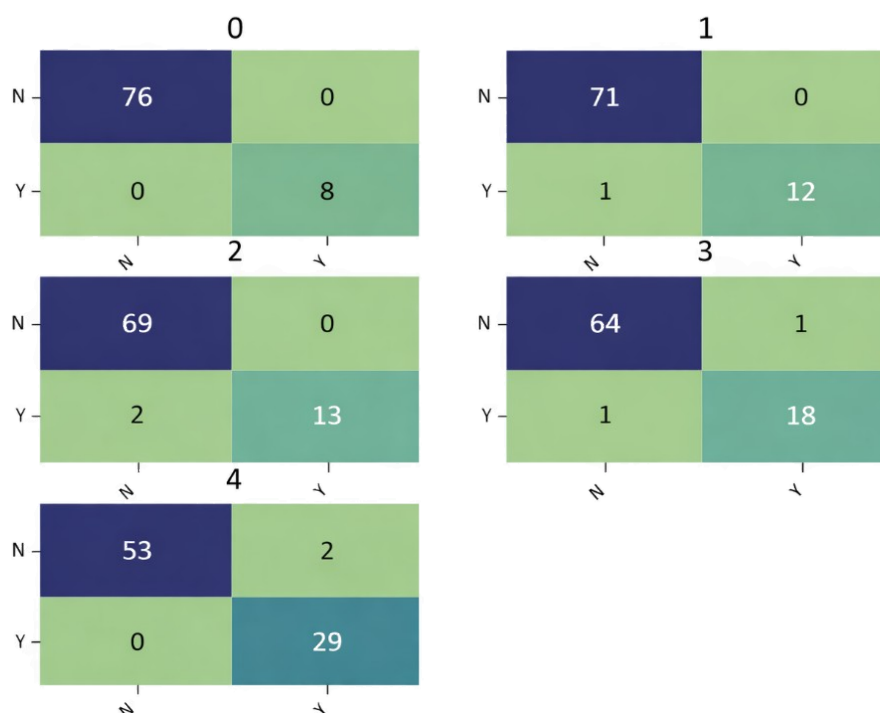


Рис. 4. Confusion matrix засоренных посевов для ResNet-50

Fig. 4. Confusion matrix of weedy crops for ResNet-50

3. The obtained results indicate the potential of using the approaches discussed for monitoring crop weed infestations. For the practical implementation of the developed methods in precision farming systems (including mobile ones), a number of additional studies are needed: a significant expansion of the training set to include the "clean crops" class (absence of weeds); a transition from scene classification to semantic segmentation or object detection, which will enable quantitative assessments of weed infestation (density, coverage area) and the informed application of targeted control measures.

СПИСОК ЛИТЕРАТУРЫ

1. *Осовин М.Н.* Анализ современных тенденций внедрения технологий искусственного интеллекта в сельское хозяйство // Островские чтения. 2024. № 1. С. 136–144.
2. *Сайфетдинов А.Р., Максименко А.А.* Применение машинного обучения и искусственного интеллекта для анализа данных сельского хозяйства и повышения урожайности // Контентус. 2023. Т. 8. № 7S. С. 28–34.
3. *Раевская Е.Г.* Применение искусственного интеллекта в сельском хозяйстве Китая (обзор) // Аграрная наука Евро-Северо-Востока. 2024. Т. 25. № 5. С. 739–753. DOI: 10.30766/2072-9081.2024.25.5.739-7534.
4. *Забалуева Д.В., Сатарина З.Е., Ерошенко Л.М., Семенова Е.Ю.* Влияние климатических факторов на урожайность ярового ячменя в условиях Владимирской области // Владимирский земледелец. 2024. № 1. С. 56–61. DOI: 10.24412/2225-2584-2024-1107-56-61.
5. *Митрофанов Д.В.* Влияние погодных условий, продуктивной влаги, макроэлементов питания почвы и сорных растений на урожайность гороха // Известия Тимирязевской сельскохозяйственной академии. 2025. № 1. С. 22–42.
6. *Гущина В.А., Лыкова А.С., Королев А.С.* Засоренность агроценоза горчицы белой в зависимости от агротехнических приемов в условиях лесостепи Среднего Поволжья // Аграрный научный журнал. 2023. № 6. С. 12–17.
7. *Хряцёв В.В., Ключников А.С., Котов Н.В., Ларионов Р.В.* Идентификация основных типов кормовых культур и сорняков на изображениях с полей методами искусственного интеллекта // Вестник АПК Верхневолжья. 2023. Т. 3. С. 63. DOI: 10.35694/YARCX.2023.63.3.013.
8. *Федосов А.Ю., Меньших А.М., Фартуков В.А., Зборовская М.И., Васильев Д.М.* Применение искусственного интеллекта при оптимизации орошения и применении гербицидов // Экономика строительства. 2023. № 2. С. 42–51.
9. *Пугачев Н.А., Гамбурцев С.Д., Фомин А.А., Сямина Е.И.* Перспективы применения техноло-

- гий искусственного интеллекта в сельском хозяйстве // Московский экономический журнал. 2024. № 1. С. 377–382. DOI: 10.55186/2413046X_2023_9_1_64.
10. Naheed R., Momin A. Smart Farming Technologies: AI-Driven Crop Monitoring and Precision Agronomy // *Innovative Research in Applied, Biological and Chemical Sciences*. 2025. Vol. 3. N 1. P. 6–14.
11. Urbina J.C.C. The Impact of Artificial Intelligence on Agronomy Students // *Sinergia Académica*. 2025. Vol. 8. N 1. P. 447–457.
12. Haq S.I.U., Tahir M.N., Lan Y. Weed detection in wheat crops using image analysis and artificial intelligence (AI) // *Applied Sciences*. 2023. Vol. 13. N 15. P. 8840.
13. Venkateswara S.M., Padmanabhan J. Deep learning based agricultural pest monitoring and classification // *Scientific Reports*. 2025. Vol. 15. N 1. P. 8684.
14. Upadhyay N., Sharma D.K., Bhargava A. 3sw-net: A feature fusion network for semantic weed detection in precision agriculture // *Food Analytical Methods*. 2025. Vol. 18. N 10. P. 2241–2257.
15. Xiao F., Wang H., Li Ya., Ying C. Object detection and recognition techniques based on digital image processing and traditional machine learning for fruit and vegetable harvesting robots: An overview and review // *Agronomy*. 2023. Vol. 13. N 3. P. 639. DOI: 10.3390/agronomy13030639.
16. Gao X., Gao J., Qureshi W.A. Applications, trends, and challenges of precision weed control technologies based on deep learning and machine vision // *Agronomy*. 2025. Vol. 15. N 8. P. 1954. DOI: 10.3390/agronomy15081954.
17. Muchhadiya R.M., Kumawat P.D., Gohil B., Sakarvadia H. Precision weed management using artificial intelligence tools and techniques for sustainable agriculture // *Agriculture & Food e-Newsletter*. 2024. Vol. 6. N 1.
18. Wu W. Research into the application of ResNet in soil: A review // *Agriculture*. 2025. T. 15. N 6. P. 661.
19. Ajayi O.G., Olufade O.O. Drone-based crop type identification with convolutional neural networks: an evaluation of the performance of RESNET architectures // *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. 2023. Vol. 10. P. 991–998.
20. Ховард Д., Гуггер С. Глубокое обучение с fastai и PyTorch: минимум формул, минимум кода, максимум эффективности: монография. СПб.: Питер, 2022. 624 с.
- Ostrovsky readings*, 2024, no. 1, pp. 136–144. (In Russian).
2. Saifetdinov A.R., Maksimenko A.A. Applying machine learning and AI to analyze agricultural data and increase yield. *Kontentus = Contentus*, 2023, vol. 8, no. 7S, pp. 28–34. (In Russian).
3. Raevskaya E.G. Introducing artificial intelligence in Chinese agriculture (review). *Agrarnaya nauka Evro-Severo-Vostoka = Agricultural Science Euro-North-East*, 2024, vol. 25, no. 5, pp. 739–753. (In Russian). DOI: 10.30766/2072-9081.2024.25.5.739-7534.
4. Zabalueva D.V., Satarina Z.E., Eroshenko L.M., Semenova E.Yu. Impact of climatic factors on the yielding capacity of spring barley in the conditions of Vladimir oblast. *Vladimirskiy Zemledelets = Vladimir agronomist*, 2024, no. 1, pp. 56–61. (In Russian). DOI: 10.24412/2225-2584-2024-1107-56-61.
5. Mitrofanov D.V. Effect of weather conditions, productive moisture, soil macronutrients and weeds on pea yield. *Izvestiya Timiryazevskoy sel'skokhozyajstvennoj akademii = Izvestiya of Timiryazev Agricultural Academy*, 2025, no. 1, pp. 22–42. (In Russian).
6. Gushchina V.A., Lykova A.S., Korolev A.S. Infestation of white mustard agrocenosis, depending on agricultural practices in the conditions of the forest-steppe of the Middle Volga region. *Agrarnyy Nauchnyy Zhurnal = Agrarian Scientific Journal*, 2023, no. 6, pp. 12–17. (In Russian).
7. Khryashchev V.V., Klyuchnikov A.S., Kotov N.V., Larionov R.V. Identification of main types of feed crops and weeds on images from the fields by artificial intelligence techniques. *Vestnik APK Verkhnevolzhya = Herald of Agroindustrial complex of Upper Volga region*, 2023, vol. 3, p. 63. (In Russian). DOI: 10.35694/YARCX.2023.63.3.013.
8. Fedosov A.Yu., Menshikh A.M., Fartukov V.A., Zborovskaya M.I., Vasiliev D.M. The use of artificial intellect in the optimization of irrigation and the use of herbicides. *Ekonomika stroitelstva = Economics of construction*, 2023, no. 2, pp. 42–51. (In Russian).
9. Pugachev N.A., Gamburtsev S.D., Fomin A.A., Syamina E.I. Prospects for the use of artificial intelligence technologies in agriculture. *Moskovskiy Ekonomicheskij Zhurnal = Moscow Economic Journal*, 2024, no. 1, pp. 377–382. (In Russian). DOI: 10.55186/2413046X_2023_9_1_64.
10. Naheed R., Momin A. Smart farming technologies: AI-driven crop monitoring and precision agronomy. *Innovative Research in Applied, Biological and Chemical Sciences*, 2025, vol. 3, no. 1, pp. 6–14.
11. Urbina J.C.C. The impact of artificial intelligence on agronomy students. *Sinergia Académica*, 2025, vol. 8, no. 1, pp. 447–457.

REFERENCES

12. Haq S.I.U., Tahir M.N., Lan Y. Weed detection in wheat crops using image analysis and artificial intelligence (AI). *Applied Sciences*, 2023, vol. 13, no. 15, p. 8840.
13. Venkateswara S.M., Padmanabhan, J. Deep learning based agricultural pest monitoring and classification. *Scientific Reports*, 2025, vol. 15, no. 1, p. 8684.
14. Upadhyay N., Sharma D.K., Bhargava A. 3sw-net: A feature fusion network for semantic weed detection in precision agriculture. *Food Analytical Methods*, 2025, vol. 18, no. 10, pp. 2241–2257.
15. Xiao F., Wang H., Li Ya., Ying C. Object detection and recognition techniques based on digital image processing and traditional machine learning for fruit and vegetable harvesting robots: An overview and review. *Agronomy*, 2023, vol. 13, no. 3, p. 639. DOI: 10.3390/agronomy13030639.
16. Gao X., Gao J., Qureshi W.A. Applications, trends, and challenges of precision weed control technologies based on deep learning and machine vision. *Agronomy*, 2025, vol. 15, no. 8, p. 1954. DOI: 10.3390/agronomy15081954.
17. Muchhadiya R.M., Kumawat P.D., Gohil B., Sakarvadia H. Precision weed management using artificial intelligence tools and techniques for sustainable agriculture. *Agriculture & Food e-Newsletter*, 2024, vol. 6, no. 1.
18. Wu W. Research into the application of ResNet in soil: A review. *Agriculture*, 2025, vol. 15, no. 6, p. 661.
19. Ajayi O.G., Olufade O.O. Drone-based crop type identification with convolutional neural networks: An evaluation of the performance of ResNet architectures. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 2023, vol. 10, pp. 991–998.
20. Howard D., Gugger S. *Deep Learning with fastai and PyTorch: Minimal Formulas, Minimal Code, Maximum Efficiency*. St. Petersburg, Piter Publ., 2022, 624 p. (In Russian).

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Экспериментальное исследование термоградиентной миграции влаги в грунте

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Передвижение влаги под влиянием температурного градиента – важный элемент водного режима сибирских степных почв. Для прогноза этой миграции в естественных условиях важно экспериментальное изучение передвижения влаги в грунте. Цель работы – исследовать в лабораторных условиях передвижение влаги в грунте под влиянием температурного градиента. Термоградиентное передвижение влаги в насыпных колонках грунта выявлено путем сравнения их исходных и итоговых профилей влажности. Колонки грунта с равномерно распределенным по профилю влагосодержанием выдержаны 14 сут в холодильной установке при температуре -6°C у поверхности колонок и не более 3°C – у основания. Влажность грунтов определена термостатно-весовым методом. Температуру фиксировали термометрами Саввинова. Глубина промерзания песчаных и суглинистых грунтов оказалась прямо пропорциональной их исходной влажности – 10,0–19,5 см. В итоговых профилях влажности в верхней промерзшей части отмечена зона аккумуляции влаги, под ней – зона подмерзлотного иссушения, прослеживаемая до основания колонок. Объем мигрировавшей влаги напрямую связан с исходной влажностью грунтов (в среднем суглинке при исходной влажности 5,9% массы отмечено намерзание 7,7 мм влаги, при влажности 17,4% – 44,4 мм). Пространственное размещение намерзшей влаги зависит от гранулометрического состава грунтов. В суглинистых вариантах отмечено уменьшение ее содержания от поверхности до нижней границы промерзшего слоя; в песчаном грунте основную прибавку влаги наблюдали в нижней части слоя промерзания. Полученные экспериментальные данные по намерзанию влаги в насыпных грунтах актуальны для разработки математических моделей термоградиентной миграции влаги в пахотных почвах южной части Сибири. На основе таких моделей возможен не только прогноз намерзания влаги в почвах при различных природно-климатических условиях, но и создание рекомендаций по воздействию на факторы внешней среды для оптимизации процессов криогенной аккумуляции влаги в пахотных почвах.

Ключевые слова: колонки насыпного грунта, гранулометрический состав, профиль влажности, глубина промерзания, пленочная влага, капиллярная вода

Experimental study of thermogradient migration of moisture in soil

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The movement of moisture under the influence of a temperature gradient is an important element of the water regime of Siberian steppe soils. It is important to experimentally study the movement of moisture in soil in order to predict this migration in natural conditions. The purpose of the work is to study in laboratory conditions the movement of moisture in soil under the influence of a temperature gradient. Thermal gradient movement of moisture in bulk soil columns was identified by comparing their initial and final moisture profiles. Soil columns with moisture content uniformly distributed along the profile were kept for 14 days in a refrigeration unit at a temperature of -6°C at the surface of the columns and no more than 3°C at the base. Soil moisture was determined by the thermostatic-weight method. The temperature was recorded with the Savvinov thermometers. The freezing depth of sandy and loamy soils turned out to be directly proportional to their initial moisture content – 10.0–19.5 cm. In the final moisture profiles in the upper frozen part, a zone of moisture accumulation is noted, beneath it – a zone of sub permafrost drying, traceable down to the base of the columns. The volume

of migrated moisture is directly related to the initial soil moisture (in an average loam with an initial moisture content of 5.9% by mass, an ice formation of 7.7 mm of moisture was observed; with a moisture content of 17.4%, it was 44.4 mm). The spatial distribution of frozen moisture depends on the granulometric composition of soils. In loamy variants, a decrease in its content from the surface to the lower boundary of the frozen layer was noted; in sandy soil, the main increase in moisture was observed in the lower part of the freezing layer. The experimental data obtained on moisture accretion in loose soils are relevant for the development of mathematical models of thermogradient moisture migration in arable soils of the southern part of Siberia. Based on such models, it is possible not only to predict the icing of moisture in soils under various natural and climatic conditions, but also to create recommendations on influencing environmental factors to optimize the processes of cryogenic moisture accumulation in arable soils.

Keywords: columns of bulk soil, granulometric composition, moisture profile, freezing depth, film moisture, capillary water

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Conflict of interest

The author declares no conflict of interest.

INTRODUCTION

The movement of moisture in soil and ground layers under the influence of a temperature gradient is an important part of the water regime in Siberian steppe soils [1]. The accumulation of this moisture determines the formation of modern hydromorphic features in the subsoil layers, delays the spring warming of the lower horizons of steppe soils, and reduces aeration porosity in these horizons. In the southern regions of Siberia, due to human activity, the groundwater level is currently above the critical depth [2, 3]. Primarily automorphic soils began developing with additional moisture from groundwater, including water that comes from the underground layers that don't freeze during the winter moisture redistribution. Because of this, the topic of thermogradient moisture movement in the soil and ground layers of Siberia is relevant.

Changes in soil moisture profiles due to seasonal freezing have been studied in various regions of Siberia [4]. The probable mechanisms of moisture movement driven by temperature gradients have been identified. The dependence

of moisture freezing volumes in Siberian soils on environmental factors has been shown [5].

Models of moisture movement have been developed to predict moisture accumulation in seasonally frozen soils. A review of methods for characterizing heat and moisture movement in soils has been done [6, 7]. A program for soil moisture transport under climate fluctuations has been created [8, 9]. A model of moisture migration in the freezing zone under the influence of a temperature gradient has been proposed. A program has been created to assess the regional impact of seasonal freezing and thawing of soils on their moisture distribution [10, 11]. A model of heat and moisture movement in partially frozen soils over a large area has been presented [12, 13]. However, these models were created using different parameters and turn out to be applicable only to specific areas. For creating numerical models of thermogradient moisture migration in the southern regions of Siberia, there isn't enough field observation data. It needs to be supplemented through laboratory experiments.

The purpose of the work is to investigate in laboratory conditions the movement of moisture

in the soil under the influence of a temperature gradient.

MATERIAL AND METHODS

The study focused on the moisture profiles of soil fill columns. The soil columns measured $7 \times 7 \times 20$ cm. The thermogradient movement of moisture is evident in the highly wet layers, which in the arable soils of the steppe are located below the layer of summer evapodesiccation, so for the research, samples were taken from the soil horizon C at a depth of 0.9–1.5 m. They were collected from an upland area of the Ishim steppe. For comparison, samples from the same layer in the watershed area of the Novosibirsk Priobye and from fresh alluvial deposits in the Ob River valley were used. The grain size composition of the samples was determined using the method of N.A. Kachinsky [14] (see Table 1).

To verify the results obtained in the experiment, three identical columns of fill-up soil were used in each case. The columns being tested were given a moisture content ranging from 4.2 to 19.3% of their mass. To prevent water movement due to moisture gradients, the initial moisture content was distributed evenly along the vertical. The columns were protected on all sides to prevent moisture loss through evaporation.

The prepared columns were placed in a refrigeration unit for 14 days. The tops of the columns were kept at a temperature of -6 °C, which is enough to freeze the soil (that is, un-

til some of the moisture in it turns solid and ice crystals appear). At the base of the columns, the temperature was no more than 3 °C. The cooling element is located above the columns, so the soil only froze from the top. The conclusion about the movement of moisture under the influence of the temperature gradient was made based on the comparison of the initial and final moisture profiles. The final vertical distribution of moisture was determined immediately after the soil cores were taken out of the freezer, while their top parts were still frozen. Soil moisture was measured using the thermostat-weighing method [15], with each 2-centimeter layer tested twice. The temperature in the soil was recorded using the Savvinov thermometers placed in the cores when they were put in the freezer.

RESULTS AND DISCUSSION

The indicators of thermogradient moisture movement are related to the depth of soil freezing (see table 2).

The frost penetration depth was 10–19.5 cm and turned out to be directly proportional to the initial soil moisture (see Fig. 1).

It's noticeable that the freezing depth of sandy soil is quite large at initial moisture levels of 13.4% and 14.4%. This is probably due to the increased thermal conductivity of soils with a lighter grain composition when their moisture is higher (somewhere between the lowest and full water capacity). According to our calculations, the thermal conductivity in sandy soil with 110%

Табл. 1. Гранулометрический состав насыпных колонок грунтов (по Н.А. Качинскому)

Table 1. Granulometric composition of bulk soil columns (according to N.A. Kachinsky)

Depth, m	Losses from HCl processing, %	Particle size, mm							
		1,00–0,25	0,25–0,05	0,05–0,01	0,01–0,005	0,005–0,001	<0,001	<0,01	>0,01
Number of particles, %									
Ishim Steppe. Heavy loam									
0,9–1,3	10,8	0,0	10,8	18,4	12,2	12,9	34,9	60,0	29,2
Novosibirsk Ob region. Medium loam									
1,4–1,5	0,0	0,3	22,3	46,3	12,4	13,1	5,6	31,1	68,9
Novosibirsk Ob Region. Sand									
0,1–0,4	0,0	37,6	43,6	8,9	1,7	3,4	4,8	9,9	90,1

Табл. 2. Объем перераспределившейся влаги при промерзании верхней части колонок грунта
Table 2. Volume of redistributed moisture during freezing of the upper part of the soil columns

Soil particle-size distribution	Initial moisture content, % of the mass	Frost penetration depth, cm	Volume of redistributed moisture	
			mm	% of initial moisture content
Heavy loam	5,5	10	15,5	16,1
	10,5	14	14,1	7,7
	15,7	18	26,2	9,5
	19,3	16,5	26,4	7,8
Medium loam	5,9	14	7,7	7,4
	11,6	17	23,6	11,6
	14,4	12	28,7	11,4
	17,4	10	44,4	14,6
Sand	4,2	12	15,0	20,3
	8,7	16	16,0	10,5
	13,4	19,5	7,0	2,9
	14,4	19,5	8,0	3,2

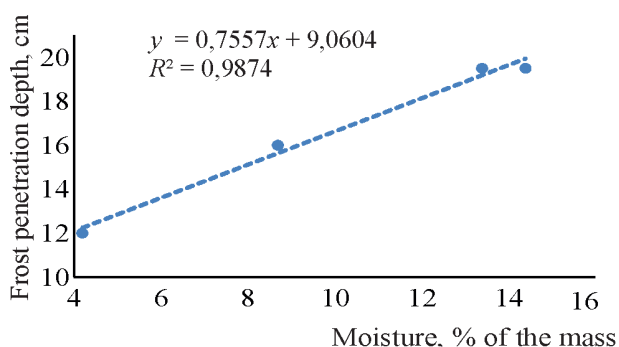


Рис. 1. Пропорциональность между исходной влажностью песчаного грунта и глубиной его промерзания

Fig. 1. The proportionality between the initial moisture content of the sandy soil and the depth of its freezing

moisture at the minimum water capacity reaches 2 W/(m·K) compared to 1.33 W/(m·K) in heavy loam with similar moisture content. This might explain the rapid and deep cooling of the moistened sandy soil.

Thermal gradient redistribution of moisture was recorded in all experimental samples (see Fig. 2).

In the final moisture profiles of the soil columns, two zones stand out. At the top of the columns, there's a moisture accumulation zone. Its lower boundary corresponds to the depth that freezing temperatures reach. At the bottom of

the columns, there's a zone of frost-dried soil, extending from the freezing front down to the base of the columns.

A special pattern of moisture distribution was observed in sandy soil with moisture levels of 13.4% and 14.4%. Here, moisture accumulation was recorded only in the 0–4 cm layer. The small vertical thickness of the frost layer in these cases is due to the fact that the soil columns froze almost to the bottom during the first 4 days, which stopped the movement of moisture in them.

The amount of redistributed moisture directly depends on the initial moisture content (see Fig. 3). With low initial moisture (less than 10%), the largest share of migrated moisture was observed in sandy soil – 10.5–20.3%. In the loamy varieties, the share of redistributed moisture reached 7.4–11.6%. With high initial moisture (over 10%), the most noticeable movement of water was recorded in medium loams – 11.4–14.6%.

Thus, the amount of redistributing moisture turned out to depend primarily on the initial moisture content of the soils, and secondly on their grain-size composition. With low and high initial moisture reserves, the volume of its migration into the freezing layer increases as the soil's grain-size composition becomes lighter.

The granulometric composition is also re-

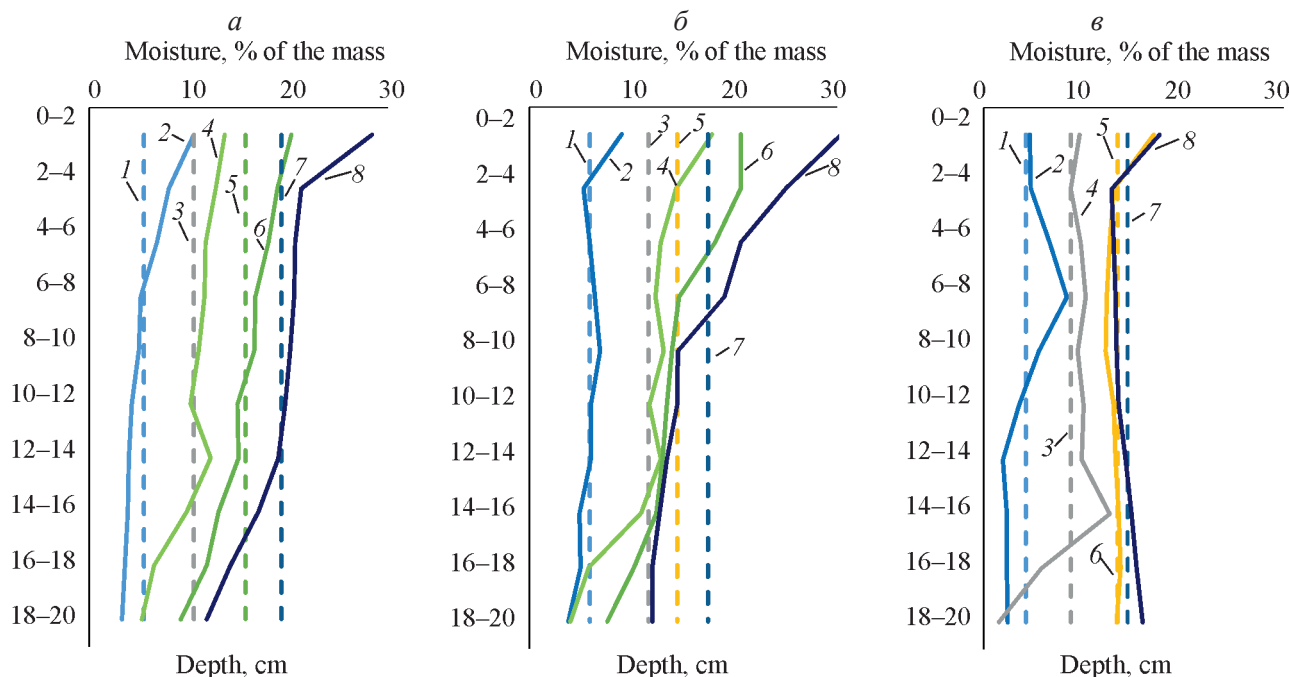


Рис. 2. Изменение профиля влажности насыпных колонок вследствие промерзания их верхней части: *а* – тяжелосуглинистого состава; *б* – среднесуглинистого; *в* – песчаного: *а*: 1 – исходная влажность 5,5%; 2 – итоговая влажность, глубина промерзания 10 см; 3 – исходная влажность 10,5%; 4 – итоговая влажность, глубина промерзания 14 см; 5 – исходная влажность 15,7%; 6 – итоговая влажность, глубина промерзания 18 см; 7 – исходная влажность 19,3%; 8 – итоговая влажность, глубина промерзания 16,5 см; *б*: 1 – исходная влажность 5,9%; 2 – итоговая влажность, глубина промерзания 14 см; 3 – исходная влажность 11,6%; 4 – итоговая влажность, глубина промерзания 17 см; 5 – исходная влажность 14,4%; 6 – итоговая влажность, глубина промерзания 12 см; 7 – исходная влажность 17,4%; 8 – итоговая влажность, глубина промерзания 10 см; *в*: 1 – исходная влажность 4,2%; 2 – итоговая влажность, глубина промерзания 12 см; 3 – исходная влажность 8,7%; 4 – итоговая влажность, глубина промерзания 16 см; 5 – исходная влажность 13,4%; 6 – итоговая влажность, глубина промерзания 19,5 см; 7 – исходная влажность 14,4%; 8 – итоговая влажность, глубина промерзания 19,5 см

Fig. 2. Changes in the moisture profile of bulk columns due to freezing of their upper part:

а – heavy loamy composition; *б* – medium loam composition; *в* – sand: *а*: 1 – initial humidity 5,5%; 2 – final moisture content, freezing depth 10 cm; 3 – initial humidity 10,5%; 4 – final moisture content, freezing depth 14 cm; 5 – initial humidity 15,7%; 6 – final moisture content, freezing depth 18 cm; 7 – initial humidity 19,3%; 8 – final moisture content, freezing depth 16,5 cm; *б*: 1 – initial humidity 5,9%; 2 – final moisture content, freezing depth 14 cm; 3 – initial humidity 11,6%; 4 – final moisture content, freezing depth 17 cm; 5 – initial humidity 14,4%; 6 – final moisture content, freezing depth 12 cm; 7 – initial humidity 17,4%; 8 – final moisture content, freezing depth 10 cm; *в*: 1 – initial humidity 4,2%; 2 – final moisture content, freezing depth 12 cm; 3 – initial humidity 8,7%; 4 – final moisture content, freezing depth 16 cm; 5 – initial humidity 13,4%; 6 – final moisture content, freezing depth 19,5 cm; 7 – initial humidity 14,4%; 8 – final moisture content, freezing depth 19,5 cm

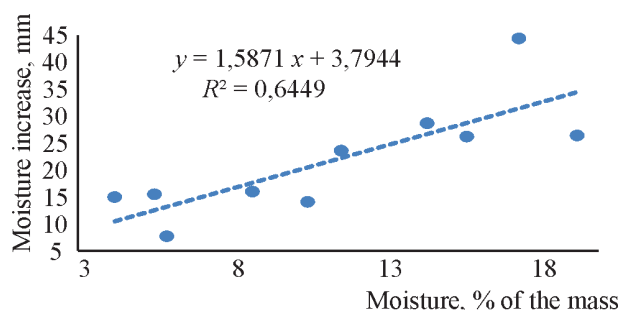


Рис. 3. Пропорциональность между исходной влажностью колонок грунта (% массы) и прибавкой влаги в слое намерзания (мм)

Fig. 3. The proportionality between the initial moisture content of the columns of the soil (% by weight) and the increase in moisture in the freezing layer (mm)

lated to the features of the vertical distribution of frozen moisture. In the loamy variants, the largest increase in moisture in the frozen layer is noted at depths of 0–2 cm (see Fig. 2). This increase can reach up to 70% of the total rise in moisture content in the frozen layer. As the depth increases, the amount of frozen moisture decreases. This water distribution is due to the high specific weight of film water in loamy soils. In sandy soils, the maximum increase in moisture is observed in the lower part of the freezing zone because of the migration of mainly capil-

lary water (see Fig. 2). The height of capillary rise in sandy soils is measured in centimeters, which matches the moisture concentration at the bottom of the frozen layer.

The initial moisture content is also associated with the uneven change in the humidity of the sub-permafrost drying zone: with an increase in humidity, this decrease with increasing depth becomes more pronounced (see Fig. 2).

This work is the first step in selecting experimental data for developing mathematical models of moisture freezing in soils. Further studies are planned for moisture migration under the influence of temperature differences in undisturbed soils.

CONCLUSIONS

1. Moisture movement in seasonally frozen soil layers under the influence of a temperature gradient is a significant element of the water regime of Siberian steppe arable soils. Therefore, it is important to develop numerical models of moisture movement to predict the parameters of its cryogenic migration. To create mathematical models, it is necessary to accumulate quantitative data on this process, including laboratory experiments.

2. A series of experiments was conducted to identify the characteristics of moisture migration under the influence of a temperature gradient in sandy and loamy varieties of bulk soil with initial moisture contents ranging from 4.2 to 19.3% by weight. It was found that at a temperature of -6°C at the surface of the bulk soil columns and no more than 3°C at their base, the freezing depth of the columns over the 14-day experiment was 10.0–19.5 cm and was directly proportional to the initial soil moisture content.

3. Changes in moisture profiles were recorded in all experimental columns. An increase in moisture content was observed in the freezing zone, while a corresponding decrease was observed in the lower subpermafrost zone. The freezing values were directly proportional to the initial soil moisture content.

4. The vertical distribution of moisture migrating into the freezing layer depends largely on the soil's particle size distribution. In loamy soils, the amount of frozen moisture gradually decreases from the surface of the soil column to the lower boundary of the frozen zone, due to the high content of film moisture in the water phase of such soils, which is uniformly distributed across the profile. In sandy soil variants, a distinct maximum of frozen moisture is found in the lower part of the frozen zone. This moisture distribution is due to the large amount of capillary water in the sandy soil, which, under the force of gravity, is quickly redistributed to the lower part of the fill column and, when it freezes, migrates in large volumes into the frozen zone.

СПИСОК ЛИТЕРАТУРЫ

1. *Мкртчян Ф.А.* Мониторинг влажности почвы как элемента регионального водного баланса // Проблемы окружающей среды и природных ресурсов. 2025. № 2. С. 145–157. DOI: 10.36535/0235-5019-2025-02-4.
2. *Орлова Е.С., Заносова Е.И., Рыбкина И.Д.* Уровни залегания, условия питания и гидрохимия водоносных горизонтов бессточной области Обь-Иртышского междуречья (на примере степной части Алтайского края) // Географический вестник. 2024. № 1 (68). С. 71–86. DOI: 10.17072/2079-7877-2024-1-71-86.
3. *Казьмин С.П., Климов О.В.* Комплекс природоохранных мер от затопления и подтопления лесов Новосибирской области // Интерэкспо-Гео-Сибирь. 2023. Т. 4. № 2. С. 49–53. DOI: 10.33764/2618-981X-2023-4-2-49-53.
4. *Кравцов Ю.В.* Влияние многолетней динамики уровня грунтовых вод на зимнее перераспределение влаги в пахотных почвах Ишимской степи // Почвы и окружающая среда. 2024. Т. 7. № 1. DOI: 10.31251/pos.v7i1.250.
5. *Кравцов Ю.В.* Факторы зимнего передвижения влаги в пахотных почвах Ишимской степи // Сибирский вестник сельскохозяйственной науки. 2024. Т. 54. № 8. С. 113–121. DOI: 10.26898/0370-8799-2024-8-12.
6. *Сидоров И.А., Гудков Г.А., Новичихин Е.П., Чижиков С.В.* Радиометрический метод измерения температуры и влажности поч-

- вы // Нанотехнологии: разработка, применение – XXI век. 2024. Т. 16. № 1. С. 50–60. DOI: 10.18127/j22250980-202401-04.
7. Ермолаева О.С., Зейлигер А.М., Колганов Д.А. Оценка влагозапасов почвы с применением индукционного рефлектометра EM38MK2 // Управление рисками в АПК. 2024. № S3 (53). С. 347–352.
8. Лавров С.А. Влияние климатических изменений на влажность почвы // Водное хозяйство России: проблемы, технологии, управление. 2025. № 2. С. 19–39. DOI: 10.35567/19994508-2025-2-19-39.
9. Мельник В.И., Буяков И.В., Яцухно В.М., Шумская Т.Г. Оценка увлажнения почв сельскохозяйственных земель Белорусского Поозерья в условиях современного изменения климата // Природопользование. 2025. № 1. С. 15–26. DOI: 10.47612/2079-3928-2025-1-15-26.
10. Deng M., Meng X., Lu Z., Zhao L., Hu Z., Chen H., Shang L., Wang Sh., Li Q. Impact and Sensitivity Analysis of Soil Water and Heat Transfer Parameterizations in Community Land Surface on the Tibetan Plateau // Journal of advances in modeling Earth systems. 2021. Vol. 13. Iss. 9. e2021MS002670. DOI: 10.1029/2021MS002670.
11. Хохлов Н.Ф., Гудков А.Г., Сидоров И.А., Чижиков С.В., Агасиева С.В. Перспективы использования влаготемпературной БПЛА-метрии для оценки состояния территорий землепользования при планировании и проведении весенних полевых работ // Наукоемкие технологии. 2024. Т. 25. № 5. С. 55–67. DOI: 10.18127/j19998465-202405-05.
12. Косарев А.В., Русинов А.В., Чумакова С.В., Колганов Д.А., Алексеев В.С., Моршинев А.Ю. Распределение влажности почвы поля данным дистанционного зондирования // Успехи современного естествознания. 2024. № 8. С. 20–29. DOI: 10.17513/use.38299.
13. Романов А.Н., Хвостов И.В., Рябинин И.В., Романов Д.А. Дистанционная оценка влагозапаса почвы в метровом слое по данным спутника SMOS // Современные проблемы дистанционного зондирования Земли из космоса. 2024. Т. 21. № 4. С. 209–222. DOI: 10.21046/2070-7401-2024-21-4-209-222.
14. Агрофизика: монография / Шеин Е.В., Мазиров М.А., Зинченко С.И. и др. Владимир: Изд-во ВНИИСХ, 2016. 124 с.
15. Ивакин М.В. Сравнительный анализ результатов исследований по определению влажности почвы с помощью влагомера МГ-44 и термостатно-весового метода // Известия Нижневолжского агроуниверситетского комплекса. 2025. № 2 (80). С. 178–187. DOI: 10.32786/2071-9485-2025-02-20.

REFERENCES

1. Mkrtchyan F.A. Monitoring of soil moisture as an element of the regional water balance. *Problemy okruzhayushchei sredy I prirodnnykh resursov = Problems of the Environment and Natural Resources*, 2025, no. 2, pp. 145–157. (In Russian). DOI: 10.36535/0235-5019-2025-02-4.
2. Orlova E.S., Zanosova E.I., Rybkina I.D. Levels of deposition, recharge conditions, and hydrochemistry of aquifers in the Ob-Irtysh interfluvium (a case study of the steppe part of the Altai Territory). *Geographicheskii vestnik = Geographical Bulletin*, 2024, no. 1 (68), pp. 71–86. (In Russian). DOI: 10.17072/2079-7877-2024-1-71-86.
3. Kazmin S.P., Klimov O.V. Complex of environmental protection measures against flooding and flooding of forests of the Novosibirsk region. *Interexpo-Geo-Sibir' = Interexpo-Geo-Siberia*, 2023, vol. 4, no. 2, pp. 49–53. (In Russian). DOI: 10.33764/2618-981X-2023-4-2-49-53.
4. Kravtsov Yu.V. The influence of groundwater level long-term dynamics on winter moisture redistribution in arable soils of the Ishim steppe. *Pochvy I okruzhayushchaya sreda = The Journal of Soils and Environment*, 2024, vol. 7, no. 1. (In Russian). DOI: 10.31251/pos.v7i1.250.
5. Kravtsov Yu.V. Factors of winter moisture movement in arable soils of the Ishim steppe. *Sibirskii vestnik sel'skokhozyaistvennoy nauki = Siberian Herald of Agricultural Science*, 2024, vol. 54, no. 8, pp. 113–121. (In Russian). DOI: 10.26898/0370-8799-2024-8-12.
6. Sidorov I.A., Gudkov G.A., Novichikhin E.P., Chizhikov S.V. Radiometric method of soil temperature and moisture measurement. *Nanotekhnologii: razvitie, primeneniye – XXI vek = Nanotechnology: the development, application - XXI Century*, 2024, vol. 16, no. 1, pp. 50–60. (In Russian). DOI: 10.18127/j22250980-202401-04.
7. Ermolaeva O.S., Zeiliger A.M., Kolganov D.A. Assessment of soil moisture content using the EM38MK2 induction reflectometer. *Upravlenie*

- riskami v APK = Risk Management in Agriculture*, 2024, no. S3 (53), pp. 347–352. (In Russian).
8. Lavrov S.A. The effect of climate change on soil moisture. *Vodnoe khozyaistvo Rossii: problemy, tekhnologii, upravlenie = Water Sector of Russia: Problems, Technologies, Management*, 2025, no. 2, pp. 19–39. (In Russian). DOI: 10.35567/19994508-2025-2-19-39.
 9. Melnik V.I., Buyakov I.V., Yatsukhno V.M., Shumskaya T.G. Assessment of soil moisture in agricultural lands of Belarusian Lake District in the context of modern climate change. *Prirodopol'zovanie = Nature Management*, 2025, no. 1, pp. 15–26. (In Russian). DOI: 10.47612/2079-3928-2025-1-15-26.
 10. Deng M., Meng X., Lu Z., Zhao L., Hu Z., Chen H., Shang L., Wang Sh., Li Q. Impact and Sensitivity Analysis of Soil Water and Heat Transfer Parameterizations in Community Land Surface on the Tibetan Plateau. *Journal of advances in modeling Earth systems*, 2021, vol. 13, iss. 9, e2021MS002670. DOI: 10.1029/2021MS002670.
 11. Khokhlov N.F., Gudkov A.G., Sidorov I.A., Chizhikov S.V., Agasieva S.V. Prospects for the use of moisture-temperature UAV metrics to assess the state of land-use territories in planning and conducting spring field work. *Naukoyomkie tekhnologii = Science Intensive Technologies*, 2024, vol. 25, no. 5, pp. 55–67. (In Russian). DOI: 10.18127/j19998465-202405-05.
 12. Kosarev A.V., Rusinov A.V., Chumakova S.V., Kolganov D.A., Alekseev V.S., Morshnev A.Yu. Distribution of soil moisture in the field according to remote sensing data. *Uspekhi sovremenno estestvoznaniya = Advances in current natural sciences*, 2024, no. 8, pp. 20–29. (In Russian). DOI: 10.17513/use.38299.
 13. Romanov A.N., Khvostov I.V., Ryabinin I.V., Romanov D.A. Remote assessment of soil moisture content in one-meter layer using SMOS satellite data. *Sovremennye problemy distantsionnogo zondirovaniya Zemli iz kosmosa = Current Problems in Remote Sensing of the Earth from Space*, 2024, vol. 21, no. 4, pp. 209–222. (In Russian). DOI: 10.21046/2070-7401-2024-21-4-209-222.
 14. *Agrophysics*. Shein E.V., Mazirov M.A., Zinchenko S.I. et al. Vladimir, VNIISKH Publishing House, 2016, 124 p. (In Russian).
 15. Ivakin M.V. Comparative analysis of the results of studies on determining soil moisture using the MG-44 moisture meter and the thermostatic-weight method. *Izvestiya Nizhnevolzhskogo agrouniversitetskogo kompleksa = Izvestia of the Lower Volga Agro-University Complex*, 2025, no. 2 (80), pp. 178–187. (In Russian). DOI: 10.32786/2071-9485-2025-02-20.

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Толерантность малины красной к пестицидам и ионам никеля

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Представлены результаты исследования толерантности к ионам никеля растений малины красной (*Rubus idaeus* L.), отобранных на устойчивость к пестицидам (глифосату, беномилу и малатиону). Микрочеренки малины культивировали на питательной среде, содержащей 0,25 мМ хлорида никеля. С использованием хлорофиллфлуориметра LPT-3 (Россия) регистрировали удельную фотосинтетическую активность тканей (Kf). Сравнивали уровень падения Kf под влиянием соли тяжелого металла на контрольной и содержащей антиоксиданты средах. Регистрировали также влияние ионов никеля на изменение Kf и скорость некротизации листьев у контрольных и пестицидотолерантных растений. Хлорид никеля на 10-е сутки культивирования снижал фотосинтетическую активность тканей от 0,531 до 0,12. Внесение в среду аскорбиновой кислоты уменьшало негативное действие токсичного вещества на 37,84% (Kf = 0,26), внесение глутатиона восстановленного – на 77,80% (Kf = 0,44). Это свидетельствует о роли антиоксидантов в реализации толерантности растений к тяжелым металлам. Установлены различия между контрольными и устойчивыми к пестицидам растениями по изменению Kf и скорости некротизации листьев при стрессовом воздействии. В присутствии токсичного вещества у контрольных растений на 10-е сутки культивирования снижение Kf составило 51,74% (от 0,172 до 0,083), у пестицидотолерантных растений – 32,20% (от 0,172 до 0,117). На среде, содержащей соль тяжелого металла, у контрольных растений *in vitro* на 30-е сутки культивирования зарегистрирована некротизация 51,33% листьев, у пестицидустойчивых – 35,65%. Это свидетельствует о более высокой толерантности к хлориду никеля устойчивых к пестицидам растений по сравнению с контрольными.

Ключевые слова: малина красная, *in vitro*, тканевая селекция, удельная фотосинтетическая активность, хлорид никеля, пестициды, толерантность

Tolerance of red raspberry to pesticides and nickel ions

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The results of a study of nickel tolerance in red raspberry (*Rubus idaeus* L.) plants selected for resistance to pesticides (glyphosate, benomyl and malathion) are presented. Raspberry micro cuttings were cultivated on a nutrient medium containing 0.25 mM nickel chloride. Using a chlorophyll fluoro-

meter LPT-3 (Russia), the specific photosynthetic activity of tissues (Kf) was recorded. The level of Kf drop under the influence of heavy metal (HM) salt on the control medium and the medium containing antioxidants was compared. The effect of nickel ions on the change of Kf and the rate of leaf necrotization in control and pesticide-tolerant plants was also recorded. Nickel chloride reduced the Kf of the tissues from 0.531 to 0.12 on the tenth day of cultivation. Adding ascorbic acid to the medium reduced the negative effect of the toxic substance by 37.84% (Kf=0.26), and adding reduced glutathione reduced it by 77.80% (Kf=0.44). This indicates the role of antioxidants in the implementation of plant tolerance to heavy metals. Differences were established between control and pesticide-resistant plants in terms of the magnitude of Kf change and the rate of leaf necrotization under stress. In the presence of a toxic substance, the Kf of control plants decreased by 51.74% (from 0.172 to 0.083) on the tenth day of cultivation, while that of the pesticide-tolerant plants decreased by 32.20% (from 0.172 to 0.117). On a medium containing heavy metal salt, 51.33% of the leaves of control plants *in vitro* were necrotized on the thirtieth day of cultivation, while 35.65% of the leaves of pesticide-resistant plants were necrotized. This indicates that pesticide-resistant plants are more tolerant to nickel chloride than control plants.

Keywords: red raspberry, *in vitro*, tissue selection, specific photosynthetic activity, nickel chloride, pesticides, tolerance

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Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

The productivity of agricultural crops is significantly reduced by negative abiotic environmental impacts. The most harmful of these are extreme temperatures, insufficient or excessive moisture, high soil salinity, pollution with heavy metal compounds (HM), and a high pesticide load. These effects disrupt the normal flow of physiological processes in plant tissues, which leads to reduced photosynthesis, slower plant growth, and lower yields [1].

The problem can be solved by developing tolerant varieties¹ [1]. However, breeding for resistance to each of the stress factors is a long and laborious process.

Abiotic stressors, besides having specific

effects, also have general ways of acting. They disrupt the balance between the production of reactive oxygen species (ROS) and their detoxification by the antioxidant system, leading to the accumulation of ROS. Superoxide anion – radical ($O_2^{\cdot-}$), hydrogen peroxide (H_2O_2), hydroxyl radical ($\cdot OH$), singlet oxygen (1O_2), hypogaloids ($HOCl$, $HOCl$, $HOBr$, HOI , $HOSCN$), nitric oxide ($NO\cdot$) and other radicals act as signaling molecules, but their excess activates oxidative processes that cause changes in the structure of lipids, proteins, and nucleoproteins. The degree of impairment depends on the intensity of the effects and their duration [2].

Oxidative stress in plants can be caused by extreme temperatures, drought [2, 3], pesticides

¹Dragavtsev V.A., Dragavtseva I.A., Efimova I.L., Morinets A.S., and Savin I.Yu. Management by "genotype-environment" interaction - most important level for increase of cultivated plants yields // Proceedings of the Kuban State Agrarian University, 2016, vol. 59, N 2, pp. 105–121.

[4], excessive soil salinity [5], heavy metal ions² [6], and more. Because of this, selecting plants that can significantly boost their antioxidant system under negative conditions could increase their ability to adapt to stress.

The process of developing tolerant varieties can be sped up using a method of cell or tissue selection, which involves selecting resistant cells or tissues in a selective *in vitro* environment and then regenerating plants from them. There are reports of successfully using this cell selection method to produce plants with increased resistance to lead [7] and copper ions. Using the method of measuring lipid peroxidation intensity in the presence of HM, it was shown that tolerance to copper ions is linked to the activity of the plant's antioxidant system. Flax cell lines selected for paraquat tolerance (a pesticide that causes ROS formation) also showed increased resistance to copper ions [8].

Considering the role of the antioxidant system in achieving tolerance, methods have been developed to assess plant resistance to heavy metals based on measuring the activity of antioxidant system enzymes and the intensity of lipid peroxidation (LPO) in the presence of heavy metals [9].

In plant tissues, the balance between the production and inactivation of ROS is maintained by enzymatic and non-enzymatic antioxidant mechanisms. The main enzymatic antioxidants are ascorbate peroxidase, superoxide dismutase, catalase, and glutathione reductase. The main non-enzymatic antioxidants include fat-soluble ones (α -tocopherol and β -carotene) as well as water-soluble ones (glutathione, ascorbic acid, etc.) [10].

At the I.V. Michurin Federal Scientific Center, the effect of reduced glutathione (GSH) and ascorbic acid (AsA) on the growth and reproduction of red raspberry plants *in vitro* was studied in the presence of sodium chloride and pesticides at toxic concentrations. A decrease in the negative effects of the mentioned toxic substanc-

es on the reproduction rate and average length of microshoots in the presence of antioxidants has been shown, which confirms the role of the latter in enabling tolerance to salinity and pesticides. During the research, methods for diagnosing *in vitro* plant resistance to stress were optimized by looking at the changes in morphometric indicators and the rate of change in fluorescence indicators in the presence of stressors [11].

From 2017 to 2024, the I.V. Michurin Federal Scientific Center worked on developing selective systems to produce plants of the *Rubus* genus that are resistant to excessive chloride salinity and pesticides. Using tissue selection, they developed blackberry plants with increased tolerance to glyphosate and chloride salinity, as well as red raspberry plants resistant to benomyl, malathion, glyphosate, and chloride salinity.

The goal of the study is to prove the role of the antioxidant system in how red raspberry plants tolerate nickel chloride.

The research objectives are:

- to study the effect of heavy metals on the physiological state of plant tissues in control media (without antioxidants) and in the media containing ascorbic acid or reduced glutathione;
- to compare the resistance to nickel chloride ions of control and pesticide-resistant raspberry plants to show the possibility of developing varieties with increased tolerance to various abiotic stressors.

MATERIAL AND METHODS

Control and pesticide-tolerant red raspberry (*Rubus idaeus* L.) plants of the Oranzhevoe Chudo variety, cultivated *in vitro*, were used as the research material. The resistant plants were developed using the tissue selection method. Initially, plants that showed increased tolerance to the fungicide benomyl from the benzimidazole group and at the same time to the insecticide malathion from the organophosphate chemicals (OPC) group were selected. Later, the selected

²Mohnish P., Kumar N. Effect of heavy metals on plants: an overview // International Journal of Application or Innovation in Engineering and Management, 2016, vol. 5, Iss. 3, pp. 56–66. DOI: 10.13140/RG.2.2.27583.87.204.

plants were also proven to be more resistant to the herbicide glyphosate (N-(phosphonomethyl) glycine) from the OPC group.

The microcuttings were grown on the MS medium containing 0.5 mg/l 6-benzylamino-purine (6-BAP), 0.1 mg/l indole-3-butyric acid (IBA), and 0.5 mg/l gibberellic acid (GA). The culture vessels were kept under a light intensity of 2500 lux, with a 16-hour photoperiod and a temperature of 23 ± 2 °C.

To test how plants tolerate heavy metals, 0.25 mM of nickel chloride hexahydrate ($\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$) was added to the growth medium. Plant tolerance was assessed based on the percentage of necrotic leaves after 15, 30, 45, and 60 days from the start of the experiment. The rate of change in this parameter was compared between control and pesticide-resistant plants in a medium containing heavy metals. Five biological replicates, with six microcuttings in each, were used in each experiment.

To determine the effect of heavy metals on chlorophyll fluorescence in the tissues of control plants and those selected for pesticide resistance, specific photosynthetic activity (Kf) was recorded using an LPT-3C chlorophyll fluorometer (Russia), which allows measurements to be taken without compromising *in vitro* sterility. Measurements were taken 10 days after microcuttings were planted on media. Before measurements, plants were kept in the dark for an hour.

In order to study the effect of exogenous antioxidants on the intensity of the damaging effect of heavy metals on plants, ascorbic acid ($\text{C}_6\text{H}_8\text{O}_6$) was added to nutrient media containing a toxic substance at a concentration of 0.75 mM or reduced glutathione (γ -glutamyl-cysteinylglycine, $\text{C}_{10}\text{H}_{17}\text{N}_3\text{O}_6\text{S}$) at a concentration of 0.5 mM (the concentrations were selected experimentally). A medium without antioxidants served as a control. After 10 days of cultivation, Kf was measured. The decrease in specific photosynthetic activity under the influence of nickel ions was compared with that in a medium without heavy metals in

the presence and absence of antioxidants.

Data processing included calculating mean values, their errors, and the significance of differences between means across experimental variants. This was performed using the Microsoft Excel statistical package.

RESULTS AND DISCUSSION

The effect of nickel chloride on the physiological condition of tissues in control raspberry plants (which hadn't previously been selected for resistance to any abiotic stressors) was studied. It was found that this toxic substance reduced the specific photosynthetic activity in all experimental setups. Adding antioxidants to the growth medium lessened the harmful impact of heavy metals. In a medium containing 0.25 mM nickel chloride, by the 10th day of cultivation, Kf decreased by 77.22% in the absence of antioxidants. In the presence of ascorbic acid, it decreased by only 48.90%, and in the presence of reduced glutathione – by 17.14% (see Fig. 1). The differences between the variants are statistically significant ($p \leq 0.05$).

The explanation for the reduction in the harmful effects of heavy metals when adding external antioxidants to the nutrient medium could be their ability to neutralize ROS. Ascorbic acid restores the superoxide radical, hydrogen peroxide, and regenerates tocopherol from the tocopheroxyl radical. In turn, tocopherols quench various ROS, prevent lipid oxidation, and stabilize membranes [12]. Reduced glutathione neutralizes a number of oxygen radicals and regenerates ascorbic acid [13]. In nature, adverse effects lead to an increase in the concentration of these antioxidants in plant cells [12, 13].

Tolerance to abiotic stressors is directly linked to how well the antioxidant system works, so it's interesting to study the resistance to other harmful effects (like heavy metals) in plants that are tolerant to pesticides.

In the medium without heavy metals, no significant differences were observed in the specific photosynthetic activity between the control

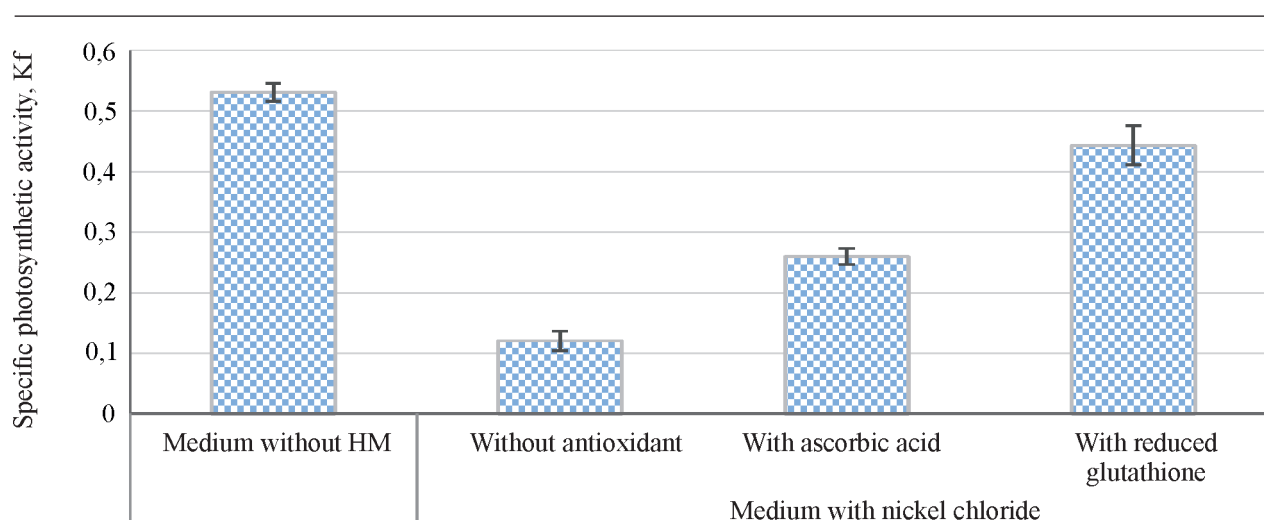


Рис. 1. Снижение удельной фотосинтетической активности в тканях малины красной *in vitro* под действием хлорида никеля на контрольной среде и средах, содержащих антиоксиданты

Fig. 1. Reduction of specific photosynthetic activity in raspberry tissues *in vitro* under the influence of nickel chloride on control medium and medium containing antioxidants

plants and the pesticide-resistant ones. Adding 0.25 mM nickel chloride to the cultivation medium caused a statistically significant ($p \leq 0.05$) decrease in the specific photosynthetic activity of the tissues in all experiment variants. However, in the control plants, the decrease in Kf compared to this indicator in the medium without nickel salt was 55.97%, while in the pesticide-tolerant plants it was 33.42% (see Fig. 2). The differences in this indicator in the medium with nickel ions between the control and pesti-

cide-resistant plants are statistically significant ($p \leq 0.05$).

The results show that plants selected for pesticide resistance have higher tolerance to nickel salt.

Testing nickel salt tolerance by measuring the rate of leaf necrosis also confirmed that pesticide-resistant plants are more tolerant to heavy metals compared to the controls. In the medium without nickel chloride, leaf necrosis was almost absent. It didn't exceed 4–5% throughout

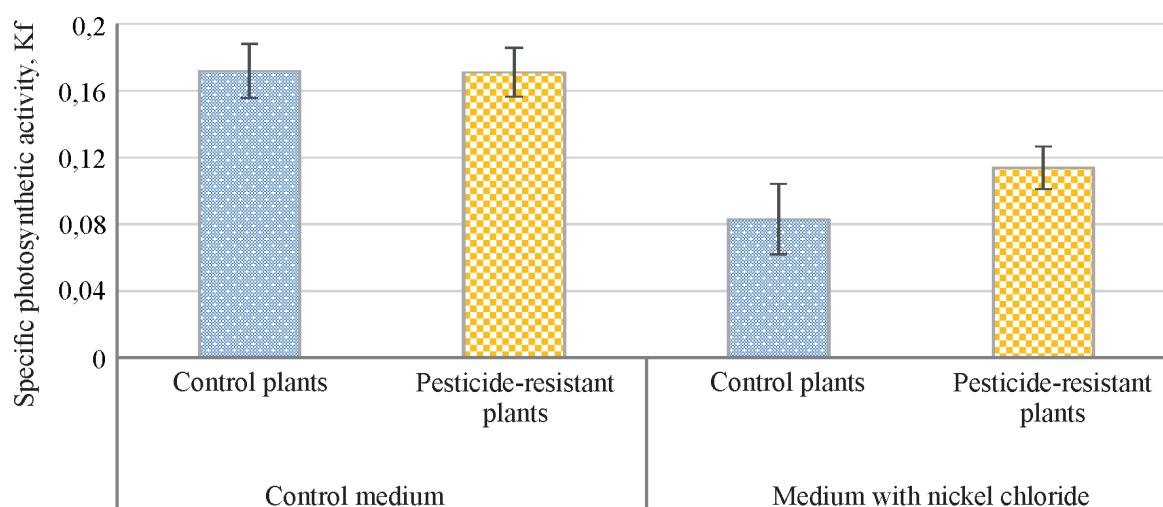


Рис. 2. Снижение удельной фотосинтетической активности тканей контрольных и устойчивых к пестицидам растений малины *in vitro* под действием ТМ

Fig. 2. Reduction of the specific photosynthetic activity of the tissues of control and pesticide-resistant raspberry plants *in vitro* under the influence of HM

the entire cultivation. There were no significant differences between the control plants and the pesticide-resistant ones in this regard when the stressor was absent.

The presence of heavy metal salt in the nutrient medium causes leaf necrosis. In pesticide-resistant plants, this process occurs more slowly compared to the control plants. After 15 days of cultivation, the percentage of dead leaves in the control plants was 4.8 times higher than in those selected for pesticide resistance. After 30–60 days, the number of necrotized leaves in the control plants exceeded that of the pesticide-tolerant forms by 38.01–51.28% (see Fig. 3).

The differences between the control plants and those resistant to pesticides in the given indicator at 15, 30, 45, and 60 days of cultivation are statistically significant ($p \leq 0.05$). In the control plants, leaves completely died after 70 days in the presence of nickel chloride, while in the pesticide-resistant plants, this occurred after 85 days.

The slower necrosis of leaves in pesticide-resistant plants compared to the control indicates their higher tolerance to nickel ions. This aligns with data from testing heavy metal tolerance in

control and pesticide-resistant forms based on changes in the specific photosynthetic activity of the tissues.

Besides the general damaging mechanisms common to various stressors, associated with the accumulation of ROS, there are a number of specific ones. Because of this, in addition to the antioxidant system, there are other protection mechanisms. For example, heavy metal ions can be bound even before entering the cell, either in the extracellular matrix or by cell walls. Plants can release metal-chelating ligands or iron-containing proteins that bind HM ions³. Resistance to pesticides can be achieved by reducing cuticle permeability, speeding up the breakdown of pesticides in tissues, and getting rid of them from the tissues.

Because of this, selecting crop varieties with highly efficient antioxidant systems can't produce varieties with maximum tolerance to all abiotic stress factors. However, relatively increasing and expanding the adaptation potential of varieties to negative impacts can make gardening more resilient amid the ever-growing instability of environmental conditions.

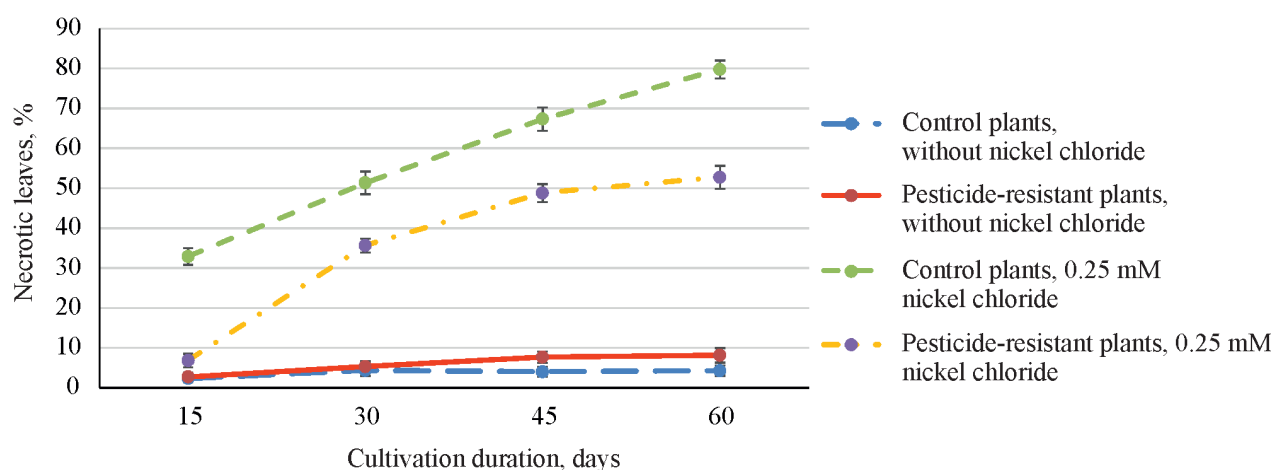


Рис. 3. Некротизация листьев контрольных и устойчивых к пестицидам растений малины красной под действием хлорида никеля *in vitro*

Fig. 3. Necrotization of the leaves of control and pesticide-resistant raspberry plants under the influence of nickel chloride *in vitro*

³Pishchik V.N., Vorobyov N.I., Provorov N.A., Khomakov Y.V. Mechanisms of plant adaptation to heavy metals // Agrophysics, 2015, N 2, pp. 38–49.

CONCLUSIONS

1. In red raspberry tissues, a decrease in specific photosynthetic activity was detected *in vitro* in the presence of a toxic concentration of nickel chloride (0.25 mM). Adding reduced glutathione or ascorbic acid to the nutrient medium reduced the negative effect of the heavy metal salt by 37.84–77.80%, indicating the role of the plant's antioxidant system in developing tolerance to the toxic substance.

2. Pesticide-resistant red raspberry plants demonstrated higher tolerance to nickel ions. This was confirmed by a lower rate of leaf necrosis and a smaller decrease in specific photosynthetic activity *in vitro* in the presence of the heavy metal salt in pesticide-resistant plants compared to control plants.

3. Higher resistance to nickel chloride in pesticide-tolerant plants obtained by tissue selection confirms the possibility of breeding for complex resistance to abiotic stressors by selecting forms that can effectively activate the antioxidant system under negative environmental influences.

СПИСОК ЛИТЕРАТУРЫ

- Путина О.В., Беседин А.Г. Абиотические стресс-факторы и их влияние на накопление ассимилятов растениями и урожайность овощного гороха // Труды по прикладной ботанике, генетике и селекции. 2019. Т. 180. № 2. С. 51–59. DOI: 10.30901/2227-8834-2019-2-51-59.
- Mishra N., Jiang C., Chen L., Paul A., Chatterjee A., Shen G. Achieving abiotic stress tolerance in plants through antioxidative defense mechanisms. *Frontiers in Plant Science*. 2023. 02 June. DOI: 10.3389/fpls.2023.1110622.
- Чумикина Л.В., Арапова Л.И., Колпакова В.В., Топунов А.Ф. Фитогормоны и абиотические стрессы (обзор) // Химия растительного сырья. 2021. № 4. С. 5–30. DOI: 10.14258/jcprm.2021049196.
- Hatamleh A.A., Danish M., Al-Dosary M.A., El-Zaidy M., Ali S. Physiological and oxidative stress responses of *Solanum lycopersicum* (L.) (tomato) when exposed to different chemical pesticides // *Royal Society of Chemistry Advances*. 2022. Vol. 12. P. 7237–7252. DOI: 10.1039/D1RA09440H.
- Zelm E., Zhang Y., Testerink C. Salt Tolerance Mechanisms of Plants: Review Article // *Annual Review of Plant Biology*. 2020. Vol. 71. P. 403–433. DOI: 10.1146/annurev-arplant-050718-100005.
- Madhu P.M., Sadagopan R.S. Effect of Heavy Metals on Growth and Development of Cultivated Plants with Reference to Cadmium, Chromium and Lead: A Review // *Journal of Stress Physiology & Biochemistry*. 2020. Vol. 16. N 3. P. 84–102.
- Gladkov E.A. Cell selection to increase lawn grass resistance to lead pollution // *Ecomed*. 2023. Vol. 30. N 9. P. 24771–24778. DOI: 10.1007/s11356-023-25437-3.
- Степанова А.Ю., Соловьева А.И., Таулиева И.И., Гладков Е.А. Изучение взаимосвязи между устойчивостью к меди (как к неблагоприятному экологическому фактору) и окислительным стрессом на примере каллусов льна многолетнего (*Linum perenne* L.) // Ученые записки Крымского федерального университета имени В.И. Вернадского. Биология. Химия. 2019. Т. 5 (71). № 4. С. 137–145.
- Бахмаков Д.И. Индекс адаптации растений к тяжелым металлам // Известия высших учебных заведений. Поволжский регион. Естественные науки. 2022. № 2. С. 84–94. DOI: 10.21685/2307-9150-2022-2-8.
- Dumanović J., Nepovimova E., Natić M., Kuča K., Jačević V. The significance of reactive oxygen species and antioxidant defense system in plants: a concise overview // *Frontiers in Plant Science*. 2021. Vol. 11. DOI: 0.3389/fpls.2020.552969.
- Соловых Н.В., Будаговская О.Н., Будаговский А.В. Отбор *in vitro* толерантных к хлориду натрия и глифосату растений ежевики методом хлорофиллфлуориметрии // Вестник Курской государственной сельскохозяйственной академии. 2023. № 8. С. 60–66.
- Kumar N., Singh H., Sharma S.K. Antioxidants: responses and importance in plant defense system // *Sustainable agriculture in the era of climate change* / eds. R. Roychowdhury, S. Choud-

- hury, M. Hasanuzzaman, S. Srivastava. Springer. 2020. July. P. 251–264. DOI: 10.1007/978-3-030-45669-6_11.
13. Hajam Y.A., Lone R., Kumar R. Role of plant phenolics against reactive oxygen species (ROS) induced oxidative stress and biochemical alterations // *Plant phenolics in abiotic stress management* / eds. R. Lone, S. Khan, Mohhamed A. Al-Sadi. Springer. 2022. January. P. 125–147. DOI: 10.1007/978-981-19-6426-8_7.
- ## REFERENCES
1. Putina O.V., Besedin A.G. Abiotic stressors and their effect on the accumulation of assimilates by plants and the yield of vegetable pea. *Trudy po prikladnoi botanike, genetike i seleksii = Proceedings on applied botany, genetics and breeding*, 2019, vol. 180, no. 2, pp. 51–59 (In Russian). DOI: 10.30901/2227-8834-2019-2-51-59.
 2. Mishra N., Jiang C., Chen L., Paul A., Chatterjee A., Shen G.. Achieving abiotic stress tolerance in plants through antioxidative defense mechanisms. *Frontiers in Plant Science*, 2023, 02 June. DOI: 10.3389/fpls.2023.1110622.
 3. Chumikina L.V., Arabova L.I., Kolpakova V.V., Topunov A.F. Phytohormones and abiotic stress (review). *Khimia Rastitel'nogo Syr'ya = Chemistry of plant raw material*, 2021, no. 4, pp. 5–30 (In Russian). DOI: 10.14258/jcprm.2021049196.
 4. Hatamleh A.A., Danish M., Al-Dosary M.A., El-Zaidy M., Ali S. Physiological and oxidative stress responses of *Solanum lycopersicum* (L.) (tomato) when exposed to different chemical pesticides. *Royal Society of Chemistry Advances*, 2022, vol. 12, pp. 7237–7252. DOI: 10.1039/D1RA09440H.
 5. Zelm E., Zhang Y., Testerink C. Salt Tolerance Mechanisms of Plants: Review Article. *Annual Review of Plant Biology*, 2020, vol. 71, pp. 403–433. DOI: 10.1146/annurev-arplant-050718-100005.
 6. Madhu P.M., Sadagopan R.S. Effect of Heavy Metals on Growth and Development of Cultivated Plants with Reference to Cadmium, Chromium and Lead: A Review. *Journal of Stress Physiology & Biochemistry*, 2020, vol. 16, no. 3, pp. 84–102.
 7. Gladkov E.A. Cell selection to increase lawn grass resistance to lead pollution. *Ecomed*, 2023, vol. 30, no. 9, pp. 24771–24778. DOI: 10.1007/s11356-023-25437-3.
 8. Stepanova A.Yu., Solov'eva A.I., Tashieva I.I., Gladkov E.A. The relationship between copper resistance (an adverse ecological factor) and oxidative stress in calluses of perennial flax (*Linum perenne* L.). *Uchenye zapiski Krymskogo federal'nogo universiteta imeni V.I. Vernadskogo Biologiya. Khimiya = Scientific Notes of V.I. Vernadsky Crimean Federal University. Biology. Chemistry*. 2019, vol. 5 (71), no. 4, pp. 137–145. (In Russian).
 9. Bashmakov D.I. Plant adaptation index to heavy metals. *Izvestiya vysshikh uchebnykh zavedenii. Povolzhskii region. Estestvennye nauki = University proceedings. Volga Region. Natural Sciences*, 2022, no. 2, pp. 84–94. (In Russian). DOI: 10.21685/2307-9150-2022-2-8.
 10. Dumanović J., Nepovimova E., Natić M., Kuća K., Jačević V. The significance of reactive oxygen species and antioxidant defense system in plants: a concise overview. *Frontiers in Plant Science*, 2021, vol. 11. DOI:10.3389/fpls.2020.552969.
 11. Solovykh N.V., Budagovskaya O.N., Budagovsky A.V. In vitro selection of sodium chloride and glyphosate tolerant blackberry plants using chlorophyll fluorimetry. *Vestnik Kurskoi gosudarstvennoi sel'skokhozyaistvennoi akademii = Bulletin of the Kursk State Agricultural Academy*, 2023, no. 8, pp. 60–66. (In Russian).
 12. Kumar N., Singh H., Sharma S.K. Antioxidants: responses and importance in plant defense system. *Sustainable agriculture in the era of climate change*, eds. R. Roychowdhury, S. Choudhury, M. Hasanuzzaman, S. Srivastava Springer, 2020, July, pp. 251–264. DOI: 10.1007/978-3-030-45669-6_11
 13. Hajam Y.A., Lone R., Kumar R. Role of plant phenolics against reactive oxygen species (ROS) induced oxidative stress and biochemical alterations. *Plant phenolics in abiotic stress management*, eds. R. Lone, S. Khan, A. Mohhamed Al-Sadi. Springer, 2022, January, pp. 125–147. DOI: 10.1007/978-981-19-6426-8_7.

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Сорные растения, засоряющие семена льна-долгунца высших репродукций, выращиваемого в Томской области

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В статье представлены результаты герботогического анализа партий семян сортов льна-долгунца томской селекции, выращенных в 2024 и 2025 гг. в подтаежной зоне Томской области. Определены видовой состав и численность семян сорных растений. Составлен перечень трудноотделимых сорняков, способных распространяться путем спейрохории с семенами льна-долгунца. В образцах семян льна-долгунца, полученных после прямого комбайнирования, выявлены диаспоры (плоды и семена) 33 видов одно- и двудольных сорных растений. Проведен сравнительный анализ засоренности сортовых семян льна-долгунца после промышленной очистки. Выявлено семь видов однодольных (злаковых) сорняков: ежовник обыкновенный (*Echinochloa crus-galli*), овес пустой (*Avena fatua*), просо сорное (*Panicum miliaceum* ssp. *ruderales*), пырей ползучий (*Elytrigia repens*), шерстняк мохнатый (*Eriochloa villosa*), щетинник зеленый (*Setaria viridis*), щетинник низкий (*Setaria pumila*), а также шесть видов двудольных сорняков: аистник цикutowый (*Erodium cicutarium*), горец развесистый (*Persicaria lapathifolia*), гречишка вьюнковая (*Fallopia convolvulus*), пикульник двунадрезанный (*Galeopsis bifida*), подмаренник Вайана (*Galium vaillantii*), щирица жминдовидная (*Amaranthus blitoides*). Все перечисленные виды являются обычными засорителями посевов сельскохозяйственных культур в разных регионах России. Кроме того, в образцах семян льна-долгунца определено наличие следующих трудноотделимых семян сорных растений: однодольные виды – ежовник обыкновенный, шерстняк мохнатый и щетинник низкий, двудольные – горец развесистый и подмаренник Вайана. Особо отметим появление в семеноводческих посевах льна-долгунца редкого для Сибири сорняка восточноазиатского происхождения – шерстняка мохнатого. Данный вид является наиболее злостным сорняком, быстро распространяющимся на сельскохозяйственных землях благодаря высокой экологической адаптации и устойчивости к гербицидам.

Ключевые слова: лен-долгунец, семена, сорные растения, герботогический анализ, Томская область

Weeds contaminating fiber-flax seeds of higher reproductions grown in the Tomsk Region

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The article presents the results of a herbological analysis of fiber flax seed batches of the Tomsk selection, grown in 2024 and 2025 in the sub-taiga zone of the Tomsk region. The species composition and number of weed seeds have been determined. The species composition and number of weed seeds in flax seed batches have been identified. A list of difficult-to-separate weeds capable of spreading by speirochory with flax seeds has been compiled. In the samples of fiber flax seeds obtained after direct combining, diaspores (fruits and seeds) of 33 species of mono- and dicotyledonous weeds have been identified. A comparative analysis of the contamination of fiber flax seeds after industrial cleaning was

carried out. 7 species of monocotyledonous (cereal) weeds: barnyard grass (*Echinochloa crus-galli*), wild oat (*Avena fatua*), weed broomcorn millet (*Panicum miliaceum* ssp. *ruderales*), devil's grass (*Elytrigia repens*), hairy cupgrass (*Eriochloa villosa*), green foxtail (*Setaria viridis*), yellow foxtail (*Setaria pumila*) and 6 species of dicotyledonous weeds: redstem filaree (*Erodium cicutarium*), pale smartweed (*Persicaria lapathifolia*), wild buckwheat (*Fallopia convolvulus*), bifid hemp-nettle (*Galeopsis bifida*), catchweed bedstraw (*Galium vaillantii*), prostrate amaranth (*Amaranthus blitoides*) have been identified. All the listed species are common contaminants of agricultural crop plantings in various regions of Russia. In addition, the fiber flax seed samples have been found to contain the following difficult-to-separate weed seeds: monocotyledonous species – barnyard grass, hairy cupgrass and yellow foxtail, and dicotyledonous ones – pale smartweed, catchweed bedstraw. Particularly noted is the appearance in fiber flax-seed crops of a weed rare for Siberia, of East Asian origin – hairy cupgrass. This species is the most pernicious weed, spreading rapidly on agricultural lands due to its high ecological adaptability and herbicide resistance.

Keywords: fiber-flax, seeds, weeds, herbological analysis, Tomsk region

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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

Fiber flax (*Linum usitatissimum* L.) is an important industrial crop in both global and Russian agriculture. The technical fiber from fiber flax is used as raw material for making a wide range of fabrics, industrial products, and other goods with high consumer value. Products made from flax fiber are in demand in strategic industries, such as the production of carbon composites – lightweight and super-strong materials [1–4].

Linen flax is a traditional agricultural crop that has long been grown in Russia. The Tomsk region, due to its soil and climate conditions, is considered one of the favorable areas for growing flax for industrial purposes, as well as for

developing seed production of this crop. Breeding work on linen flax beyond the Urals has a long history¹. Since 2005, the work on breeding and seed production of linen flax in the Tomsk region has been carried out by the Siberian Research Institute of Agriculture and Peat – a branch of the Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences (SRIAT – branch of the SFSCA RAS). Over 89 years, Tomsk breeders have developed 27 varieties of linen flax, 11 of which are included in the State Register of Breeding Achievements of the Russian Federation. Alongside the breeding work, they also carry out initial seed production for new varieties and maintain those already listed in the State Register.

¹Krepkov A.P. Selection of fiber flax in Siberia. Tomsk, 2000, 186 p.

Seeds of the Tomsk linen flax varieties are in demand in the regions of Siberia and the European part of Russia [5, 6]. According to the Department of Primary Processing of Flax and Hemp at the Rosselkhozcenter, in 2024, 31 varieties of linen flax were sown in the Russian Federation on an area of 40.6 thousand hectares. The top six varieties in terms of the sowing area include the following Tomsk-bred sorts: Tomsky 17 (4.14 thousand ha; 10.2%), Tomich 2 (3.10 thousand ha; 7.6%), Tomsky 18 (2.87 thousand ha; 7.1%). SRIAT has the capacity to produce 8–18 tons of elite breeder seeds of high-yield early-maturing flax varieties annually, which in some years makes up 20–23% of the total similar seeds produced across Russia.

A limiting factor for the development of flax growing in our country is the lack of seeds of domestic varieties with high sowing qualities [1].

There are special requirements for the sowing qualities of high-reproduction flax seeds (breeding nurseries of the 1st and 2nd generations, super-elite), including the absence of contamination by diaspores (fruits and seeds) of weeds. According to GOST R 52325–2005, in high-reproduction flax seeds intended for sowing, the content of weed diaspores should not exceed 320 pieces per kilogram of seeds². What's important here is not only the number of weed fruits and seeds but also their species composition.

Linen flax is a small-seeded agricultural crop, the cultivation of which requires strict adherence to all elements of zonal technology, including the use of herbicides³ [7–10]. Seed farms using modern chemical plant protection products are not always able to achieve absolute purity of flax seeds. Therefore, the issue of phytosanitary monitoring of flax crops and the seed material used is quite pressing.

The relevance of this study is due to the emergence of weeds resistant to the preparations used in flax crops for herbicidal weed control, and, as a consequence, changes in the species composition of weed vegetation [11–13].

Considering the demand and significant economic importance of original seeds of linen flax varieties of the Tomsk selection for the further development of flax growing in Russia, it is necessary to keep track of the weediness of crops and seeds.

The purpose of the study is to identify the weeds and hard-to-separate plant species that contaminate batches of linen flax seeds during industrial cleaning in the Tomsk region.

MATERIAL AND METHODS

The study focused on the samples of flax seed varieties of the highest reproductions, obtained from seed-growing plots of the Bogashevsky Scientific Department of SRIAT in 2024 and 2025.

In 2024, analysis of seed lots from nurseries propagating the 1st and 2nd generations of the varieties Tomich, Tomsky 17, Tomich 2, Tomsky 18, Tomich 3, and the super-elite variety TOST 3 was conducted. In 2025, analysis of seed lots from nurseries propagating the 1st and 2nd generations (mother elite of the 1st and 2nd years) of the varieties Tomich 2, Tomich 3, TOST 3, TOST 4, TOST 5, and Pamyati Krepkova was carried out.

The samples were taken from seed lots before industrial cleaning and after the processing of finished products on sorting machines.

For each variety, two seed samples were analyzed:

- 1) obtained after direct combining, uncleaned (grain chaff and weed seeds);
- 2) industrially purified.

During industrial cleaning, fiber flax seeds collected by direct combining were dried in a Petkus container-drying complex (Germany) at a temperature of 38–40 °C for 8–24 hours to a moisture content of 10–12%. The seeds were then processed using a Petkus K541 seed cleaning and sorting machine (Germany) in two stages. In the first stage, cleaning was performed

²GOST R 52325–2005. Agricultural crop seeds. Varietal and sowing qualities. General specifications. Moscow: Standartinform, 2009, 20 p.

³Popova G.A. Effect of chemical and agrotechnical weed control measures on fiber flax yield // 60 Years of Research on Fiber Flax at the Tomsk State Agricultural Experimental Station of the Siberian Branch of the Russian Academy of Agricultural Sciences: Collection of Scientific Papers. Tomsk, 1997, pp. 108–113.

with a 17 mm upper screen and a 1.5 mm lower screen, and in the second stage, with a 14.0 mm screen and a 1.5 mm lower screen, respectively. This method allows flax seeds to be cleaned of easily separated weeds.

To identify weed diaspores, a herbological analysis method was used. For this purpose, weed fruits and seeds were manually isolated from batches of flax seeds. Species identification was carried out according to standard guidelines for identifying weed seeds⁴ using the samples stored in the carpological collections of the Tomsk branch of the Federal State Budgetary Institution “All-Russian Plant Quarantine Center”.

The number of weed diaspores was determined based on the degree of infestation of the samples and the purpose of our research. To determine the number of weeds in a flax grain chaff and weed seeds, ten 5-g samples were taken from an average batch weighing 1 kg. All seeds were then isolated, identified to species level, and the number was counted.

To determine the species composition and abundance of hard-to-separate weeds, all fiber flax seed samples were analyzed after final (industrial) cleaning. Ten 50-g samples were taken from an average 1-kg seed sample of each flax variety, from which all weed diaspores were isolated and counted. Table 1 presents a sample

herbological analysis report for a TOST 3 flax seed sample from the 2024 harvest.

To determine the number of diaspores (pcs/g), the arithmetic mean and the error of the mean were calculated ($M \pm m$). Statistical data processing was carried out using Microsoft Excel 2016.

RESULTS AND DISCUSSION

A herbological analysis of flax seeds obtained after direct harvesting revealed diaspores of 33 species of mono- and dicotyledonous weeds. The following weed seeds were most frequently found in the grain heap of all studied samples: barnyard grass, pale smartweed, lamb's-quarters, bifid hemp-nettle, catchweed bedstraw, common bedstraw, weed broomcorn millet, hairy cupgrass, green foxtail, and yellow foxtail (see Table 2).

After industrial cleaning of flax seeds, the number of identified species decreased by 3 times. Of these, seven species are monocotyledonous (cereal) weeds (barnyard grass, wild oats, weed broomcorn millet, devil's grass, green foxtail, yellow foxtail and hairy cupgrass), six species – dicotyledonous weeds (redstem filaree, pale smartweed, wild buckwheat, bifid hemp-nettle, catchweed bedstraw, prostrate amaranth) (see Table 2).

Табл. 1. Численность диаспор сорняков, выявленных по результатам герботологического анализа в пробах очищенных семян льна-долгунца (ТОСТ 3, 2024 г.)

Table 1. The number of weed diaspores identified based on the results of the herbological analysis in the samples of cleaned fiber flax seeds (TOST 3, 2024)

Species	Sample number								
	1	2	3	4	5	6	7	8	9
<i>Echinochloa crus-galli</i> (L.) Beauv.	0	0	0	0	0	0	0	1	0
<i>Eriochloa villosa</i> (Thunb.) Kunth	4	1	5	4	2	2	1	2	1
<i>Galeopsis bifida</i> Boenn.	1	0	0	0	0	0	0	0	1
<i>Panicum miliaceum</i> ssp. <i>rudera</i> le (Kitag.) Tzvelev	0	1	0	0	1	0	1	0	0
<i>Persicaria lapathifolia</i> (L.) Delarbre s.l.	4	1	1	2	3	5	9	6	8
<i>Setaria pumila</i> (Poir.) Schult.	4	6	4	11	8	4	5	5	8
Total species	4	4	3	2	4	3	4	4	4
Number of diaspores in a trial batch, pcs./50 g	13	9	10	17	14	11	16	14	18

⁴DobrokhotoV V.N. Weed Seeds. Moscow, 1961, 414 p.

Табл. 2. Видовой состав семян сорных растений в зерновом ворохе и очищенных семенах льна-долгунца

Table 2. Species composition of weed seeds in grain heap and cleaned fiber flax seeds

Latin name	Russian name	Life form	Detections (before/after industrial cleaning)	
			2024	2025
Monocotyledons				
Avena fatua L.	Wild oats	Annual plant	+/-	+/+
Echinochloa crus-galli (L.) Beauv.	Barnyard grass, barnyard millet	Annual plant	+/+	+/+
Elytrigia repens (L.) Nevski	Devil's grass	Perennial plant	+/+	+/-
Eriochloa villosa (Thunb.) Kunth	Hairy cupgrass	Annual plant	+/+	+/+
Panicum miliaceum ssp. ruderale (Kitag.) Tzvelev	Weed broomcorn millet	Annual plant	+/+	+/+
Phleum pratense L.	Timothy grass	Perennial plant	+/-	–
Setaria pumila (Poir.) Schult.	Yellow foxtail	Annual plant	+/+	+/+
Setaria viridis (L.) P. Beauv.	Green foxtail	Annual plant	+/+	+/-
Dicotyledons				
Amaranthus blitoides S. Watson	Prostrate amaranth	Annual plant	–	+/+
Amaranthus retroflexus L.	Redroot amaranth	Annual plant	+/-	+/-
Arctium tomentosum Mill.	Cotton burdock	Biennial plant	+/-	+/-
Chenopodium album L.	Lamb's-quarters	Annual plant	+/-	+/-
Cirsium arvense (L.) Scop. s.l.	Canada thistle	Perennial plant	+/-	–
Erodium cicutarium (L.) L'Hér.	Redstem filaree	Annual plant	+/+	+/+
Fallopia convolvulus (L.) Á. Löve	Wild buckwheat	Annual plant	+/+	+/-
Fumaria officinalis L.	Common fumitory	Annual plant	+/-	+/-
Galeopsis bifida Boenn.	Bifid hemp-nettle	Annual plant	+/+	+/+
Galium vaillantii DC.	Catchweed bedstraw	Annual plant	+/+	+/+
Lappula squarrosa (Retz.) Dumort.	Squarrose sticktight	Annual plant / biennial plant	–	+/-
Linaria vulgaris Mill.	Common toadflax	Perennial plant	+/-	+/-
Myosotis arvensis (L.) Hill	Field scorpion grass	Annual plant / perennial plant	+/-	–
Neslia paniculata (L.) Desv.	Ball mustard	Annual plant	+/-	+/-
Oberna behen (L.) Ikonn.	Bladder campion	Perennial plant	+/-	+/-
Persicaria lapathifolia (L.) Delarbre s.l.	Pale smartweed	Annual plant	+/+	+/+
Polygonum aviculare L.	Knotgrass	Perennial plant	+/-	+/-
Silene noctiflora L.	Night-flowering campion	Annual plant	+/-	+/-
Spergula arvensis L.	Common spurrey	Annual plant	+/-	+/-
Stachys palustris L.	Clown's woundwort	Perennial plant	+/-	–
Stellaria graminea L.	Lesser starwort	Perennial plant	+/-	+/-
Thlaspi arvense L.	Field pennycress	Annual plant	+/-	+/-
Trifolium pratense L.	Meadow clover	Perennial plant	+/-	–
Vicia cracca L.	Bird vetch	Perennial plant	+/-	–
Viola arvensis Murray	Field pansy	Annual plant / biennial plant	+/-	+/-
Total species			31/11	27/10

A comparative analysis of the contamination of varietal seeds after industrial cleaning made it possible to identify a group of dominant species among weeds that are difficult to separate from fiber flax seeds (see Table 3). In 2024, the main weeds were yellow foxtail, pale smartweed, and hairy cupgrass. If the cultivation area is contaminated with couch grass, a rhizome weed, its seeds can also create a problem when cleaning flax seeds, which we observed when analyzing

Табл. 3. Численность диаспор трудноотделимых сорняков в партиях семян льна-долгунца, прошедших очистку

Table 3. The number of difficult-to-separate weed diaspores in the batches of cleaned fiber flax seeds

Variety	Number of weed species	Number of weed seeds, pcs/kg	Dominant weeds	
			species	proportion of the total number of weeds, %
2024				
Tomich	6	128,0 ± 11,0	Hairy cupgrass	50,0
			Pale smartweed	20,3
			Yellow foxtail	18,8
Tomich 2	6	154,0 ± 22,3	Devil's grass	51,9
			Pale smartweed	11,7
Tomich 3	4	126,0 ± 12,0	Yellow foxtail	47,6
			Hairy cupgrass	27,0
			Pale smartweed	22,2
Tomsky 17	1	14,0 ± 4,9	Pale smartweed	100,0
Tomsky 18	5	114,0 ± 13,7	Yellow foxtail	45,6
			Pale smartweed	42,1
TOST 3	9	262,0 ± 21,3	Yellow foxtail	43,5
			Pale smartweed	32,8
			Hairy cupgrass	19,1
2025				
Pamyati Krepkova	6	100,0 ± 19,1	Yellow foxtail	34,0
			Barnyard grass	32,0
			Catchweed bedstraw	26,0
Tomich 2	9	318,0 ± 12,8	Yellow foxtail	28,3
			Catchweed bedstraw	27,0
			Barnyard grass	25,8
Tomich 3	6	88,0 ± 13,6	Yellow foxtail	27,3
			Barnyard grass	22,7
			Catchweed bedstraw	15,9
TOST 3	6	268,0 ± 22,0	Pale smartweed	47,8
			Hairy cupgrass	17,9
			Yellow foxtail	14,9
TOST 4	5	188,0 ± 13,6	Barnyard grass	62,8
			Catchweed bedstraw	28,7
TOST 5	5	50,0 ± 6,5	Barnyard grass	64,0
			Pale smartweed	16,0

a batch of seeds of the Tomich 2 variety. The following hard-to-remove weed species were prevalent in the 2025 flax seed samples: barnyard grass, yellow foxtail, pale smartweed and catchweed bedstraw.

The study identified weed species that are difficult to separate from flax seeds grown in experimental fields at the Bogashevsky Scientific Department of SRIAT. These include: barnyard grass yellow foxtail, hairy cupgrass (monocotyledons), pale smartweed, catchweed bedstraw (dicotyledons). These species are common weeds of agricultural crops in various regions of Russia⁵. Particular attention should be paid to the appearance of such a rare weed of East Asian origin in fiber flax seed crops, such as hairy cupgrass. In European countries, hairy cupgrass is an invasive species that spreads rapidly on agricultural and disturbed lands due to its high ecological adaptation and resistance to herbicides [14]. In Russia, hairy cupgrass can be found, for example, in the Primorsky Territory, where this species is the most malicious weed in grain and oilseed (soybean) crops [15]. It is also occasionally found in the southern regions of the European part of the country. In Siberia, *E. villosa* is still a relatively rare alien species [16]. However, in recent years it has begun to spread in Siberia, including in the agrocenoses of the Tomsk region [16, 17]. An interesting fact is its appearance in fiber flax crops of the Bogashevsky Scientific Department of SRIAT, as well as its ability to contaminate the seeds of this crop and spread further by speyorchory (with the seeds of the main crop).

CONCLUSION

Herbological analysis of flax seeds after direct harvesting, as well as those subjected to industrial cleaning, made it possible to establish the species composition of weeds that most often contaminate the seeds of this crop. The main difficult-to-remove weeds in the studied lots of fiber flax seeds grown in the experimental fields

of the Bogashevsky Scientific Department of SRIAT are: barnyard grass, yellow foxtail and hairy cupgrass (monocotyledons), pale smartweed and catchweed bedstraw (dicotyledons). Separately, it should be noted that a rare weed species, hairy cupgrass, has appeared in fiber flax seed crops. Its fruits can spread by speyorchory, as evidenced by its discovery in flax seed crops in the Tomsk region.

СПИСОК ЛИТЕРАТУРЫ

1. Понажес В.П., Виноградова Е.Г. Развитие селекции и семеноводства льна-долгунца – важнейший ресурс повышения эффективности льноводства России // Технические культуры. Научный сельскохозяйственный журнал. 2022. № 1 (2). С. 30–39. DOI: 10.54016/SVI-TOK.2022.71.55.004.
2. Kaur V., Singh M., Wankhede D.P., Gupta K., Langyan S., Aravind J., Thangavel B., Yadav S.K., Kalia S., Singh K., Kumar A. Diversity of *Linum* genetic resources in global genebanks: from agro morphological characterisation to novel genomic technologies: a review // Frontiers in Nutrition. 2023. N 10. P. 1165580. DOI: 10.3389/fnut.2023.1165580.
3. Морыганов А.П., Дымникова Н.С., Киселев М.Г., Кокишаров С.А., Данилов А.Р., Трещалин Ю.М. Техничко-экономическое обоснование создания центра глубокой переработки лубяных волокон и сопутствующих компонентов растительного сырья для производства широкого спектра высокорентабельной инновационной продукции // Известия высших учебных заведений. Технология текстильной промышленности. 2022. № 1 (397). С. 69–73. DOI: 10.47367/0021-3497_2022_1_69.
4. Захарчук Д.Д., Болтовский В.С. Комплексная переработка льна с получением инновационной продукции (обзор) // Труды Белорусского государственного технологического университета. Сер. 2: Химические технологии, биотехнология, геоэкология. 2024. № 2 (283). С. 77–91. DOI: 10.52065/2520-2669-2024-283-10.
5. Попова Г.А., Рогальская Н.Б., Трофимова В.М. Мировые генетические ресурсы льна коллекции ВИР в создании сортов томской селекции // Сибирский вестник сельскохозяй-

⁵Atlas of Major Weed Species of Russia / T.V. Papaskiri, L.A. Ushakova, N.V. Skorokhodova, et al.; edited by T.V. Papaskiri. Moscow, 2024. 392 p.

- ственной науки. 2023. Т. 53. № 4. С. 34–47.
6. Попова Г.А., Полякова О.И., Рогальская Н.Б., Трофимова В.М., Шулейко А.А. Сорта льна-долгунца отечественной селекции в условиях Томской области // Сибирский вестник сельскохозяйственной науки. 2024. Т. 54. № 8. С. 36–47. DOI: 10.26898/0370-8799-2024-8-4.
 7. Кудрявцев Н.А. Производственная оценка и применение результатов НИР по защите растений в льноводстве // Аграрный вестник Верхневолжья. 2023. № 4. С. 16–23. DOI: 10.35523/2307-5872-2023-45-4-16-2.
 8. Рожмина Т.А., Андреева И.А. Влияние гербицида Магнум на продуктивность и качество современных сортов льна-долгунца // Аграрная наука Евро-Северо-Востока. 2024. Т. 25. № 5. С. 805–817. DOI: 10.30766/2072-9081.2024.25.5.805-817.
 9. Саломатина К.С., Порсев И.Н., Купцевич Н.А. Значение сорта и оперативных мер защиты в фитосанитарной технологии возделывания льна-долгунца в Южном Зауралье: монография. Курган, 2022. 156 с.
 10. Акимов А.А., Беленков А.И. Эффективность баковых смесей гербицидов в системе защиты льна-долгунца в ООО «Тверская АПК» // Экологический вестник Северного Кавказа. 2024. Т. 20. № 2. С. 50–57.
 11. Бочкарев Д.В., Столяров А.В., Никольский А.Н., Кузнецова Г.Н., Бочкарев В.Д., Вишняков А.Г. Многолетний мониторинг засоренности посевов льна как основа для разработки эффективной системы защиты // Вестник Новосибирского государственного аграрного университета. 2024. № 1 (70). С. 14–24. DOI: 10.31677/2072-6724-2024-70-1-14-24.
 12. Kudryavtsev N.A., Zaitseva L.A., Savoskina O.A., Chebanenko S.I., Zavertkin I.A. Herbological and agrotechnological approaches to weeding plants in modern flax growing // Caspian Journal of Environmental Sciences. 2021. Vol. 19. N 5. P. 903–908. DOI: 10.22124/CJES.2021.5263.
 13. Benaragama D.I., May W.E., Gulden R.H., Wilkenborg C.J. Functionally diverse flax-based rotations improve wild oat (*Avena fatua*) and cleavers (*Galium spurium*) management // Weed Science. 2022. N 70. P. 220–234. DOI: 10.1017/wsc.2021.79.
 14. Lele S.F., Balta I., Dumitrescu G., Cristea T., Morariu F.E., Nan A., Cristea D.A., Pet I. Overview of the invasive weed species *Eriochloa villosa* (Thunb.) Kunth and its management in Europe // Agriculture. 2025. Vol. 15. P. 1180. DOI: 10.3390/agriculture15111180.
 15. Степанов А.С., Мороховец Т.В., Фомина Е.А., Мороховец В.Н., Степанова А.А. Оценка засоренности посевов сои на юге Дальнего Востока по данным спутника Sentinel-2 // Достижения науки и техники АПК. 2025. Т. 39. № 3. С. 16–21. DOI: 10.53859/02352451_2025_39_3_16.
 16. Эбель А.Л., Михайлова С.И., Эбель Т.В. Распространение и некоторые биологические особенности чужеродного вида *Eriochloa villosa* (Poaceae: Paniceae) в Сибири // Российский журнал биологических инвазий. 2024. № 2. С. 180–194. DOI: 10.35885/1996-1499-17-2-180-194.
 17. Плиско А.О., Михайлова С.И., Эбель Т.В. Результаты мониторинга зерна яровой пшеницы в Томской области в 2024 г. // Фитосанитария. Карантин растений. 2025. № 3 (24). С. 42–56. DOI: 10.69536/FKR.2025.14.59.003.

REFERENCES

1. Ponazhev V.P., Vinogradova E.G. The development of selection and seed production of flax is the most important resource for improving the efficiency of flax growing in Russia. *Tekhnicheskije kul'tury. Nauchnyi sel'skokhozyaistvennyi zhurnal = Technical Crops. Scientific Agricultural Journal*, 2022, no. 1 (2), pp. 30–39. (In Russian). DOI: 10.54016/SVITOK.2022.71.55.004.
2. Kaur V., Singh M., Wankhede D.P., Gupta K., Langyan S., Aravind J., Thangavel B., Yadav S.K., Kalia S., Singh K., Kumar A. Diversity of *Linum* genetic resources in global genebanks: from agro morphological characterisation to novel genomic technologies: a review. *Frontiers in Nutrition*, 2023, no. 10, p. 1165580. DOI: 10.3389/fnut.2023.1165580.
3. Moryganov A.P., Dymnikova N.S., Kiselev M.G., Koksharov S.A., Danilov A.R., Treshchalin Yu.M. Feasibility study for creation of bast fibers deep processing and related plant raw materials components center for the production of a wide range of highly profitable innovative products. *Izvestiya vysshikh uchebnykh zavedenii. Tekhnologiya tekstil'noi promyshlennosti*.

- sti = Izvestiya Vysshikh Uchebnykh Zavedenii. Seriya: Tekhnologiya Tekstil'noi Promyshlennosti*, 2022, no. 1 (397), pp. 69–73. (In Russian). DOI: 10.47367/0021-3497_2022_1_69.
4. Zakharchuk D.D., Boltovsky V.S. Complex processing of flax with the production of innovative products (review). *Trudy Belorusskogo gosudarstvennogo tekhnologicheskogo universiteta. Seriya 2: Khimicheskie tekhnologii, biotekhnologiya, geoekologiya = Proceedings of BSTU. Issue 2: Chemical Engineering, Biotechnologies, Geoecology*, 2024, no. 2 (283), pp. 77–91. (In Russian). DOI: 10.52065/2520-2669-2024-283-10.
5. Popova G.A., Rogalskaya N.B., Trofimova V.M. World's genetic resources of the VIR flax collection in the creation of Tomsk selection varieties. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2023, vol. 53, no. 4, pp. 34–47. (In Russian).
6. Popova G.A., Polyakova O.I., Rogalskaya N.B., Trofimova V.M., Shuleiko A.A. Fiber flax varieties of domestic selection under conditions of the Tomsk region. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2024, vol. 54, no. 8, pp. 36–47. (In Russian). DOI: 10.26898/0370-8799-2024-8-4.
7. Kudryavtsev N.A. Production assessment and application of research results on plant protection in flax growing. *Agrarnyi vestnik Verkhnevolzh'ya = Agrarian Journal of Upper Volga region*, 2023, no. 4, pp. 16–23. (In Russian). DOI: 10.35523/2307-5872-2023-45-4-16-2.
8. Rozmina T.A., Andreeva I.A. Effect of Magnum herbicide on productivity and quality of modern fiber flax cultivars. *Agrarnaya nauka Evro-Severo-Vostoka = Agricultural Science Euro-North-East*, 2024, vol. 25, no. 5, pp. 805–817. (In Russian). DOI: 10.30766/2072-9081.2024.25.5.805-817.
9. Salomatina K.S., Porsev I.N., Kuptsevich N.A. *The importance of variety and operational protective measures in phytosanitary technology of fiber flax cultivation in the Southern Trans-Urals*. Kurgan, 2022, p. 156. (In Russian).
10. Akimov A.A., Belenkov A.I. Efficiency of tank mixtures of herbicides in the flax protection system at Tverskaya APK LLC. *Ekologicheskii vestnik Severnogo Kavkaza = The North Caucasus Ecological Herald*, 2024, vol. 20, no. 2, pp. 50–57. (In Russian).
11. Bochkarev D.V., Stolyarov A.V., Nikolsky A.N., Kuznetsova G.N., Bochkarev V.D., Vishnyakov A.G. Long-term monitoring of weed contamination in flax crops as a basis for developing an effective protection system. *Vestnik Novosibirskogo gosudarstvennogo agrarnogo universiteta = Bulletin of NSAU (Novosibirsk State Agrarian University)*, 2024, no. 1 (70), pp. 14–24. (In Russian). DOI: 10.31677/2072-6724-2024-70-1-14-24.
12. Kudryavtsev N.A., Zaitseva L.A., Savoskina O.A., Chebanenko S.I., Zvertkin I.A. Herbological and agrotechnological approaches to weeding plants in modern flax growing. *Caspian Journal of Environmental Sciences*, 2021, vol. 19, no. 5, pp. 903–908. DOI: 10.22124/CJES.2021.5263.
13. Benaragama D.I., May W.E., Gulden R.H., Wilenborg C.J. Functionally diverse flax-based rotations improve wild oat (*Avena fatua*) and cleavers (*Galium spurium*) management. *Weed Science*, 2022, no. 70, pp. 220–234. DOI: 10.1017/wsc.2021.79.
14. Lele S.F., Balta I., Dumitrescu G., Cristea T., Morariu F.E., Nan A., Cristea D.A., Pet I. Overview of the invasive weed species *Eriochloa villosa* (Thunb.) Kunth and its management in Europe. *Agriculture*, 2025, vol. 15, p. 1180. DOI: 10.3390/agriculture15111180.
15. Stepanov A.S., Morokhovets T.V., Fomina E.A., Morokhovets V.N., Stepanova A.A. Assessment of weed infestation of soybean crops in the southern Far East using Sentinel-2 satellite data. *Dostizheniya nauki i tekhniki APK = Achievements of Science and Technology of AIC*, 2025, vol. 39, no. 3, pp. 16–21. (In Russian). DOI: 10.53859/02352451_2025_39_3_16.
16. Ebel A.L., Mikhailova S.I., Ebel T.V. Distribution and some biological features of the alien species *Eriochloa villosa* (Poaceae: Paniceae) in Siberia. *Rossiiskii zhurnal biologicheskikh invazii = Russian Journal of Biological Invasions*, 2024, no. 2, pp. 180–194. (In Russian). DOI: 10.35885/1996-1499-17-2-180-194.
17. Plisko A.O., Mikhailova S.I., Ebel T.V. Results of monitoring spring wheat grain in Tomsk Oblast in 2024. *Fitosanitariya. Karantin rastenii = Plant Health and Quarantine*, 2025, no. 3 (24), pp. 42–56. (In Russian). DOI: 10.69536/FKR.2025.14.59.003.

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Скрининг сортов и сортообразцов люпина узколистного по показателям качества зерна

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В статье сделан акцент на характеристику качества зерна люпина узколистного (*Lupinus angustifolius* L.), используемого в кормопроизводстве. В конкурсном сортоиспытании в Брянской области изучили 3 сорта и 8 сортообразцов люпина узколистного (стандарт – сорт Витязь), по продолжительности вегетационного периода относящиеся к группе «очень ранних» (70–100 дней). Средний период вегетации за время исследований – 89 дней. Урожайность зерна в опыте в среднем составила 2,82 т/га, по сорту-стандарту – 2,49 т/га. Максимальные значения отмечены у сортообразцов СБС 56-15-1 и Узколистный 53-02 УФ. Среднее значение урожайности зеленой массы за период наблюдения составило 39,7 т/га, по стандарту – 33,6 т/га. Статистически значимые данные по этому показателю выявлены у сортообразцов Гибрид 1314, Гибрид 1246, СБС 56-15-1 и Узколистный 53-02 УФ. Прибавка к стандарту по урожайности зеленой массы варьировала в пределах от 8,4 до 14,1 т/га. В зерне изучаемых сортов и сортообразцов сырой протеин содержался в диапазоне 29,2–35,6%. Максимальный уровень по сырому протеину (35,6%) отмечен у сортообразца СБС 56-15-1. По содержанию белка выделен образец Узколистный 53-02 УФ (1435 кг/га). Все изученные сорта и сортообразцы по содержанию алкалоидов в зерне (0,034–0,062%) отнесены к малоалкалоидной группе. По содержанию лизина лидировали сортообразец СБС 56-15-1 и сорт Бело-розовый 144 (2,3 и 2,27%). Наиболее высокое содержание жира выявлено у сорта Брянский кормовой (5,29%). Наибольшей энергетической ценностью обладают сортообразцы СБС 56-15-1 и БСв 51-19 (11,48 и 11,33 МДж). Выделены перспективные сортообразцы СБС 56-15-1 и Узколистный 53-02 УФ, которые могут быть использованы в дальнейшей селекции новых кормовых сортов.

Ключевые слова: люпин узколистный, сорт, урожайность зерна и зеленой массы, сырой протеин, жир, лизин, алкалоиды, обменная энергия

Screening of the narrow-leaved lupine varieties and variety specimens according to grain quality indicators

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The article focuses on the characteristics of the grain quality of narrow-leaved lupine (*Lupinus angustifolius* L.), used in forage production. In a competitive variety trial in the Bryansk region, 3 varieties and 8 variety specimens of the narrow-leaved lupine (the standard is the Vityaz variety) were studied, which, according to the length of the growing season, belong to the “very early” group

(70–100 days). The average vegetation period during the research made 89 days. Grain yield in the experiment averaged 2.82 t/ha, for the standard variety – 2.49 t/ha. The maximum values were observed in the variety specimens SBS 56-15-1 and Uzkolistny 53-02 UF. The average value of green mass yield for the period of observation was 39.7 tons/ha, the standard – 33.6 tons/ha. Statistically significant data for this indicator were found in the variety specimens Hybrid 1314, Hybrid 1246, SBS 56-15-1 and Uzkolistny 53-02 UF. The increase in the standard for green mass yield varied from 8.4 to 14.1 t/ha. The crude protein content in the grain of the studied varieties and variety specimens was in the range of 29.2–35.6%. The maximum level of crude protein (35.6%) was observed in the variety specimen SBS 56-15-1. The Uzkolistny 53-02 UF variety specimen stood out for protein content (1435 kg/ha). All studied varieties and variety specimens are classified as low-alkaloid group according to the level of alkaloid content in grain (0.034–0.062%). The leading varieties for lysine content were SBS 56-15-1 and Belo-rozovy 144 varieties (2.3 and 2.27%, respectively). The highest amount of fat was found in the Bryansky fodder variety (5.29%). The SBS 56-15-1 and BSv 51-19 variety specimens had the highest energy value (11.48 and 11.33 MJ, respectively). The promising variety specimens SBS 56-15-1 and Uzkolistny 53-02 UF were identified which can be used for further breeding to develop new fodder varieties for forage production.

Keywords: narrow-leaved lupine, variety, grain and green mass yield, crude protein, oil, lysine, alkaloids, metabolic energy

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Conflict of interest

The authors declare no conflict of interest.

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INTRODUCTION

For the successful development of the livestock industry amid a shortage of feed plant protein, the key factor for fully balanced nutritious feeding of farm animals is the quality of the feed material. The productivity of feed is determined by its protein content [1, 2].

To reduce costs in producing protein feed, among the grain and legume crops, soy and lupine are highlighted first of all, as they are adapted to specific soil and climate conditions. However, the amount of soy grown in Russia does not meet the needs of the feed supply in agri-

culture, which leads to increasing imports from the USA, Brazil, and Argentina, and its anti-nutritional components – pectins, protease inhibitors, allergens, and others – limit its use without special heat treatment [3, 4]. The cost of importing soybeans is pushing domestic producers of cattle, poultry, and aquaculture feed to take a closer look at lupine and its processing products, since thanks to the grain's nutritional value, high yield of green mass and groats, lupine can largely meet the needs of modern animal husbandry for plant-based protein [5–7]. The high protein content (in the grain – 32–37%, in the dry matter

of green mass – 20%) allows lupine to be used as a high-protein base for making various protein-vitamin-mineral supplements¹.

Narrow-leaved lupine, thanks to its early maturity and fast growth, is adapted to a wide range of soil and climatic conditions. Its northern limit for stable seed production runs through the territories of Leningrad, Vologda, Kirov regions, and the Perm Territory, and it can be grown for green fodder and silage in Karelia, the Komi Republic, and Murmansk region. As an early-maturing, fairly cold-resistant, high-protein crop, it is of great interest for cultivation both in the European part of our country and in the Siberian regions and the Primorsky Territory [8, 9].

The level of alkaloid content limits the use of lupine in feeding farm animals [10]. Modern forage varieties of lupine are considered low-alkaloid² and are allowed in feeding all kinds of animals and birds [11–13].

The goal of the study is to identify promising varieties and breeding lines of narrow-leaved lupine based on key indicators considered when creating animal feed rations: grain and green mass yield, crude protein, carotene, fat, lysine content, metabolizable energy level, and protein yield per unit area.

The scientific novelty lies in evaluating varieties and new breeding lines of narrow-leaved lupine for nutritional productivity in the conditions of the southwestern Non-Black Earth region.

MATERIAL AND METHODS

Field studies were conducted at the All-Russian Research Institute of Lupin (Bryansk region) from 2021 to 2023 on sod-podzolic soil with 2.1–2.5% humus in the arable layer, 16.1–18.2 mg/100 g of available phosphorus, 14.5–

16.0 mg/100 g of exchangeable potassium, and a salt extract pH of 5.4–5.6. The object of study is presented by three zoned varieties (Vityaz, Belorozovy 144, and Bryansky Kormovoy) and eight new narrow-leaved lupine breeding lines in a competitive variety trial.

The competitive variety trial sowing was carried out at the end of April or in the first ten days of May, the plot area was 16.5 m², with four-fold repetition. The setup of the experiments and phenological observations were conducted according to commonly accepted methods in breeding work³; biochemical tests were carried out according to the methods of plant biochemical research⁴.

The statistical processing of yield data was done using the analysis of variance⁵.

The weather conditions during the years of the experiment varied. The growing season in 2021 was characterized by high humidity (HTC = 1.95), 2022 by moderate humidity (HTC = 1.43), and 2023 by dry conditions (HTC = 1.15). The amount of rainfall and temperature patterns during the growth stages of lupine plants also varied. The contrasting weather conditions allowed for a more objective assessment of the grain quality indicators of narrow-leaved lupine varieties.

RESULTS AND DISCUSSION

Narrow-leaved lupine is the fastest-maturing (on average 70–100 days) and most adaptable of the species grown in our country. The studied varieties and breeding lines belong to the very early group. In the trial for the competition test, the average growing period was 89 days (see Table 1). The shortest ripening time was noted for the Bryansky Kormovoy variety (85 days),

¹Artyukhov A.I., Vashchekin E.P., Efimenko E.A. Recommendations on the practical use of lupin-based feeds in farm animal diets. SSI VNII Lupina, FSEI HPE "Bryansk State Agricultural Academy", 2009. 80 p.

²Stepanova S., Nazarova N., Korneychuk V., Lehmann Chr., Mikołajczyk J. Broad unified CMEA classifier and international CMEA classifier for the genus *Lupinus* L. Leningrad: VIR, 1983, 39 p.

³Methodology for State Variety Testing of Agricultural Crops. Moscow, 1985, 269 p.

⁴Yermakov A.I. Methods of biochemical analysis of plants. Leningrad: Agropromizdat, 1987, 456 p.

⁵Dospekhov B.A. Methodology of field experiments. Moscow, 1985, 351 p.

Табл. 1. Характеристика сортов и сортообразцов люпина узколистного по урожайности и качеству зерна в конкурсном испытании, 2021–2023 гг.

Table 1. Characteristics of the varieties and variety specimens of narrow-leaved lupine for yield and grain quality in a competitive trial, 2021–2023

Variety, cultivar	Grain yield, t/ha		Content in grain, %		Growing season, days	Protein yield, kg/ha
	variety	± to the standard	CP	alkaloids		
Vityaz, standard	2,49	–	29,2	0,057	87	907
Bryansky Kormovoy	2,87	+0,38	31,3	0,062	85	713
Belorozovy 144	2,25	–0,24	31,0	0,040	92	1056
Hybrid 1314	2,73	+0,24	32,5	0,034	93	1120
SN 78-07	2,85	+0,36	33,1	0,057	90	926
Hybrid 1246	2,92	+0,43	34,8	0,040	87	1207
SN 39-20	2,98	+0,49	32,6	0,046	90	1040
G-1031	2,97	+0,48	33,3	0,043	89	1234
CBS 56-15-1	3,17	+0,69	35,6	0,043	90	1322
Uzkolistny 53-02 UF	3,04	+0,55	33,7	0,042	89	1435
BSv 51-19	2,76	+0,27	31,1	0,041	86	894
LSD ₀₅	0,18					

which is two days shorter than the standard Vityaz – an early-ripening, indeterminate variety that is moderately resistant to pests and diseases. The tall varieties with intensive side branching, Belorozovy 144 and hybrid 1314, had a longer growing period – 92 and 93 days.

In the experimental material, grain yield and the content of key organic substances that reflect the nutritional value of the varietal material were considered. Over the years of research, with favorable moisture levels during flowering and pod setting, the yield turned out to be 9.6–27.3% higher than that of the Vityaz variety (2.49 t/ha) (see Table 1). The highest yield in the trial was recorded for the variety SBS 56-15-1 (3.17 t/ha). The increase over the standard was 0.69 t/ha. The second highest yield (3.04 t/ha with an increase of 0.55 t/ha) was achieved by the variety Uzkolistny 53-02 UF. According to statistical analysis, nine out of ten options showed a yield increase. Based on the results of the three-year study, the new varieties SBS 56-15-1 and Uzkolistny 53-02 UF were identified.

The protein content and its essential amino acids, which are needed for a balanced diet, determine the nutritional properties of feed. The *L. angustifolius* gene pool includes the biotypes with protein content in seeds of more than 38%. Varieties developed by the All-Russian Research Institute of Lupin breeding program, such as Bryansky Kormovoy, Belorozovy 144, Vityaz, and others, showed high crude protein content in the grain (33.7–39.2%) under the conditions of the Kirov region [14].

Over the years of competitive variety trials esting, the grain protein content ranged from 29.2% to 35.6%. The raw protein content of the Vityaz variety was 29.2%, with a protein yield from the grain harvest of 907 kg/ha. The highest level of raw protein was recorded in the variety sample SBS 56-15-1 (35.6%). In terms of protein yield from the grain harvest, the Uzkolistny 53-02 UF sample stood out with 1,435 kg/ha.

The acceptable level of alkaloids in lupine grain and green mass⁶ ranges from 0.03–0.1%, and when fed in mixtures – up to 0.3%. The share

⁶GOST R 54632–2011 Fodder lupin. Specifications. Moscow: Standartinform, 2020, 8 p.

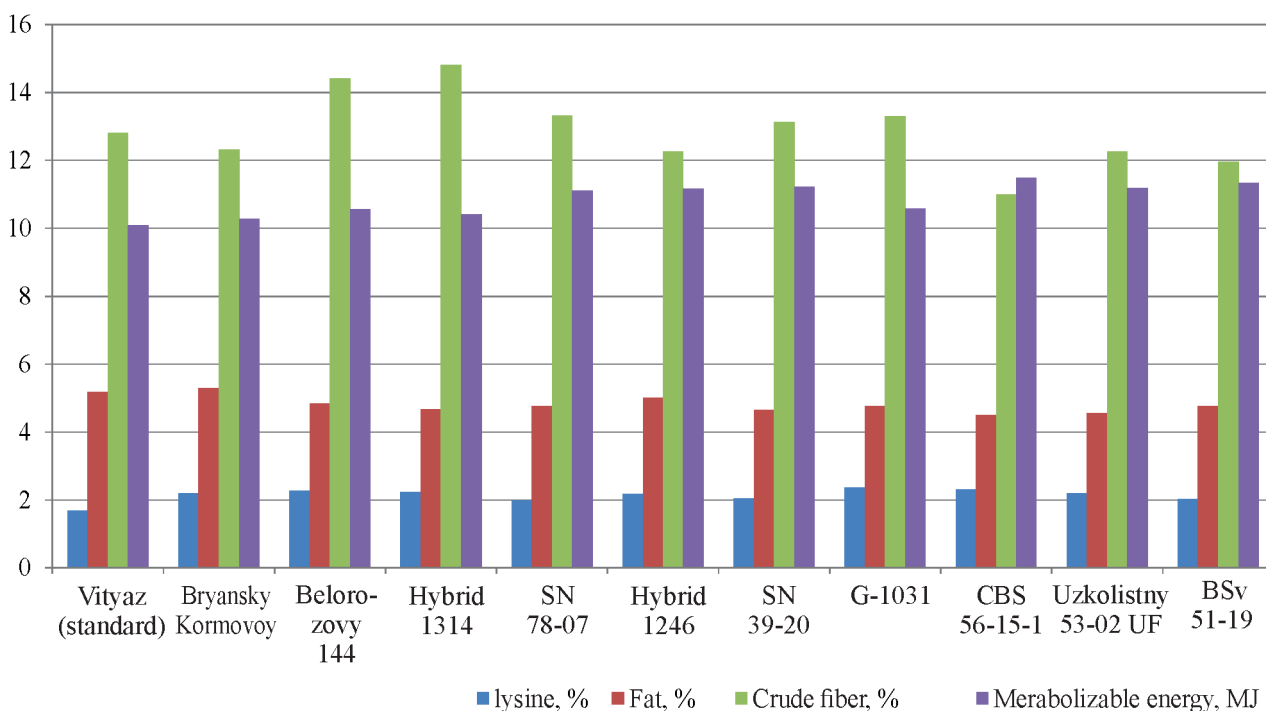
of lupine grain in animal diets should be 10–30%. The feed varieties of narrow-leaved lupine developed by the All-Russian Research Institute of Lupin breeding program are characterized by low alkaloid content. With the acceptable level being 0.1%, in our experiments the lowest alkaloid level was observed in hybrid 1314 (0.034%) (see Table 1). In the six samples we studied, the alkaloid content from 2021 to 2023 ranged from 0.040% to 0.046%.

The assessment of the feed value of narrow-leaved lupine grain takes into account the content of major organic substances and metabolizable energy. The grain quality indicators – lysine, fat, and crude fiber – have been analyzed. Lysine is a limiting essential amino acid in the diet of farm animals and poultry. Its deficiency leads to disrupted protein metabolism and reduced productivity. The average lysine content during the study period for the studied varieties and breeding lines ranged from 1.68% in the Vityaz standard to 2.36% in hybrid 1031 (see the figure). Samples SBS 56-15-1 and the Belor-

zovy 144 variety had lysine levels close to the maximum (2.30% and 2.27%).

The fat content determines the energy potential of the material used for making animal feed [15–17]. Lupine seed fat contains essential fatty acids that animals' bodies cannot produce. A lack of them or an imbalance can lead to metabolic disorders, infectious diseases, and reduced productivity.

The fat content in the grains of the lupine samples studied ranged from 4.49 to 5.29% (see the figure). The highest amount (5.29%) was found in the Bryansky Kormovoy variety, while the standard Vityaz variety had 5.17%. Among the studied samples, hybrid 1246 stood out with 5.01%. As part of joint research, the All-Russian Research Institute of Lupin and the All-Russian Research Institute of Fat (St. Petersburg) determined the fatty acid composition of the seeds of the Vityaz and Bryansky Kormovoy varieties. The oil of narrow-leaved lupine consists mainly (over 70% of the total amount) of unsaturated



Показатели качества зерна сортов и сортообразцов узколистного люпина в конкурсном сортоиспытании, 2021–2023 гг.

Seed quality indicators of narrow-leaved lupine varieties and variety specimens in competitive variety trial, 2021–2023

fatty acids, oleic and linoleic, which is close to their content in soybean oil.

The fiber content in lupine grains is quite high – 12–16%. This amount can be significantly reduced by using dehulled grains instead of native ones, meaning without the husk. It has been found that in native white lupine grains, the crude fiber content ranged from 12.25 to 17.50%, while in the seed kernel it was 2.49% [18]. The fiber content in narrow-leaved lupine grain is relatively low, ranging from 11.0% to 13.31% (see the figure). The highest amounts of crude fiber (over 14%) were found in hybrid 1314 (14.81%), the variety Belorozovy 144 (14.41%), and hybrid SN 39-20 (14.12%).

In terms of metabolizable energy, the highest energy value per 1 kg of dry matter was noted for the varieties SBS 56-15-1 and BSv 51-19 – 11.48 and 11.33 MJ. A negative correlation was found between the level of metabolizable energy and the content of crude fiber ($r = -0,44$), that means at a higher fiber level, the energy value of

the grain goes down. At the same time, a positive relationship has been noted between the content of crude protein, fat, and metabolizable energy, with correlation coefficients of $r = 0,87$ and $r = 0,52$. Increasing the levels of crude protein and fat boosts the energy value of narrow-leaved lupine feed grain.

The biological value of lupine as a forage crop is also determined by the fact that its green mass can make up to 35–40% of the nutritional content in the annual feed balance for all types of farm animals. During the summer, it can serve as the only feed, on which, for example, ruminants grow and develop well, reproduce normally, and give maximum productivity⁷. In the dry matter of narrow-leaved lupine green mass, there is 16–20% crude protein, up to 14% sugar, 60 mg/kg of carotene, and 0.005–0.012% alkaloids.

In our experiments, the green mass yield of the CBS 56-15-1 and Uzkolistny 53-02 UF varieties was higher than that of the Vityaz standard (see Table 2) – the increase was 14.1 t/ha (41.9%)

Табл. 2. Характеристика зеленой массы сортообразцов в конкурсном испытании, 2021–2023 гг.

Table 2. Characteristics of the green mass of variety specimens in competitive testing, 2021–2023

Variety, cultivar	Yield, t/ha			Dry matter content of green mass, %		Protein yield, kg/ha	Carotene content, mg/kg
	variety	± to the standard	dry matter	alkaloids	crude protein		
Vityaz (standard)	33,6	–	5,54	0,021	14,1	781	31,46
Bryansky Kormovoy	36,0	+2,4	9,43	0,020	14,3	911	34,32
Belorozovy 144	33,0	–0,6	6,48	0,012	15,0	1062	38,32
Hybrid 1314	43,5	+9,9	8,43	0,009	15,6	1118	30,32
SN 78-07	40,0	+6,4	9,30	0,006	12,4	915	36,61
Hybrid 1246	42,0	+8,4	8,11	0,016	14,7	1001	40,04
SN 39-20	37,3	+3,7	6,90	0,014	15,2	1035	39,81
G-1031	38,7	+5,1	7,74	0,019	14,8	1145	45,76
CBS 56-15-1	47,7	+14,1	6,48	0,018	16,4	1371	50,34
Uzkolistny 53-02 UF	45,7	+12,1	5,83	0,019	15,8	1225	31,46
BSv 51-19	33,0	–0,6	6,10	0,002	14,0	909	34,32
LSD ₀₅	3,1						

⁷Tokarev V.S., Lisunova L.I. Feeding Farm Animals. Feedstuffs (characteristics and use): a teaching and methodological manual for students majoring in veterinary medicine. Vitebsk: VSAVM, 2023, 195 p.

and 12.1 t/ha (36.0%). The most productive in terms of green forage yield were Hybrids 1314 and 1246 (43.5 and 42.0 t/ha), with an increase of 9.9 and 8.4 t/ha, which is 25.0–29.4% higher than the standard. The highest yields of dry matter in green mass and protein harvested per unit area were noted in the varieties Bryansky Kormovoy and SBS 56-15-1: 9.43 t/ha and 1371 kg/ha.

During the research years, the crude protein content in the dry matter of green mass was higher than the standard in 8 out of 10 varieties and breeding lines. The highest value of this indicator was observed in the breeding line SBS 56-15-1 (16.4%). The yield of crude protein with a green mass harvest of 15.0% was recorded for the variety Uzkolistny 53-02 and the breeding lines SN 39-20 UF and hybrid 1314.

The alkaloid content in the green mass is quite low. The highest level of alkaloids was observed in the Vityaz standard – 0.021% (see Table 2). Only the Bryansky Kormovoy variety came close to this value – 0.020%. In the other samples studied, the alkaloid content ranged from 0.002 to 0.019%.

Lupiny is rich in carotene, which determines the quality of the feed. Its content depends on the plant's stage of development. The highest level of carotene accumulates in the green mass of lupin before it flowers; in the later stages of vegetation (flowering, seed formation), the carotene content in the leaves drops sharply. The content of this substance is influenced by weather and agricultural conditions. For example, carotene breaks down easily under the effects of moisture, sunlight, an acidic environment, and high temperatures. According to the literature, the amount of carotene in green lupine mass averages 35–50 mg/kg (1.8–2.0%), which is 1.4 times higher than in cereal grasses (25–35 mg/kg) [19]. In our studies, the highest carotene content was observed in the hybrid forms SBS 56-15-1 and G-1031 (50.34 and 45.76 mg/kg, respectively) (see Table 2).

CONCLUSION

As a result of research on the main indicators considered when compiling feed rations, new promising breeding varieties from the All-Russian Research Institute of Lupin have been identified – SBS 56-15-1 and Uzkolistny 53-02 UF. These varieties are characterized by high grain yield, crude protein content, and protein harvest per unit area. It should be noted that the SBS 56-15-1 sample also performed well in terms of exchange energy, which indicates its high potential for developing new high-yielding lupine varieties adapted to specific conditions. Hybrid 1314 stood out for its green mass yield (43.5 t/ha) and crude protein content in the green mass (15.6%).

Creating high-protein feed varieties developed domestically will help provide our country's feed base with affordable plant protein, which will lower its cost and allow for more effective development of the livestock industry.

СПИСОК ЛИТЕРАТУРЫ

1. Николаев С.И., Каранетян А.К., Корнеева О.В., Бородин С.М. Эффективность применения зерна люпина сорта Деко в свиноводстве и птицеводстве // Известия Нижневолжского агроуниверситетского комплекса: наука и высшее профессиональное образование. 2023. № 3 (71). С. 289–297. DOI: 10.32786/2071-9485-2023-03-29.
2. Кублин И.М., Прущак О.В., Санинский С.А. Люпин: переворот в производстве белковых кормов для сельскохозяйственной отрасли // Аграрный научный журнал. 2024. № 6. С. 32–39. DOI: 10.28983/asj.y2024i6pp32-39.
3. Николаев С.И., Даниленко И.Ю., Каранетян А.К., Бубуёк А.В. Сравнительная оценка химического и аминокислотного состава полножирной сои и зерна люпина // Известия Нижневолжского агроуниверситетского комплекса: наука и высшее профессиональное образование. 2024. № 5 (77). С. 196–201. DOI: 10.32786/2071-9485-2024-05-21.
4. Милушев Р.К., Шулаев Г.М. Концентраты из растительного сырья для балансирования кормов: теория и практика использования // Свиноводство. 2022. № 3. С. 40–43. DOI: 10.37925/0039-713x-2022-3-40-43.

5. Гатаулина Г.Г. Люпин поможет ликвидировать дефицит растительного белка // Аграрная наука. 2021. № 9. С. 73–75.
6. Агеева П.А., Почутина Н.А., Коннова Л.В. Агробиологическая оценка сортов и сортообразцов узколистного кормового люпина // Сибирский вестник сельскохозяйственной науки. 2024. Т. 54. № 1. С. 71–81. DOI: 10.26898/0370-8799-2024-1-8.
7. Гапонов Н.В., Шмат Е.В., Амироков М.А. Биометрические и гистопатологические показатели радужной форели при снижении содержания животного протеина в рационе // Инновации и продовольственная безопасность. 2024. № 4 (46). С. 74–81. DOI: 10.31677/2311-0651-2024-46-4-74-81.
8. Вишнякова М.А., Власова Е.В., Егорова Г.П. Генетические ресурсы люпина узколистного (*Lupinus angustifolius* L.) и их роль в доместикации и селекции культуры // Вавиловский журнал генетики и селекции. 2021. Т. 25. № 6. С. 620–630. DOI: 10.18699/VJ21.070.
9. Агеева П.А., Почутина Н.А., Громова О.М., Зайцева Н.М. Люпин узколистный – результаты изучения сортов и сортообразцов по адаптивности и комплексу хозяйственно-биологических признаков // Аграрная наука Евро-Северо-Востока. 2022. Т. 23. № 2. С. 211–220. DOI: 10.30766/2072-9081.2022.23.2.211-220.
10. Попов В.С., Саликова А.В., Перчук И.Н., Конькова Н.Г., Егорова Г.П., Вишнякова М.А., Шеленга Т.В. Экспресс-оценка основных показателей хозяйственной ценности в образцах муки люпина узколистного с помощью ИК-спектроскопии // Труды по прикладной ботанике, генетике и селекции. 2024. Т. 185. № 1. С. 99–108. DOI: 10.30901/2227-8834-2024-1-99-108.
11. Osorio C.E., Till B.J. A bitter-sweet story: unraveling the genes involved in quinolizidine alkaloid synthesis in *Lupinus albus* // Frontiers in plant science. 2022. № 12. С. 795091. DOI: 10.3389/fpls.2021.795091.
12. Caramona A., Martins A., Seixas J., Marto J. The use, reuse and valorization of lupin and its industry by-products for dermocosmetics applications // Sustainable chemistry and pharmacy. 2024. № 38 (17). С. 101477. DOI: 10.1016/j.scp.2024.101477.
13. Руцкая В.И., Тимошенко Е.С. Особенности люпина и перспективы его использования в пищевой промышленности // Известия Нижневолжского агроуниверситетского комплек-
са: наука и высшее профессиональное образование. 2025. № 4 (82). С. 183–191. DOI: 10.32786/2071-9485-2025-04-19.
14. Кузякина Л.И., Лыбенко Е.С., Емелев С.А. Оценка питательности зерна узколистного люпина ФНЦ ВИК, выращенного в условиях Кировской области // Технологии пищевой и перерабатывающей промышленности АПК – продукты здорового питания. 2022. № 4. С. 195–199. DOI: 10.24412/2311-6447-2022-4-195-199.
15. Наумкин В.Н., Лукашевич М.И., Киселева С.Г., Блинник А.С., Артемова О.Ю. Урожайность и качество новых сортов и сортообразцов люпина белого в условиях Белгородской области // Зернобобовые и крупяные культуры. 2023. № 3 (47). С. 90–95. DOI: 10.24412/2309-348X-2023-3-90-95.
16. Пташник О.П. Изучение продуктивности и качества зерна сортов и сортообразцов люпина белого (*Lupinus albus* L.) // Таврический вестник аграрной науки. 2021. № 3 (27). С. 155–163. DOI: 10.33952/2542-0720-2021-3-27-155-163.
17. Зубова Е.В., Залетова Т.В., Капитанова Г.И., Терехова О.Б., Родыгина Н.В. Пищевая ценность белого люпина и перспективы его использования в производстве продуктов питания из растительного сырья // Аграрная наука. 2023. № 4. С. 137–144. DOI: 10.32634/0869-8155-2023-369-4-137-144.
18. Цыгуткин А.С. Содержание питательных веществ в зерне белого люпина // Агрохимический вестник. 2024. № 4. С. 55–60. DOI: 10.24412/1029-2551-2024-4-011.
19. Муравьев А.А., Кадыров С.В., Муравьева И.С. Формирование продуктивности и эффективность возделывания люпина белого различных сортов в условиях ЦЧР // Вестник Воронежского государственного аграрного университета. 2023. Т. 16. № 4 (79). С. 22–30. DOI: 10.53914/issn2071-2243_2023_4_22-30.

REFERENCES

1. Nikolaev S.I., Karapetyan A.K., Korneeva O.V., Borodin S.M. The effectiveness of the use of lupin grain of the Deco variety in pig and poultry breeding. *Izvestiya Nizhnevolzhskogo agrouniversitetskogo kompleksa: nauka i vysshee professional'noe obrazovanie* = *Izvestia of the Lower Volga Agro-University Complex*, 2023,

- vol. 3 (71), pp. 289–297. (In Russian). DOI: 10.32786/2071-9485-2023-03-29.
2. Kublin I.M., Prushchak O.V., Saninsky S.A. Lupine: a revolution in the production of protein feeds for the agricultural industry. *Agrarnyj nauchnyj zhurnal = Agrarian Scientific Journal*, 2024, no. 6, pp. 32–39. (In Russian). DOI: 10.28983/asj.y2024i6pp32-39.
 3. Nikolaev S.I., Danilenko I.Yu., Karapetyan A.K., Bubuyok A.V. Comparative assessment of the chemical and amino acid composition of full-fat soybeans and lupine grain. *Izvestiya Nizhnevolzhskogo agrouniversitetskogo kompleksa: nauka i vysshee professional'noe obrazovanie = Izvestia of the Lower Volga Agro-University Complex*, 2024, no. 5 (77), pp. 196–201. (In Russian). DOI: 10.32786/2071-9485-2024-05-21.
 4. Milushev R.K., Shulaev G.M. Concentrates from vegetative components for balancing of mixed fodders: theory and use practice. *Svinovodstvo = Industrial & Pure-bred pig-breeding*, 2022, no. 3, pp. 40–43. (In Russian). DOI: 10.37925/0039-713x-2022-3-40-43.
 5. Gataulina G.G. Lupine will help to eliminate the deficiency of vegetable protein. *Agrarnaya nauka = Agrarian science*, 2021, no. 9, pp. 73–75. (In Russian).
 6. Ageeva P.A., Potchutina N.A., Konnova L.V. Agrobiological evaluation of the varieties and cultivars of narrow-leaved fodder lupine. *Sibirskij vestnik sel'skokhozyajstvennoj nauki = Siberian Herald of Agricultural Science*, 2024, vol. 54, no. 1, pp. 71–81. (In Russian). DOI: 10.26898/0370-8799-2024-1-8.
 7. Gaponov N.V., Shmat E.V., Amirokov M.A. Biometric and histopathological parameters of rainbow trout with a decrease in animal protein content in the diet. *Innovatsii i prodovol'stvennaya bezopasnost' = Innovations and Food Safety*, 2024, no. 4 (46), pp. 74–81. (In Russian). DOI: 10.31677/2311-0651-2024-46-4-74-81.
 8. Vishnyakova M.A., Vlasova E.V., Egorova G.P. Genetic resources of narrow-leaved lupine (*Lupinus angustifolius* L.) and their role in its domestication and breeding. *Vavilovskij zhurnal genetiki i seleksii kul'tury = Vavilov Journal of Genetics and Breeding*, 2021, vol. 25, no. 6, pp. 620–630. (In Russian). DOI: 10.18699/VJ21.070.
 9. Ageeva P.A., Potchutina N.A., Gromova O.M., Zajceva N.M. Blue lupin (*Lupinus angustifolius* L.) – the results of varieties and accessions study according to adaptivity and a set of commercialbiological traits. *Agrarnaya nauka Evro-Severo-Vostoka = Agricultural Science Euro-North-East*, 2022, vol. 23, no. 2, pp. 211–220. (In Russian). DOI: 10.30766/2072-9081.2022.23.2.211-220.
 10. Popov V.S., Salikova A.V., Perchuk I.N., Konnova N.G., Egorova G.P., Vishnyakova M.A., Shelenga T.V. Rapid assessment of the main economic value indicators in lupine flour samples using infrared spectroscopy. *Trudy po prikladnoj botanike, genetike i seleksii = Proceedings on applied botany, genetics and breeding*, 2024, vol. 185, no. 1, pp. 99–108. (In Russian). DOI: 10.30901/2227-8834-2024-1-99-108.
 11. Osorio C.E., Till B.J. A bitter-sweet story: unraveling the genes involved in quinolizidine alkaloid synthesis in *Lupinus albus*. *Frontiers in plant science*, 2022, vol. 12, p. 795091. DOI: 10.3389/fpls.2021.795091.
 12. Caramona A., Martins A., Seixas J., Marto J. The use, reuse and valorization of lupin and its industry by-products for dermocosmetics applications. *Sustainable chemistry and pharmacy*, 2024, no. 38 (17), p. 101477. DOI: 10.1016/j.scp.2024.101477.
 13. Rutsкая V.I., Timoshenko E.S. Features of lupine and prospects for its use in the food industry. *Izvestiya Nizhnevolzhskogo agrouniversitetskogo kompleksa: nauka i vysshee professional'noe obrazovanie = Izvestia of the Lower Volga Agro-University Complex*, 2025, no. 4 (82), p. 183–191. (In Russian). DOI: 10.32786/2071-9485-2025-04-19.
 14. Kuzyakina L.I., Lybenko E.S., Emelev S.A. Evaluation of nutritional grain of narrow-leaved lupine bred by FNC VIK grown in the conditions of the Kirov region. *Tekhnologii pishchevoj i pererabatyvayushchej promyshlennosti APK – produkty zdorovogo pitaniya = Technologies for the food and processing industry of AIC – healthy food*, 2022, no. 4, pp. 195–199. (In Russian). DOI: 10.24412/2311-6447-2022-4-195-199.
 15. Naumkin V.N., Lukashevich M.I., Kiseleva S.G., Blinnik A.S., Artemova O.Yu. Yield and quality of new varieties and cultivars of white lupine under conditions of Belgorod oblast. *Zernobobovye i krupyanye kul'tury = Legumes and Groat Crops*, 2023, no. 3 (47), pp. 90–95. (In Russian). DOI: 10.24412/2309-348X-2023-3-90-95.

16. Ptashnik O.P. Yield and grain quality of varieties and cultivars of white lupine (*Lupinus albus* L.). *Tavrisheskij vestnik agrarnoj nauki = Taurida Herald of the Agrarian Sciences*, 2021, no. 3 (27), pp. 155–163. (In Russian). DOI: 10.33952/2542-0720-2021-3-27-155-163.
17. Zubova E.V., Zaletova T.V., Kapitanova G.I., Terekhova O.B., Rodygina N.V. Nutritional value of white lupin and prospects of its use in the production of food from vegetable raw materials. *Agrarnaya nauka = Agrarian science*, 2023, no. 4, pp. 137–144. (In Russian). DOI: 10.32634/0869-8155-2023-369-4-137-144.
18. Tsygutkin A.S. Nutrients content in white lupine grain. *Agrokhimicheskij vestnik = Agrochemical Herald*, 2024, no. 4, pp. 55–60. (In Russian). DOI: 10.24412/1029-2551-2024-4-011.
19. Muravyov A.A., Kadyrov S.V., Muravyova I.S. Formation of productivity and efficiency of cultivation of white lupine varieties in the conditions of the Central Chernozem Region. *Vestnik Voronezhskogo gosudarstvennogo agrarnogo universiteta = Vestnik of Voronezh State Agrarian University*, 2023, vol. 16, no. 4 (79), pp. 22–30. (In Russian). DOI: 10.53914/issn2071-2243_2023_4_22-30.

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Мониторинг резистентности сорняков рода *Echinochloa* к гербициду Цитадель, МД, применяемому в посевах риса в Приморском крае

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Исследование выполнено в 2013–2024 гг. в хозяйствах Приморского края, занимающихся выращиванием риса, а также на опытной базе Дальневосточного научно-исследовательского института защиты растений – филиала Федерального научного центра агробиотехнологий Дальнего Востока им. А.К. Чайки. Обследованы посевы риса в 12 хозяйствах, расположенных в степной, лесостепной и южной таежной почвенно-климатических зонах Приморья. С растений, уцелевших после обработки гербицидами, были собраны семена трех биотипов *Echinochloa*: *E. crusgalli* (ежовник обыкновенный, или куриное просо), *E. occidentalis* (ежовник западный или спиральный) и *E. phyllorogon* (ежовник бородчатый). Семена чувствительных (природных, нативных) популяций собраны с участков, где гербициды ранее никогда не применяли. Выращенные из собранных семян растения в фазу 2–3 листьев обрабатывали раствором Цитадель, МД в разных нормах расхода. Для обработки использовали лабораторный опрыскиватель ОЛ-5 конструкции Всероссийского научно-исследовательского института фитопатологии. Степень устойчивости популяций *Echinochloa* к гербициду Цитадель, МД оценивали по снижению надземной массы растений в процентах к безгербицидному варианту (контролю), а также к эталону. По данным регрессионного анализа «доза – эффект» определяли $СД_{50}$ для обладающих и не обладающих устойчивостью видов, рассчитывали показатель резистентности (отношение $СД_{50}R$ устойчивого вида к $СД_{50}S$ чувствительного вида). Показатель резистентности популяций *Echinochloa* к гербициду Цитадель, МД в среднем по рисоводческим хозяйствам Приморского края в 2024 г. приблизился к 100, что свидетельствует о высокой степени устойчивости к данному препарату. Ранее наблюдалось большое количество биотипов *Echinochloa*, резистентных к применявшемуся продолжительное время на посевах риса гербициду Фацет, КС, который так же, как и Цитадель, ингибирует ацетолактатсинтазу. На основе результатов многолетнего опыта можно предположить наличие перекрестной резистентности у всех форм ежовников к гербициду Цитадель, МД или его аналогам.

Ключевые слова: *Echinochloa*, гербицид, препарат, резистентность, устойчивость популяции, биотипы

Monitoring the resistance of weeds of the genus *Echinochloa* to the herbicide Citadel, OD used in rice crops in the Primorsky Territory

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The studies were carried out in 2013–2024 at the farms of the Primorsky Territory engaged in growing rice and at the experimental base of the Federal Scientific Center of Agricultural Biotechnology

of the Far East named after A.K. Chaiki. Rice crops of 12 farms located in three soil and climatic zones of Primorye were examined. Seeds of three *Echinochloa* biotypes were collected from the plants that survived herbicide treatment: *E. crusgalli* (barnyard grass or barnyard millet), *E. occidentalis* (occidental or spiral barnyard grass) and *E. phyllopogon* (bearded barnyard grass). Seeds of sensitive (natural, native) populations were collected from the areas where herbicides had never been used before. The plants grown from the collected seeds were treated with Citadel, OD solutions at different consumption rates in the phase of 2–3 leaves. A laboratory sprayer OL-5 designed by the All-Russian Research Institute of Phytopathology was used for the treatment. The degree of resistance of *Echinochloa* populations to the herbicide Citadel, OD was assessed by the reduction in the aboveground mass of plants as a percentage of the herbicide-free variant (control), as well as the standard. Based on the dose-effect regression analysis, SD_{50} was determined for resistant and non-resistant species, and the resistance index was calculated (RI) (the ratio of $SD_{50}R$ of the resistant species to $SD_{50}S$ of the sensitive species). The resistance rate of *Echinochloa* populations to the herbicide Citadel, OD on average in rice-growing farms of the Primorsky Territory approached 100 in 2024, this indicated a high degree of resistance to this drug. Previously, a large number of *Echinochloa* biotypes were observed that were resistant to the herbicide Facet, SC, which, like Citadel, inhibits acetolactate synthase and was used for a long time on rice crops. Based on the results of many years of experience, it can be assumed that all forms of barnyard grasses have cross-resistance to the herbicide Citadel, OD or its analogues.

Keywords: *Echinochloa*, herbicide, preparation, resistance, stability populations, biotypes

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Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Rice is one of the oldest and most important crops in the modern world. Its grain is the main food for half of the world's population. Today, rice is grown on every continent except Antarctica [1, 2].

The Primorsky Territory is one of the few regions in Russia where large-scale cultivation of this crop is possible. At the moment, Far Eastern rice farming is in a crisis, but it is still seen as a promising area not just for meeting domestic needs, but also for exporting agricultural products [3]. In 2024, 8.88 thousand hectares of rice were sown in the Primorsky Territory. During the most favorable periods in history, the Primorsky Territory became the second region in

the country for rice production after the Krasnodar Territory.

The reasons for the decrease in rice planting areas are heavy weed infestation and the development of herbicide resistance in *Echinochloa* (barnyard grass) weeds. For instance, research conducted by the staff of the Far Eastern Scientific Research Institute of Plant Protection found that a significant reduction in rice yield of 10.2–15.0 c/ha (33–41%) was observed when the barnyard grass density reached 80 plants/m². When this number increased to 160–240 plants/m², the yield loss reached 19.0–24.1 c/ha¹.

Five species belonging to the genus *Echinochloa* grow in the southern part of the Russian Far East: caudate barnyard grass (*E. caudate*

¹Kostyuk A.V., Lukacheva N.G., Ginevsky N.K. Harmfulness of weeds in rice crops in the Primorsky Territory // *Zemledelie*, 2006, N 2, pp. 42–43.

Roshev.), occidental or spiral barnyard grass (*E. occidentalis* (Wiegand) Rydb.), barnyard grass or barnyard millet (*E. crusgalli* (L.) Beauv.), bearded barnyard grass (*E. phyllopogon* (Staps) Kossenko), rice barnyard grass (*E. macrocarpa* Vasing)².

Monitoring and forecasting the spread of weeds across administrative regions are tasks assigned to the regional branches of the Russian Agricultural Centre and agricultural research institutes. These entities are also responsible for developing regional strategies to protect crops from weed infestation, including recommendations on the use of various chemical agents [4].

The uncontrolled use of herbicides in crop production in general, and in rice cultivation in particular, leads to serious problems, including the emergence of resistant weed populations [5]. In developed countries, this issue is considered so serious that it is compared to the development of multidrug resistance to antibiotics in human pathogens³. In Primorye, cases of resistance in *Echinochloa* weeds to the herbicide Facet, SC (active ingredient: quinclorac)—which had been used for a prolonged period in rice crops—were observed in 2005. Its annual application relatively quickly increased the level of tolerance and raised the resistance of the weeds⁴. The emergence of herbicide-resistant weed populations is a serious agricultural problem, although in Russia it is currently less acute than abroad [6, 7].

The long-term use of quinclorac-based herbicides has led to the development of resistance in *Echinochloa* biotypes in various countries [8, 9]. To overcome resistance to these products, herbi-

cides with a different mode of action—Citadel (OD), Nominee (SC), and Segment—which are acetolactate synthase inhibitors, have been employed. However, after prolonged use, reports emerged regarding the development of resistance to the herbicide Citadel OD in three species of the genus *Echinochloa* in both Primorye and the Krasnodar Territory [10].

Foreign publications contain a great deal of information regarding *Echinochloa* populations resistant to penoxsulam-based herbicides (Citadel OD, Tsitata OD, Kreposhans OD). For example, C.A. Damalas and S.D. Koutroubas report that a large number of cases of resistance in plants of the genus *Echinochloa* to herbicides used in crops—including penoxsulam—are currently being recorded worldwide [11]. Cross-resistance to this herbicide has been observed in 29 populations of *E. phyllopogon* in Greece⁵, and in Uruguay – in three [12]. A population of *E. crusgalli* was discovered in the United States; eradicating 50% of the plants required four times the standard application rate of the herbicide⁶. Cases of cross-resistance to penoxsulam in *E. crusgalli* and *E. phyllopogon* have been recorded in South Korean rice fields⁷. A similar situation prevails in most of China's rice-growing provinces. In some cases, the application rate had to be increased more than tenfold to eliminate 50% of *E. crusgalli* plants [13, 14]. In India, herbicides based on bispyribac-sodium and pendimethalin have demonstrated high efficacy in controlling weeds of the genus *Echinochloa* [15–17].

The purpose of the study is to monitor the resistance of *Echinochloa* species weeds to the

²Probatova N.S. Family Poaceae // Vascular Plants of the Soviet Far East: in 8 vols. / ed. S.S. Kharkevich. Leningrad: Nauka, 1985, vol. 1, pp. 89–382.

³Bragina O.A. On weed resistance to herbicides // Rice Growing, 2016, N 1–2 (30–31), pp. 46–49.

⁴Lukacheva N.G., Kostyuk A.V. Resistance of barnyard grass species in rice crops and the origins thereof // Problems of Agroecosystem Ecology: Ways and Methods of Solution: Proceedings of the All-Russian Scientific Conference (Novosibirsk, Dec. 3, 2009). Novosibirsk, 2009, pp. 70–73.

⁵Kaloumenos N.S., Chatzitaridou S.L., Mylona P.V., Polidoros A.N., Eleftherohorinos I.G. Target-site mutation associated with cross resistance to ALS – inhibiting herbicides in late water-grass (*Echinochloa oryzicola* Vasing) // Pest management science, 2013, vol. 69, pp. 865–873.

⁶Norsworthy J.K., Wilson M.J., Skott R.C., Gbur E.E. ALS – resistant barnyard grass // Weed biology and management, 2014, vol. 14, pp. 50–58.

⁷Song J.-S., Lim S.-H., Yook M.-J., Kim J.-W., Kim D.-S. Cross – resistant of *Echinochloa* species to acetoacetate synthase inhibitor herbicides // Weed biology and management, 2017, vol. 17, pp. 91–102.

herbicide Citadel, OD, used in rice crops in the Primorye region.

It should be noted separately that similar studies had not previously been conducted in the southern part of the Russian Far East.

MATERIAL AND METHODS

The research was conducted from 2013 to 2024 in the rice fields of the Primorsky Territory, as well as in a vegetation house at the Far East Research Institute of Plant Protection.

Seeds of resistant *Echinochloa* populations (barnyard grass, western barnyard grass, and bearded barnyard grass) were collected from rice fields that had been treated for many years with the herbicide Citadel OD or its analogues. The monitoring covered 12 rice-growing farms. Applications of the herbicide Citadel, OD, were carried out at the early developmental stage of *Echinochloa* species (2–4 leaf stage). N.S. Probatova's identification key was used to identify plants of the genus *Echinochloa*. Seeds from native and reference populations were collected from the sites where the herbicide under study had never previously been applied.

The bioassay is the most accessible method, involving the testing of various herbicide doses under growing conditions. For this purpose, meadow-gley soil was sieved (5 mm) and placed into 300 g plastic cups. Seeds of the *Echinochloa* biotypes under study were pre-germinated and then planted in the cups (five plants per cup). At the same time, seeds of pure populations were sown to serve as reference standards in the experiments. The soil was moistened to 60–70% of field capacity. The experiment was conducted with five replicates. When the plants reached the 2–3 leaf stage, they were treated with the herbicide Citadel, OD. In the initial stages of the study, the product was applied at rates of 0.8, 1.0, 1.6, and 2.0 l/ha, and subsequently at 1.0, 2.0, 4.0, and 8.0 l/ha. An OL-5 laboratory sprayer, designed by the All-Russian Research Institute of Phytopathology, was used to treat

the plants. The day after treatment, the plant containers were filled with water to a level of 1.0–1.5 cm, which was maintained until the end of the experiment.

To determine the level of resistance development in *Echinochloa* biotypes to the herbicide Citadel, OD, studies were conducted under greenhouse conditions starting in 2014, using both 3 kg pots and, in parallel, plastic cups. Three weeks after the treatment of actively growing plants in small containers, the plants were cut and weighed. Barnyard grass plants in pots that survived the herbicide application were grown until their seeds fully matured; these seeds were subsequently collected separately for each treatment variant and stored for further study.

The level of resistance of *Echinochloa* populations to the herbicide Citadel, OD, was evaluated based on the reduction in plant fresh weight expressed as a percentage of the herbicide-free variant (control) and the reference standard. The SD_{50} was determined using "effect-dose" regression analysis. According to the "effect-dose" regression analysis, SD_{50} was determined (the amount of the drug that reduces plant weight by 50%) for species with and without resistance, and the resistance index (RI) was calculated, i.e. the ratio of SD_{50R} of a resistant species to SD_{50S} of a sensitive species.

RESULTS AND DISCUSSION

Phytosanitary monitoring of rice fields is conducted on a regular basis to determine the ecological damage threshold of weeds and to develop economically sound measures in order to control their population levels, prevent resistance, select appropriate herbicides, and establish the frequency of chemical treatments [5].

Rice cultivation in the Primorsky Territory is concentrated in three soil-climatic zones: the steppe zone (Khankaysky and Khorolsky districts), the forest-steppe zone (Spassky and Chernigovsky districts), and the southern taiga zone (Anuchinsky district). Research has shown that the first cases of *Echinochloa* biotypes de-

veloping resistance to the herbicide Citadel, OD, were recorded in 2014 in the rice fields of the OOO “AgroDesun-Khanka” in the Khankaysky district and the Lugovoe agricultural cooperative in the Khorolsky district. In the Primorye region, the use of this product began in 2011, replacing the herbicide Facet SC, which had been used for a long time. On average across the region in 2014, the RI was 5, which is approximately at the tolerance level (4) (see Fig. 1).

In 2015, two additional cases of resistance in *Echinochloa* biotypes were identified. Insufficient efficacy of the herbicide Citadel, OD, was observed in rice fields belonging to the OOO “Vladimiro-Petrovskoye” in the Khankaysky District and the OOO “Devichanskoye” in the Khorolsky District. In 2016, the geographical spread of *Echinochloa* populations resistant to the herbicide expanded. Resistance was detected in the fields of the ZAO “Novoselskoye” (Spassky District), OOO “Saturn” (Khankaysky District), and OOO “SangSeng” (Anuchinsky District). In 2017, the OOO “Petrovichanskoye” (Khorolsky District) and “Smena” (Chernigovsky District) were added to the list. By 2024, the resistance index of *Echinochloa* populations to the herbicide Citadel, OD had risen to 100; specifically, it was 83 for *E. crusgalli*, 136 for *E. occidentalis*, and 81 for *E. phyllopogon* (see Fig. 2).

Complete eradication of *E. crusgalli* and *E. occidentalis* biotypes was achieved in only a few fields using 4 l/ha of the product (the recommended application rate is 1.0–1.6 l/ha), whereas application of the solution at 8.0 l/ha resulted in only 26–96% mortality of the *E. phyllopogon* biotype.

Three-year studies (2013–2015) aimed at identifying the onset of resistance development in *Echinochloa* populations to the herbicide Citadel, OD with clean (native) seeds that had never been exposed to the chemical before, didn't show anything. No resistance buildup occurred. Starting in 2016, experiments began using seeds of resistant forms that carried genes for resistance to the herbicide Facet, SC. In the very first year of the study, resistance was observed in the *Echinochloa* population: the RR averaged 14, including 21 for *E. crusgalli*, and 10 for *E. occidentalis* and *E. phyllopogon* (see Fig. 3).

In the following years, it continued to grow and by 2023 and 2024 reached 284–293. Treatment with the product at a rate of 8 l/ha had no effect on the plants of the studied *Echinochloa* biotypes, and their aboveground mass in some cases even exceeded the control levels. At the same time, plants grown from native seeds were killed by the recommended doses of the herbicide.

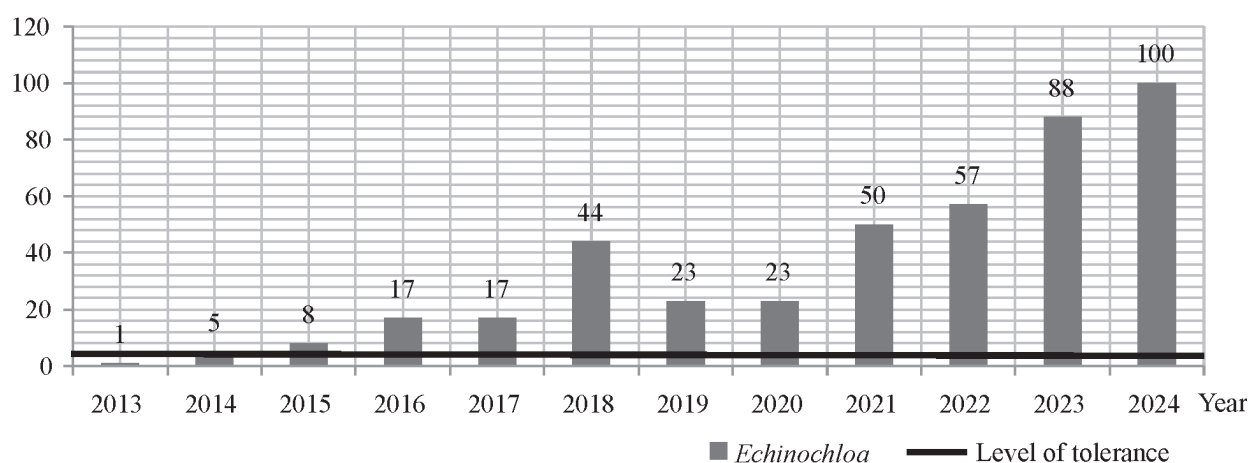


Рис. 1. Устойчивость сорняков рода *Echinochloa* к гербициду Цитадель, МД в посевах риса в Приморском крае

Fig. 1. Resistance of *Echinochloa* weeds to the herbicide Citadel, OD in rice crops in the Primorsky Territory

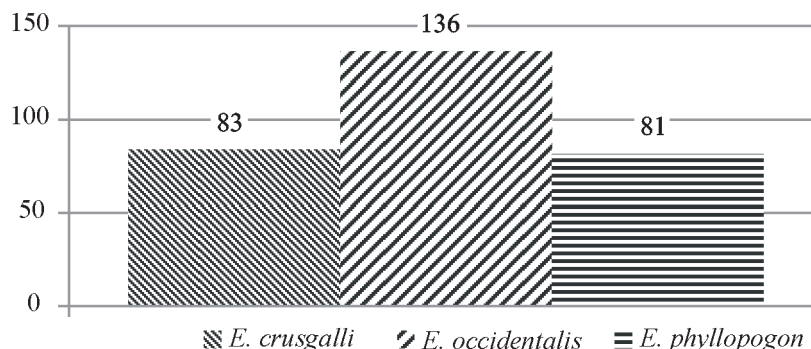


Рис. 2. Показатель резистентности биотипов *Echinochloa* к гербициду Цитадель, МД в посевах риса на территории Приморского края (2024 г.)

Fig. 2. Resistance index of *Echinochloa* biotypes to the herbicide Citadel, OD rice crops in the Primorsky Territory (2024)

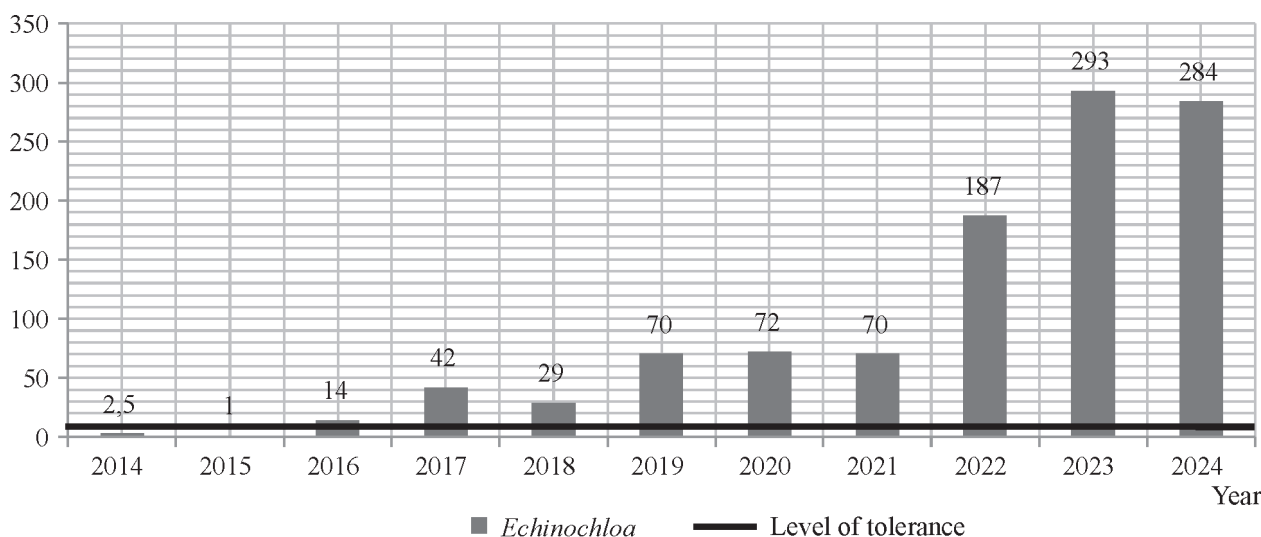


Рис. 3. Нарастание устойчивости популяций *Echinochloa* к гербициду Цитадель, МД (многолетний опыт)

Fig. 3. Building resistance of *Echinochloa* populations to the herbicide Citadel, OD (long-term experience)

Some of the main reasons for the emergence of herbicide-resistant forms of *Echinochloa* weeds in rice crops are poor field leveling, untimely water supply to the paddies after applying herbicides, an insufficient water layer to boost the effectiveness of the chemicals, as well as a limited range of herbicides.

CONCLUSION

Monitoring studies have revealed the existence of *Echinochloa* populations that show resistance to the herbicide Citadel, OD, which has been used for a long time in rice fields in the Primorsky Territory. The accumulation of re-

sistance in *Echinochloa* forms occurred rapidly in those farms where previously resistant biotypes were found, which were initially resistant to the herbicide Facet, SC. Years of experience show that populations of *Echinochloa* can have cross-resistance to the herbicide Citadel, OD. This has also been observed on the farms growing rice in the Primorsky Territory, since seeds of the *E. crusgalli*, *E. occidentalis*, and *E. phyllopogon* biotypes were originally collected from fields where the studied forms might have carried genes for resistance to the herbicide Facet, SC.

СПИСОК ЛИТЕРАТУРЫ

1. Ткаченко М.А., Зеленский Г.Л. Состояние и перспективы создания сортов риса с новым морфотипом растения (обзор) // Рисоводство. 2023. № 3 (60). С. 6–13. DOI: 10.33775/1684-2426-2023-60-3-6-13.
2. Зеленский П.Г., Зеленская О.В. Мировое производство риса и пути его инновационного развития (обзор) // Рисоводство. 2022. № 4 (57). С. 6–11.
3. Илюшко М.В., Ромашова М.В., Гученко С.С., Емельянов А.Н. Продуктивность образцов риса *Oryza sativa* L. краснодарской и зерноградской селекции в коллекционном питомнике в условиях Приморского края // Аграрная Россия. 2024. № 5. С. 8–13.
4. Лунева Н.Н. Выделение уровней фитосанитарного районирования территории в отношении сорных растений на примере Ленинградской области // Вестник защиты растений. 2020. № 103 (2). С. 119–133. DOI: 10.31993/2308-6459-2020-103-2-13406.
5. Зеленская О.В. Экологический риск распространения на рисовых полях сорных растений, устойчивых к гербицидам (обзор) // Рисоводство. 2021. № 1 (50). С. 76–87. DOI: 10.33775/1684-2464-2021-50-1-76-87.
6. Колупаев М.В. Резистентность сорняков к гербицидам нарастает // Защита и карантин растений. 2021. № 4. С. 15–16.
7. Берестецкий А.О. Перспективы разработки новых гербицидов на основе природных соединений // Вестник защиты растений. 2023. № 106 (1). С. 5–25. DOI: 10.31993/2308-6459-2023-106-1-15502.
8. Ul Haq M.Z., Zang Z., Wei J., Qang S. Ethylene biosynthesis inhibition combined with cyanide degradation confer resistance to quinclorac in *Echinochloa crus-galli* var. *mitis* // International journal of molecular sciences. 2020. Vol. 21 (5). P. 1573. DOI: 10.3390/ijms21051573.
9. Vignola V.D., Sainz M., Saldain N.E., Marchesi C., Bonnacarrere V., Gadea P.D. Limited induction of ethylene and cyanide synthesis are observed in quinclorac-resistant barnyardgrass (*Echinochloa crus-galli*) in Uruguay // Weed science. 2020. Vol. 68. Iss. 4. P. 348–357. DOI: 10.1017/wsc.2020.32.
10. Костюк А.В., Лукачева Н.Г., Ляшенко Е.В. Устойчивость биотипов ежовников к гербицидам, применяемым в посевах риса в Приморском крае // Вестник Дальневосточного отделения РАН. 2022. № 3. С. 61–69. DOI: 10.37102/0869-7698-2022-223-03-6.
11. Damalas C.A., Koutroubas S.D. Herbicide – resistant barnyard grass (*Echinochloa crusgalli*) in global rice production // Weed biology and management. 2023. Vol. 23. N 1. P. 23–33. DOI: 10.1111/wbm.12262.
12. Marchesi C., Saldain E. First report of herbicide – resistant *Echinochloa crusgalli* in Uruguayan rice fields // Agronomy. 2019. Vol. 9 (12). P. 790. DOI: 10.3390/agronomy9120790.
13. Fang J., Liu T., Zhang Y., Li J., Dong L. Target site-based Penoxsulam resistance in barnyard grass (*Echinochloa crusgalli*) from China // Weed science. 2019. Vol. 67. Iss. 3. P. 281–287. DOI: 10.1017/wsc.2019.5.
14. Liu J., Fang J., He Z., Li G., Dong L. Target site-based resistance to Penoxsulam in late water-grass (*Echinochloa phyllopogon*) from China // Weed science. 2019. Vol. 67. Iss. 4. P. 380–388. DOI: 10.1017/wsc.2019.14.
15. Kokilam Vasantha M., Rathika S., Ramesh T., Baskar M. Weed dynamics and productivity of direct wet seeded rice under different weed management practices // Indian journal of agricultural research. 2023. Vol. 57. N 3. P. 347–351. DOI: 10.18805/IJARE.A-5586.
16. Bandyopadhyay P., Mondal T., Poddar P., Reza W. Effect of different Integrative Weed Management Tactics on Paddy (*Oryza sativa* L.) during kharif in terai Region of West Bengal // Indian journal of agricultural research. 2024. Vol. 58. N 5. P. 788–793. DOI: 10.18805/IJARE.A-6156.
17. Kashyap S., Singh V.P., Guru S.K., Pratap T., Singh S.P., Kumar R. Effect of integrated weed management on weed and yield of direct seeded rice // Indian journal of agricultural research. 2022. Vol. 56. N 1. P. 33–37. DOI: 10.18805/IJARE.A-5775.

REFERENCES

1. Tkachenko M.A., Zelensky G.L. Status and prospects of creating rice varieties with a new plant morphotype (review). *Risovodstvo = Rice growing*, 2023, no. 3 (60), pp. 6–13. (In Russian). DOI: 10.33775/1684-2426-2023-60-3-6-13.
2. Zelensky P.G., Zelenskaya O.V. World rice production and ways of its innovative development (review). *Risovodstvo = Rice growing*, 2022, no. 4 (57), pp. 6–11. (In Russian).
3. Ilyushko M.V., Romashova M.V., Guchenko S.S., Emelyanov A.N. Productivity of *Oryza sativa* L. samples of Krasnodar and Zernograd selection in a collection nursery under the Primorsky kray conditions. *Agrarnaya Rossiya = Agrarian Russia*, 2024, no. 5, pp. 8–13. (In Russian).

4. Luneva N.N. Allocation of levels of phytosanitary zoning of the territory concerning weeds using Leningrad region as an example. *Vestnik zaschity rastenii = Plant Protection News*, 2020, no. 103 (2), pp. 119–133. (In Russian). DOI: 10.31993/2308-6459-2020-103-2-13406.
5. Zelenskaya O.V. Ecological risk of herbicide-resistant weeds distribution in rice fields (review). *Risovodstvo = Rice growing*, 2021, no. 1 (50), pp. 76–87. (In Russian). DOI: 10.33775/1684-2464-2021-50-1-76-87.
6. Kolupaev M.V. Resistance of weeds to herbicides is being progressively promoted. *Zashchita i karantin rasteniy = Plant Protection and Quarantine*, 2021, no. 4, pp. 15–16. (In Russian).
7. Berestetsky A.O. Prospects for the development of new herbicides based on natural compounds. *Vestnik zaschity rastenii = Plant protection news*, 2023, no. 106 (1), pp. 5–25. (In Russian). DOI: 10.31993/2308-6459-2023-106-1-15502.
8. UI Haq M.Z., Zang Z., Wei J., Qang S. Ethylene biosynthesis inhibition combined with cyanide degradation confer resistance to quinclorac in *Echinochloa crus-galli* var. *mitis*. *International journal of molecular sciences*, 2020, vol. 21 (5), p. 1573. DOI: 10.3390/ijms21051573.
9. Vignola V.D., Sainz M., Saldain N.E., Marchesi C., Bonnacarrere V., Gadea P.D. Limited induction of ethylene and cyanide synthesis are observed in quinclorac-resistant barnyardgrass (*Echinochloa crus-galli*) in Uruguay. *Weed science*, 2020, vol. 68, iss. 4, pp. 348–357. DOI: 10.1017/wsc.2020.32.
10. Kostyuk A.V., Lukacheva N.G., Lyashenko E.V. Resistance of barnyard grass biotypes to the herbicides applicable in the rice fields of the Primorye Territory. *Vestnik DVO RAN = Vestnik of the Far East Branch of the Russian Academy of Sciences*, 2022, no. 3, pp. 61–69. (In Russian). DOI: 10.37102/0869-7698-2022-223-03-6.
11. Damalas C.A., Koutroubas S.D. Herbicide – resistant barnyard grass (*Echinochloa crus-galli*) in global rice production. *Weed biology and management*, 2023, vol. 23, no. 1, pp. 23–33. DOI: 10.1111/wbm.12262.
12. Marchesi C., Saldain E. First report of herbicide – resistant *Echinochloa crus-galli* in Uruguayan rice fields. *Agronomy*, 2019, vol. 9 (12), p. 790. DOI: 10.3390/agronomy9120790.
13. Fang J., Liu T., Zhang Y., Li J., Dong L. Target site-based Penoxsulam resistance in barnyard grass (*Echinochloa crus-galli*) from China. *Weed science*, 2019, vol. 67, iss. 3, pp. 281–287. DOI: 10.1017/wsc.2019.5.
14. Liu J., Fang J., He Z., Li G., Dong L. Target site-based resistance to Penoxsulam in late water-grass (*Echinochloa phyllipogon*) from China. *Weed science*, 2019, vol. 67, iss. 4, pp. 380–388. DOI: 10.1017/wsc.2019.14.
15. Kokilam Vasanth M., Rathika S., Ramesh T., Baskar M. Weed dynamics and productivity of direct wet seeded rice under different weed management practices. *Indian journal of agricultural research*, 2023, vol. 57, no. 3, pp. 347–351. DOI: 10.18805/IJARE.A-5586.
16. Bandyopadhyay P., Mondal T., Poddar P., Reza W. Effect of different Integrative Weed Management Tactics on Paddy (*Oryza sativa* L.) during kharif in terai Region of West Bengal. *Indian journal of agricultural research*, 2024, vol. 58, no. 5, pp. 788–793. DOI: 10.18805/IJARE.A-6156.
17. Kashyap S., Singh V.P., Guru S.K., Pratap T., Singh S.P., Kumar R. Effect of integrated weed management on weed and yield of direct seeded rice. *Indian journal of agricultural research*, 2022, vol. 56, no. 1, pp. 33–37. DOI: 10.18805/IJARE.A-5775.

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Сведения о фитофагах редкого декоративного растения *Alangium platanifolium* (Siebold et Zucc.) Harms (Alangiaceae DC.) в Приморском крае

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Одним из редких декоративных восточноазиатских видов, эколого-биологические особенности которого позволяют рекомендовать его для озеленения городов, является алангиум платанолистный. Естественное местонахождение этого листопадного кустарника, расположенное в юго-западной части хребта Сихотэ-Алинь на территории Приморского края, является единственным в России. Для подготовки программы интродукционных исследований и озеленительной практики необходимо изучить биологические и фитоценотические свойства, особенности развития и размножения кустарника, оценить степень воздействия различных негативных факторов (в том числе вредителей). Информация о насекомых-фитофагах, связанных с алангиумом платанолистным, до настоящего времени отсутствовала. Цель исследования – получение сведений о питании полужесткокрылых (Heteroptera) на алангиуме платанолистном, произрастающем в Приморском крае. Исследования проводили с мая по октябрь в 2013, 2024 и 2025 гг. в маршрутных поездках и на полевом стационаре. Применяли визуальное наблюдение, ручной сбор насекомых и фотосъемку. Трофические связи изучали в полевых условиях и стационарных садках для кратковременного и длительного содержания насекомых. На алангиуме платанолистном было выявлено шесть видов клопов-полифагов, принадлежащих к трем семействам (Miridae, Scutelleridae, Pentatomidae): *Neolygus aceris*, *Poecilocoris lewisi*, *Palomena viridissima*, *Eurydema dominulus*, *Plautia stali*, *Lelia decempunctata*. На стадии цветения растения наблюдается питание насекомых на листьях и цветках, на стадии плодоношения и окончания вегетации – сосание клеточного сока на стеблях, черешках, листовых пластинках и плодах. После оценки полученных данных сделан вывод о негативном воздействии выявленных насекомых на физиологию растения (нарушение развития листовых почек, завязей, плодов). В случае использования алангиума платанолистного в озеленении населенных пунктов Приморского края необходимо дальнейшее наблюдение за разнообразием и распространением его фитофагов.

Ключевые слова: Heteroptera, имаго, личинки, питание, Alangiaceae, *Alangium platanifolium*, Приморский край

Information on phytophages of the rare ornamental plant *Alangium platanifolium* (Siebold et Zucc.) Harms (Alangiaceae DC.) in the Primorsky Territory

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One of the rare ornamental East Asian species whose ecological and biological characteristics make it suitable for landscaping is *Alangium platanifolium* (Alangiaceae). The natural habitat of this deciduous shrub, located in the southwestern part of the Sikhote-Alin ridge in the Primorsky Territory, is the only one in Russia. To prepare a program for introductory studies and landscaping practice, it is necessary to study the biological and phytocenotic properties, features of development and reproduction of the shrub, and to assess the degree of impact of various negative factors (including pests). Information about phytophagous insects associated with *A. platanifolium* has been lacking until now. The purpose of the study was to obtain information about the nutrition of Heteroptera on the *A. platanifolium*.

nifolium growing in the Primorsky Territory. The study was conducted from May to October in 2013, 2024 and 2025 during field trips and at a field station. Visual observation, manual collection of insects, and photography were used. Trophic relationships were studied in the field and in stationary cages for short- and long-term maintenance of insects. Six species of polyphagous bugs belonging to three families (Miridae, Scutelleridae, Pentatomidae) were identified on *A. platanophyllum*: *Neolygus aceris*, *Poecilocoris lewisi*, *Palomena viridissima*, *Eurydema dominulus*, *Plautia stali*, and *Lelia decempunctata*. At the flowering stage, insects feed on the leaves and flowers; at the fruiting stage and at the end of vegetation, they suck cell sap from the stems, petioles, leaf blades, and fruits. After evaluating the collected data, a conclusion was made about the negative impact of the identified insects on the plant's physiology (disruption of the development of leaf buds, ovary, and fruits). In the case of using *A. platanifolium* in the landscaping of settlements in the Primorsky Territory, further observations are necessary regarding the diversity and distribution of its phytophages.

Keywords: Heteroptera, imago, larvae, nutrition, Alangiaceae, *Alangium platanifolium*, Primorsky Territory

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Conflict of interest

The authors declare no conflict of interest.

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INTRODUCTION

The development of industry and agriculture leads to an increase in human impact on natural ecosystems and worsens environmental conditions in residential areas. Well-designed landscape compositions can significantly reduce the negative effects of both natural and man-made factors on people¹.

The selection of trees and shrubs for urban landscaping is carried out according to various criteria, the main ones being winter hardiness and frost resistance [1–3]. The relevance of introducing new species with decorative and eco-

nomically valuable traits is due to the expansion of the range of tree and shrub species used in landscaping towns in the Russian Far East. The researchers' works include a floristic analysis, an assessment of decorative qualities, information on reproductive biology, adaptive potential, and possible pests of plants used in landscaping [4–8].

For example, employees of the Mountain-Taiga Station of the Far Eastern Branch of the Russian Academy of Sciences (MTS FEB RAS) carried out an assessment of the long-term cultivation of East Asian plants in the introduc-

¹Bunkova N.P., Zalesov S.V. Forest management in recreational forests: a study guide. Yekaterinburg, 2024, 129 p.

tion nurseries and in the arboretum. The most promising East Asian species, whose ecological adaptability allows them to be cultivated in various areas of the Primorsky Territory, include *Catalpa ovata* G. Don., *Cotoneaster dielsianus* E. Pritz. ex Diels, *Ginkgo biloba* L., *Exochorda giraldii* Hesse, *Lonicera demissa* Rehder, *Magnolia sieboldii* K. Koch, *Rhododendron japonicum* (A. Gray) etc. [6].

Other East Asian types of woody shrubs are less commonly used for landscaping because they are less widespread. One of these types is *Alangium platanifolium* (Siebold et Zucc.) Harms (Alangiaceae DC.) (plane-tree-leaved alangium). In Russia, this species is the only representative of the genus *Alangium* Lam. Plane-tree-leaved alangium is common in China, Korea, and Japan; in northeastern Asia, its range goes far beyond the tropical zone, reaching the southern borders of the Manchurian floristic province. This plant became known to Russian science from the collections of the well-known scientist-botanist V.L. Komarov². For the first time in the flora of Russia, this deciduous shrub was recorded in 2001 – the plants were found in the southwest end of the Sikhote-Alin ridge, in the Nadezhdinsky District of the Primorsky Territory [9]. This location is the only one in Russia and is 300–400 km away from the main range. This species is listed in the Red Book of the Russian Federation and the International Union for Conservation of Nature as “vulnerable” (see footnote 2).

Plane-tree-leaved alangium is highly decorative, very unusual and original. Lemon-yellow coloration in autumn, bizarre flowers with twisting petals and lobed large leaves give it a special attractiveness (see Fig. 1). The plant is

undemanding to soil conditions, shade tolerant and frost-resistant, which opens up the possibility of its use in urban landscape design^{3,4}. As an ornamental plant, *A. platanifolium* is cultivated in botanical gardens in America and Europe (see footnote 4). In Russia, the species' gene pool is grown in the botanical gardens of Novosibirsk and Perm, and it has been introduced into cultivation in Moscow (see footnote 2). In the arboretum of MTS FEB RAS in 2022, several specimens were planted to preserve and further introduce this rare species into cultivation.

Thanks to the presence of glycoside compounds and terpenoids, *Alangium* is used for medicinal purposes in East and Southeast Asia [10, 11, etc.]. There is information about the toxicity of its chemical components and the potential insecticidal activity of *Alangium* species



Рис. 1. Куст алангиума платанолистного в естественных условиях (28.09.2025, Приморский край, Надеждинский район). Фото М.В. Маслова

Fig. 1. *A. platanifolium* bush in natural conditions (28.09.2025, Primorsky Territory, Nadezhdinsky District). Photo by M.V. Maslov

²Prokopenko S.V. *Alangium platanifolium* (Siebold et Zucc.) Harms // Red Data Book of the Russian Federation: Plants and Fungi / Ministry of Natural Resources and Environment of the Russian Federation et al.; Ed.-in-Chief D.V. Geltman. 2nd ed. Moscow: VNI "Ekologiya", 2024, pp. 70.

³Barnes H.W. Propagation of *Alangium platanifolium* and *Alangium platanifolium* var. *macrophyllum* // Combined Proceedings International Plant Propagators' Society, 2004, vol. 54, pp. 510–511.

⁴Schulz B. *Alangium* Lam. (Cornaceae) species cultivated in central Europe // Yearbook of the International Dendrological Society, 2011, pp. 72–86. URL: <https://www.dendrology.org/publications/dendrology/alangium-lam-cornaceae-species-cultivated-in-central-europe/>.

against insects in both adult and larval stages⁵. The insecticidal and larvicidal properties of the organic compounds found in the leaves of these plants serve as a potential defense against phytophagous insects. It has been noted that *A. platanifolium* does not have any serious pests, at least in the northeastern part of the USA (see footnote 3). Therefore, information about possible pests that could threaten this species (aphids, spider mites, scale insects) is general, occasional, and only published in popular science sources⁶. By now, there is data showing active visiting and pollination of *A. salvifolium* flowers by hymenopteran insects in India [11 et al.] and *A. platanifolium* in Japan⁷. We have previously noted the bug *Poecilocoris lewisi* (Distant, 1883) (Heteroptera, Scutelleridae) as an insect sucking and damaging the leaves of *A. platanifolium* [12]. To date, there has been no information about other insects associated with *A. platanifolium*.

The goal of the study is to get information about the feeding of hemipterans (Heteroptera) on *A. platanifolium* in the Primorsky Territory (Russian Far East).

MATERIAL AND METHODS

The research was conducted from May to October in 2013, 2024, and 2025 during route trips in the Nadezhdinsky District of the Primorsky Territory (around the village of Alekseevka, 43°33'30" N, 131°59'03" E) and at a field station in the Ussuriysk Urban District (village of Kaimanovka, 43°38'29" N, 132°15'19" E). Visual observation, hand collection of insects, and photography were used.

Trophic relationships were studied in the field and in stationary enclosures for short-term and long-term insect keeping. During the research, more than 150 insects (adults and larvae of stages II–V) were collected or recorded. Below is a

summary of information about the insect species collected from *A. platanifolium* and mentioned by the authors for the first time.

RESULTS AND DISCUSSION

In the Primorsky Territory, there have been cases of bugs feeding on *A. platanifolium*: sucking sap from the vegetative parts, flowers, and fruits of the plant (see table). Such species as *Leila decempunctata*, *Palomena viridissima* (see Fig. 2, a, б), *Plautia stali*, *Eurydema dominulus* (see Fig. 3, a, б) in the larval and imaginal stages, they use both the vegetative and reproductive parts of the plant for feeding, *Poecilocoris lewisi* (see Fig. 3, в) in the larval stage – only vegetative, *Neolygus aceris* in the imaginal stage – only the reproductive organs (see Fig. 4).

According to data from the period of July 11 to August 20, 2025, *A. platanifolium* goes through developmental stages from young larvae to adult winged forms for two species of hemipterans: *E. dominulus* (10 specimens) and *P. stali* (15 specimens). The signs of negative effects on the plant from sucking cell sap by hemipterans are: 1) disruption of normal leaf bud development; 2) dropping of flower buds; 3) stunted growth, development issues, and dropping of ovary after fertilization; 4) slow growth of the fruit tissue; 5) problems in development and dropping of fruits. Tiny punctures on the leaves and fruits can be visually seen (see Fig. 2, a, в).

Nymphs of *P. lewisi* of V age were collected from *A. platanifolium* in September 2024 in their natural habitats (Nadezhdinsky District) and were transferred to a station (Kaimanovka village). The bugs were kept on *A. platanifolium* in cages under natural conditions and fed on the leaf blades from mid-September to mid-October 2024. The insects that survived the winter continued feeding on the budding shoots until mid-

⁵Srinivasan P., Ponsankar A., Edwin E.S., Pradeepa V. Toxicity of *Alangium salvifolium* Wang. chemical constituents against the tobacco cutworm *Spodoptera litura* Fab. // Pesticide Biochemistry and Physiology. 2016. Vol. 126. P. 92–101.

⁶Flat-leaved alangium // Plant Encyclopedia. URL: https://www.picturethisai.com/wiki/Alangium_platanifolium.html.

⁷Kasagi T. The relationship between pollinator insect diversity and plant mating patterns in the Daisen region. 2019. P. 47–52. URL: <https://www.kankyo-u.ac.jp/f/introduction/research/innovation/business-report/2019/07.pdf>.

Виды полужесткокрылых, обнаруженных на *A. platanifolium* в естественных условиях и стационарных садках (2013, 2024, 2025 гг.)

Types of Hemiptera on *A. platanifolium* in natural conditions and stationary cages (2013, 2024, 2025)

Family, species	Insect developmental stage	Duration of presence on the plant	Vegetative phase	Part of the plant used for food
Miridae, <i>Neolygus aceris</i> Kerzhner	Imago	The third ten-day period of June – the second ten-day period of July	Flowering	Pedicels and flowers: sepals, petals (sterile parts), stamens (fertile parts)
Scutelleridae, <i>Poecilocoris lewisi</i> (Distant)	5th-instar nymphs	The first ten-day period of September – the third ten-day period of October, The second ten-day period of May next year	Fruiting, end of the growing season; bud break (the following year)	Leaf blades, unfolding buds
Pentatomidae, <i>Plautia stali</i> Scott*	Nymphs of instars II–V, imago	The first ten-day period of July – the third ten-day period of September	Fruiting, end of the growing season	Leaf blades, fruits
Pentatomidae, <i>Palomena viridissima</i> (Poda)	5th-instar nymphs, imago	The first ten-day period of July – the third ten-day period of September	Fruiting, end of the growing season	Leaf blades, fruits
Pentatomidae, <i>Lelia decempunctata</i> (Motsch.)	4th and 5th instar nymphs, imago	The first ten-day period of July – The first ten-day period of August	Fruiting	Stems, petioles, leaf blades, fruits
Pentatomidae, <i>Eurydema dominulus</i> (Scop.)*	Nymphs of instars II–V, imago	The first ten-day period of July – the third ten-day period of September	Fruiting, end of the growing season	Leaf blades, fruits

*Complete development on the plant is possible. *Complete development on the plant is possible.

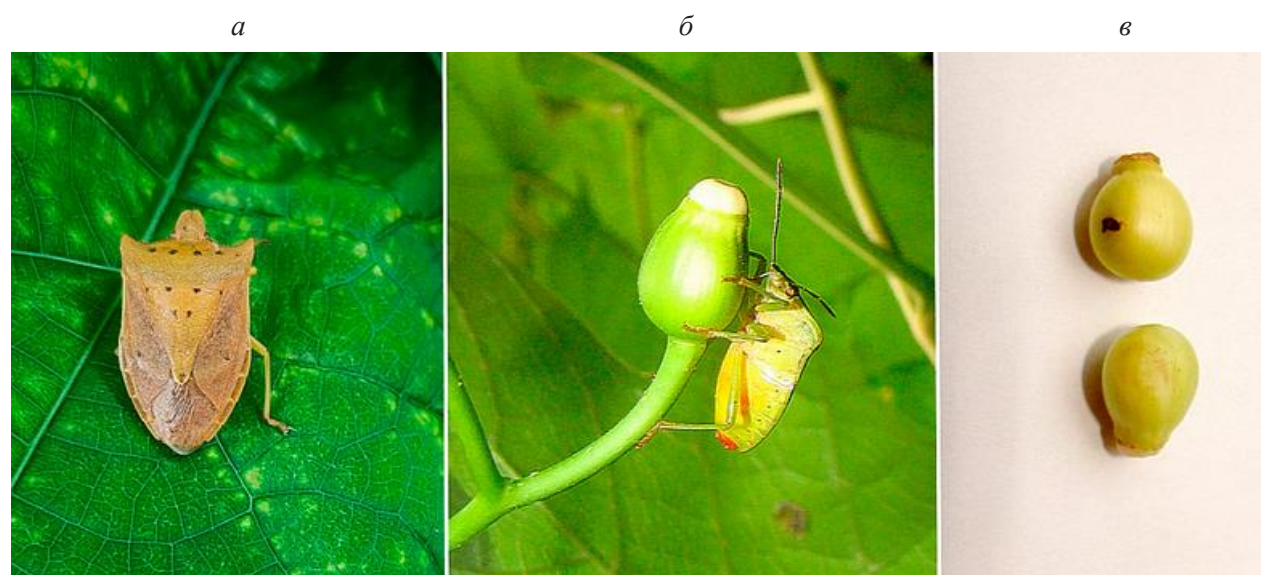


Рис. 2. Питание полужесткокрылых, повреждения листовых пластинок и плодов *A. platanifolium* (10–20.07.2025, Приморский край, с. Каймановка, стационар):

a – имаго *L. decempunctata* (Pentatomidae) на листовой пластинке и следы проколов в результате сосания клеточного сока; *б* – питание имаго *P. viridissima* (Pentatomidae) на плоде; *в* – следы питания клопа на плодах. Фото М.В. Маслова

Fig. 2. Feeding of Hemiptera and damage to leaf blades and fruits of *A. platanifolium*

(10–20.07.2025, Primorsky Territory, Kaimanovka village, station):

a – *L. decempunctata* (Pentatomidae) adult on a leaf blade and puncture marks from sucking cell sap; *б* – feeding of the adult *P. viridissima* (Pentatomidae) on the fruit; *в* – traces of bug feeding on fruits. Photo by M.V. Maslov

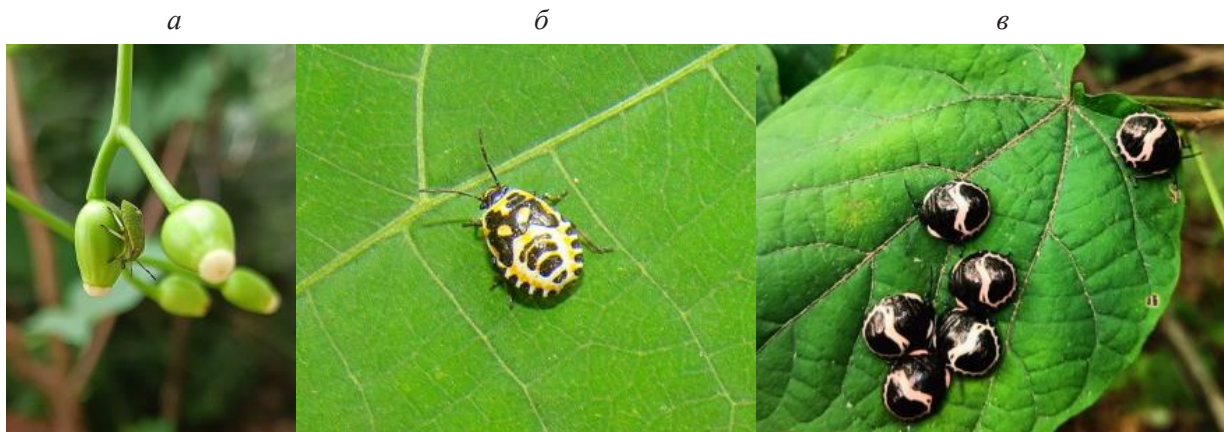


Рис. 3. Нимфы полужесткокрылых IV и V возрастов на *A. platanifolium*:

a – *P. stali* (Pentatomidae) на плоде (11.07.2025, Приморский край, с. Каймановка, стационар); *б* – *E. dominulus* (Pentatomidae) на листовой пластинке (11.07.2025, Приморский край, с. Каймановка, стационар); *в* – *P. lewisi* (Scutelleridae) на листовой пластинке (16.09.2024, Приморский край, окрестности с. Алексеевка). Фото М.В. Маслова

Fig. 3. 4th–5th instar hemipteran nymphs on *A. platanifolium*:

a – *P. stali* (Pentatomidae) on the fruit (11.07.2025, Primorsky Territory, Kaimanovka village, station); *б* – *E. dominulus* (Pentatomidae) on a leaf blade (11.07.2025, Primorsky Territory, Kaimanovka village, station); *в* – *P. lewisi* (Scutelleridae) on a leaf blade (16.09.2024, Primorsky Territory, near the village of Alekseevka). Photo by M.V. Maslov



Рис. 4. *N. aceris* (Miridae) на чашечке цветка (23.06.2025, Приморский край, Уссурийский городской округ, стационар). Фото М.В. Маслова

Fig. 4. *N. aceris* (Miridae) on a flower calyx (23.06.2025, Primorsky Territory, Kaimanovka village, station). Photo by M.V. Maslov

May 2025. We weren't able to raise *P. lewisi* to adulthood on this same plant.

CONCLUSION

The ecological and biological characteristics of *A. platanifolium* (being mesophytic, shade-tolerant, and long-lived) make it suitable for landscaping in both sunny and shady areas. To prepare a program for introduction research and landscaping practice, it is necessary to study the biological and phytocoenotic traits of this rare ornamental plant, identify its growth and reproduction patterns, and monitor damaging factors (including regular checks for the presence of herbivorous pests).

Our research found six species of polyphagous bugs on the plane-tree-leaved alangium, belonging to three families. During the flowering stage from the end of June, adults of *N. aceris* were seen feeding on both the sterile and fertile parts of the flowers. During the fruiting stage and the end of vegetation, from mid-July to mid-September, there were cases of sucking cell sap from stems, petioles, leaf blades, and fruits by adult *P. viridissima*, as well as adults and larvae of *L. decempunctata*, *P. stali*, and *E.*

dominulus. *P. lewisi* nymphs fed on the leaves of *A. platanifolium* from mid-September to mid-October, and the overwintered individuals continued feeding on the budding shoots until mid-May of the following year. Thus, hemipterans can negatively affect plants: they cause disruption in the development of leaf buds, growth and development of ovaries, and fruits, which their larvae damage before softening and ripening. When using plants for landscaping in the Primorsky Territory, it is necessary to continue monitoring for phytophagous insects.

СПИСОК ЛИТЕРАТУРЫ

1. Криворотов С.Б., Мельченко А.И., Капралова Н.И. Экологические особенности декоративных и лекарственных древесных растений урбоэкосистемы города Коломны Московской области // Рисоводство. 2023. Т. 3. № 60. С. 84–89. DOI: 10.5281/zenodo.10377896.
2. Семкина Л.А., Епанчинцева О.В. Обоснование ассортимента древесных растений для озеленения г. Екатеринбурга // Ботанические сады в современном мире. 2023. № 3. С. 188–191.
3. Борзенкова Т.Г., Цыренова Д.Ю. Чужеродные древесные растения в озеленении города Хабаровска // Социально-экологические технологии. 2024. Т. 14. № 1. С. 121–137.
4. Коляда А.С., Коляда Н.А., Белов А.Н., Берсенева С.А. Флористический анализ древесных растений, используемых в озеленении придомовых территорий г. Уссурийска Приморского края // Вестник Красноярского государственного аграрного университета. 2022. № 1. С. 83–92. DOI: 10.36718/1819-4036-2022-1-83-92.
5. Коляда Н.А. Распространение вредителей *Robinia pseudoacacia* на юге Дальнего Востока России // Сибирский вестник сельскохозяйственной науки. 2024. Т. 54. № 8. С. 59–66. DOI: 10.26898/0370-8799-2024-8-6.
6. Мальшева С.К. Декоративность видов рода *Spiraea* L. при интродукции на юге Приморского края // Вестник Красноярского государственного аграрного университета. 2023. № 1. С. 34–39.
7. Маркова Т.О., Маслов М.В. Клещи *Coreus marginatus orientalis* Kir. и *Molipteryx fuliginosa* Uhl. (Heteroptera, Coreidae) – вредители культурных Розовых (Rosaceae) в Примор-

ском крае // Сибирский вестник сельскохозяйственной науки. 2023. Т. 53. № 8. С. 68–74. DOI: 10.26898/0370-8799-2023-8-8.

8. Nakonechnaya O., Nesterova S., Kalachev A. Reproductive biology of *Aristolochia trilobata* L. (Aristolochiaceae) // Botanical Journal of the Linnean Society. 2024. Vol. 208 (2). P. 197–211. DOI: 10.1093/botlinnean/boae063.
9. Fedina L.A., Maslov M.V., Malysheva S.K., Nakonechnaya O.V., Markova T.O. Natural Populations of the Rare Medicinal Species *Alangium platanifolium* (Alangiaceae) in Russia // Biology Bulletin. 2024. Vol. 51 (2). P. 472–479. DOI: 10.1134/S1062359023605189.
10. Lian D., Chen T., Yan L., Hou H., Gao S., Hu Q., Zhang G., Li H., Song L., Gao Y., Pu Y., Chen Y., Peng B. Protective effect of compatible herbs in Jin-Gu-Lian formula against *Alangium chinense*-induced neurotoxicity via oxidative stress, neurotransmitter metabolisms, and pharmacokinetics // Frontiers in Pharmacology. 2023. Vol. 14. P. 1133982. DOI: 10.3389/fphar.2023.1133982.
11. Mahendra D., Santosh K.Ch., Charan A. Bee diversity and pollination dynamics on *Ankol* (*Alangium salvifolium*) in the foothills of Mount Abu // Rajasthan Uttar Pradesh Journal of Zoology. 2024. Vol. 45 (21). P. 153–166. DOI: 10.56557/upjoz/2024/v45i214625.
12. Kanyukova E.V., Ostapenko K.A., Markova T.O., Maslov M.V. The Clown Stink Bug, *Poecilocoris lewisi* (Distant, 1883) (Heteroptera, Scutelleridae) in the South of the Russian Far East // Entomological Review. 2025. Vol. 105 (1). P. 53–57. DOI: 10.1134/S0013873825010051.

REFERENCES

1. Krivorotov S.B., Melchenko A.I., Kapralova N.I. Ecological features of ornamental and medicinal woody plants in the urban ecosystem of the city of Kolomna, Moscow region. *Risovodstvo* = *Rice Growing*, 2023, vol. 3, no. 60, pp. 84–89. (In Russian). DOI: 10.5281/zenodo.10377896.
2. Semkina L.A., Epanchintseva O.V. Justification of the range of woody plants for landscaping in Yekaterinburg. *Botanicheskie sady v sovremenom mire* = *Botanical gardens in the modern world*, 2023, no. 3, pp. 188–191. (In Russian).
3. Borzenkova T.G., Tsyrenova D.Yu. Alien woody plants in the landscaping of Khabarovsk. *Social'no-ekologicheskie tekhnologii* = *Environment and Human: Ecological Studies*, 2024,

- vol. 14, no. 1, pp. 121–137. (In Russian).
4. Kolyada A.S., Kolyada N.A., Belov A.N., Berse-
neva S.A. Wooden plants floristic analysis used
in Ussuriysk house territories landscaping in the
Primorsky region. *Vestnik KrasGAU = Bulletin
of KrasSAU*, 2022, no. 1, pp. 83–92. (In Rus-
sian). DOI: 10.36718/1819-4036-2022-1-83-92.
 5. Kolyada N.A. Distribution of Robinia pseudo-
acacia pests in the south of the Russian Far East.
*Sibirskii vestnik sel'skokhozyaistvennoi nauki =
Siberian Herald of Agricultural Science*, 2024,
vol. 54, no. 8, pp. 59–66. (In Russian). DOI:
10.26898/0370-8799-2024-8-6.
 6. Malysheva S.K. Decorative effect of the ge-
nus Spiraea L. species during introduction
in the south of the Primorsky region. *Vestnik
KrasGAU = Bulletin of KrasSAU*, 2023, no. 1,
pp. 34–39. (In Russian).
 7. Markova T.O., Maslov M.V. Leaf-footed bugs
Coreus marginatus orientalis Kir. and *Molipteryx
fuliginosa* Uhl. (Heteroptera, Coreidae) – pests
of cultivated Roses (Rosaceae) in the Primorsky
Territory. *Sibirskii vestnik sel'skokhozyaistven-
noi nauki = Siberian Herald of Agricultural Sci-
ence*, 2023, vol. 53, no. 8, pp. 68–74. (In Rus-
sian). DOI: 10.26898/0370-8799-2023-8-8.
 8. Nakonechnaya O., Nesterova S., Kalachev A.
Reproductive biology of *Aristolochia triloba-
ta* L. (Aristolochiaceae). *Botanical Journal of
the Linnean Society*, 2024, vol. 208 (2), pp. 197–
211. DOI: 10.1093/botlinnean/boae063.
 9. Fedina L.A., Maslov M.V., Malysheva S.K., Na-
konechnaya O.V., Markova T.O. Natural Popu-
lations of the Rare Medicinal Species *Alangium
platanifolium* (Alangiaceae) in Russia. *Biology
Bulletin*, 2024, vol. 51 (2), pp. 472–479. DOI:
10.1134/S1062359023605189.
 10. Lian D., Chen T., Yan L., Hou H., Gao S.,
Hu Q., Zhang G., Li H., Song L., Gao Y., Pu Y.,
Chen Y., Peng B. Protective effect of com-
patible herbs in Jin-Gu-Lian formula against
Alangium chinense-induced neurotoxicity via
oxidative stress, neurotransmitter metabolisms,
and pharmacokinetics. *Frontiers in Pharmaco-
logy*, 2023, vol. 14, p. 1133982. DOI: 10.3389/
fphar.2023.1133982.
 11. Mahendra D., Santosh K.Ch., Charan A. Bee di-
versity and pollination dynamics on Ankol (*Alan-
gium salvifolium*) in the foothills of Mount Abu.
Rajasthan Uttar Pradesh Journal of Zoology,
2024, vol. 45 (21), pp. 153–166. DOI: 10.56557/
upjoz/2024/v45i214625.
 12. Kanyukova E.V., Ostapenko K.A., Marko-
va T.O., Maslov M.V. The Clown Stink Bug,
Poecilocoris lewisi (Distant, 1883) (Heteroptera,
Scutelleridae) in the South of the Russian Far
East. *Entomological Review*, 2025, vol. 105 (1),
pp. 53–57. DOI: 10.1134/S0013873825010051.

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Оценка влияния комплекса вредных организмов на урожайность яровой мягкой пшеницы в лесостепи Западной Сибири

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Представлены результаты оценки влияния комплекса вредных организмов на урожайность и качество сортов яровой мягкой пшеницы в условиях лесостепи новосибирского Приобья с 2009 по 2011 г., а также за 2021 и 2023 гг. Экспериментальные исследования проведены на шести районированных сортах яровой мягкой пшеницы разной спелости: среднеранние (Новосибирская 29 и Омская 36), среднеспелые (Новосибирская 89 и Омская 29), среднепоздние (Баганская 95 и Омская 28). Небольшие суммарные потери урожая от комплекса вредных организмов имели место на сортах Омская 29 и Баганская 95. Минимальные потери продуктивности отмечены на более урожайном сорте Омская 36. Анализ множественной регрессии по данным развития болезней с урожайностью свидетельствует о том, что изученные сорта яровой мягкой пшеницы по-разному реагировали на пораженность растений листостеблевыми инфекциями. Отмечена отрицательная связь урожайности с пораженностью растений мучнистой росой. Наибольшая чувствительность к данному заболеванию установлена у сорта Омская 36. В целом по комплексу листостеблевых инфекций (мучнистая роса и бурая ржавчина) менее вынослив сорт Омская 36. При изучении реакции на септориоз при наблюдавшемся уровне пораженности растений не установлено статистически достоверной отрицательной связи между болезнью и урожаем. Отметим определенную тенденцию к такой связи у сортов Новосибирская 89 и Омская 29, что свидетельствует об их относительной устойчивости к септориозу. Максимальную чувствительность к поражению комплексом вредных организмов имели сорта Новосибирская 89, Омская 36 и Омская 28. Минимальная чувствительность выявлена у сортов Новосибирская 29 и Омская 29. Отмечено, что данные сорта в большей степени реагировали на болезни в сравнении с вредителями.

Ключевые слова: яровая мягкая пшеница, сорт, вредные организмы, устойчивость, урожайность, структура урожая, качество зерна

Assessment of the impact of a complex of harmful organisms on the spring wheat yield in the forest-steppe of Western Siberia

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The results of assessing the impact of a complex of harmful organisms on the yield and quality of spring soft wheat varieties in the forest-steppe zone of the Novosibirsk Ob region from 2009 to 2011, as well as in 2021 and 2023 are presented. Experimental studies were conducted on six zoned varieties of spring soft wheat of different maturity: middle-early (Novosibirskaya 29 and Omskaya 36), medium-maturing (Novosibirskaya 89 and Omskaya 29), and middle-late (Baganskaya 95 and Omskaya 28). Small total crop losses from a complex of harmful organisms occurred on the medium-maturing variety Omskaya 29 and the middle-late variety Baganskaya 95. Minimal productivity losses were noted on the more productive middle-early variety Omskaya 36. The multiple regression analysis based on the disease development and yield indicates that the studied varieties of spring soft wheat reacted differently to leaf-stem infections. A negative correlation between yield and plant infection with powdery mildew has been noted. The highest susceptibility to this disease has been established in the middle-early variety Omskaya 36. Overall, in terms of the complex of leaf-stem infections (powdery mildew and brown rust), the middle-early variety Omskaya 36 is less resistant. When studying the

reaction of the varieties to septoria leaf spot disease, no statistically significant negative relationship between the disease and the yield was found at the observed level of plant infection. One can only speak of a certain tendency toward such a connection in the varieties Novosibirskaya 89 and Omskaya 29, which indicates their relative resistance to septoria leaf spot disease. The varieties Novosibirskaya 89, Omskaya 36, and Omskaya 28 were the most sensitive to the complex of harmful organisms. The varieties Novosibirskaya 29 and Omskaya 29 were the least sensitive. It has been noted that these varieties responded more to diseases compared to pests

Keywords: spring soft wheat, variety, harmful organisms, resistance, yield, crop structure, grain quality

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Конфликт интересов

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Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Currently, there is an urgent problem with rational land use. In the existing conditions of import substitution, the country's food security is necessary, and the optimal use of agricultural land is a factor for the stable development of territories¹ [1–3]. According to statistics, over the past 10 years, sown areas in Russia have decreased by 326,000 hectares. In Western Siberia, most of the crops are grown in the forest-steppe and steppe zones, where the climate is extreme and weather conditions fluctuate a lot, which noticeably affects the variability of crop yield and grain quality^{2,3} [4, 5].

In this regard, it is necessary to optimize technology elements, primarily soil cultivation, fertilizer application, and especially the use of

protection means for spring soft wheat varieties adapted to the extreme climate conditions of Western Siberia [6–9], in order to improve yield and grain quality^{4,5}. The use of mineral fertilizers also plays an important role in the cultivation of crops – it is known that they have a great impact on the productivity and quality of spring wheat grain [10].

An important role is given to the variety – it is one of the key factors in increasing yield and total grain harvest [11–14]. It is necessary to study the resistance of wheat varieties to various harmful organisms [15].

The goal of the study is a comprehensive assessment of the impact of harmful organisms on the yield and quality of spring soft wheat varieties in the forest-steppe of Western Siberia.

¹Galeev R.R. Adaptive technology for cereal crop cultivation in Western Siberia. Novosibirsk: Agro-Sibir, 2015, 176 p.

²Slobodchikov A.A. Phytosanitary situation in spring wheat crops and the role of plant protection products in stabilizing grain productivity and quality: Abstract of a Candidate of Science in Agriculture dissertation. Novosibirsk, 2010, 18 p.

³Korobov V.A., Vlasenko N.G. Protection of soft spring wheat against a complex of specialized pests in Western Siberia: recommendations. Novosibirsk, 2007, 24 p.

⁴Pozdnyakov S.P. Spring wheat in the Non-Black Earth Region. Kirov: Knigoizdat, 2016, 129 p.

⁵Loktionov S.P., Galeev R.R. Prospects for grain crop production in Western Siberia. Novosibirsk: Ritm Information Center, 2016, 212 p.

MATERIAL AND METHODS

The research was carried out in 2009–2011 and 2021–2023 on experimental fields of the Novosibirsk State Agrarian University's "Tulinsky" farm in the Novosibirsk district of the Novosibirsk region. For the research, Siberian-bred spring soft wheat varieties were used: middle-early Novosibirskaya 29 and Omskaya 36, medium-maturing Novosibirskaya 89 and Omskaya 29, and middle late Baganskaya 95 and Omskaya 28. The plot size is 80 m², with a fourfold repetition. At the beginning of vegetation, 12 permanent observation plots measuring 50 × 50 cm were set up on the plots, and during the grain filling phase, leaf and stem infections were recorded.

The soils of the experiment site are leached chernozems with a humus content of 6.27%, a cation exchange capacity of 478 mmol/kg of soil, pH of 6.3. Agrochemical characteristics of soils: the content of easily hydrolyzable nitrogen is 92.6 mg/kg, mobile phosphorus is 139 mg/kg and exchangeable potassium is 193 mg/kg of soil. The weather conditions during the years of the experimental work varied in terms of temperature and total precipitation. In terms of weather, 2011 was more favorable, with a total precipitation of 339 mm during the growing season and an average daily temperature above the long-term average. In 2021–2023, the precipitation during the growing season ranged from 327 to 389 mm.

On the designated plots, during the growing season of spring wheat, diseases were monitored using the method of the All-Russian Research Institute of Plant Protection according to Zubkov⁶. At the end of the tillering phase, the number of plants damaged by hidden stem pests and

their susceptibility to root rot was counted using the method of the All-Russian Research Institute of Plant Protection⁷.

Observations of plant growth and development were carried out according to the generally accepted methodology of the State variety testing of agricultural crops⁸. The yield was taken into account based on the methodological guidelines of B.A. Dospekhov⁹. The quality of the grain was determined according to the relevant GOST standards based on the methodological guidelines of the All-Russian Research Institute of Grain Crops¹⁰. For statistical processing, the Snedecor VS application package according to O.D. Sorokin¹¹ was used.

RESULTS AND DISCUSSION

In the experiments from 2009–2011, the varietal characteristics of the productive development process of spring soft wheat were evaluated. The studied varieties, belonging to different maturity groups, had varying effects on the formation of yield structure elements. On average, the lowest number of seedlings was observed in the sowings of the Novosibirskaya 29 and Novosibirskaya 89 varieties, with the minimum value recorded for the Baganskaya 95 variety. It should be noted that for the Baganskaya 95 variety, the number of spikelets – 60.2 pcs – had a significant impact. The formation of the tillering phase was more influenced by the manifestation of biological traits in the Omskaya 36 and Omskaya 29 varieties.

The total number of stems varied from 0.01 to 44.8 units depending on the year. The highest number of stems was recorded for the Omskaya 28 (44.8) and Omskaya 36 (30.4) varieties. It was found that the grain weight varies depending

⁶Zubkov A.F. Methodological guidelines for collecting field biocenotic data to assess the harmfulness of a pest complex. Leningrad: VIZR, 1978, 18 p.

⁷Environmental Monitoring and Methods for Improving the Protection of Cereal Crops Against Pests, Diseases, and Weeds: Methodological Recommendations / V.I. Tansky, M.M. Levitin, V.A. Pavlyushin, V.N. Burov, N.R. Goncharov. St. Petersburg–Pushkin: VIZR, 2002, 76 p.

⁸Methodology for State Variety Testing of Agricultural Crops. Moscow: Selkhoziz, 1986, 329 p.

⁹Dospekhov B.A. Methodology of Field Experiments. Moscow: Alliance, 2014, 348 p.

¹⁰Grain Quality Assessment: Methodological Guidelines. Krasnodar, 2017, 72 p.

¹¹Sorokin O.D. Applied Statistics on the Computer. Novosibirsk: EPA RAAS, 2009, 222 p.

on the variety, with the highest value observed in the Omskaya 36 variety – 50.9 g (see Table 1).

To assess the impact of the set of harmful organisms on yield, the partial correlation parameters were calculated. The analysis of the resulting values shows that the studied varieties showed weak to medium sensitivity to root rot ($r = 0,10-0,68$). Varietal differences were noted in susceptibility to septoriose: the Baganskaya 95 variety showed a strong correlation ($r = -0,97$) and weak – Novosibirskaya 29 ($r = -0,09$). The susceptibility of the Novosibirskaya 89 variety was positively correlated with yield. The Baganskaya 95, Novosibirskaya 89, and Omskaya 28 varieties showed a weak negative response to powdery mildew, while the other varieties were positively correlated with yield. Regarding competition with weeds, the studied varieties showed a sensitivity ranging from weak to strong ($r =$ from $-0,92$ up to $-0,11$). The Baganskaya 95 variety is highly sensitive to damage from hidden-stem pests (r

$= -0,92$), while the other varieties showed only a low level of sensitivity. For wheat thrips damage, the varieties were sensitive from medium to low levels ($r =$ from $-0,11$ to $-0,46$). Two varieties, Novosibirskaya 89 and Omskaya 36, responded negatively to infestation by the cereal striped flea beetle. The other varieties were positively correlated with yield (see Tables 2 and 3). No rust was recorded in the plots.

In terms of grain quality and technological parameters, the varieties Novosibirskaya 29 and Omskaya 36 stood out, having the highest levels of raw gluten, protein, and vitreousness.

We have determined the dependence of spring wheat variety yields on various diseases (see Table 4).

The analysis of multiple regressions of disease development with yield showed that the studied spring wheat varieties responded differently to leaf-stem infections. Almost all varieties showed a statistically significant negative relationship between yield and powdery mildew in-

Табл. 1. Вклад элементов структуры урожая сортов в общую урожайность

Table 1. Contribution of crop structure elements to total yield

Variety	Sowing density, pcs.	Productive tillering, pcs.	Ear grain size, g	Caryopsis weight, g
Novosibirskaya 29	86,8	0,01	12,2	1,0
Omskaya 36	12,0	30,4	6,7	50,9
Novosibirskaya 89	86,4	0,9	12,6	0,1
Omskaya 29	30,3	0,1	53,4	16,2
Baganskaya 95	10,0	22,1	60,2	7,7
Omskaya 28	36,2	44,8	0,5	18,5

Табл. 2. Корреляционная связь вредных организмов с урожаем на стационарных площадках

Table 2. Correlation of harmful organisms with yield at the stationary plots

Variety	Partial correlation (r)						
	root rot	septoriose	powdery mildew	weeds	cereal flea beetle	stem-boring pests	wheat thrips
Baganskaya 95	-0,51	-0,97	-0,34	0,92	1,00	-0,92	-0,11
Novosibirskaya 29	-0,68	-0,09	0,33	-0,15	0,30	-0,18	-0,26
Novosibirskaya 89	-0,46	0,45	-0,34	-0,55	-0,06	-0,24	0,18
Omskaya 28	-0,18	-0,25	-0,27	0,72	-0,57	-0,34	-0,42
Omskaya 36	-0,10	-0,99	0,93	-0,50	1,00	-0,39	-0,46
Omskaya 29	-0,26	-0,38	0,20	0,11	0,01	-0,16	-0,31

Табл. 3. Урожайность и ее структура различных сортов яровой пшеницы в полевом опыте

Table 3. Yield and its structure of different spring wheat varieties in a field experiment

Variety	Productive tillering, pcs.	Number of grains per spike, pcs.	1000-kernel weight, g	Grain weight, biological yield, g/m ²	Crude gluten, %	Protein, %	Grain unit, g/l	Vitreousness, %
Novosibirskaya 29	1,0	16,6	34,7	182,0	30,4	13,9	728	82
Omskaya 36	1,1	16,9	38,3	273,0	28,2	13,2	706	76
Novosibirskaya 89	1,1	18,5	34,4	227,0	26,8	12,9	684	74
Omskaya 29	1,2	21,8	36,7	263,0	25,7	13,0	690	72
Baganskaya 95	1,0	19,5	34,5	226,0	27,2	12,1	701	70
Omskaya 28	1,3	19,0	35,2	240,0	27,0	11,8	656	69
LSD ₀₅	0,17	1,7	2,1	11,5	0,34	0,25	12,1	1,23

Табл. 4. Регрессионная зависимость между развитием листостеблевых инфекций и урожайностью сортов яровой пшеницы

Table 4. Regression relationship between the development of leaf-stem infections and the yield of spring wheat varieties

Variety	Septoriose	Powdery mildew	Brown rust	Yield, t/ha
Novosibirskaya 29	0,358 ± 0,790	-0,845 ± 0,220***	0,088 ± 0,303	2,05
Omskaya 36	0,021 ± 0,651	-1,602 ± 0,326***	-0,598 ± 0,258**	2,87
Novosibirskaya 89	-0,545 ± 0,461	-0,652 ± 0,201**	-0,335 ± 0,172*	2,13
Omskaya 29	-0,509 ± 0,560	-0,602 ± 0,324*	0,333 ± 0,398	2,48
Baganskaya 95	1,294 ± 0,564**	-0,860 ± 0,285***	0,242 ± 0,221	2,76
Omskaya 28	1,192 ± 0,685*	-0,862 ± 0,257**	-0,256 ± 0,208	2,41

* $p \geq 0,90$.

** $p \geq 0,95$.

*** $p \geq 0,99$.

fection. According to the regression coefficients, the variety Omskaya 36 was the most sensitive to the disease. The least affected by the drop in yield caused by disease were the Novosibirskaya 89 and Omskaya 29 varieties. The other varieties are about equally sensitive to powdery mildew. As for brown rust, just like with powdery mildew, Omskaya 36 is the most sensitive variety. Novosibirskaya 89 reacted to it more weakly, but still negatively. At the observed level of plant infection with septoriose, no statistically significant negative correlation between the disease and yield was found. There may be a certain trend towards such a connection in the Novosibirskaya 89 and Omskaya 29 varieties, which

indicates their relative resistance to septoriose. Overall, the Omskaya 36 variety turned out to be the least resistant to leaf and stem infections (powdery mildew and brown rust). At the same time, it showed the highest yield, which makes it promising to expand its cultivation in Western Siberia, provided it is actively protected against leaf and stem infections.

The three-year studies showed that none of the regional varieties studied showed strong resistance to leaf and stem infections. However, the varieties differed significantly in this regard, which is obviously something that needs to be taken into account when developing their disease protection strategies (see Table 5).

The Novosibirskaya 89 variety is the most sensitive to damage by the complex. According to A.A. Slobodchikov¹², in field trials, this variety showed the highest responsiveness to plant protection products among the mid-maturing varieties. The varieties Omskaya 36 and Omskaya 28 also showed fairly high sensitivity to them. The least sensitive to the treatment were the varieties Novosibirskaya 29 and Omskaya 29. Overall, they reacted more to diseases than to pests.

At the experimental fields of the educational and research farm "Praktik" (Novosibirsk region), we studied the adaptability of spring soft wheat varieties (see Table 6). It was shown that the highest response to intensive cultivation technology, which includes a full cycle of plant

protection measures, was observed in the Baganskaya 95 variety (yield increase – 42%) and with traditional technology using minimal plant protection, in the Omskaya 29 variety – 34%, as well as in the Novosibirskaya 29 variety – 23%. However, for the Omskaya 36 variety, the increase under intensive technology was only 7%, which points to its overall resistance to pests. Almost all varieties of different maturity groups showed an increase in raw gluten and protein content when grown using intensive technology. The grain weight and vitreousness indicators are higher when using intensive cultivation methods for spring soft wheat varieties.

The overall resistance of varieties to harmful organisms is an important factor for making

Табл. 5. Изменчивость урожайности яровой пшеницы в зависимости от вредных организмов, %
Table 5. Variability of spring wheat yield depending on harmful organisms, %

Variety	Diseases		Pests		The entire complex (pests and diseases)	
	2009	2010	2009	2010	2009	2010
Novosibirskaya 29	4,9	10,6	2,4	1,0	7,3	11,6
Omskaya 36	39,0	36,0	0,8	13,7	39,8	49,7
Novosibirskaya 89	49,7	57,3	0,1	20,8	49,8	78,1
Omskaya 29	0,1	12,2	8,5	0	8,6	12,2
Baganskaya 95	0,9	0	6,6	21,0	7,5	21,0
Omskaya 28	4,7	18,7	7,8	19,6	12,5	38,3

Табл. 6. Средние значения урожайности и качества зерна яровой мягкой пшеницы в зависимости от интенсификации производства (2021–2023 гг.)

Table 6. Yield and quality of spring soft wheat grain, depending on production intensification (2021–2023)

Variety	Yield			Protein, %	Grain unit, g/l	Vitreousness, %
	t/ha	Gain				
		t/ha	%			
Novosibirskaya 29	3,20/3,92	0,72	23	13,4/13,7	779/782	76/80
Omskaya 36	3,56/3,80	0,234	7	12,8/13,2	760/767	74/78
Omskaya 29	2,82/3,79	0,97	34	11,5/11,4	727/725	69/72
Baganskaya 95	2,67/3,80	1,13	42	12,8/13,4	748/762	75/79
Omskaya 28	3,15/3,84	0,69	22	11,4/11,6	729/742	67/74
LSD ₀₅	0,15/0,24	—	—	0,10/0,14	15,6/11,8	1,85/2,2

Note. In the numerator—traditional technology; in the denominator—intensive technology.

¹²Slobodchikov A.A. Phytosanitary situation in spring wheat crops and the role of plant protection products in stabilizing grain productivity and quality. Abstract of a Candidate of Science in Agriculture dissertation. Novosibirsk, 2010, 18 p.

farming more eco-friendly and for the wider adoption of organic farming. We have studied the regional and promising varieties of spring soft wheat from Siberian breeding, covering three maturity periods – middle-early, medium-maturing, and middle late. The elements of spike productivity serve as key factors affecting the yield of different spring soft wheat varieties. Our data indicate that among the varieties studied from different maturity groups, the Omskaya 36 variety showed the greatest resistance to harmful organisms. At the same time, it was shown that against the background of intensified farming with optimal mineral nutrition and a set of plant protection measures, there was an increase in yield, as well as in the quality indicators of the raw product – gluten, protein, and grain unit.

CONCLUSIONS

1. In the forest-steppe conditions of Western Siberia (the northern forest-steppe of the Novosibirsk Priobye), the specificity of spring soft wheat varieties for resistance to various pathogens and pests has been determined on leached chernozem soils in different years with varying meteorological conditions.

2. In a comprehensive evaluation of six spring wheat varieties (middle-early, medium-maturing, and middle late), they were ranked by their resistance to diseases and pests in order of increasing resistance: Omskaya 29, Baganskaya 95, Novosibirskaya 29, Novosibirskaya 89, Omskaya 28, Omskaya 36.

3. The use of intensive farming technology increased the yield of Baganskaya 95 by 42% compared to traditional methods (with minimal use of pesticides and fertilizers), Omskaya 29 by 34%, Novosibirskaya 29 by 23%, Omskaya 28 by 22%, Omskaya 36 by 7%, which indicates the overall resistance of the latter variety to harmful organisms.

СПИСОК ЛИТЕРАТУРЫ

1. Альберт М.А., Галеев Р.Р., Ковалев Е.А. Совершенствование технологии дифференцированного внесения удобрений в лесостепи

Новосибирского Приобья // Вестник НГАУ (Новосибирский государственный аграрный университет). 2022. № 2 (63). С. 4–10. DOI: 10.31677/2072-6724-2022-63-2-4-10.

2. Альберт М.А., Петров А.Ф., Шульга М.С., Галеев Р.Р., Ковалев Е.А. Особенности использования инновационных регуляторов роста при возделывании картофеля и сои в лесостепи Приобья // Инновации и продовольственная безопасность. 2022. № 2 (36). С. 45–51. DOI: 10.31677/2311-0651-2022-36-245-51.
3. Закиевская Е.В., Куksин С.В. Тенденции и прогнозные параметры развития производства, потребления и экспорта зерна в России // Научное обозрение: теория и практика. 2021. Т. 11. № 8. С. 2314–2326. DOI: 10.35679/2226-0226-2021-11-8-2314-2326.
4. Агеева Е.В., Леонова И.Н., Лихенко И.Е., Советов В.В. Масса зерна колоса и масса тысячи зерен как признаки продуктивности у сортов яровой мягкой пшеницы разных групп спелости в условиях лесостепи Приобья // Письма в Вавиловский журнал генетики и селекции. 2021. Т. 7. № 1. С. 5–11. DOI: 10.18699/LettersVJ2021-7-01.
5. Chai Y., Senay S., Horvath D., Pardey P. Multi-peril pathogen risks to global wheat production: A probabilistic loss and investment assessment // Frontiers in Plant Science. 2022. Vol. 13. P. 1034600. DOI: 10.3389/fpls.2022.1034600.
6. Del Ponte E.M., Moriera G.M., Ward T.J., O'Donnell K. et al. Fusarium graminearum species complex: a bibliographic analysis and web-accessible database for global mapping of species and trichothecene toxin chemotypes // Phytopathology. 2022. Vol. 112. P. 741–751. DOI: 10.1094/PHYTO-06-21-0277-RVW.
7. Hossain A., Skalicky M., Brestic M., Maitra S et al. Consequences and Mitigation Strategies of Abiotic Stresses in Wheat (*Triticum aestivum* L.) under the Changing Climate // Agronomy. 2021. No. 11 (2). P. 241. DOI: 10.3390/agronomy11020241.
8. Aoun M., Rouse M.N., Kolmer J.A., Kumar A., Elias E.M. Genome-Wide Association Studies Reveal All-Stage Rust Resistance Loci in Elite Durum Wheat Genotypes // Frontiers in Plant Science. 2021. Vol. 12. Pp. 1–20. DOI: 10.3389/fpls.2021.640739.
9. Li H., Hua L., Zhao S., Hao M. et al. Cloning

- of the wheat leaf rust resistance gene Lr47 introgressed from *Aegilops speltoides* // *Nature Communications*. 2023. Vol. 14. P. 6072. DOI: 10.1038/s41467-023-41833-2.
10. Сычев В.Г., Гречишкина Ю.И., Бурлай А.В., Матвиенко А.В. Анализ использования минеральных удобрений под озимую пшеницу в Ставропольском крае // *Плодородие*. 2021. № 2. С. 3–5. DOI: 1025680/S19948603.2021.119.01.
11. Грабовец А.И., Фоменко М.А., Олейникова Т.А. Новые сорта озимой мягкой пшеницы – итог реализации разработок по селекции на продуктивность и адаптивность // *Вестник российской сельскохозяйственной науки*. 2021. № 2. С. 19–23. DOI: 10.30850/vrsn/2021/2/19-23.
12. Сандухадзе Б.И., Мамедов Р.З., Крахмалева М.С., Бугрова В.В. Научная селекция озимой мягкой пшеницы в Нечерноземной зоне России: история, методы и результаты // *Вавиловский журнал генетики и селекции*. 2021. Т. 25. № 4. С. 367–373. DOI: 10.18699/VJ21.53-о.
13. Левакова О.В., Гладышева О.В., Костаньянц М.И. Сравнительный анализ зерновой урожайности и биометрических элементов сортов пшеницы озимой в зависимости от периодов сортосмены // *Зерновое хозяйство России*. 2023. Т. 15. № 3. С. 42–47. DOI: 10.31367/2079-8725-2023-86-3-42-47.
14. Иванисова А.С., Марченко Д.М. Использование селекционных индексов при оценке продуктивности озимой твердой пшеницы // *Аграрная наука*. 2024. № 8. С. 150–154. DOI: 10.32634/0869-8155-2024-385-8-150-154.
15. Шаманин В.П., Потоцкая И.В., Чурсин А.С., Шепелев С.С., Нардин Д.С., Пожерукова В.Е., Кёксель Х., Моргунов А.И. Селекция сортов яровой мягкой пшеницы (*Triticum aestivum* L.) с функциональными свойствами зерна для экологически чистого выращивания в Западной Сибири // *Сельскохозяйственная биология*. 2024. Т. 59. № 3. С. 492–506. DOI: 10.15389/agrobiology.2024.3.492rus.
1. Albert M.A., Galeev R.R., Kovalev E.A. Improvement of differentiated fertilizer application technology in the forest-steppe of Novosibirsk Priobye. *Vestnik NGAU (Novosibirskij gosudarstvennyj agrarnyj universitet) = Bulletin of NSAU (Novosibirsk State Agrarian University)*, 2022, no. 2 (63), pp. 4–10. (In Russian). DOI: 10.31677/2072-6724-2022-63-2-4-10.
2. Albert M.A., Petrov A.F., Shul'ga M.S., Galeev R.R., Kovalev E.A. Peculiarities of the use of innovative growth regulators in potato and soybean cultivation in the forest-steppe of the Priobye area. *Innovatsii i prodovol'stvennaya bezopasnost' = Innovations and Food Safety*, 2022, no. 2 (36), pp. 45–51. (In Russian). DOI: 10.31677/2311-0651-2022-36-245-51.
3. Zakshevskaya E.V., Kuksin S.V. Trends and forecast parameters of grain production, consumption, and export development in Russia // *Nauchnoe obozrenie: teoriya i praktika = Scientific Review: Theory and Practice*, 2021, vol. 11, no. 8, pp. 2314–2326. (In Russian). DOI: 10.35679/2226-0226-2021-11-8-2314-2326.
4. Ageeva E.V., Leonova I.N., Likhenko I.E., Sovevov V.V. The ear grain weight and the thousand grain weight as productivity traits in varieties of spring bread wheat of different ripening groups in the conditions of the Priob'e steppe. *Pis'ma v Vavilovskij zhurnal genetiki i seleksii = Letters to Vavilov Journal of Genetics and Breeding*, 2021, vol. 7, no. 1, pp. 5–11. (In Russian). DOI: 10.18699/LettersVJ2021-7-01.
5. Chai Y., Senay S., Horvath D., Pardey P. Multi-peril pathogen risks to global wheat production: A probabilistic loss and investment assessment // *Frontiers in Plant Science*, 2022, vol. 13, p. 1034600. DOI: 10.3389/fpls.2022.1034600.
6. Del Ponte E.M., Moriera G.M., Ward T.J., O'Donnell K. et al. Fusarium graminearum species complex: a bibliographic analysis and web-accessible database for global mapping of species and trichothecene toxin chemotypes // *Phytopathology*, 2022, vol. 112, pp. 741–751. DOI: 10.1094/PHYTO-06-21-0277-RVW.
7. Hossain A., Skalicky M., Brestic M., Maitra S. et al. Consequences and Mitigation Strategies of Abiotic Stresses in Wheat (*Triticum aestivum* L.) under the Changing Climate // *Agronomy*, 2021, no. 11 (2), p. 241. DOI: 10.3390/agronomy11020241.
8. Aoun M., Rouse M.N., Kolmer J.A., Kumar A., Elias E.M. Genome-Wide Association Studies Reveal All-Stage Rust Resistance Loci in Elite Durum Wheat Genotypes // *Frontiers in Plant Science*, 2021, vol. 12, pp. 1–20. DOI: 10.3389/fpls.2021.640739.

REFERENCES

9. Li H., Hua L., Zhao S., Hao M. et al. Cloning of the wheat leaf rust resistance gene *Lr47* introgressed from *Aegilops speltoides* // *Nature Communications*, 2023, vol. 14, p. 6072. DOI: 10.1038/s41467-023-41833-2.
10. Sychev V.G., Grechishkina Yu.I., Burlai A.V., Matvienko A.V. Analysis of the use of mineral fertilizers for winter wheat in the Stavropol Territory // *Plodorodie = Plodorodie*, 2021, no. 2, pp. 3–5. (In Russian). DOI: 10.25680/S19948603.2021.119.01.
11. Grabovets A.I., Fomenko M.A., Oleinikova T.A. New varieties of winter soft wheat results from selection in adaptability and productivity. *Vestnik Rossiiskoi sel'skokhozyaistvennoi nauki = Vestnik of the Russian agricultural science*, 2021, № 2, pp. 19–23. (In Russian). DOI: 10.30850/vrsn/2021/2/19-23.
12. Sandukhadze B.I., Mamedov R.Z., Krakhmaleva M.S., Bugrova V.V. Scientific breeding of winter bread wheat in the Non-Chernozem zone of Russia: the history, methods and results. *Vavilovskii zhurnal genetiki i seleksii = Vavilov Journal of Genetics and Breeding*, 2021, vol. 25, no. 4, pp. 367–373. (In Russian). DOI: 10.18699/VJ21.53-o.
13. Levakova O.V., Gladysheva O.V., Kostan'yants M.I. Comparative analysis of grain productivity and biometric elements of winter wheat varieties depending on the variety change periods. *Zernovoe khozyaistvo Rossii = Grain Economy of Russia*, 2023, vol. 15, no. 3, pp. 42–47. (In Russian). DOI: 10.31367/2079-8725-2023-86-3-42-47.
14. Ivanisova A.S., Marchenko D.M. The use of breeding indices when estimating winter durum wheat productivity. *Agrarnaya nauka = Agrarian science*, 2024, no. 8, pp. 150–154. (In Russian). DOI: 10.32634/0869-8155-2024-385-8-150-154.
15. Shamanin V.P., Pototskaya I.V., Chursin A.S., Shepelev S.S., Nardin D.S., Pozherukova V.E., Köksel Kh., Morgunov A.I. Breeding spring bread wheat varieties (*Triticum aestivum* L.) with functional properties of grain for environmentally friendly growing in Western Siberia. *Sel'skokhozyajstvennaya biologiya = Agricultural Biology*, 2024, vol. 59, no. 3, pp. 492–506. (In Russian). DOI: 10.15389/agrobiology.2024.3.492rus.

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Роль кровососущих насекомых и иксодовых клещей в возможной передаче вируса лейкоза крупного рогатого скота

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Наблюдаемое в настоящее время широкое распространение лейкоза крупного рогатого скота, особенно в регионах с развитым молочным животноводством, остается одной из актуальнейших проблем ветеринарной науки. Сельскохозяйственные предприятия, не только крупные компании, но и небольшие фермерские хозяйства, несут огромные экономические потери, связанные с вирусом лейкоза крупного рогатого скота. Развитие лейкоза в стаде может привести к снижению общего здоровья и продуктивности всего поголовья, что сказывается на рентабельности хозяйства в долгосрочной перспективе. Лейкоз приводит к снижению продуктивности, ухудшению здоровья и сокращению периода использования высокопродуктивных коров. Лейкоз как вторичный иммунодефицит выступает причиной сокращения плодовитости у коров, роста числа абортосов, снижению процента выживаемости телят, развития различных сопутствующих заболеваний. Особый интерес в распространении инфекции представляют пути передачи вируса. Неплохо изучены три из них: вертикальный, горизонтальный и ятрогенный. Трансмиссивный путь передачи инфекции в настоящее время остается под вопросом. В последнее десятилетие активно изучаются кровососущие насекомые и клещи как потенциальные переносчики возбудителей вирусных болезней у сельскохозяйственных животных, в том числе лейкоза крупного рогатого скота. Возможно, насекомые выступают как фактор, способствующий распространению вируса, особенно в периоды массовых вспышек и при наличии большого числа инфицированных животных. В статье представлен обширный систематический анализ литературных данных из авторитетных научных изданий об участии слепней из семейства Tabanidae, зоофильных мух *Stomoxys calcitrans*, а также клещей из семейства Ixodidae в трансмиссивной передаче возбудителей болезней у сельскохозяйственных животных, в частности возбудителя лейкоза крупного рогатого скота.

Ключевые слова: инфекция, вирус лейкоза крупного рогатого скота, бактерии, вирусы, трансмиссивный путь передачи, Ixodidae, Tabanidae, *Stomoxys calcitrans*

The role of blood-sucking insects and ixodid ticks in the possible transmission of bovine leukemia virus

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The currently observed widespread prevalence of bovine leukemia, especially in the regions with developed dairy farming, remains one of the most pressing problems in veterinary science. Agricultural enterprises, not only large companies but also small farms, bear huge economic losses associated with bovine leukemia virus. The development of leukemia in a herd can lead to a decrease in the overall health and productivity of the entire livestock, which affects the profitability of the farm in the long term. Leukemia leads to decreased productivity, poor health, and a shortened lifespan of highly productive cows. Leukemia, as a secondary immunodeficiency, leads to reduced fertility in cows, an increased incidence of abortions, a decreased calf survival rate, and the development of various associated diseases. Of particular interest in the spread of the infection are the routes of virus transmission. Three of these have been extensively studied: vertical, horizontal, and iatrogenic. Vector-mediated transmission remains questionable. Over the past decade, bloodsucking insects and ticks have been actively studied as potential vectors of pathogens causing viral diseases in farm animals, including bovine leukemia. Insects may act as a factor facilitating the spread of the virus, especially during periods of mass outbreaks and when large numbers of infected animals are present. The article presents an extensive systematic analysis of literature from reputable scientific publications on the involvement of gadflies from the Tabanidae family, zoophilous flies *Stomoxys calcitrans*, as well as ticks of the family Ixodidae in the vector-mediated transmission of pathogens in farm animals, particularly the bovine leukemia pathogen.

Keywords: infection, bovine leukemia virus, bacteria, viruses, vector-borne transmission, Ixodidae, Tabanidae, *Stomoxys calcitrans*

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Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Currently, cattle leukemia remains a relevant issue. This disease is widespread in many countries around the world, especially in those where dairy and beef farming are well developed. In the Russian Federation, cattle leukemia is the predominant infection in most regions and holds a leading position among infectious diseases in this type of livestock [1, 2].

Agricultural businesses (both large holdings and small farms) are facing huge economic losses due to bovine leukemia virus (BLV). The spread of leukemia in a herd can lead to a

decline in the overall health and productivity of the entire livestock, which affects the farm's profitability in the long run. Leukemia causes reduced productivity, worsening health, and a shorter lifespan for high-yield cows. The economic costs include loss and deterioration of milk quality, slower weight gain, and expenses for treatment and preventive measures.

Leukemia, as a secondary immunodeficiency, leads to reduced fertility in cows, an increase in the number of abortions, a lower survival rate of calves, and the development of various other related diseases. There is no specific treatment

for leukemia. Farms have to spend significant amounts on diagnostics, isolation, and culling of sick animals, as well as other veterinary and zootechnical measures aimed at eliminating BLV. Killing infected and sick animals, in turn, leads to losses in genetic diversity and the herd's potential. Livestock products from infected animals may have a lower market value. On top of that, a ban is put in place on selling such animals [3, 4].

Bovine leukemia is a chronic infectious disease caused by the bovine leukemia virus (family Retroviridae). Leukemia is part of a group of malignant blood diseases. The virus mainly infects B-cells in the blood, leading to their overgrowth and the development of lymphocytosis. These cells are usually found in the blood and lymphoid organs. The virus can also be present in endothelial cells and epithelial cells of the mammary gland, which explains the presence of viral particles in milk. The main cellular targets of BLV are B-lymphocytes. Other types of cells, like monocytes (a virus reservoir), CD8 T-lymphocytes, and granulocytes, can also get infected. In Russia, cattle leukemia is classified as a quarantine animal disease.

Without carrying out health measures, the virus continues to spread throughout the entire herd. In the context of intensive dairy cow farming, only 5% of infected animals develop leukemia or lymphoma, which leads to the disposal of the carcass. The remaining 95% of infected animals show no clinical signs or changes in their bloodwork [5, 6].

BLV is able to cross species barriers both in natural conditions and in experiments. It is related to human T-cell leukemia viruses (HTLV I-III) and simian T-cell leukemia viruses (STLV). Animals closely related to cattle (Asian buffalo, sheep, alpacas) get infected with BLV under natural conditions. In experiments, the virus was able to infect rabbits, rats, pigs, goats, and sheep [7–9].

There are several known ways of transmitting BLV: vertical, horizontal, and iatrogenic.

The vector-borne transmission route of the infection is still in question. In the past decade, bloodsucking insects and ixodid ticks have been actively studied as potential carriers of viral pathogens in farm animals, including BLV. It is possible that bloodsucking insects and ticks act as a factor that helps spread the virus, especially during major outbreaks and when there are many infected animals.

The purpose of the study is to analyze and summarize the literature on the involvement of ixodid ticks (family Ixodidae) and blood-sucking insects, particularly horseflies (family Tabanidae) and the zoophilic fly *Stomoxys calcitrans* (stable fly), in the spread of pathogens of farm animals, including the bovine leukemia virus.

MATERIAL AND METHODS

The study analyzed data from domestic and international publications over the past decades, indexed in RSCI, PubMed, Crossref, Web of Science, and Scopus, about representatives of the Ixodidae and Tabanidae families, as well as *S. calcitrans* flies, as potential carriers of pathogens of farm animals. Special attention was given to the Ixodidae family as a possible carrier of BLV [10–12].

RESULTS AND DISCUSSION

Bloodsucking insects, like flies (*Siphona calcitrans*, *Stomoxys calcitrans*, *Haematobia irritans*), mosquitoes, horseflies, and ticks are not only a serious stress factor for animals, causing restlessness and skin damage, but also an important way to spread infectious agents. Most researchers consider blood-sucking insects to be vectors of viral infections. They help spread viral, bacterial, and parasitic diseases widely. At the same time, information about the role of blood-sucking insects and ixodid ticks in transmitting BLV remains contradictory or preliminary and needs further research.

Horseflies belong to the suborder Brachycera (Short-horned), in the group Orthorapha (Straight-seamed). They are the largest members

of the biting fly fauna in Western Siberia. Horseflies are widespread in the taiga, forest, and forest-steppe zones. Russia has over 100 species of horseflies, with 89 found in Siberia. Members of the family Tabanidae cause significant economic losses in livestock farming due to reduced milk production and weight gain [13].

Horseflies actively attack sick and weakened animals, and they also suck blood from fresh carcasses, which plays a big role in spreading infections. Only the females attack animals, as they are facultative hematophags. Many researchers point out the significant role of horseflies as carriers of various disease pathogens. In particular, it has been proven that horseflies play a role in spreading tularemia in natural foci of this infection and anthrax from infected animals or carcasses [14]. Horseflies retain the ability to transmit the infection with a proboscis puncture for up to 5 days after an infective feeding. Also, due to the feeding habits of the females and the potential for long-term retention of the pathogen, members of the Tabanidae family play a significant role in the spread of leptospirosis, anaplasmosis, equine infectious anemia, necrobacillosis in reindeer, cattle besnoitia, horse filarid, blackleg, trypanosomiasis, hemosporidial infection, and more [15].

Currently, the possibility of transmitting BLV by horseflies has not been proven. This is due to the difficulty of creating conditions for feeding the insects in experiments. But it's not worth ruling out the Tabanidae family from the list of potential carriers of this virus.

In recent years, researchers have been focusing on a member of the genus – the stable fly (*S. calcitrans*) – as an important factor in mechanically transmitting infections to cattle. This blood-sucking insect is widespread in livestock facilities around the world. *S. calcitrans* plays an important role in the chain of disease transmission. So, in France, outbreaks of such a highly contagious disease as bovine nodular dermatitis are directly linked to *S. calcitrans* [16]. With *S. calcitrans* involved, the African Swine Fever

Virus (ASFV) can also be transmitted. According to K.A. Olesen et al. [17], the presence of ASFV in these flies after feeding on infected blood means they are capable of carrying the viral infection. Studies by Russian scientists have also confirmed the persistence of the virus in the bodies of autumn stable flies and demonstrated the possibility of infecting pigs via the parenteral administration of a fly suspension containing virus-contaminated blood.[18].

In the territory of the Russian Federation, *S. calcitrans* is one of the main types of zoophilic flies found on livestock farms [18, 19]. The stable fly can travel several hundred meters, which makes it a serious disease vector [20]. The size of the fly population is closely linked to the condition of the environment: humidity, temperature, and availability of blood sources. Some experts note an increase in the number of *S. calcitrans* in pastures, which is most often related to the use of organic fertilizers and storing manure in piles near livestock grazing areas [21].

The stable fly is active in warm climates, especially during the summer months. The intensity of its bites increases the risk of pathogen transmission. Feeding on the blood of various types of farm animals (cattle, sheep, goats, horses), *S. calcitrans* serves as a carrier of many viral, bacterial, and parasitic diseases of cattle. Infectious agents have been found in the intestines, oral cavity, and saliva of *S. calcitrans*. In addition to lumpy skin disease of cattle and African swine fever, autumn burners are a vector for the spread of anthrax, sepsis, tularemia, trypanosomiasis, etc. [22].

Several foreign authors have established the role of horseflies and stable flies in transmitting BLV under experimental conditions. In these studies, *S. calcitrans* were fed *in vitro* with blood from a cow infected with bovine leukemia virus. Sequencing results confirmed the presence of the provirus in *S. calcitrans*. Based on the data obtained, scientists concluded that leukemia virus transmission is possible, at least experimen-

tally¹ [23]. However, the role of stable flies as carriers of BLV in the natural animal husbandry system is still being discussed and requires further study.

Ixodid ticks are of particular interest among the many blood-sucking parasites because they are widespread around the world, highly adaptable, come in a variety of species, and can carry dangerous infections.

There are over 700 species of ixodid ticks in the world. They are widely spread across Eurasia, especially in forests, pastures, and fields. In Russia, there are about 60 species of ixodid ticks belonging to five genera, and 12 species live in Western Siberia [24]. In the commonly accepted classification, ticks are divided into two main orders – Acariformes and Parasitiformes, which are grouped into the subclass Acari. Ixodid ticks belong to the order Parasitiformes, the suborder Metastigmata (Ixodides), the superfamily Ixodoidea, and the family Ixodidae. According to the latest taxonomy data, the family Ixodidae is divided into several subfamilies, of which four subfamilies parasitize mammals and birds: Ixodinae (genus *Ixodes*), Amblyomminae (genus *Amblyomma*), Haemaphysalinae (genus *Haemaphysalis*), Rhipicephalinae (includes five genera – *Rhipicephalus*, *Boophilus*, *Dermacentor*, *Anomalohimalaya*, *Hyalomma*). Ticks of the Ixodidae family belong to the ecological group of temporary parasites with long feeding periods. All ixodids without exception are highly specialized parasites of terrestrial vertebrate animals².

Ticks have a huge variety of shapes and ways of life. Most ixodid ticks in Western Siberia belong to the pasturing group, where hungry individuals attack hosts outside of shelters, lurking among the vegetation [25]. However, in recent years near Tomsk and Novosibirsk, the appearance of the Pavlovsky tick has been noted, even to the point of complete dominance. According to scientists, the high abundance of the Pavlov-

sky tick, which is more drought-resistant than the taiga tick and can successfully survive outside the favorable urban and suburban habitats of the taiga tick, may increase the persistence of natural tick-borne encephalitis foci [26].

The life cycle of the Ixodidae family includes the following developmental stages: egg, larva, nymph (one or several stages), and adult. There are one-, two-, and three-host life cycles. Females can pass pathogens of dangerous diseases to their offspring even at the stage of egg formation inside their own bodies. This is a typical development and feeding cycle for many species of ixodid ticks, which is important to keep in mind when studying their role in spreading infections and developing prevention measures. The larvae and nymphs usually live in the lower layers of plants and feed on small mammals and birds. This feeding pattern helps spread ticks among small animals and, indirectly, among their hosts. Adult ticks feed on larger mammals (cattle, horses, sheep, deer) and medium-to-large birds. The large blood volume of these animals increases the likelihood of successful reproduction for ixodid ticks. It should be noted that prolonged feeding on the host is characteristic only of females; males of *Ixodes* pasture ticks are facultative hematophages, whereas males of other genera are obligate hematophages. The biological characteristics of ixodid ticks—including their camouflage tactics and feeding habits across various developmental stages—make them highly effective vectors of infection.

Ixodid ticks are natural vectors for many protozoal, bacterial, viral, and rickettsial diseases affecting humans and animals. It is known that ixodid ticks transmit the causative agents of tick-borne encephalitis, borreliosis (Lyme disease), tularemia, anaplasmosis, piroplasmosis, and others. They may also play a role in transmitting certain types of fungi, toxoplasma species, and flagellates. Such close and diverse as-

¹Foil L.D., Gorham J.R., French D.D. Mechanical transmission of bovine leukaemia virus by horse flies (Tabanidae: Diptera) // Veterinary microbiology, 1988, vol. 16 (3), pp. 253–258.

²Saitov V.R., Salnikova M.M. Ixodid Ticks: general and specific aspects of studying the family: a teaching and methodological manual. Kazan, 2019, 28 p.

sociations between blood-feeding ticks and various microorganisms are typically attributed to the long evolutionary history of their parasitism and the variety of ecological relationships with their hosts—terrestrial vertebrates. Furthermore, blood-feeding parasites of the family Ixodidae can serve as natural reservoirs for diseases [27, 28].

Experts have suggested that ixodid ticks act as a factor contributing to the spread of the leukemia virus, particularly during periods of tick activity and in the presence of a large number of animals infected with the bovine leukemia virus. For instance, Italian scientists conducted a study on 1,200 *Rhipicephalus bursa* and *Rhipicephalus sanguineus* ticks collected from farms with BLV-positive cows. Viral DNA was detected in 8.4% of the ticks, and the gene sequence matched the BLV strain circulating on the farm. Laboratory studies have demonstrated the virus's ability to persist across developmental stages: larva → nymph → adult. According to available data, 30% of nymphs derived from larvae that had fed on BLV-positive blood tested positive by PCR [29].

Japanese scientists concluded that the mechanical transfer of infected blood residues on the chelicerae is possible during brief but deep bites. They conducted an experiment using a sterile colony of *Haemaphysalis longicornis*. The ticks fed on seropositive calves for 30 minutes and were then immediately transferred to seronegative calves. After 16 weeks, two of the ten healthy calves were found to be infected with the leukemia virus [30].

T.R. Machado et al. [31] established that BLV-infected lymphocytes survive in tick hemolymph for up to 48 hours. A.M. Sato et al. [32] detected the gp51 protein in the gut of *H. longicornis* 24 hours after a blood meal, confirming the preservation of the virus's antigenic integrity within the tick.

In a study on the susceptibility of *Dermacentor reticulatus* ticks to bovine leukemia virus (BLV), Yu.V. Glazunov et al. [33] determined

that BLV proviral DNA can persist in the bodies of adult ixodid ticks for up to one year. PCR analysis of samples from ixodid ticks collected from BLV-infected animals confirmed the presence of BLV DNA in $87.7 \pm 2.3\%$ of cases, indicating the potential for the virus to be maintained within the bodies of ixodid ticks.

CONCLUSION

Numerous studies conducted by scientists worldwide have confirmed the role of blood-sucking insects and ixodid ticks in the transmission of viruses, bacteria, and parasites. It has been demonstrated that the bovine leukemia virus can persist in ixodid ticks throughout their developmental stages, from larva to adult. Vector-borne diseases—including viral ones transmitted by blood-feeding insects—require continuous monitoring, preventive measures, and control efforts to protect cattle from blood-feeding parasites in both housing and pasture environments, thereby preserving herd productivity.

Nevertheless, the role of blood-feeding insects in the transmission of viral infections such as BLV requires further research, as the data remain contradictory or preliminary. The question of whether ixodid ticks can transmit the bovine leukemia virus from infected to susceptible animals remains a subject of debate.

СПИСОК ЛИТЕРАТУРЫ

1. Донник И.М., Петропавловский М.В. Лейкоз крупного рогатого скота: современный подход // Животноводство России. 2022. № 2. С. 57–59.
2. Донник И.М., Петропавловский М.В., Гулюкин М.И., Кривонос Р.А., Черных О.Ю., Палагин С.Ю. Эффективность противоэпизоотических мероприятий на административных территориях Российской Федерации с разной эпизоотической обстановкой // Ветеринария и кормление. 2025. № 1. С. 1–6.
3. Гулюкин М.И., Барабанов И.И., Иванова Л.А., Степанова Т.В. Мониторинг эпизоотической ситуации по лейкозу крупного рогатого скота в товарных и племенных хозяйствах Российской Федерации за 2014–2015 гг. // Ветеринария и кормление. 2016. № 4. С. 5–39.

4. Генджиев А.Я., Гулюкин М.И., Абакин С.С., Убушиева А.В. Диагностика эпизоотий и факторы риска лейкоза у крупного рогатого скота в период с 2000 по 2024 г. // Ветеринария и кормление. 2025. № 3. С. 35–39.
5. Polat M., Takeshima S., Aida Y. Epidemiology and genetic diversity of bovine leukemia virus // Virology journal. 2017. N 14. P. 209–224.
6. Баскаран Д., Спиринов П.В., Прасолов В.С. Активированные лейкозные онкогены, определяющие злокачественное перерождение кроветворных клеток // Молекулярная биология. 2010. № 3. С. 418–430.
7. Buehring G.C., De Laney A., Shen H.M., Chu D.L., Razavian N., Schwartz D.A., Demkovich Z.R., Bates M.N. Bovine leukemia virus discovered in human blood // BMC Infectious Diseases. 2019. N 19. P. 297.
8. Гулюкин М.И., Козырева Н.Г., Иванова Л.А., Степанова Т.В., Клименко А.И., Коваленко А.В., Дробин Ю.Д., Василенко В.Н. Межвидовая передача вируса лейкоза крупного рогатого скота в эксперименте // Вопросы вирусологии. 2015. № 60 (5). С. 32–37.
9. Lee L.C., Scarrett W.K., Buehring G.C., Saunders G.K. Bovine leukemia virus infection in a juvenile alpaca with multicentric lymphoma // Canadian veterinary journal. 2012. Vol. 53. P. 283–286.
10. Глазунов Ю.В., Кабицкая Я.А., Донник И.М., Бойко Е.Г., Глазунова Л.А. Изучение возможности резервации вируса лейкоза крупного рогатого скота в имаго *Dermacentor reticulatus* // Вестник Бурятской государственной сельскохозяйственной академии им. В.Р. Филиппова. 2020. № 4 (61). С. 40–47.
11. Крутько К.С., Кинарейкина А.Г., Серкова М.И., Селиванова Е.А., Федорова О.А. Выявление в кровососущих двукрылых насекомых Тюменской области генетического материала возбудителей вирусных болезней животных // Российский паразитологический журнал. 2022. Т. 16. № 4. С. 389–402.
12. Василевич Ф.И. Эколого-биологические особенности кровососущих насекомых Центральной Нечерноземной зоны России // Ветеринария. 2020. № 2. С. 32–38.
13. Сивкова Е.И. Вредоносное воздействие слепней (Diptera, Tabanidae) на организм животного и человека (обзор) // Теория и практика борьбы с паразитарными болезнями. 2019. № 20. С. 575–579.
14. Домацкий В.Н., Глазунова Л.А. Природные очаги туляремии на территории Российской Федерации // Вестник Башкирского государственного аграрного университета. 2023. № 4. С. 88–96.
15. Сивкова Е.И., Хлызова Т.А., Федорова О.А. Некоторые аспекты изучения слепней (Diptera, Tabanidae) Азиатской части России // Мир инноваций. 2017. № 3–4. С. 137–140.
16. Saegerman C., Speybroeck N., Vanbinst T., Berkvens D. Bovine leukaemia virus transmission by the stable fly (*Stomoxys calcitrans*): quantifying the herd-level impact under Belgian field conditions // Preventive veterinary medicine. 2021. Vol. 193. P. 105442.
17. Olesen K.A., Hish G.B., Pedersen H.G. Mechanical transmission of bovine leukaemia virus by the stable fly, *Stomoxys calcitrans*: a Danish field-to-pen study // Veterinary microbiology. 2022. Vol. 270. P. 109412. DOI: 10.1016/j.vetmic.2022.109412.
18. Власов М.Е., Середа А.Д., Балышев В.М. Сохраняемость вируса африканской чумы свиней в осенних жигалках и падальных мухах // Ветеринария. 2019. № 8. С. 22–25.
19. Левченко М.А., Силиванова Е.А. *Stomoxys calcitrans* (Diptera: Muscidae): средства и методы борьбы. Обзор // Российский паразитологический журнал. 2020. Т. 14. № 2. С. 103–113.
20. Lempereur L., Sohler C., Smeets F., Maréchal F., Berkvens D., Madder M., Francis F., Losson B. *Haematopota* spp. and *Stomoxys calcitrans* using a mark-releaserecapture approach in Belgium // Medical and veterinary entomology. 2018. Vol. 32 (3). P. 298–303.
21. Friesen K.M., Johnson G.D. Stable Fly Phenology in a Mixed Agricultural-Wildlife Ecosystem in Northeast Montana // Environmental entomology. 2013. Vol. 42 (1). P. 49–57.
22. Baldacchino F., Muenworn V., Desquesnes M., Desoli F., Charoenviriyaphap T., Duvallet G. Transmission of pathogens by *Stomoxys* flies (Diptera, Muscidae): a review // Parasite. 2013. N 20. P. 26.
23. Ooshiro M., Hayashida K., Kono Y., Murakami K. Mechanical transmission of bovine leukaemia virus by the stable fly: a laboratory feeding trial // Journal of veterinary medical science. 2018. Vol. 80 (3). P. 485–488. DOI: 10.1292/jvms.17-0479.
24. Якименко В.В., Малькова М.Г., Шпынов С.Н. Иксодовые клещи Западной Сибири: фауна, экология, основные методы исследования: монография. Омск, 2013. 240 с.
25. Балашов Ю.С. Паразитизм клещей и насекомых на наземных позвоночных: монография. СПб.: Наука, 2009. 357 с.

26. Чичерина Г.С., Бахвалова В.Н., Потапова О.Ф., Панов В.В., Малькова М.Г., Морозова О.В. Динамика феногенетических свойств вируса клещевого энцефалита при моделировании трансмиссии от иксодовых клещей диким грызунам // Национальные приоритеты России. 2014. № 3 (13). С. 121–126.
27. Цапко Н.В. Список видов иксодовых клещей (Acari: Ixodidae) России // Паразитология. 2020. Т. 54. № 4. С. 341–352.
28. Коренберг Э.И. Изучение микробиома иксодовых клещей и возбудителей трансмиссивных инфекций в их соотношении // Национальные приоритеты России. 2021. № 3 (42). С. 182–186.
29. Pascucci I., Di Domenico M., Camma C., Savini G., Di Provvido A., Morrone F., Di Sabatino D., Monaco F., Lorusso A. First detection of bovine leukaemia virus DNA in field-collected *Rhipicephalus bursa* and *R. sanguineus* ticks: evidence for trans-stadial passage // Ticks and Tick-borne Diseases. 2023. Vol. 14 (5). P. 102152. DOI: 10.1016/j.ttbdis.2023.102152.
30. Wang Y., Kono Y., Kubota T., Inokuma H., Kamio T. Mechanical transmission of bovine leukemia virus by contaminated mouthparts of *Haemaphysalis longicornis*: a laboratory proof-of-concept // Veterinary microbiology. 2022. N 270. P. 109414. DOI: 10.1016/j.vetmic.2022.109414.
31. Machado T.R., Rodrigues-da-Silva F.O., Oliveira G.H.N., Ribeiro C.F., Bastos G.Q., Aguirre A.A., Herrera H.V. Survival of BLV-infected bovine lymphocytes in tick haemolymph and maintenance of infectivity // Veterinary microbiology. 2020. N 247. P. 108764.
32. Sato A.M., Aguirre A.A., Herrera H.V., Machado T.R., Ribeiro C.F., Rodrigues-da-Silva F.O., Romero M.H. Western-blot detection of BLV gp51 antigen in the midgut of *Haemaphysalis longicornis* ticks after artificial feeding // Journal of virological methods. 2024. N 319. P. 114370.
33. Глазунов Ю.В., Домацкий В.Н., Глазунова Л.А. Видовой состав и численность иксодовых клещей, нападающих на крупный рогатый скот, инфицированный вирусом лейкоза в Тюменской области // АПК: инновационные технологии. 2023. № 4 (63). С. 26–32.
2. Donnik I.M., Petropavlovsky M.V., Gulyukin M.I., Krivonos R.A., Chernykh O.Yu., Palagin S.Yu. Effectiveness of anti-epidemic measures in the administrative territories of the Russian Federation with different epizootic situations. *Veterinariya i kormlenie = Veterinaria i kormlenie*, 2025, no. 1, pp. 1–6. (In Russian).
3. Gulyukin M.I., Barabanov I.I., Ivanova L.A., Stepanova T.V. Monitoring the epizootic situation of bovine leukemia in commercial and breeding farms of the Russian Federation for 2014–2015. *Veterinariya i kormlenie = Veterinaria i kormlenie*, 2016, no. 4, pp. 5–39. (In Russian).
4. Gendzhiev A.Ya., Gulyukin M.I., Abakin S.S., Ubushieva A.V. Diagnostics of epizootics and risk factors for bovine leukosis in cattle in the period from 2000 to 2024. *Veterinariya i kormlenie = Veterinaria i kormlenie*, 2025, no. 3, pp. 35–39. (In Russian).
5. Polat M., Takeshima S., Aida Y. Epidemiology and genetic diversity of bovine leukemia virus. *Virology journal*, 2017, no. 14, pp. 209–224.
6. Baskaran D., Spirin P.V., Prasolov V.S. Activated leukemic oncogenes responsible for neoplastic transformation of hematopoietic cells. *Molekulayrnaya biologiya = Molecular biology*, 2010, no. 3, pp. 418–430. (In Russian).
7. Buehring G.C., De Laney A., Shen H.M., Chu D.L., Razavian N., Schwartz D.A., Demkovich Z.R., Bates M.N. Bovine leukemia virus discovered in human blood. *BMC Infectious Diseases*, 2019, no. 19, p. 297.
8. Gulyukin M.I., Kozyreva N.G., Ivanova L.A., Stepanova T.V., Klimenko A.I., Kovalenko A.V., Drobin Yu.D., Vasilenko V.N. Experimental interspecies transmission of the bovine leukemia virus. *Voprosy virologii = Problems of Virology*, 2015, no. 60 (5), pp. 32–37. (In Russian).
9. Lee L.C., Scarlett W.K., Buehring G.C., Saunders G.K. Bovine leukemia virus infection in a juvenile alpaca with multicentric lymphoma. *Canadian veterinary journal*, 2012, vol. 53, pp. 283–286.
10. Glazunov Yu.V., Kabitskaya Ya.A., Donnik I.M., Boyko E.G., Glazunova L.A. Studying the possibility of bovine leukemia virus reservation in imago *Dermacentor reticulatus*. *Vestnik Buryatskoy gosudarstvennoy selskohozyastvennoy akademii im. V.R. Filippova = Vestnik of Buryat state academy of agriculture named after V. Philippov*, 2020, no. 4 (61), pp. 40–47. (In Russian).
11. Krutko K.S., Kinareykina A.G., Serkova M.I., Selivanova E.A., Fedorova O.A. Detection of

REFERENCES

- genetic material of causative agents of animal viral diseases in blood-sucking dipterans from the Tyumen region. *Rossiyskiy parazitologicheskii zhurnal = Russian Journal of Parasitology*, 2022, vol. 16, no. 4, pp. 389–402. (In Russian).
12. Vasilevich F.I. Ecological and biological features of blood-sucking midges in the Central Non-Chernozem zone of Russia. *Veterinaria = Veterinary Medicine*, 2020, no. 2, pp. 32–38. (In Russian).
 13. Sivkova E.I. Harmful impact of horseflies (Diptera, Tabanidae) on the organism of animals and human (review). *Teoriya i praktika bor'by s parazitarnymi boleznyami = Theory and practice of combating parasitic diseases*, 2019, no. 20, pp. 575–579. (In Russian).
 14. Domatsky V.N., Glazunova L.A. Natural foci of tularemia on the territory of the Russian Federation. *Vestnik Bashkirskogo gosudarstvennogo agrarnogo universiteta = Bulletin of Bashkir State Agrarian University*, 2023, no. 4, pp. 88–96. (In Russian).
 15. Sivkova E.I., Khlyzova T.A., Fedorova O.A. Some aspects of studying of gadflies (Diptera, Tabanidae) in Asian part of Russia. *Mir innovatsii = World of innovations*, 2017, no. 3-4, pp. 137–140. (In Russian).
 16. Saegerman C., Speybroeck N., Vanbinst T., Berkvens D. Bovine leukaemia virus transmission by the stable fly (*Stomoxys calcitrans*): quantifying the herd-level impact under Belgian field conditions. *Preventive veterinary medicine*, 2021, vol. 193, p. 105442.
 17. Olesen K.A., Hish G.B., Pedersen H.G. Mechanical transmission of bovine leukaemia virus by the stable fly, *Stomoxys calcitrans*: a Danish field-to-pen study. *Veterinary microbiology*, 2022, vol. 270, p. 109412. DOI: 10.1016/j.vetmic.2022.109412.
 18. Vlasov M.E., Sereda A.D., Balyshv V.M. African swine virus maintenance in stable flies (*Stomoxys Calcitrans*) and blowflies (*Calliphoridae*). *Veterinaria = Veterinary Medicine*, 2019, no. 8, pp. 22–25. (In Russian).
 19. Levchenko M.A., Silivanova E.A. *Stomoxys calcitrans* (Diptera: Muscidae): means and methods of control. Overview. *Rossiyskiy parazitologicheskii zhurnal = Russian Journal of Parasitology*, 2020, vol. 14, no. 2, pp. 103–113. (In Russian).
 20. Lempereur L., Sohler C., Smeets F., Maréchal F., Berkvens D., Madder M., Francis F., Losson B. *Haematopota* spp. and *Stomoxys calcitrans* using a mark-releaserecapture approach in Belgium. *Medical and veterinary entomology*, 2018, vol. 32 (3), pp. 298–303.
 21. Friesen K.M., Johnson G.D. Stable Fly Phenology in a Mixed Agricultural-Wildlife Ecosystem in Northeast Montana. *Environmental entomology*, 2013, vol. 42 (1), pp. 49–57.
 22. Baldacchino F., Muenworn V., Desquesnes M., Desoli F., Charoenviriyaphap T., Duvallet G. Transmission of pathogens by *Stomoxys* flies (Diptera, Muscidae): a review. *Parasite*, 2013, no. 20, p. 26.
 23. Ooshiro M., Hayashida K., Kono Y., Murakami K. Mechanical transmission of bovine leukaemia virus by the stable fly: a laboratory feeding trial. *Journal of veterinary medical science*, 2018, vol. 80 (3), pp. 485–488. DOI: 10.1292/jvms.17-0479.
 24. Yakimenko V.V., Malkova M.G., Shpynov S.N. *Ixodid mites of Western Siberia: fauna, ecology, basic research methods*. Omsk, 2013, 240 p. (In Russian).
 25. Balashov Yu.S. *Parasitism of ticks and insects on terrestrial vertebrates*. St. Petersburg: Nauka, 2009, 357 p. (In Russian).
 26. Chicherina G.S., Bakhvalova V.N., Potapova O.F., Panov V.V., Malkova M.G., Morozova O.V. Dynamics of phenogenotypical properties of encephalitis virus in modeling of transmission from ixodids to wild rodents. *Natsionalnie prioritety Rossii = National priorities of Russia*, 2014, no. 3 (13), pp. 121–126. (In Russian).
 27. Tsapko N.V. A checklist of the ticks (Acari: Ixodidae) of Russia. *Parazitologia = Parazitologiya*, 2020, vol. 54, no. 4, pp. 341–352. (In Russian).
 28. Korenberg E.I. Study of the microbiome of ixodic ticks and transmissible infection agents in their relationship. *Natsionalnie prioritety Rossii = National priorities of Russia*, 2021, no. 3 (42), pp. 182–186. (In Russian).
 29. Pascucci I., Di Domenico M., Camma C., Savini G., Di Provvido A., Morrone F., Di Sabatino D., Monaco F., Lorusso A. First detection of bovine leukaemia virus DNA in field-collected *Rhipicephalus bursa* and *R. sanguineus* ticks: evidence for transstadial passage. *Ticks and Tick-borne Diseases*, 2023, vol. 14 (5), p. 102152. DOI: 10.1016/j.ttbdis.2023.102152.
 30. Wang Y., Kono Y., Kubota T., Inokuma H., Kamio T. Mechanical transmission of bovine leukaemia virus by contaminated mouthparts of *Haemaphysalis longicornis*: a laboratory proof-of-concept. *Veterinary microbiology*, 2022, no. 270, p. 109414. DOI: 10.1016/j.vetmic.2022.109414.

31. Machado T.R., Rodrigues-da-Silva F.O., Oliveira G.H.N., Ribeiro C.F., Bastos G.Q., Aguirre A.A., Herrera H.V. Survival of BLV-infected bovine lymphocytes in tick haemolymph and maintenance of infectivity. *Veterinary microbiology*, 2020, no. 247, p. 108764.
32. Sato A.M., Aguirre A.A., Herrera H.V., Machado T.R., Ribeiro C.F., Rodrigues-da-Silva F.O., Romero M.H. Western-blot detection of BLV gp51 antigen in the midgut of *Haemaphysalis longicornis* ticks after artificial feeding. *Journal of virological methods*, 2024, no. 319, p. 114370.
33. Glazunov Yu.V., Domatsky V.N., Glazunova L.A. Species composition and number of ixodid ticks attacking cattle infected with leukemia virus in the Tyumen region. *APK: innovacionnie tehnologii = AIC: innovative technologies*, 2023, no. 4 (63), pp. 26–32. (In Russian).

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Молочная продуктивность и воспроизводительные качества коров симментальской породы с разными генотипами *CSN3*, *BLG*, *SCD1*, *PIT1* генов

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Представлены результаты исследований по выявлению ассоциативных связей генов *CSN3*, *BLG*, *SCD1*, *PIT1* с молочной продуктивностью и воспроизводительными качествами коров симментальской породы. Молочная продуктивность изучена по трем и старше лактациям в стаде коров Алтайского края ($n = 86$). Показано положительное влияние генотипа *CSN3AA* и *CSN3AB* на удои, содержание молочного жира и белка. Максимальные различия в сравнении с генотипом *CSN3BB* достигали по удою 1971,2 кг, молочному жиру – 84, молочному белку – 63,6 кг (вторая лактация). Определены желательные варианты гена *BLG*. Коровы с генотипом *BLGAA* превосходили сверстниц с альтернативными генотипами по удою в зависимости от лактации на 1132,2–1209,7 кг. Коровы с генотипами *BLGAA* и *BLGAB* имели более высокое содержание молочного жира и белка на 42,8–53,4 и 36,4–39,0 кг, чем животные с генотипом *BLGBB*, соответственно. По гену *SCD1* по третьей лактации и старше коровы с генотипом *SCD1TT* имели преимущество над сверстницами с альтернативными генотипами по удою на 1271,9–1349,7 кг, массовой доле жира на 0,03 и 0,04%, молочного жира на 54,9–58,5 кг, молочного белка на 41,0–43,6 кг. При анализе ассоциативных связей генотипов гена *Pit1* показано, что по второй и третьей лактациям лучшим был гомозиготный вариант этого гена *Pit1AA*. Превосходство удоя над генотипом *Pit1AB* было на уровне 2451,8 кг, массовой доле жира на 0,06%, молочного жира на 106,7 кг, молочного белка на 79,2 кг. Сухостойный и сервис-период у коров симментальской породы анализируемого стада соответствовали физиологическим нормам: сухостойный период составлял 57,7–61,3 дня, сервис-период между лактациями – 73,8–124,6 дня.

Ключевые слова: ген, генотип, симментальская порода, лактация, удои, жир, белок

Milk productivity and reproductive traits of the Simmental cows with different genotypes of *CSN3*, *BLG*, *SCD1*, *PIT1* genes

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The results of the studies aimed at identifying associations between the *CSN3*, *BLG*, *SCD1*, and *PIT1* genes and milk productivity and reproductive performance in the Simmental cows are presented. Milk productivity was studied for the third and older lactations in the herd of cows in the Altai Krai ($n=86$). A positive effect of the *CSN3AA* and *CSN3AB* genotypes on milk yield, milk fat and milk protein content was demonstrated. Maximum differences compared to the *CSN3BB* genotype were 1971.2 kg in milk yield, 84 kg in milk fat, and 63.6 kg in milk protein (second lactation). Desirable variants of the *BLG* gene were identified. Cows with the *BLGAA* genotype outperformed their peers with alternative genotypes in milk yield by 1132.2 kg to 1209.7 kg, depending on the lactation. Cows with the *BLGAA* and *BLGAB* genotypes had higher milk fat and protein content by 42.8–53.4 kg and 36.4–36.9 kg, respectively, than animals with the *BLGBB* genotype. According to the *SCD1* gene, in the third lactation and later, cows with the *SCD1TT* genotype had an advantage over their peers with alternative genotypes in milk yield by 1271.9–1349.7 kg, fat mass fraction by 0.03 and 0.04%, milk fat

by 54,9–58,5 kg, and milk protein by 41.0–43.6 kg. Analysis of the associations between the *Pit1* gene genotypes revealed that the homozygous *Pit1AA* variant of this gene was superior in the second and third lactations. The superiority of milk yield over the *Pit1AB* genotype was at the level of 2451.8 kg, fat content by 0.06%, milk fat by 106.7 kg, milk protein by 79.2 kg. The dry stage and service stage between lactations in the Simmental cows in the analyzed herd correspond to physiological norms: the dry stage was 57.7–61.3 days, and the service stage between lactations was 73.8–124.6 days.

Keywords: gene, genotype, Simmental breed, lactation, milk yield, fat, protein

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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 Simmental breed population, despite high-quality milk indicators, especially its protein content, decreased by 6.88% compared to 2010. However, milk yield increased by 2,298 kg and reached an average of 6,089 kg in Russia in 2024, with fat content of 4.0% and protein of 3.27%¹. The preservation of a breed depends on increasing its productivity, improving reproductive traits, and resistance to various diseases. Along with traditional methods of selecting animals for these traits, using DNA markers is a more effective way to quickly achieve the desired result. For this purpose, this study used the most significant genes *CSN3*, *BLG*, *SCD1*, *PIT1*, whose expression is associated with milk productivity and reproductive abilities.

In dairy cattle farming, the *CSN3* gene has not lost its value and informativeness. As numerous studies have shown, it is associated with the

technological properties of milk, especially its suitability for cheese-making [1, 2]. At the same time, studies have noted the priority of certain genotypes of this gene for milk yield and fat content, but the data are contradictory [3–6]. Whey protein *BLG* affects milk yield, fat, and protein content in cows of different breeds, but the conclusions aren't always clear-cut [5–8]. Lately, when looking for gene markers, the *SCD1* gene has been getting attention, as it's involved in regulating saturated and unsaturated fatty acids. Because of this, it can be considered a potential marker for the quality of milk. However, there is information about this gene affecting other important breeding traits as well. According to reports^{2, 3} [9, 10], his genotypes are linked to milk yield, fat and protein content, as well as the reproductive traits of cows and heifers [11]. The *Pit1* gene (pituitary-specific transcription factor)

¹Yearbook on breeding work in dairy cattle farming in the Russian Federation. Moscow: VNIIPlem, 2024, 274 p.

²Yulmetyeva Yu.R., Safina N.Yu., Sharafutdinov G.S., Shakirov Sh.K. Polymorphism of the stearyl-CoA desaturase gene (*SCD1*) for loci of quantitative traits of milk productivity // *Agricultural Scientific Journal*, 2018, N 11, pp. 43–45. DOI: 10.28983/asj.v0i11.416.

³Pozovnikova M.V., Serdyuk G.N., Tulanova O.V., Terletsky V.P., Demyteyeva N.V., Mitrofanova O.V. Association of stearyl-CoA desaturase (*SCD1*) gene polymorphic variants with economically important traits in the Russian Ayrshire cattle population // *Agricultural Biology*, 2017, vol. 52, N 6, pp. 1139–1147. DOI: 10.15389/agrobiology.2017.6.1139rus.

is a marker of the quality composition of milk and meat productivity⁴.

The goal of the work is to determine the influence of *CSN3*, *BLG*, *SCD1*, *PIT1* genotypes on the milk productivity of the Simmental cows and their reproductive abilities.

MATERIAL AND METHODS

Molecular-genetic research on SNP markers was carried out in the biotechnology lab of the Siberian Research and Design and Technological Institute of Animal Husbandry of the SFSCA RAS. The study focused on Simmental cows from a herd in the Altai Territory ($n = 109$). Genomic DNA was extracted from the animals' blood using the clinical material extraction kit "Ampli Prime DNA-Sorb-V" according to the instructions from the manufacturer, ООО "NextBio" (Moscow). PCR-PDRF reactions were carried out in a programmable amplifier DRAWELL NC 1000-S. The quality and concentration of the extracted DNA, as well as the identification of genotypes, were evaluated on an agarose gel using the E-Box-CX5 TS-20.M gel documentation system under UV light with ethidium bromide fluorescence.

Polymorphism of the *CSN3* and *BLG* genes was determined using the method described in the recommendations of the All-Russian Research Institute of Animal Breeding⁵. The genotypes of the *SCD1* gene were determined according to protocol [11]. The genotypes of the *Pit1* genes were identified following the method (see footnote 4). The obtained gene amplification products were treated with the restriction endonucleases Hind III, EcoICRI, Nae III, RsaI (SibENZYM, Novosibirsk) according to the manufacturer's instructions.

The milk productivity of cows was evaluated over 305 days of lactation separately for the first, second, third, and subsequent lactations

based on livestock records. When assessing the reproductive performance of cows, factors like the length of the dry period and service period were taken into account.

The statistical processing of the collected data was carried out using Microsoft Excel and generally accepted biometric methods in animal husbandry.

RESULTS AND DISCUSSION

The associative links of genetic markers with productive traits have some features related to breed and previous selection. Because of this, our research focused on identifying them in a herd of Simmentals, formed using German and Austrian breeding material. The *CSN3* gene, which is significant for protein content and cheese-making quality, is especially important for the Simmental breed. In the first lactation, we did not identify any priority genotypes for any of the traits considered (see Table 1).

In the second lactation, cows with the *CSN3BB* genotype produced 1,521.6 and 1,971.2 kg less milk compared to *CSN3AA* and *CSN3AB* cows, respectively ($p < 0,001$). The pattern was confirmed for the third lactation and older. Cows with the *CSN3AA* and *CSN3AB* genotypes had milk yields 1936.8 and 1387.3 kg higher compared to the *CSN3BB* genotype ($p < 0,001$, $p < 0,01$).

There were no significant differences in the overall fat content between these genotypes, but when it came to milk fat in the second and third lactations, the differences reached the threshold of significance. Milk fat content in cows with *CSN3AA* and *CSN3AB* genotypes was higher by 64.1 and 84 kg (second lactation), 83.5 and 60.5 kg (third lactation and beyond) compared to cows with the *CSN3BB* genotype ($p < 0,001$). A similar situation was observed with protein. The protein percentage in the herd didn't vary, but in

⁴Drozov E.V., Zayakin V.V., Nam I.Ya. Allelic polymorphism of the *PIT-1* gene in cattle herds of the Bryansk region and its association with milk production // Izvestia of Samara Scientific Center of the Russian Academy of Sciences, 2011, vol. 13, N 5-3, pp. 235–240.

⁵Kalashnikova L.A., Khabibrakhmanova A.Ya., Pavlova I.Yu., Ganchenkova T.B., Dunin N.M., Pridanovich I.E. Recommendations on the genomic evaluation of cattle // Lesnye Polyany, 2015, 33 p.

terms of total amount, the heterozygous and homozygous *CSN3AA* genotypes were in the lead. Cows with these genotypes had higher totals in their second lactation by 49.2 and 63.6 kg, respectively ($p < 0,001$). By the third lactation, the differences between them were 62.5 and 44.7 kg, respectively ($p < 0,001$, $p < 0,01$).

Similar conclusions were reached in studies [12] on cows of several groups: purebred local and Austrian Simmentals, as well as those improved with the Holstein breed. Jersey cows with the *CSN3BB* genotype stand out for their higher protein-milk content (3.93%), while heterozygous cows have the highest milk yield [5]. In a comparative analysis of several breeds, no clear results were obtained, but an increase

in milk yield in Holstein cows was influenced by the *CSN3AA* genotype, while in Simmental cows, the *CSN3BB* genotype had a positive effect on milk fat content [13].

When analyzing the associative link of *BLG* gene genotypes, it was also found that cows with the *BLGAA* genotype had higher milk yield, total fat, and protein content in both the first and third lactations (see Table 2). In the first lactation, cows with the *BLGAA* genotype outperformed *BLGBB* animals by 1,132.2 kg ($p < 0,01$). Heterozygous cows for this gene also outperformed the homozygous ones for the *BLGB* allele by 1054.4 kg ($p < 0,05$). The fat and protein content in cows with different genotypes didn't show any significant differences, but the amount of milk

Табл. 1. Продуктивность коров симментальской породы за 305 дней лактации в зависимости от носительства генотипа по гену *CSN3*

Table 1. Productivity of Simmental cows over 305 days of lactation depending on the genotype carrier status for the *CSN3* gene

Indicator	Genotype		
	<i>CSN3AA</i>	<i>CSN3AB</i>	<i>CSN3BB</i>
<i>First lactation</i>			
<i>n</i>	36	41	9
Yield, kg	6558,5 ± 194,5	6819,0 ± 183,1	6480,8 ± 623,0
Fat, %	4,17 ± 0,01	4,16 ± 0,01	4,17 ± 0,02
Fat, kg	273,7 ± 8,1	283,9 ± 7,57	270,6 ± 26,6
Protein, %	3,22 ± 0,00	3,22 ± 0,00	3,20 ± 0,02
Protein, kg	211,4 ± 6,3	222,0 ± 5,6	208,2 ± 20,4
<i>Second lactation</i>			
<i>n</i>	25	24	5
Yield, kg	7007,0 ± 208,0	7456,6 ± 303,8	5485,4 ± 339,1
Fat, %	4,13 ± 0,01	4,14 ± 0,01	4,11 ± 0,02
Fat, kg	289,6 ± 8,7	309,5 ± 12,8	225,5 ± 15,1
Protein, %	3,22 ± 0,00	3,22 ± 0,00	3,22 ± 0,00
Protein, kg	225,8 ± 6,7	240,2 ± 9,8	176,6 ± 11,0
<i>Third lactation and older</i>			
<i>n</i>	32	29	15
Yield, kg	8313,3 ± 255,3	7763,8 ± 391,2	6376,5 ± 260,9
Fat, %	4,16 ± 0,01	4,16 ± 0,01	4,12 ± 0,02
Fat, kg	346,4 ± 10,9	323,4 ± 16,6	262,9 ± 11,1
Protein, %	3,22 ± 0,00	3,22 ± 0,00	3,22 ± 0,00
Protein, kg	268,0 ± 8,2	250,2 ± 12,6	205,5 ± 8,4

Табл. 2. Продуктивность коров симментальской породы за 305 дней лактации в зависимости от носительства генотипа по гену *BLG*

Table 2. Productivity of cows over 305 days of lactation depending on the genotype carrier status for the *BLG* gene

Indicator	Genotype		
	<i>BLGAA</i>	<i>BLGAB</i>	<i>BLGBB</i>
<i>First lactation</i>			
<i>n</i>	34	42	10
Yield, kg	6844,2 ± 172,8	6766,4 ± 197,4	5712,0 ± 484,0
Fat, %	4,18 ± 0,01	4,16 ± 0,01	4,19 ± 0,04
Fat, kg	285,8 ± 7,2	281,5 ± 8,3	238,7 ± 19,3
Protein, %	3,22 ± 0,00	3,22 ± 0,00	3,21 ± 0,02
Protein, kg	220,6 ± 5,6	220,1 ± 6,1	183,7 ± 15,7
<i>Second lactation</i>			
<i>n</i>	19	25	10
Yield, kg	7460,5 ± 359,7	6908,5 ± 220,8	6709,8 ± 436,0
Fat, %	4,14 ± 0,01	4,13 ± 0,01	4,12 ± 0,02
Fat, kg	309,5 ± 15,1	285,7 ± 9,3	277,2 ± 18,8
Protein, %	3,22 ± 0,00	3,22 ± 0,00	3,22 ± 0,00
Protein, kg	240,4 ± 11,6	222,5 ± 7,2	216,2 ± 14,1
<i>Third lactation and older</i>			
<i>n</i>	15	38	23
Yield, kg	8453,1 ± 400,6	7721,9 ± 307,4	7243,4 ± 349,5
Fat, %	4,17 ± 0,01	4,16 ± 0,01	4,13 ± 0,02
Fat, kg	353,0 ± 16,9	321,6 ± 12,9	299,6 ± 15,2
Protein, %	3,22 ± 0,00	3,22 ± 0,00	3,22 ± 0,00
Protein, kg	272,5 ± 12,9	248,9 ± 9,9	233,5 ± 11,3

fat and protein varied by 42.8–47.1 and 36.4–36.9 kg in favor of the *BLGAA* and *BLGAB* genotypes, respectively ($p < 0,05$).

In the third lactation, differences in milk yield, total fat, and protein content were found only between the *BLGAA* and *BLGBB* genotypes. Cows with the *BLGAA* genotype outperformed those with the *BLGBB* genotype by 1,209.7 kg in milk yield, 53.4 kg in milk fat, and 39.0 kg in milk protein ($p < 0,05$).

Comparison with the literature data showed some contradictions. According to [5], higher milk yield in Jersey cows was noted in animals with the heterozygous *BLGAB* genotype, while the lowest was in those with the *BLGBB* genotype. Cows with the *BLGBB* genotype were characterized by high milk fat, whereas the highest protein content was in cows with the *BLGAB* genotype. The same dependence has been found in the Holstein breed. Higher levels of fat, protein, SOMO, and dry matter were observed in Holstein cows with the *BLGAB* genotype [14]. It's worth noting that study [15] didn't find any significant differences between *BLG* gene genotypes in the milk quality of Black-and-White cows.

The *SCD1* gene, which is linked to cholesterol levels in cow blood, had a weak effect on milk production and milk quality during the first and second lactations, except for the fat content. Higher levels were noted in cows with the *SCDITT* genotype – 4.15%, which is 0.03% higher than in cows with the *SCDICC* genotype ($p < 0.05$) (see Table 3). It should be noted that in the third lactation and beyond, cows with the *SCDITT* genotype outperformed their peers with other genotypes in milk yield by 1271.9–1349.7 kg ($p < 0.05$), fat content by 0.03 and 0.04% ($p < 0.05$), milk fat by 54.9–58.5 kg ($p < 0.01$), and milk protein by 41.0–43.6 kg ($p < 0,05$).

The association between *SCD1* gene genotypes and milk production and quality hasn't been studied as much as protein metabolism genes, probably because they have a weaker effect on these traits. However, it has been found

Табл. 3. Продуктивность коров симментальской породы за 305 дней лактации в зависимости от носительства генотипа по гену *SCD1*

Table 3. Productivity of cows over 305 days of lactation depending on the genotype carrier status for the *SCD1* gene

Indicator	Genotype		
	<i>SCDICC</i>	<i>SCDITC</i>	<i>SCDITT</i>
<i>First lactation</i>			
<i>n</i>	26	42	18
Yield, kg	6531,5 ± 229,4	6690,1 ± 216,7	6844,9 ± 229,6
Fat, %	4,17 ± 0,01	4,17 ± 0,01	4,17 ± 0,01
Fat, kg	272,4 ± 9,7	278,6 ± 8,9	285,7 ± 9,7
Protein, %	3,22 ± 0,00	3,22 ± 0,00	3,22 ± 0,00
Protein, kg	213,7 ± 6,9	215,5 ± 7,0	220,6 ± 7,4
<i>Second lactation</i>			
<i>n</i>	16	27	11
Yield, kg	7213,1 ± 339,3	6853,7 ± 250,6	7372,8 ± 438,5
Fat, %	4,12 ± 0,01	4,14 ± 0,01	4,15 ± 0,01
Fat, kg	298,0 ± 14,5	283,6 ± 10,4	306,5 ± 18,8
Protein, %	3,22 ± 0,00	3,22 ± 0,00	3,22 ± 0,00
Protein, kg	232,2 ± 11,0	220,8 ± 8,1	237,6 ± 14,1
<i>Third lactation and older</i>			
<i>п</i>	25	36	15
Yield, kg	7507,2 ± 355,7	7429,4 ± 280,2	8779,1 ± 467,1
Fat, %	4,15 ± 0,01	4,14 ± 0,01	4,18 ± 0,01
Fat, kg	312,0 ± 14,9	308,4 ± 12,1	366,9 ± 19,6
Protein, %	3,22 ± 0,00	3,22 ± 0,00	3,22 ± 0,00
Protein, kg	242,0 ± 11,5	239,4 ± 9,0	283,0 ± 15,0

that the *C* alleles of the *SCD1* gene have a bigger impact on milk fat and fatty acid content. Holsteinized Black-and-White cows with the *CT* and *CC* genotypes of the *SCD1* gene outperformed those with the *TT* genotype [16].

When analyzing the associative links of the *Pit1* gene with major economically valuable traits, the results for lactations were mixed (see Table 4). In the first lactation, higher milk yield was observed in cows with the *Pit1BB* genotype – 6,931.9 kg, which is 716.8 kg more than in first-calf heifers with the *Pit1AB* genotype ($p < 0,05$). The milk fat content was also higher in these animals by 30.2 kg ($p < 0.05$). In addition, first-time heifers with the *Pit1BB* genotype had

Табл. 4. Продуктивность коров симментальской породы за 305 дней лактации в зависимости от носительства генотипа по гену *Pit1***Table 4.** Productivity of Simmental cows over 305 days of lactation depending on the genotype carrier status for the *Pit1* gene

Indicator	Genotype		
	<i>Pit1AA</i>	<i>Pit1AB</i>	<i>Pit1BB</i>
<i>First lactation</i>			
<i>n</i>	5	31	50
Yield, kg	6949,8 ± 334,5	6215,1 ± 231,2	6931,9 ± 169,1
Fat, %	4,18 ± 0,02	4,16 ± 0,01	4,17 ± 0,01
Fat, kg	290,6 ± 14,5	258,8 ± 9,6	289,0 ± 7,0
Protein, %	3,22 ± 0,00	3,22 ± 0,00	3,22 ± 0,00
Protein, kg	223,9 ± 10,8	202,4 ± 7,4	223,4 ± 5,4
<i>Second lactation</i>			
<i>n</i>	4	22	28
Yield, kg	7795,0 ± 443,1	6735,5 ± 256,3	7221,4 ± 275,9
Fat, %	4,18 ± 0,02	4,12 ± 0,01	4,14 ± 0,01
Fat, kg	325,8 ± 19,4	277,9 ± 10,8	299,2 ± 11,6
Protein, %	3,22 ± 0,00	3,22 ± 0,00	3,2 ± 0,00
Protein, kg	251,2 ± 14,4	216,9 ± 8,3	232,7 ± 8,9
<i>Third lactation and older</i>			
<i>n</i>	5	45	26
Yield, kg	9694,4 ± 642,0	7242,6 ± 236,3	8170,6 ± 367,5
Fat, %	4,20 ± 0,01	4,14 ± 0,01	4,18 ± 0,00
Fat, kg	406,7 ± 26,3	300,0 ± 10,1	341,3 ± 15,4
Protein, %	3,23 ± 0,00	3,22 ± 0,00	3,22 ± 0,00
Protein, kg	312,6 ± 20,6	233,4 ± 7,6	263,4 ± 11,8

a higher milk protein content by 21.0 kg compared to their peers with the *Pit1AB* genotype ($p < 0,05$).

In the second and third lactations, the homozygous variant of the *Pit1AA* gene became the priority genotype, outperforming the heterozygous *Pit1AB* genotype in milk yield by 1,059.5 kg ($p < 0.05$). The superiority over heterozygotes of this gene was also noted in fat content by 0.06%, milk fat by 47.9 kg, and milk protein by 34.3 kg ($p < 0,05$).

In the third lactation, the established pattern persisted. Cows with the *Pit1AA* genotype had

higher values for all the traits considered compared to the *Pit1AB* heterozygotes. For example, milk yield was higher by 2,451.8 kg, fat content by 0.06%, milk fat by 106.7 kg, protein content by 0.01%, and milk protein by 79.2 kg ($p < 0,001$). It was also found that cows with the *Pit1BB* genotype exceeded those with *Pit1AB* in these indicators: by 928.0 kg in milk yield, by 41.3 kg in milk fat content, and by 30 kg in milk protein ($p < 0,05$).

Similar results were obtained in Jersey cows. Higher milk yield and fat content were found in cows with the *Pit1AA* genotype, but for protein content and milk protein, the *Pit1AB* genotype was the most favorable [17]. Research⁶ conducted on the Black-and-White breed in the Stavropol region also supports the priority of the *Pit1AA* and *Pit1AB* genotypes.

Our study found the influence of certain genotypes on the reproductive traits of Simmental cows (see Table 5). For instance, a shorter dry period (45 days) was observed in cows after their first lactation with the *CSN3BB* genotype, which is 13.8–14.7 days shorter than in animals with other genotypes ($p < 0,05$). The shortest service period was also noted in cows with the *CSN3BB* genotype, while, on the contrary, the longer service period was in heterozygotes – 124.6 days. The 43-day difference reaches the threshold of significance ($p < 0,05$).

Cows with the *BLGAB* genotype had the longest service period after their first lactation – 107.2 days, which is 32.2 days longer than cows with the *BLGBB* genotype ($p < 0.01$). Variation in the dry period was noted among cows with different *Pit1* genotypes. A shorter dry period was observed in cows with the *Pit1BB* genotype – 60.5 days compared to 67.6 days in cows with the *Pit1AA* genotype ($p < 0,05$). At the same time, the service period for the third lactation and older was shortest in cows with the *Pit1AA* genotype – 73.8 days, while for *Pit1BB* it was around 116 days, and a bit less – 101.8 days – for

⁶Mikhailenko T.N., Selionova M.I., Surzhikova E.S. Milk productivity of Black-and-White cows with different genotypes at the *PIT-1* and *PRL* gene loci // News of Science in the Agro-Industrial Complex, 2018, N 2, pp. 190–194. DOI: 10.25930/e31p-8q49.

Табл. 5. Воспроизводительные качества коров в зависимости от генотипов генов *CSN3*, *BLG*, *LEP*, *ORL*, *SCD1*, *Pit1*

Table 5. Reproductive traits of cows depending on the genotypes of the *CSN3*, *BLG*, *LEP*, *ORL*, *SCD1*, *Pit1* genes

Genotype	Dry period, days		Service period, days		
	Lactation				
	Second	Third and older	First	Second	Third and older
<i>CSN3AA</i>	59,7 ± 2,3	60,6 ± 1,4	92,9 ± 7,4	102,8 ± 12,1	99,7 ± 9,7
<i>CSN3AB</i>	58,8 ± 1,0	63,1 ± 1,2	107,0 ± 8,9	103,4 ± 9,8	124,6 ± 14,5
<i>CSN3BB</i>	45,0 ± 6,9	64,7 ± 1,9	88,9 ± 14,3	88,2 ± 21,5	81,6 ± 10,7
<i>BLGAA</i>	58,6 ± 2,1	62,0 ± 1,7	96,6 ± 8,1	103,3 ± 12,3	113,4 ± 18,9
<i>BLGAB</i>	58,3 ± 1,5	62,8 ± 1,1	107,2 ± 8,7	95,6 ± 10,5	102,2 ± 7,6
<i>BLGBB</i>	57,7 ± 5,3	61,5 ± 2,1	75,0 ± 8,0	115,9 ± 19,6	104,4 ± 15,9
<i>SCD1CC</i>	61,3 ± 2,8	61,8 ± 1,4	88,3 ± 8,2	109,6 ± 15,5	92,7 ± 9,1
<i>SCD1CT</i>	57,8 ± 1,6	61,8 ± 1,4	103,1 ± 8,0	100,8 ± 10,5	119,0 ± 12,3
<i>SCD1TT</i>	55,6 ± 2,5	64,2 ± 1,7	104,0 ± 13,5	93,5 ± 12,7	88,7 ± 10,6
<i>Pit1AA</i>	57,8 ± 1,3	67,6 ± 3,1	119,6 ± 25,6	108,5 ± 29,3	73,8 ± 8,6
<i>Pit1AB</i>	59,2 ± 2,8	62,9 ± 1,4	89,0 ± 8,6	109,0 ± 13,1	101,8 ± 9,4
<i>Pit1BB</i>	57,8 ± 1,27	60,5 ± 0,9	103,1 ± 7,2	96,6 ± 9,4	116,0 ± 13,1

heterozygotes of this gene. The difference was 28.0–42.2 days ($p < 0,05$, $p < 0,01$).

Comparing our results with the literature shows that they are contradictory. For instance, researchers considered the *Pit1AB* genotype of the *Pit1* gene to be the desirable one, as cows of the Holstein breed with this genotype have the shortest calving interval and dry periods compared to the alternative genotypes [18].

CONCLUSIONS

1. In the Simmental herd, for each of the studied genes *CSN3*, *BLG*, *SCD1*, and *Pit1*, genotypes were identified that have a positive effect on milk productivity, the quality composition of milk, and some reproductive performance indicators. Cows with the genotypes *CSN3AA*, *CSN3AB*, *BLGAA*, *BLGAB*, *SCD1TT*, *Pit1AA* showed higher milk yields, with differences between individual lactations for alternative genotypes reaching 2,451.8 kg. The highest milk yield was observed in full-grown cows (third lactation and older), among which the top performers were animals with the genotypes *CSN3AA* – 8,313.3 kg, *BLGAA* – 8,453.1 kg, *SCD1TT* – 8,779.1 kg, and *Pit1AA* – 9,694.4 kg.

The obtained data can be used when selecting animals for the breeding group.

2. The variability in the fat content of milk is small: 4.12–4.20%. The highest levels were observed in cows with the *BLGBB* and *SCD1TT* genotypes – 4.19% and *Pit1AA* – 4.20%. There's also low variability in protein content in milk among cows with different genotypes – 3,20–3,22%.

3. The dry period and service period in the Simmental cows of the analyzed herd corresponded to physiological norms. Cows with lower milk production had the shortest dry period – 45 days – and the service period between lactations 81,6– 88,9 days (*CSN3BB*). More productive cows had longer rest periods – from 107.2 (*BLGBB*) to 119.6 days (*Pit1AA*).

СПИСОК ЛИТЕРАТУРЫ

1. Кручинин А.Г., Большакова Е.И. Особенности молекулярно-массового фракционирования молока, полученного от коров с полиморфизмом гена *CSN3* // Пищевая промышленность. 2022. № 2. С. 32–35. DOI: 10.52653/PPI.2022.2.2.007.

2. Глотова Г.Н., Позолотина В.А. Действие аллельных вариантов гена *CSN3* молока на его состав и физико-химические показатели при переработке творога // Вестник Рязанского государственного агротехнологического университета им. П.А. Костычева. 2021. Т. 13. № 2. С. 14–19. DOI: 10.36508/RSATU.2021.50.2.002.
3. Панин В.А. Оценка генотипа по генам *CSN3* и *LGB*, влияющим на синтез молочного белка и жира в молоке симментальских коров // Известия Оренбургского государственного аграрного университета. 2020. Т. 81. № 1. С. 197–201.
4. Панин В.А. Молокопродуктивность симментальских коров в условиях степной зоны Оренбургской области // Известия Оренбургского государственного аграрного университета. 2020. Т. 82. № 2. С. 247–251. DOI: 10.37670/2073-0853-2020-82-2-247-251.
5. Зиннатов Ф.Ф., Тюлькин С.В., Ахметов Т.М., Якупов Т.Р., Зиннатова Ф.Ф., Николаева К.Ю., Зарубежнова Д.В. Характерные особенности влияния генов белкового обмена на показатели качества молока коров джерсейской породы // Ученые записки Казанской государственной академии ветеринарной медицины им. Н.Э. Баумана. 2024. Т. 257. № 1. С. 98–104. DOI: 10.31588/2413_4201_1883_1_257_98.
6. Лиходеевская О.Е., Горелик О.В., Лиходеевский Г.А. Исследование генов, ассоциированных с молочной продуктивностью черно-пестрого скота // Известия Оренбургского государственного аграрного университета. 2021. Т. 87. № 1. С. 279–284.
7. Гильманов Х.Х., Тюлькин С.В., Ржанова И.В., Вафин Р.Р. Характеристика быков-производителей с комплексными генотипами генов *BLG* и *INOS* по молочной продуктивности женских предков // Ученые записки Казанской академии ветеринарной медицины им. Н.Э. Баумана. 2020. Т. 241. № 1. С. 71–75. DOI: 10.31588/2413-4201-1883-241-1-71-76.
8. Зиннатов Ф.Ф., Ахметов Т.М., Чевтаева Н.Д., Стафикопуло М.А., Горева Э.Р. Идентификация и анализ полиморфизма генов белкового обмена у коров голштинской породы // Вестник Марийского государственного университета. 2024. Т. 10. № 1. С. 17–26.
9. Зиннатов Ф.Ф., Якупов Т.Р., Зиннатова Ф.Ф., Ахметов Т.М., Овсянников А.П., Чевтаева Н.Д. Взаимосвязь генов *LEP*, *TG5*, *SCD1* с жирномолочностью коров // Ученые записки Казанской государственной академии ветеринарной медицины им. Н.Э. Баумана. 2022. Т. 250. № 2. С. 85–92. DOI: 10.31588/2413_4201_1883_2_250_85.
10. Лейбова В.Б., Позовникова М.В. Биохимический профиль крови в послелетельный период у коров-первотелок в связи с полиморфными вариантами гена *SCD1* и репродуктивной способностью // Аграрный вестник Урала. 2020. Т. 195. № 4. С. 56–63.
11. Лейбова В.Б., Позовникова М.В. Биохимический статус коров сухостойного периода в связи с полиморфными вариантами гена (*SCD1*) и репродуктивным потенциалом // Известия Тимирязевской сельскохозяйственной академии. 2021. № 1. С. 78–86.
12. Фолин П.Ю., Гладырь Е.А., Ламонов С.А., Скоркина И.А. Полиморфизм гена каппа-казеина у коров симментальской породы и показатели их молочной продуктивности за первую лактацию // Вестник Мичуринского государственного аграрного университета. 2023. Т. 73. № 2. С. 160–163.
13. Гатилова Е.В., Ефимова Л.В., Иванова О.В. Встречаемость генотипов каппа-казеина и их влияние на молочную продуктивность коров разных пород // Вестник АПК Ставрополя. 2020. Т. 40. № 4. С. 42–47.
14. Фаттахова З.Ф., Сафина Н.Ю., Гайнутдинова Э.Р., Шакиров Ш.К. Ассоциация полиморфизма гена β -лактоглобулин с биохимическими показателями крови и качественным составом молока голштинского скота // Аграрный научный журнал. 2022. № 10. С. 93–96. DOI: 10.28983/asj.y2022i10pp93-96.
15. Парамонова М.А., Валитов Ф.Р. Роль генов каппа-казеина (*CSN3*), бета-казеина (*CSN2*), бета-лактоглобулина (*BLG*) и альфа-лактальбумина (*LALBA*) в формировании молочной продуктивности коров черно-пестрой породы // Ученые записки Казанской академии ветеринарной медицины им. Н.Э. Баумана. 2025. Т. 262. № 2. С. 105–110. DOI: 10.31588/2413_4201_1883_2_262_105.
16. Зарипов О.Г. Влияние полиморфизмов генов *SCD1* (СТЕРОЛ-КоА ДЕСАТУРАЗА) И *AGPAT6* (1-АЦИЛГЛИЦЕРИН-3-ФОСФАТ-О-АЦИЛТРАНСФЕРАЗА) на содержание и жирнокислотный состав молочного жира у коров голштинизированной черно-пестрой породы // Международный научно-исследовательский журнал. 2023. Т. 137. № 11. DOI: 10.23670/IRJ.2023.137.148.

17. Зарубежная Д.В. Молочная продуктивность коров джерсейской породы с разными генотипами *PIT1*, *GH* // Ученые записки Казанской академии ветеринарной медицины им. Н.Э. Баумана. 2025. Т. 263. № 3. С. 119–123. DOI: 10.31588/2413_4201_1883_3_263_119.
18. Гайнутдинова Е.Р., Сафина Н.Ю., Зиннатова Ф.Ф., Шакиров Ш.К. Связь полиморфизма гена *PIT-1* (*POU1F1*) с признаками молочной продуктивности и воспроизводительной способности голштинского крупного рогатого скота // Достижения науки и техники АПК. 2019. Т. 33. № 11. С. 69–73. DOI: 10.24411/0235-2451-2019-11115.

REFERENCES

1. Kruchinin A.G., Bol'shakova E.I. Peculiarities of molecular weight fractionation of milk obtained from cows with *CSN3* gene polymorphism. *Pishchevaya promyshlennost' = Food Industry*, 2022, no. 2, pp. 32–35. (In Russian). DOI: 10.52653/PPI.2022.2.2.007.
2. Glotova G.N., Pozolotina V.A. The effect of allelic variants of the *CSN3* gene of milk on its composition and physico-chemical parameters in the production of cottage cheese. *Vestnik Ryazanskogo gosudarstvennogo agrotekhnologicheskogo universiteta im. P.A. Kostycheva = Herald of Ryazan State Agrotechnological University named after P.A. Kostychev*, 2021, vol. 13, no. 2, pp. 14–19. (In Russian). DOI: 10.36508/RSATU.2021.50.2.002.
3. Panin V.A. The genotype assessment by the *CSN3* and *LGB* genes, affecting the synthesis of milk protein and fat in the milk of Simmental cows. *Izvestiya Orenburgskogo gosudarstvennogo agrarnogo universiteta = Izvestia Orenburg State Agrarian University*, 2020, vol. 81, no. 1, pp. 197–201. (In Russian).
4. Panin V.A. Milk yields of Simmental cows in the conditions of the steppe zone of Orenburg region. *Izvestiya Orenburgskogo gosudarstvennogo agrarnogo universiteta = Izvestia Orenburg State Agrarian University*, 2020, vol. 82, no. 2, pp. 247–251. (In Russian). DOI: 10.37670/2073-0853-2020-82-2-247-251.
5. Zinnatov F.F., Tyul'kin S.V., Akhmetov T.M., Yakupov T.R., Zinnatova F.F., Nikolaeva K.Yu., Zarubezhnova D.V. Characteristic features of the effect of protein metabolism genes on milk quality indicators of Jersey cows. *Uchenye zapiski Kazanskoi akademii veterinarnoi meditsiny im. N.E. Bauman = Scientific Notes of the Kazan Academy of Veterinary Medicine named after N.E. Bauman*, 2024, vol. 257, no. 1, pp. 98–104. (In Russian). DOI: 10.31588/2413_4201_1883_1_257_98.
6. Likhodeevskaya O.E., Gorelik O.V., Likhodeevsky G.A. Research of genes associated with dairy productivity of Black-Potted cattle. *Izvestiya Orenburgskogo gosudarstvennogo agrarnogo universiteta = Izvestia Orenburg State Agrarian University*, 2021, vol. 87, no. 1, pp. 279–284. (In Russian).
7. Gilmanov Kh.Kh., Tyulkin S.V., Rzhanova I.V., Vafin R.R. Characteristics of bull-producers with complex genotypes genes of *BLG* and *INOS* by milk productivity of female ancestors. *Uchenye zapiski Kazanskoi akademii veterinarnoi meditsiny im. N.E. Bauman = Scientific Notes of the Kazan Academy of Veterinary Medicine named after N.E. Bauman*, 2020, vol. 241, no. 1, pp. 71–75. (In Russian). DOI: 10.31588/2413-4201-1883-241-1-71-76.
8. Zinnatov F.F., Akhmetov T.M., Chevtayeva N.D., Stafikopulo M.A., Goreva E.R. Identification and analysis of polymorphism of protein metabolism genes in Holstein cows. *Vestnik Mariiskogo gosudarstvennogo universiteta = Vestnik of the Mari State University*, 2024, vol. 10, no. 1, pp. 17–26. (In Russian).
9. Zinnatov F.F., Yakupov T.R., Zinnatova F.F., Akhmetov T.M., Ovsyannikov A.P., Chevtayeva N.D. Relationship of *LEP*, *TG5*, and *SCD1* genes with milk fat in cows. *Uchenye zapiski Kazanskoi akademii veterinarnoi meditsiny im. N.E. Bauman = Scientific Notes of the Kazan Academy of Veterinary Medicine named after N.E. Bauman*, 2022, vol. 250, no. 2, pp. 85–92. (In Russian). DOI: 10.31588/2413_4201_1883_2_250_85.
10. Leibova V.B., Pozovnikova M.V. Postpartum blood biochemical profile in heifers in connection with polymorphic variants of the *SCD1* gene and reproductive ability. *Agrarnyi vestnik Urala = Agrarian Bulletin of the Urals*, 2020, vol. 195, no. 4, pp. 56–63. (In Russian).
11. Leibova V.B., Pozovnikova M.V. Biochemical status of cows of the interlactation period relative to polymorphic variants of the *SCD1* gene and reproductive performance. *Izvestiya Timiryazevskoi sel'skokhozyaistvennoi akademii = Izvestiya of Timiryazev Agricultural Academy*, 2021, no. 1, pp. 78–86. (In Russian).
12. Folin P.Yu., Gladyr' E.A., Lamonov S.A., Skorkina I.A. Polymorphism of the kappa-casein gene in Simmental cows and indicators of their milk productivity during the first lacta-

- tion. *Vestnik Michurinskogo gosudarstvennogo agrarnogo universiteta* = *Bulletin of Michurinsk State Agrarian University*, 2023, vol. 73, no. 2, pp. 160–163. (In Russian).
13. Gatilova E.V., Efimova L.V., Ivanova O.V. Kappa-casein genotypes frequency and their effect on milk production in cows of different breeds. *Vestnik APK Stavropol'ya* = *Agricultural Bulletin of Stavropol Region*, 2020, vol. 40, no. 4, pp. 42–47. (In Russian).
14. Fattakhova Z.F., Safina N.Yu., Gainutdinova E.R., Shakirov Sh.K. Association of β -lactoglobulin gene polymorphism with biochemical parameters of blood and qualitative composition of milk of Holstein cattle. *Agrarnyi nauchnyi zhurnal* = *Agrarian Scientific Journal*, 2022, no. 10, pp. 93–96. (In Russian). DOI: 10.28983/asj.y2022i10pp93-96.
15. Paramonova M.A., Valitov F.R. The role of kappa-casein (CSN3), beta-casein (CSN2), beta-lactoglobulin (BLG) and alpha-lactalbumin (LALBA) genes in the formation of milk productivity of Black-and-White cows. *Uchenye zapiski Kazanskoi akademii veterinarnoi meditsiny im. N.E. Bauman* = *Scientific Notes of the Kazan Academy of Veterinary Medicine named after N.E. Bauman*, 2025, vol. 262, no. 2, pp. 105–110. (In Russian). DOI: 10.31588/2413_4201_1883_2_262_105.
16. Zaripov O.G. Influence of SCD1 (sterol-coa desaturase) and AGPAT6 (1-acylglycerol-3-phosphate-o-acyltransferase) genes polymorphisms on content and fat composition of milk fat in Holsteinized Black-and-White cows. *Mezhdunarodnyi nauchno-issledovatel'skii zhurnal* = *International Research Journal*, 2023, vol. 137, no. 11. (In Russian). DOI: 10.23670/IRJ.2023.137.148.
17. Zarubezhnova D.V. Milk productivity of Jersey cows with different PIT1, GH genotypes. *Uchenye zapiski Kazanskoi akademii veterinarnoi meditsiny im. N.E. Bauman* = *Scientific Notes of the Kazan Academy of Veterinary Medicine named after N.E. Bauman*, 2025, vol. 263, no. 3, pp. 119–123. (In Russian). DOI: 10.31588/2413_4201_1883_3_263_119.
18. Gainutdinova E.R., Safina N.Yu., Zinnatova F.F., Shakirov Sh.K. Relationship between PIT-1 (POU1F1) gene polymorphism with milk productivity and reproductive capacity of Holstein cattle. *Dostizheniya nauki I tekhniki APK* = *Achievements of Science and Technology of AIC*, 2019, vol. 33, no. 11, pp. 69–73. (In Russian). DOI: 10.24411/0235-2451-2019-11115.

ИНФОРМАЦИЯ ОБ АВТОРАХ

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Антимикробная резистентность и чувствительность к бактериофагам штаммов зоопатогенных *Moraxella* spp., выделенных в Центральном регионе России

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Инфекционный кератоконъюнктивит крупного рогатого скота, вызываемый преимущественно бактериями рода *Moraxella* spp., представляет серьезную экономическую проблему в животноводстве. Глобальной угрозой является рост антимикробной резистентности возбудителей, что снижает эффективность терапии. В Российской Федерации данные о профилях резистентности *Moraxella* spp. ограничены, что затрудняет разработку адекватных протоколов лечения. Цель исследования – охарактеризовать профили антимикробной резистентности и оценить чувствительность к бактериофагам клинических штаммов *Moraxella* spp., выделенных от крупного рогатого скота с признаками инфекционного кератоконъюнктивита в Центральном регионе России. В период с апреля по июль 2025 г. в хозяйствах Московской и Владимирской областей было отобрано 35 проб конъюнктивальных смывов от 26 животных с клиническими проявлениями заболевания. Выделение культур проводили на 10%-м кровяном агаре. Идентификацию изолятов осуществляли на основании культурально-морфологических свойств, биохимических тестов (оксидаза, каталаза) и масс-спектрометрии. Чувствительность к 11 антимикробным препаратам определяли диско-диффузионным методом. Литическую активность четырех штаммов бактериофагов оценивали методом спот-теста. Из исследованных проб было выделено и идентифицировано два изолята – *M. bovis* и *M. bovoculi*. Оба штамма продемонстрировали фенотип множественной лекарственной устойчивости, проявив полную резистентность к β-лактамам (пенициллин, ампициллин, флоксациллин, цефалотин), тетрациклинам (тетрациклин, окситетрациклин), сульфаниламидам (сульфадиазин) и макролидам (эритромицин). Сохранилась чувствительность к фторхинолонам (ципрофлоксацин) и аминогликозидам (канамицин, гентамицин). В отношении штамма *M. bovis* литическую активность проявили три из четырех исследованных бактериофагов (vB_MboC_M3; vB_Mbo_W17; vB_Mbo_R2), штамм *M. bovoculi* был чувствителен к двум фагам (vB_MboC_M3; vB_Mbo_W17). Результаты исследования указывают на циркуляцию в Центральной России штаммов *Moraxella* spp. с множественной лекарственной устойчивостью к антибиотикам первой линии, что может являться причиной неэффективности стандартной эмпирической терапии. Проявленная *in vitro* эффективность специфических бактериофагов в отношении мультирезистентных изолятов свидетельствует о потенциале фаготерапии как альтернативной стратегии для контроля данного заболевания.

Ключевые слова: инфекционный кератоконъюнктивит, антибиотикорезистентность, *Moraxella bovis*, *Moraxella bovoculi*, фаготерапия

Antimicrobial resistance and sensitivity to bacteriophages of zoopathogenic *Moraxella* spp. strains isolated in the Central region of Russia

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Infectious keratoconjunctivitis in cattle, primarily caused by the bacteria from the genus *Moraxella* spp., poses a significant economic challenge in the field of animal husbandry. A global threat is the growth of antimicrobial resistance in pathogens, which reduces the effectiveness of

therapy. In the Russian Federation, data concerning the resistance profiles of *Moraxella* species are limited, which hinders the development of adequate treatment protocols. The objective of the study was to characterize the antimicrobial resistance profiles and evaluate the sensitivity to bacteriophages of the clinical strains of *Moraxella* spp. isolated from cattle with signs of infectious keratoconjunctivitis in the Central region of Russia. From April to July of 2025, a total of 35 conjunctival lavage samples were collected from 26 animals exhibiting clinical indications of the disease on the farms located in the Moscow and Vladimir regions. Isolation of the cultures was carried out on 10% blood agar. Identification of the isolates was conducted through the examination of cultural and morphological characteristics, the implementation of biochemical tests (e.g., oxidase, catalase), and mass spectrometry. The degree of sensitivity to 11 antimicrobial agents was ascertained by the disc diffusion method. The lytic activity of four bacteriophage strains was evaluated by the spot test method. Two isolates were identified from the samples studied: *M. bovis* and *M. bovoculi*. Both strains exhibited a multi-drug resistance (MDR) phenotype, indicating complete resistance to β -lactams (penicillin, ampicillin, cloxacillin, cephalothin), tetracyclines (tetracycline, oxytetracycline), sulfonamides (sulfadiazine), and macrolides (erythromycin). Sensitivity to fluoroquinolones (ciprofloxacin) and aminoglycosides (kanamycin, gentamicin) was preserved. Three of the four bacteriophages studied (vB_Mboc_M3; vB_Mbo_W17; vB_Mbo_R2) exhibited lytic activity against the *M. bovis* strain; the *M. bovoculi* strain was sensitive to two phages (vB_Mboc_M3; vB_Mbo_W17). The findings of the study suggest the circulation of *Moraxella* spp. strains with MDR to first-line antibiotics in the Central region of Russia, which may be the underlying cause of the ineffectiveness of standard empirical therapy. The demonstrated *in vitro* efficacy of specific bacteriophages against multidrug-resistant isolates indicates the potential of phage therapy as an alternative strategy for controlling this disease.

Keywords: infectious keratoconjunctivitis, antibiotic resistance, *Moraxella bovis*, *Moraxella bovoculi*, phage therapy

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Conflict of interest

The authors declare no conflict of interest.

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INTRODUCTION

Infectious keratoconjunctivitis (IKC) is one of the most common and economically significant diseases of cattle worldwide. The disease causes considerable economic damage to the livestock industry, leading to reduced weight gain in young animals, decreased milk production in cows, and sometimes culling of animals due to irreversible eye damage (up to blindness), and so on [2].

The main causative agents of IKC are recognized as bacteria of the genus *Moraxella* spp. [3]. *M. bovis* is considered the primary pathogen, capable of causing the disease on its own due to virulence factors like type IV pili for adhering to the cornea and the RTX cytotoxin, which causes lysis of epithelial cells and neutrophils, leading to the characteristic corneal ulceration [4–6]. The role of *M. bovoculi* in the pathogenesis of IKC is not fully understood. Although bacteria of this

species are often isolated from the eyes of not only sick but also healthy animals, their presence is associated with more severe disease [4, 7].

Traditionally, the IKC therapy has been based on the use of broad-spectrum antimicrobial drugs—mainly β -lactams and tetracyclines [8]. However, in recent decades, there has been a worrying global trend of increasing antibiotic resistance among the pathogens that cause this disease. For example, studies conducted in the USA, Brazil, and other countries show the emergence and spread of *Moraxella* spp. strains that are resistant to one or more classes of antibiotics¹.² The development of multiple drug resistance (MDR) reduces the effectiveness of standard treatment regimens, slows down the recovery of animals, and contributes to the further spread of resistant pathogens in populations [9]. In the Russian Federation, systematic studies of antibiotic resistance profiles of *Moraxella* spp. are limited, which creates a 'blind spot' in understanding the epidemiological situation and makes it harder to choose the right empirical therapy.

In light of the global antibiotic resistance crisis, finding and developing alternative ways to fight bacterial infections is one of the top priorities in modern microbiology and veterinary science [10]. Among the most promising areas, one can highlight phage therapy—that is, the use of viruses that specifically infect and lyse bacterial cells [11, 12]. Due to their high specificity, ability to self-replicate at the site of infection, and a fundamentally different mechanism of action, bacteriophages are capable of effectively eliminating multidrug-resistant (MDR) bacterial strains [13, 14]. The potential of phage therapy against infectious keratoconjunctivitis (IKC) has been little studied, and data on the lytic activity of bacteriophages against clinical isolates of *Moraxella* spp. remain scarce in the scientific literature.

Thus, studying the antibiotic resistance profiles of *Moraxella* species as IKC causative agents in Central Russia and evaluating the po-

tential of bacteriophages for their elimination constitute an important scientific and practical issue.

The purpose of the study was to characterize the antimicrobial resistance profiles and evaluate the bacteriophage susceptibility of clinical *Moraxella* spp. strains isolated from cattle exhibiting signs of infectious keratoconjunctivitis in the Central region of Russia.

MATERIAL AND METHODS

Sampling and objects of study

The study was conducted from April to July 2025 in the Moscow and Vladimir regions. To this end, 35 samples of biological and clinical material—specifically conjunctival sac swabs collected using standard methods into transport media for bacteriological analysis—were obtained from cows ($n = 16$) and from sheep ($n = 5$) and goats ($n = 5$) exhibiting clinical signs of infectious keratoconjunctivitis.

Isolation and identification of bacteria

Under laboratory conditions, the samples were plated on 10% blood agar and incubated at 37°C for 24 hours. Colonies exhibiting morphology characteristic of *Moraxella* spp. (small, with a zone of hemolysis) were selected for further analysis.

Identification involved Gram staining and biochemical tests (oxidase and catalase). Species identity was conclusively confirmed using MALDI-TOF mass spectrometry on a BactoSCREEN analyzer (OOO RPC “LYTECH”). Sample preparation for analysis was performed according to the standard protein extraction protocol.

Antibiotic susceptibility testing

The susceptibility of the isolated strains was determined using the disk diffusion method. A 100 μ L volume of a bacterial suspension equivalent to a turbidity standard of 1×10^8 CFU/ml was evenly distributed over the surface of Muel-

¹Loy J.D., Brodersen B.W. *Moraxella* spp. isolated from field outbreaks of infectious bovine keratoconjunctivitis: a retrospective study of case submissions from 2010 to 2013 // Journal of Veterinary Diagnostic Investigation, 2014, vol. 26, N 6, pp. 761–768.

²Maboni G., Gressler L.T., Espindola J.P., Tasca C., de Vargas A.C. Differences in the antimicrobial susceptibility profiles of *Moraxella bovis*, *M. bovoculi* and *M. ovis* // Brazilian Journal of Microbiology, 2015, vol. 46, N 2, pp. 545–549.

ler-Hinton agar to create a confluent lawn.

Discs containing the following antibiotics were used: penicillin, ampicillin, gentamicin, ciprofloxacin, erythromycin, kanamycin, sulfadiazine, cloxacillin, cephalothin, oxytetracycline, and tetracycline. The results were interpreted based on the measurement of growth inhibition zone diameters in accordance with standard clinical criteria.

Assessment of sensitivity to bacteriophages

The lytic activity of four previously characterized bacteriophages (vB_Mboc_M3; vB_Mbo_W17; vB_Mbo_R2; vB_Mboc_G9) [15, 16] against the isolated *Moraxella* strains was evaluated using the spot test method.

RESULTS AND DISCUSSION

The obtained isolates

From 35 samples obtained from 26 animals with clinical signs of IBK, two isolates of the genus *Moraxella*—*M. bovis* and *M. bovoculi*—were isolated and identified. All other isolated cultures consisted of Gram-negative rods and coccobacilli identified via MALDI-TOF; these were not the subject of the present study: *Staphylococcus*, *Streptococcus*, *Pseudomonas* spp., *Klebsiella* spp., *Acinetobacter* spp., *Corynebacterium* spp.

Sensitivity to antimicrobial drugs

The results of the analyses revealed an alarming level of multidrug resistance in *M. bovis* and *M. bovoculi* strains isolated within the Russian Federation (see Table 1).

Both strains demonstrated complete resistance to most β -lactam antibiotics (penicillin, ampicillin, cloxacillin, cephalothin), as well as to tetracycline, sulfadiazine, and erythromycin. Ciprofloxacin, kanamycin, and gentamicin showed the greatest efficacy.

The observed resistance of *Moraxella* to β -lactams and tetracyclines sharply contrasts with the data from other geographic regions. For example, in a large retrospective study conducted in the US from 2010 to 2013, both *M. bovis* and *M. bovoculi* showed high sensitivity (>95%) to ampicillin, penicillin, and oxytetracycline (see

footnote 1). Similarly, in a study by J.A. Angelos et al. among 57 *M. bovoculi* isolates from California, no resistance to ampicillin was found, and only 12.3% of the strains were resistant to penicillin, while 3.5% were resistant to oxytetracycline³. Research in South America also shows significantly lower levels of resistance. For example, V. Sosa and P. Zunino found that *M. bovis* circulating in Uruguay is more resistant to cloxacillin (14%) and tetracycline (6%) than *M. bovoculi* (3% and 0%, respectively)⁴. But these figures are far from the 100% resistance shown in our work.

Even in the study by G. Maboni et al. in Brazil, where some of the highest rates were noted (40% resistance to penicillin and 20% to oxytetracycline in *M. bovis*), the resistance level turned out to be significantly lower (see footnote 2). It's also worth noting that the high resistance to cloxacillin observed in the study by G. Maboni et al. may indicate that *Moraxella* spp. have mechanisms of resistance to penicillinase-stable penicillins, which aligns with our findings on broad β -lactam resistance.

A similar situation is seen with sulfonamides. In our case, the strains were completely resistant to sulfadiazine, whereas in the study by J.A. An-

Табл. 1. Чувствительность штаммов *Moraxella* spp. к антибактериальным препаратам

Table 1. Sensitivity of *Moraxella* spp. strains to antibacterial drugs

Antibiotic	<i>M. bovis</i>	<i>M. bovoculi</i>
Penicillin	R	R
Ampicillin	R	R
Gentamycin	I	S
Ciprofloxacin	S	S
Erythromycin	R	R
Kanamycin	S	S
Sulfadiazine	R	R
Cloxacillin	R	R
Cefalotin	R	R
Oxytetracycline	I	R
Tetracycline	R	R

Note. S – sensitive; I – moderately sensitive (intermediate sensitivity); R – resistant.

gelos et al., resistance to sulfadimethoxine was 19.3% (see footnote 3). Such a discrepancy may reflect intense selective pressure linked to the local practice of using antibiotics. As G. Maboni et al. suggested, the irrational use of oxytetracycline over many years could have contributed to the selection of resistant *Moraxella* spp. strains. High genetic variability within *Moraxella* spp., shown by V. Sosa and P. Zunino (see footnote 4), provides a basis for the rapid adaptation of bacteria and the spread of resistance genes in populations.

Unlike resistance to traditional drugs, the high effectiveness of fluoroquinolones and aminoglycosides in our study fully agrees with international data. J.D. Loy and B.W. Brodersen, as well as J.A. Angelos et al., report almost 100% sensitivity of *M. bovis* and *M. bovoculi* to fluoroquinolones and gentamicin (see notes 1, 3). Similarly, in the study by K. Karthik et al., conducted in India, the isolated *M. bovoculi* was sensitive to ciprofloxacin and gentamicin [17]. This suggests that these classes of antibiotics still remain reliable therapeutic options of choice for treating IKC.

Our data indicate that empirical treatment of IKC using penicillins and tetracyclines—drugs of choice in the farms across Russia's Central region—may prove ineffective, leading to economic losses due to a lack of therapeutic response and exacerbating animal suffering. It is also worth noting the need for antimicrobial susceptibility testing of circulating clinical strains to select appropriate initial therapy.

Sensitivity to bacteriophages

Given the antibiotic resistance we observed in clinical *Moraxella* spp. strains—specifically to first-line antibiotics—identifying alternative therapeutic strategies has become a priority. In this context, phage therapy emerges as a promising approach for combating IKC caused by multidrug-resistant (MDR) pathogens.

The results of the study demonstrate the significant potential of this approach: three of the four bacteriophages investigated showed lytic activity against clinical isolates of multidrug-resistant moraxella. Given the differences in the mechanisms of action of phages and antibiotics, bacteriophages can effectively eliminate even those bacteria that have developed resistance to traditional drugs. The results are presented in Table 2.

The bacteriophages used successfully lysed moraxella isolates *in vitro*. Against *M. bovis*, three of the four phages demonstrated lytic activity, whereas against *M. bovoculi*—only vB_Mboc_M3 and vB_Mbo_W17.

CONCLUSION

The study revealed the emergence of *M. bovis* and *M. bovoculi* strains exhibiting multidrug resistance to most first-line antibiotics, a situation that differs significantly from that in other countries. This trend could make traditional IKC treatment plans less effective and will require a review of therapeutic approaches, definitely taking antibiotic sensitivity data into account. Fluoroquinolones and aminoglycosides are still effective drugs, but they should be used wisely to prevent resistance from developing to these classes as well.

Against this background, one promising direction is phage therapy. Our *in vitro* studies have shown that specific bacteriophages can effectively lyse multi-resistant *Moraxella* spp. strains. Phages with a broad spectrum of action, active against both *M. bovis* and *M. bovoculi*, are particularly valuable, making them ideal for treating mixed infections that are often found in the field.

Further research should focus on the molecular-genetic characterization of resistance mechanisms and monitoring their spread in populations of IKC pathogens.

³Angelos J.A., Ball L.M., Byrne B.A. Minimum inhibitory concentrations of selected antimicrobial agents for *Moraxella bovoculi* associated with infectious bovine keratoconjunctivitis // Journal of Veterinary Diagnostic Investigation, 2011, vol. 23, N 3, pp. 552–555.

⁴Sosa V., Zunino P. Diversity of *Moraxella* spp. strains recovered from infectious bovine keratoconjunctivitis cases in Uruguay // Journal of infection in developing countries, 2013, vol. 7, N 11, pp. 819–824.

Табл. 2. Спектр литической активности бактериофагов

Table 2. Spectrum of lytic activity of bacteriophages

Pathogen	Bacteriophage			
	vB_Mboc_M3	vB_Mbo_W17	vB_Mbo_R2	vB_Mboc_G9
<i>M. bovis</i>	+	+	+	–
<i>M. bovoculi</i>	+	+	–	–

СПИСОК ЛИТЕРАТУРЫ

1. Kneipp M. Defining and diagnosing infectious bovine keratoconjunctivitis // Veterinary clinics of North America: Food animal practice. 2021. Vol. 37. N 2. P. 237–252. DOI: 10.1016/j.cv-fa.2021.03.001.
2. Gameda Dima F., Fikedu T. Review on infectious bovine keratoconjunctivitis // Journal of bacteriology and infectious diseases. 2021. Vol. 4 (4). P. 1–6.
3. Angelos J.A., Agulto R.L., Mandzyuk B., Chigerwe M. Randomized controlled field trial to assess the efficacy of an intranasal *Moraxella bovis* cytotoxin vaccine against naturally occurring infectious bovine keratoconjunctivitis // Vaccine X. 2023. Vol. 15. P. 100378. DOI: 10.1016/j.jvax.2023.100378.
4. Loy J.D., Hille M., Maier G., Clawson M.L. Component causes of infectious bovine keratoconjunctivitis: the role of *Moraxella species* in the epidemiology of infectious bovine keratoconjunctivitis // Veterinary clinics of North America: Food animal practice. 2021. Vol. 37. N 2. P. 279–293. DOI: 10.1016/j.cv-fa.2021.03.004.
5. Hille M.M., Clawson M.L., Dickey A.M., Lowery J.H., Loy J.D. MALDI-TOF MS Biomarker Detection Models to Distinguish RTX Toxin Phenotypes of *Moraxella bovoculi* Strains Are Enhanced Using Calcium Chloride Supplemented Agar // Frontiers in cellular and infection microbiology. 2021. Vol. 11. P. 642647. DOI: 10.3389/fcimb.2021.632647.
6. Angelos J.A., Clothier K.A., Agulto R.L., Mandzyuk B., Tryland M. Relatedness of type IV pilin PilA amongst geographically diverse *Moraxella bovoculi* isolated from cattle with infectious bovine keratoconjunctivitis // Journal of medical microbiology. 2021. Vol. 70. N 2. P. 001293. DOI: 10.1099/jmm.0.001293.
7. Kuibagarov M., Abdullina E., Ryskeldina A., Abdigulov B., Amirgazin A., Shevtsov A., Angelos J.A. Association of different microbes and pathogenic factors in cases of infectious bovine keratoconjunctivitis in cattle from Eastern Kazakhstan // Veterinary world. 2023. Vol. 16 (9). P. 1833–1839. DOI: 10.14202/vet-world.2023.1833-1839.
8. O'Connor A.M., Angelos J.A., Dennis E.J., Elizalde P., Kneipp M., Loy J.D., Maier G. Future directions for research in infectious bovine keratoconjunctivitis // Veterinary clinics of North America: Food animal practice. 2021. Vol. 37. N 2. P. 371–379. DOI: 10.1016/j.cv-fa.2021.03.011.
9. Acosta A., Roland-Holst D., Nicolli F., Tirka-so W., Rocha J.S., Song J. A one health framework to assess the economic returns on investment in livestock antimicrobial stewardship // One health. 2025. Vol. 21. P. 101188. DOI: 10.1016/j.onehlt.2025.101188.
10. Loponte R., Pagnini U., Iovane G., Pisanelli G. Phage therapy in veterinary medicine // Antibiotics. 2021. Vol. 10. N 4. P. 421. DOI: 10.3390/antibiotics10040421.
11. Abedon S.T. Phage therapy: combating evolution of bacterial resistance to phages // Viruses. 2025. Vol. 17. N 8. P. 1094. DOI: 10.3390/v17081094.
12. Danis-Wlodarczyk K., Dąbrowska K., Abedon S.T. Phage Therapy: the pharmacology of antibacterial viruses // Current issues in molecular biology. 2021. N 40. P. 81–164. DOI: 10.21775/cimb.040.081.
13. Kortright K.E., Chan B.K., Koff J.L., Turner P.E. Phage therapy: a renewed approach to combat antibiotic-resistant bacteria // Cell host microbe. 2019. Vol. 25. N 2. P. 219–232. DOI: 10.1016/j.chom.2019.01.014.
14. Olszewska P., Spietelun M., Sygula K., Ossowski A., Grygorcewicz B. Bacteriophages as a modern diagnostic tool: innovations, applications and challenges // Molecular biology reports. 2025. Vol. 52. N 1. P. 997. DOI: 10.1007/s11033-025-10967-5.
15. Мохаммед З.С., Пименов Н.В. Селекция штаммов-кандидатов бактериофагов против *Moraxella bovoculi* // Ветеринарный врач. 2024. № 6. С. 75–79. DOI: 10.33632/1998-698X_2024_6_75.
16. Мохаммед З.С., Пименов Н.В. Биологические свойства двух новоизолированных бактериофагов, специфичных для *Moraxella bovis* // Известия Уфимского научного центра РАН. 2025. № 1. С. 68–74. DOI: 10.31040/2222-8349-2025-0-1-68-74.

17. Karthik K., Mahaprabhu R., Roy P., Raman M. Emergence of *Moraxella bovoculi* associated with keratoconjunctivitis in an organized dairy farm of India // *Proceedings of the National Academy of Sciences India. Section B: Biological sciences*. 2018. Vol. 88. N 4. P. 1409–1412.

REFERENCES

1. Kneipp M. Defining and diagnosing infectious bovine keratoconjunctivitis. *Veterinary clinics of North America: Food animal practice*, 2021, vol. 37, no. 2, pp. 237–252. DOI: 10.1016/j.cvfa.2021.03.001.
2. Gameda Dima F., Fikedu T. Review on infectious bovine keratoconjunctivitis. *Journal of bacteriology and infectious diseases*, 2021, vol. 4 (4), pp. 1–6.
3. Angelos J.A., Agulto R.L., Mandzyuk B., Chigerwe M. Randomized controlled field trial to assess the efficacy of an intranasal *Moraxella bovis* cytotoxin vaccine against naturally occurring infectious bovine keratoconjunctivitis. *Vaccine X*, 2023, vol. 15, p. 100378. DOI: 10.1016/j.jvacx.2023.100378.
4. Loy J.D., Hille M., Maier G., Clawson M.L. Component causes of infectious bovine keratoconjunctivitis: the role of *Moraxella* species in the epidemiology of infectious bovine keratoconjunctivitis. *Veterinary clinics of North America: Food animal practice*, 2021, vol. 37, no. 2, pp. 279–293. DOI: 10.1016/j.cvfa.2021.03.004.
5. Hille M.M., Clawson M.L., Dickey A.M., Lowery J.H., Loy J.D. MALDI-TOF MS Biomarker Detection Models to Distinguish RTX Toxin Phenotypes of *Moraxella bovoculi* Strains Are Enhanced Using Calcium Chloride Supplemented Agar. *Frontiers in cellular and infection microbiology*, 2021, vol. 11, p. 642647. DOI: 10.3389/fcimb.2021.632647.
6. Angelos J.A., Clothier K.A., Agulto R.L., Mandzyuk B., Tryland M. Relatedness of type IV pilin PilA amongst geographically diverse *Moraxella bovoculi* isolated from cattle with infectious bovine keratoconjunctivitis. *Journal of medical microbiology*, 2021, vol. 70, no. 2, p. 001293. DOI: 10.1099/jmm.0.001293.
7. Kuibagarov M., Abdullina E., Ryskeldina A., Abdigulov B., Amirgazin A., Shevtsov A., Angelos J.A. Association of different microbes and pathogenic factors in cases of infectious bovine keratoconjunctivitis in cattle from Eastern Kazakhstan. *Veterinary world*, 2023, vol. 16 (9), pp. 1833–1839. DOI: 10.14202/vet-world.2023.1833-1839.
8. O'Connor A.M., Angelos J.A., Dennis E.J., Elizalde P., Kneipp M., Loy J.D., Maier G. Future directions for research in infectious bovine keratoconjunctivitis. *Veterinary clinics of North America: Food animal practice*, 2021, vol. 37, no. 2, pp. 371–379. DOI: 10.1016/j.cvfa.2021.03.011.
9. Acosta A., Roland-Holst D., Nicolli F., Tirka-so W., Rocha J.S., Song J. A one health framework to assess the economic returns on investment in livestock antimicrobial stewardship. *One health*, 2025, vol. 21, p. 101188. DOI: 10.1016/j.onehlt.2025.101188.
10. Loponte R., Pagnini U., Iovane G., Pisanelli G. Phage therapy in veterinary medicine. *Antibiotics*, 2021, vol. 10, no. 4, p. 421. DOI: 10.3390/antibiotics10040421.
11. Abedon S.T. Phage therapy: combating evolution of bacterial resistance to phages. *Viruses*, 2025, vol. 17, no. 8, p. 1094. DOI: 10.3390/v17081094.
12. Danis-Włodarczyk K., Dąbrowska K., Abedon S.T. Phage therapy: the pharmacology of antibacterial viruses. *Current issues in molecular biology*, 2021, no. 40, pp. 81–164. DOI: 10.21775/cimb.040.081.
13. Kortright K.E., Chan B.K., Koff J.L., Turner P.E. Phage therapy: a renewed approach to combat antibiotic-resistant bacteria. *Cell host microbe*, 2019, vol. 25, no. 2, pp. 219–232. DOI: 10.1016/j.chom.2019.01.014.
14. Olszewska P., Spietelun M., Sygula K., Osowski A., Grygorcewicz B. Bacteriophages as a modern diagnostic tool: innovations, applications and challenges. *Molecular biology reports*, 2025, vol. 52, no. 1, p. 997. DOI: 10.1007/s11033-025-10967-5.
15. Mohammed Z.S., Pimenov N.V. Selection of candidate strains of bacteriophages against *Moraxella bovoculi*. *Veterinarnyi vrach = Veterinarny Vrach*, 2024, no. 6, pp. 75–79. (In Russian). DOI: 10.33632/1998-698X_2024_6_75.
16. Mohammed Z.S., Pimenov N.V. Biological properties of two newly isolated bacteriophages specific to *Moraxella bovis*. *Izvestiya Ufimskogo nauchnogo tsentra RAN = Proceedings of the RAS Ufa Scientific Centre*, 2025, no. 1, pp. 68–74. (In Russian). DOI: 10.31040/2222-8349-2025-0-1-68-74.
17. Karthik K., Mahaprabhu R., Roy P., Raman M. Emergence of *Moraxella bovoculi* associated with keratoconjunctivitis in an organized dairy farm of India. *Proceedings of the National Academy of Sciences India. Section B: Biological sciences*, 2018, vol. 88, no. 4, pp. 1409–1412.

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Оценка средней потенциальной плодовитости таймырских тундровых диких оленей (*Rangifer tarandus* L. 1758) в репродуктивные циклы 1987–2006 гг.

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Исследованы параметры средней потенциальной плодовитости таймырской популяции диких оленей в 1987–2006 гг. Средний взвешенный показатель в данный промежуток мониторинга определен в 0,399 плода-самки на одну взрослую самку. Среди репродуктивных поколений максимальной потенциальной плодовитостью обладала возрастная группа 6-летних самок (0,451 плода-самки на одну взрослую самку), минимальной – молодые 2-летние самки (0,117 плода-самки на одну взрослую самку). У этой же возрастной группы выявлены и наиболее высокие значения яловости – 76,1%. В каждый репродуктивный сезон среди всех поколений взрослых самок таймырских диких оленей встречаются животные, взявшие репродуктивную паузу в размножении (*lim* 9,87–76,10%). Наибольший суммарный репродуктивный вклад в потенциальном размножении зафиксирован среди поколений 3–5-летних животных – 63,7%, самых многочисленных групп в популяции на том мониторинговом интервале. Предельный возраст участия в потенциальной репродукции – 15 лет. Результаты исследования свидетельствуют: в период хозяйственного использования охотничьих ресурсов таймырских тундровых оленей в 1987–2006 гг. поголовье взрослых самок таймырской популяции еще обладало весомым репродуктивным потенциалом, покрывая интенсивную промысловую нагрузку и годовую элиминацию от других факторов среды, уравнивая убыль стабильным размножением. Суммарные показатели средней потенциальной плодовитости в весенние периоды составили для населения взрослых самок таймырской популяции 79,95 эмбрионов обоих полов на 100 половозрелых самок при средней яловости 20,1%. В настоящее время таймырская популяция диких оленей не обладает подобными высокими показателями потенциальной плодовитости, что не позволяет ей поддерживать промысловую численность на достаточно устойчивом уровне при существующей промысловой нагрузке на ее охотничьи ресурсы.

Ключевые слова: таймырская популяция, самка, возрастные группы, яловость, размножение, плодовитость, репродуктивный успех

Assessment of the average potential fertility of Taimyr wild tundra reindeers (*Rangifer tarandus* L. 1758) in the reproductive cycles of 1987–2006

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Parameters of the average potential fertility of the Taimyr wild reindeer population were studied in the period 1987–2006. The average weighted indicator for this monitoring period was determined to be 0.399 fetuses per adult female. Among the reproductive generations, the maximum potential fertility was demonstrated by the age group of 6-year-old females (0.451 fetuses per adult female), and the minimum by young 2-year-old females (0.117 fetuses per adult female). The highest values of barrenness were also revealed in this age group – 76.1%. In general, in each reproductive season, among all generations of sexually mature female Taimyr wild reindeer, there are animals that have taken a reproductive pause in reproduction (*lim* 9.87–76.10%). The highest total reproductive contribution to potential reproduction was recorded among the generations of 3-5-year-old animals – 63.7%, the most

numerous groups in the population in that monitoring interval. The maximum age for participation in potential reproduction is 15 years. The results of the study show that during the period of economic use of the hunting resources of Taimyr tundra reindeer in 1987–2006, the population of adult females of the Taimyr population still had significant reproductive potential, covering the intensive commercial load and annual elimination from other environmental factors, balancing the decline with stable reproduction. The total indicators of average potential fertility in spring periods for the population of adult females of the Taimyr population were 79.95 embryos of both sexes per 100 sexually mature females, with an average infertility of 20.1%. Currently, the Taimyr wild reindeer population does not have such high rates of potential fertility, which does not allow it to maintain commercial numbers at a sufficiently high level given the existing commercial pressure on its hunting resources.

Keywords: Taimyr population, female, age groups, barrenness, reproduction, fertility, reproductive success

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INTRODUCTION

To effectively manage hunting resources of commercial animal populations while ensuring their viability, you need accurate information on the species' fertility rates across different reproductive cycles. In other words, ecological monitoring of hunting resources in a managed population largely relies on identifying the levels of seasonal and multi-year reproduction and how this affects overall population numbers over time. Nevertheless, the complexity of the age structure of a natural population, the different times it takes animals to reach sexual maturity, the fact that not all adults of the same generation participate in reproduction (reproductive pauses), the varying lifespans, the timing and intensity of commercial exploitation of a par-

ticular natural population, and the selectivity of commercial hunting make it impossible to accurately predict reproduction rates and population growth in each yearly biological cycle.

It's worth noting that in practice, the self-recovery potential of a species population of hoofed animals is most often determined through aerial surveys, during which the demographic structure of herds, current replenishment, spatial cohesion, and the decline or maintenance of local group numbers that make up a given natural population are identified. Moreover, this kind of monitoring needs to be done regularly for commercially valuable species. On the other hand, figuring out the exact number of mature females and the population of juvenile offspring in a specific area is only possible roughly, so in many

cases, people also rely on extrapolation and expert estimates [1]. Meanwhile, the Taymyr population of wild reindeer belongs to long-exploited hunting populations, which have been closely monitored for resources for many decades, and a lot of empirical data has been gathered on their reproduction [2–7].

The goal of the study is to assess the average potential fertility parameters of Taymyr wild reindeer from 1987 to 2006, during the final phase of the Soviet planned model of controlled hunting and under the market-based model of wildlife management that replaced it. At this time, both legal and “shadow” fishing pressures on the population were steadily increasing. So, it's necessary to mark the point where the population's resources are overexploited, which in the 21st century is undermined by unsustainable commercial fishing, and the population size keeps declining, approaching a critical level.

MATERIAL AND METHODS

The average potential fertility of reproductive females of wild reindeer in the Taymyr population during periods of intensive use of hunting resources of this commercial population (planned and market models of commercial reindeer herding) was studied based on materials from L.A. Kolpashchikov¹ and A.M. Shapkin [7]. The total number of commercial samples was 1,491 individuals aged 2 to 15 years.

Fertility is measured by the number of offspring per adult female². During the spring migration of animals from their wintering areas to calving grounds (April–May) within the population range of the species on the Taymyr Peninsula (northern Central Siberia), scientific spring culls were conducted from 1987–1990 and 1996–2006, during which 1,491 female

wild reindeer from the spring migration of the Taymyr population were examined [7]. Upon dissection, pregnant and dry (embryo-free) females were identified. Each collected specimen was assigned an identification number, and its lower incisors were removed for subsequent age determination. The reproductive success of adult females from different age groups was assessed based on potential fecundity values.

When calculating the average reproductive success of females (before calving) based on the collected commercial samples from 1987–2006, the sex ratio in these samples between male and female fetuses of pregnant females was taken as 1:1^{3, 4}. The proportion of non-pregnant females in age groups was calculated using percentages [8], where the number of pregnant and dry females (animals without offspring) makes up 100%, so the infertility will be $x\%$ of the number of females in that age group.

The average fertility (potential) by age cohorts during the reproductive seasons was calculated using G. Koli's² proposed method with data from females older than two years.

The errors of the obtained age-specific fertility values from these materials (average potential) were calculated using the formula for the standard deviation of the “successes” proportion for n trials in a binomial distribution:

$$D_{(\text{proportions})} = pq / n, \quad (1)$$

where p – probability of success (the chance that the female will produce a female offspring), $q = 1 - p$ – the probability of failure, i.e., the female won't produce a female offspring; n – sample size. So, the error (standard deviation) is the square root of the variance [9]:

$$\sigma = \sqrt{D}. \quad (2)$$

¹Kolpashchikov L.A. Taymyr wild reindeer population: biological foundations for management and sustainable resource use: Doctoral Dissertation (Biological Sciences): 11.00.11. Norilsk, 2000, 379 p.

²Caughley G. Analysis of Vertebrate Populations. Moscow: Mir, 1979, 362 p.

³Michurin L.N. Wild reindeer of the Taymyr Peninsula and the rational use of their stocks: Candidate of Science in Biology Dissertation / Norilsk, 1964. 227 p.

⁴Bolshakov V.N., Kubantsev B.S. Sexual structure of mammal populations and its significance. Moscow, Nauka Publ., 1984, 233 p.

The reproductive contribution for each age class of females is found using the formula:

$$m_v = f_x m_x, \quad (3)$$

f_x – size of the age group; m_x – the number of females born to each female in the age interval x .

The average potential fertility for sexually mature females of different ages in the reproductive cycles of 1987–1990, 1996–1998, and 1999–2007 for this part of the Taimyr population was calculated using a weighted average by age according to the Koli² formula:

$$m_w = \frac{n_2 + n_3 + n_4 + \dots}{N_2 + N_3 + N_4 + \dots}, \quad (4)$$

where n – the number of newborn female offspring, N – the number of females of this age.

The individual age of the females was determined under laboratory conditions based on the layered structures of the incisors⁵, specifically, the formed layers of incisor cementum I_1 , preliminarily decalcified with a 5% nitric acid solution. Sections of the incisors from females were prepared using a domestic MRTU-12 rotary microtome. To count the annual rings, the samples were stained with Ehrlich's hematoxylin. N.F. Arsentyeva determined the age of the female Taimyr wild reindeer [7].

All observations and the collection of primary data on the reproductive capabilities of female wild reindeer were conducted using standard zoological research methods⁶.

RESULTS AND DISCUSSION

The results regarding the average potential fecundity of Taimyr wild reindeer during the 1987–2006 biological cycles are presented in the table.

During this period, the Taymyr population still possessed a reproductive core of adult females spanning 14 reproductive generations—aged 2 to 15 years—that, despite intensive har-

vesting and other elimination factors, managed to offset herd losses and maintain the biological productivity of the population's local migratory flows at a reasonably stable level. Moreover, given the current level of commercial harvesting, animals in the 3- and 4-year-old age groups continued to constitute the largest segment of the adult female population in the Taymyr herd; data from harvest samples collected between 1987 and 2006 indicate that they accounted for 43.06% of the total. According to our data, the potential reproductive contribution of these two age groups to herd replenishment (specifically, female offspring) amounted to nearly 45%. Together with the 5-year-old group—which still constitutes a significant portion of the population—adult females from these three reproductive classes could produce 63.7% of the potential offspring.

Young two-year-old females exhibited both the lowest potential fecundity—0.117 female offspring per female in this age group—and the highest rate of barrenness among all age groups (76.1%; see table). This indicates that the majority of female Taimyr tundra reindeer reach sexual maturity in their third year of life (only 15.9% of animals in this group showed signs of barrenness; see table). The 6-year-old age group exhibited the highest average potential fecundity: 0.451 female fetuses per female. This group also recorded the lowest rate of barrenness among the cohorts of adult females (9.87%), meaning 90.13% of the animals in this age group were pregnant. According to the collected data, 6-year-old females accounted for 10.2% of the population's reproductive core; consequently, their reproductive contribution to the population's growth is effectively lower than that of the more numerous 3–5-year-old female cohorts. In other words, after reaching the age of six, females exhibit a decline in potential fecundity with each subsequent reproductive year due

⁵Klevezal G.A., Kleinenberg S.E. Age determination of mammals by layered structures in teeth and bones. Moscow: Nauka, 1967, 144 p.

⁶Novikov G.A. Field studies on the ecology of terrestrial vertebrates. Moscow: Sovetskaya Nauka, 1953, 502 p.

Средняя потенциальная плодовитость возрастных классов таймырских тундровых диких северных оленей в период 1987–2006 гг. ($n = 1491$ самка)

Average potential fertility of age classes of the Taimyr tundra wild reindeer in the period 1987–2006 ($n = 1491$ females)

Age, years, x	Size of the age group, f_x	Number of pregnant, B_x	Number of the offspring ($m_x \pm \sigma$) per female ($B_x / 2f_x$)	Barrenness across age groups, %	Reproductive contribution of the age group (offspring-female), (f_x) m_x
2+	117	28	$0,117 \pm 0,029$	76,10	13,70
3+	327	275	$0,420 \pm 0,027$	15,90	137,34
4+	315	262	$0,416 \pm 0,028$	16,80	131,04
5+	255	222	$0,435 \pm 0,031$	12,94	110,93
6+	152	137	$0,451 \pm 0,040$	9,87	68,60
7+	119	103	$0,433 \pm 0,045$	13,40	51,53
8+	81	68	$0,420 \pm 0,055$	16,05	34,02
9+	45	36	$0,4 \pm 0,073$	20,00	18,00
10+ and older	80	61	$0,381 \pm 0,054$	23,70	30,50
Total	1491	1192	$0,399 \pm 0,013$	20,10	595,61

to fishing and natural mortality resulting from various abiotic and biotic environmental factors. Furthermore, the survival function decreases with age [10]. On the other hand, among older animals (over 10 years of age), females with high potential fecundity—ranging from 0.402 to 0.437 fetuses per adult female [7]—are still encountered during certain reproductive seasons; this can likely be attributed to favorable summer foraging and overwintering conditions for these animals. The upper age limit for potential reproduction among adult female Taimyr wild reindeer is 15 years. However, evidence of actual reproduction has been observed at the age of 16 (in a single individual) within the herds comprising the population's local migratory groups [7].

Aggregate indicators of average potential fecundity for adult females of the Taimyr population during the spring periods of 1987–2006 amounted to 79.95 embryos (of both sexes) per 100 sexually mature females, with an average barrenness rate of 20.1%. These figures represent a high reproductive potential for the migratory segments of this natural population, given the combined legal and "shadow" harvesting pressure on their resources in northern Central Siberia. The weighted average potential fecundity was 0.399 female offspring per adult fe-

male. Thus, during that period of exploitation, the Taimyr wild reindeer population possessed a sufficient number of adult females to maintain reproductive rates and preserve an effective population size for harvesting. Based on the data regarding realized reproduction (aerial survey monitoring), the number of young-of-the-year offspring in July 1990 was estimated at 75.31 calves per 100 sexually mature females [7]. The average figures for realized reproduction (August–October)—accounting for juvenile mortality—during the 2002–2007 period stood at 59.03 calves of both sexes per 100 adult females (*lim* 49–76).

CONCLUSION

An assessment of the status of the Taimyr wild reindeer population—based on the results of conducted research—indicates that between 1987 and 2006, the exploited segments of this natural population maintained a reliable level of effective recruitment despite existing harvest levels: fourteen generations of females of various reproductive ages contributed to reproduction. The total number of adult females in the herds of this natural population (*lim*: 189.8–201.5 thousand) offset the demographic

consequences of continuous annual commercial harvesting. The mean potential fecundity among reproductive age classes (animals aged 2 to 15 years) fluctuated between 0.117 and 0.451 female fetuses per sexually mature female. The potential of the Taymyr population remained intact during the 2006–2007 reproductive season as well: monitoring of realized fecundity under natural field conditions—conducted within the autumn migration flows of animals in the Pyasina area—revealed 64 calves of both sexes per 100 adult females [7]. However, by the summer of 2009, the realized fertility rates of the Taymyr population had dropped significantly: aerial surveys recorded 54.12 calves per 100 sexually mature females, while the post-harvest size of the reproductive core stood at 165.2 thousand females. By the summer of 2021, there were only 15.6 calves per 100 adult females, and the size of the population's reproductive core had fallen to just 132.9 thousand females [7]. Thus, the hunting seasons from 2007–2009 to the present can be considered the starting point of overharvesting and excessive, unsustainable pressure on the hunting resources of the Taymyr population in northern Central Siberia. To conserve the resources of this natural population, the question of imposing a total ban on the hunting of Taymyr tundra reindeer for all categories of hunters in the Yenisei North is now being raised.

СПИСОК ЛИТЕРАТУРЫ

1. Чернов Ю.И. Биота Арктики: таксономическое разнообразие // Зоологический журнал. 2002. Т. 81. № 12. С. 1413–1431.
2. Колпащиков Л.А., Павлов Б.М. Плодовитость самок диких северных оленей // Научное обеспечение рационального природопользования Енисейского Севера. Сборник научных трудов. Новосибирск, 2001. С. 55–65.
3. Лайшев К.А., Мухачев А.Д., Колпащиков Л.А., Зеленский В.М., Пикuleва И.Н. Северные олени Таймыра: монография. Новосибирск, 2002. 340 с.
4. Михайлов В.М., Колпащиков Л.А. Три стадии в документированной истории таймырской популяции диких северных оленей // Зоологический журнал. 2012. Т. 91. № 4. С. 486–502.

5. Якушкин Г.Д., Кокорев Я.И., Колпащиков Л.А. Дикий северный олень *Rangifer tarandus* // Природные зоны и мир животных Таймыра: монография. Белгород: ЛитКараВан, 2012. С. 53–69.
6. Бондарь М.Г., Колпащиков Л.А. Оценка численности и летнее размещение таймырской популяции диких оленей в 2017 году // Научные труды Федерального государственного бюджетного учреждения «Объединенная дирекция заповедников Таймыра». Вып. 2. Норильск: Апекс, 2018. С. 29–69.
7. Шапкин А.М. О репродуктивном потенциале таймырских диких северных оленей (*Rangifer tarandus*) в период 1987–2021 гг. // Зоологический журнал. 2024. Т. 103. № 7. С. 57–77. DOI: 10.31857/SO044513424070066.
8. Бабичева И.В., Болдовская Т.Е. Справочник по математике (в формулах, таблицах, рисунках). Под. ред. Т.И. Кукиной. Омск: Изд. Сибирской государственной автомобильно-дорожной академии, 2010. 148 с.
9. Балинова В.С. Статистика в вопросах и ответах: учебное пособие. М.: Проспект, 2004. 344 с.
10. Шилов И.А. Экология. М.: Юрайт, 2011. 512 с.

REFERENCES

1. Chernov Yu.I. Arctic biota: taxonomic diversity. *Zoologicheskij zhurnal = Russian Journal of Zoology*, 2002, vol. 81, no. 12, pp. 1413–1431. (In Russian).
2. Kolpashchikov L.A., Pavlov B.M. Fertility of wild reindeer females. *Scientific support for rational nature management of the Yenisei North. Collection of scientific papers*. Novosibirsk, 2001, pp. 55–65. (In Russian).
3. Laishev K.A., Mukhachev A.D., Kolpashchikov L.A., Zelensky V.M., Pikuleva I.N. *Reindeer of Taimyr*. Novosibirsk, 2002. 340 p. (In Russian).
4. Mikhailov V.M., Kolpashchikov L.A. Three stages in the documented history of the Taimyr population of wild reindeer. *Zoologicheskij zhurnal = Russian Journal of Zoology*, 2012, vol. 91, no. 4, pp. 486–502. (In Russian).
5. Yakushkin G.D., Kokorev Ya.I., Kolpashchikov L.A. Wild reindeer *Rangifer tarandus*. *Natural zones and animal world of Taimyr*. Belgorod: LitCaraVan Publ., 2012, pp. 53–69. (In Russian).
6. Bondar M.G., Kolpashchikov L.A. Estimation of

- the size and summer distribution of the Taimyr wild reindeer population in 2017. *Nauchnye trudy Federal'nogo gosudarstvennogo byudzhetskogo uchrezhdeniya «Ob"edinennaya direkciya zapovednikov Tajmyra» = Scientific works of the Federal State Budgetary Institution "United Directorate of Taimyr Nature Reserves"*, no. 2, Norilsk: Apeks Publ., 2018, pp. 29–69. (In Russian).
7. Shapkin A.M. Reproductive potential of the Taimyr wild reindeer (*Rangifer tarandus*) in 1987–2021. *Zoologicheskij zhurnal = Russian Journal of Zoology*, 2024, vol. 103, no. 7, pp. 57–77. DOI: 10.31857/SOO44513424070066. (In Russian).
8. Babicheva I.V., Boldovskaya T.E. *Handbook of Mathematics (in formulas, tables, figures)*. Edited by T.I. Kukina. Omsk: Publishing House of the Siberian State Automobile and Highway Academy, 2010. 148 p. (In Russian).
9. Balinova V.S. *Statistics in Questions and Answers: Study Guide*. Moscow: Prospect Publ., 2004, 344 p. (In Russian).
10. Shilov I.A. *Ecology*. Moscow: Urait Publ., 2011. 512 p. (In Russian).

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The guidelines are drawn up in accordance with the ethical principles, common for all the members of the scientific community, and the rules for publications in international and local scientific periodic magazines as well as in compliance with the requirements stipulated by the State Commission for Academic Degrees and Titles for the periodicals included in the List of Russian peer-reviewed scientific journals in which the major scientific outcomes of theses for the degrees of Doctor or Candidate of Sciences must be published.

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Monograph

Klimova E.V. Field crops of Zabaikalya: monograph. Chita: Poisk, 2001. 392 p.

Part of a book

Kholmov V.G. Minimum tillage of coulisse-strip fallow for spring wheat with intensification of arable agriculture in southern forest-steppe of Western Siberia // Resource-saving tillage systems. Moscow: Agropromizdat, 1990. pp. 230-235.

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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References are compiled in the same order as the Russian version, according to the following rules:

Names and surnames of the authors are given in the established way of transliteration, English title of the article, *transliteration of the name of the Russian-language source (for example through the site: <https://antropophob.ru/translit-bsi>) = English title of the source*. The order of presentation for a monograph is the following: city, English name of the publisher, year, number of pages; for a journal: year, volume, number, pages. (In Russian).

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Transliteration of the authors. English title of the article.

Zaglavie jurnala = Title of Journal, 2012, vol. 10, no. 2, pp. 49–54.

Transliteration of the source = English name of the source

Monograph

Klimova E.V. *Field crops of Zabaikalya*. Chita, Poisk Publ., 2001, 392 p. (In Russian).

Part of a book

Kholmov V.G. Minimum tillage of coulisse-strip fallow for spring wheat with intensification of arable agriculture in southern forest-steppe of Western Siberia. *Resource-saving tillage systems*, Moscow, Agropromizdat Publ., 1990, pp. 230–235. (In Russian).

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FOOTNOTES:

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