



ISSN 0370-8799 (Print)
ISSN 2658-462X (Online)

Volume 55 No 9 2025

SIBERIAN HERALD OF AGRICULTURAL SCIENCE

SIBERIAN HERALD OF AGRICULTURAL SCIENCE

No 9

Volume 55



SEPTEMBER

2025



THE SCIENTIFIC JOURNAL
SIBERIAN HERALD
OF AGRICULTURAL SCIENCE

SIBIRSKII VESTNIK SEL'SKOKHOZYAISTVENNOI NAUKI

FOUNDERS: SIBERIAN FEDERAL SCIENTIFIC CENTRE OF AGRO-BIOTECHNOLOGIES OF THE RUSSIAN ACADEMY OF SCIENCES;
SIBERIAN BRANCH OF THE RUSSIAN ACADEMY OF SCIENCES

ESTABLISHED IN 1971

12 ISSUES PER YEAR

Volume 55, No. 9 (322)

DOI: 10.26898



2025
September

The purpose of the journal is to promptly inform scientists and practitioners of agricultural production about the latest achievements of agricultural science. The "Siberian Herald of Agricultural Science" publishes original articles on fundamental and applied problems in the following areas: general agriculture and crop production; plant breeding, seed production and biotechnology; agrochemistry, soil science, plant protection and quarantine; fodder production; infectious diseases and animal immunology; private zootechnics, feeding, technology of feed preparation and production of livestock products; breeding, selection, genetics, and animal biotechnology; technologies, machinery and equipment for the agro-industrial complex.

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Certificate PI FS77-64832 issued by the Federal Service for Supervision of Media,
Communications and Information Technologies on February 2, 2016

Publisher: Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences

Editorial and publisher's address: PO Box 463, office 456, SFSCA RAS Building, Krasnoobsk, Novosibirsk District, Novosibirsk Region, 630501, Russia.

Printing house address: room 156, SRI of Fodder Crops building, Krasnoobsk, Novosibirsk District, Novosibirsk Region, 630501, Russia.

Tel/fax: +7-383-348-37-62; e-mail: sibvestnik@sfsca.ru; https://sibvest.elpub.ru

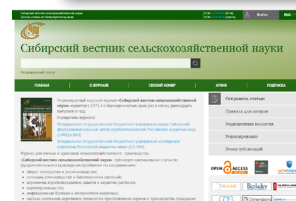
Published on 15.10.2025. Format 60 × 84¹/₈. Paper type. No. 1. Offset printing. Printer's sheet 15,25.

Publisher's signature 15,0. Circulation 500 copies. The price is free.

Printed at the Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences

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СИБИРСКИЙ ВЕСТНИК СЕЛЬСКОХОЗЯЙСТВЕННОЙ НАУКИ

SIBIRSKII VESTNIK SEL'SKOKHOZYAISTVENNOI NAUKI

УЧРЕДИТЕЛИ: СИБИРСКИЙ ФЕДЕРАЛЬНЫЙ НАУЧНЫЙ ЦЕНТР АГРОБИОТЕХНОЛОГИЙ РОССИЙСКОЙ АКАДЕМИИ НАУК;
СИБИРСКОЕ ОТДЕЛЕНИЕ РОССИЙСКОЙ АКАДЕМИИ НАУК

ОСНОВАН В 1971 г.

ВЫХОДИТ 12 РАЗ В ГОД

Том 55, № 9 (322)

DOI: 10.26898



2025
сентябрь

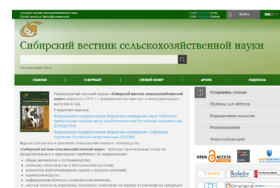
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Издатель: Сибирский федеральный научный центр агrobiотехнологий Российской академии наук

Адрес редакции и издателя: 630501, Новосибирская обл., Новосибирский р-н, р.п. Краснообск, здание СФНЦА РАН, к. 456, а/я 463
Адрес типографии: 630501, Новосибирская обл., Новосибирский р-н, р.п. Краснообск, здание СибНИИ кормов, к. 156

Тел./факс: (383)348-37-62; e-mail: sibvestnik@sfsc.ru; <https://sibvest.elpub.ru/jour>

Вышел в свет 15.10.2025. Формат 60 × 84¹/₈. Бумага тип. № 1. Печать офсетная. Печ. л. 15,25

Уч.-изд. л. 15,0. Тираж 500 экз. Цена свободная.

Отпечатано в Сибирском федеральном научном центре агrobiотехнологий Российской академии наук

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Отбор эффективных штаммов клубеньковых бактерий *Bradyrhizobium japonicum* для сортов сои сибирской селекции в условиях Республики Башкортостан

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Соя – высокоэффективная и перспективная зернобобовая культура. В новых районах возделывания в почвах отсутствуют клубеньковые бактерии *Bradyrhizobium japonicum* (Kirchner) Jordan для сои, поэтому вопрос подбора наиболее эффективных штаммов является очень актуальным. В работе исследованы влияние 10 штаммов клубеньковых бактерий на морфологические и физиологические показатели, продуктивность сортов сои СибНИИК 315 и Омская 4. Выявлены штаммы, эффективные в отношении обоих сортов (6346, 626а, 6406), штаммы, снижающие показатели продуктивности обоих сортов (10к, БД32 и 605д). Некоторые штаммы (МИД10 и 71т) были эффективными в симбиозе с сортом Омская 4, а на сорте СибНИИК 315 они снижали урожайность и сбор белка с гектара. В становлении успешного симбиоза задействованы оба его участника. Анализ структуры урожая сои показал, что в наибольшей степени продуктивность зависит от количества бобов и семян на растении, т.е. признаков, которые формируются очень рано – в фазе ветвления, когда закладываются генеративные почки. В этот момент симбиотический аппарат еще не полностью сформировался, поэтому неэффективный штамм может оказаться дополнительной нагрузкой на растение, который затрачивает его энергетические ресурсы и снижает его продуктивность. Другие элементы продуктивности – масса 1000 семян, содержание белка – формируются в более поздние сроки, во время налива семян, и на них оказывает положительное влияние инокуляция практически любым штаммом. Среди всех вариантов штамм 402 способствовал наибольшему повышению содержания белка в семенах обоих сортов, а штамм 605д – наименьшему. Сорт Омская 4 лучше реагировал на инокуляцию: большинство штаммов способствовали повышению массы и количества семян на растении, количества семян в бобе и массы 1000 семян по сравнению с контролем и вариантом с азотом в дозе 60 кг/га.

Ключевые слова: инокуляция, симбиоз, клубеньковые бактерии, продуктивность, структура урожая

Selection of effective strains of nodule bacteria *Bradyrhizobium japonicum* for soybean varieties of Siberian selection in the conditions of the Republic of Bashkortostan

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Soy is a highly efficient and promising legume crop. In new cultivation areas, the soils do not contain nodule bacteria *Bradyrhizobium japonicum* (Kirchner) Jordan for soybeans, so the issue of selecting the most effective strains is very relevant. The work investigated the effect of 10 strains of nodule bacteria on the morphological and physiological parameters, productivity of 2 soybean varieties

SibNIIK 315 and Omskaya 4. The strains were identified that were effective for both cultivars (634b, 626a, 640b), while other strains reduced the productivity of both cultivars (10k, BD32 and 605d). Some strains (MID10 and 71t) were effective in symbiosis with the cultivar Omskaya 4, but they reduced the yield and protein production per hectare in the cultivar SibNIIK 315. Both participants are involved in the development of a successful symbiosis. Analysis of the soybean yield structure showed that productivity depends most on the number of beans and seeds on the plant, i.e. the characteristics that are formed very early in the branching phase, when generative buds are laid. At this time, the symbiotic apparatus has not yet fully formed, so an ineffective strain may be an additional burden on the plant, which consumes its energy resources and reduces its productivity. Other elements of productivity like the mass of 1000 seeds and the protein content are formed at a later stage, during seed filling, and they are positively affected by inoculation with almost any strain. Among all the variants, strain 402 contributed to the greatest increase in protein content in the seeds of both varieties, and strain 605d contributed to the least. The Omskaya 4 variety responded better to inoculation: most strains contributed to an increase in the weight and number of seeds per plant, the number of seeds in the bean and the mass of 1000 seeds compared to the control and the variant with nitrogen at a dose of 60 kg/ha.

Keywords: inoculation, symbiosis, nodule bacteria, productivity, crop structure

Для цитирования: Сатаева Л.В., Андриянова Э.М., Гумерова Л.Ф. Отбор эффективных штаммов клубеньковых бактерий *Bradyrhizobium japonicum* для сортов сои сибирской селекции в условиях Республики Башкортостан // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 9. С. 5–13. <https://doi.org/10.26898/0370-8799-2025-9-1>

For citation: Sataeva L.V., Andrianova E.M., Gumerova L.F. Selection of effective strains of nodule bacteria *Bradyrhizobium japonicum* for soybean varieties of Siberian selection in the conditions of the Republic of Bashkortostan. *Sibirskii vestnik sel'skokhozyaistvennoi nauki* = *Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 9, pp. 5–13. <https://doi.org/10.26898/0370-8799-2025-9-1>

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

Благодарность

Работа выполнена в рамках субсидии из федерального бюджета образовательным организациям высшего образования на реализацию мероприятий, направленных на поддержку студенческих научных сообществ (IV Конкурс студенческих научных обществ – 2025).

Acknowledgments

The work was carried out within the framework of a subsidy from the federal budget to educational organizations of higher education for the implementation of activities aimed at supporting student scientific communities (IV Competition of student scientific societies – 2025).

INTRODUCTION

In connection with the growing demand for vegetable protein and oil, the widespread use of soybean crops (*Glycine max* (L.) Merr.) is of great importance, which is due to the high quality of the product and the possibility of its universal use for food, feed and technical purposes.

Short-day soybean varieties, which require heat and moisture and have a long growing season, predominate in global production. The development of new early-maturing varieties has allowed soybean cultivation to expand into more continental regions; soybeans are now considered a promising crop for the Volga and Ural regions. However, soybean cultivation in Bashkortostan is limited by the lack of sufficient research into its introduction into new northern

ecotopes. The reasons for the instability of soybean yields in different years remain unclear; many physiological aspects of the interaction of soybeans with nodule bacteria, the influence of legume-rhizobial symbiosis on the formation of the yield under varying weather factors and different levels of mineral nutrition in new soil and climatic conditions have not been studied.

The aim of the research is to determine the influence of various physiological and morphological characteristics of the symbiosis of soybeans and nodule bacteria *Br. japonicum* on the formation of soybean productivity elements in the conditions of the Bashkir Cis-Urals.

The objectives of the work were as follows:

– to determine the responsiveness of individual elements of the soybean crop structure to in-

oculation with various strains of nodule bacteria, to identify the strains complementary to the soybean variety SibNIIK 315, approved for use in the Republic of Bashkortostan, and the Omskaya 4 variety;

- to determine the relationships between various physiological parameters in the soybean–*Br. japonicum* system, their influence on energy metabolism and the distribution of assimilates between the plant and nodule bacteria in order to identify the criteria for the effectiveness of symbiosis; to evaluate the role of macro- and microsymbionts in the implementation of symbiotic traits;

- to compare the effect of mineral and bacterial forms of nitrogen fertilizer on the productivity of soybean variety SibNIIK 315, to evaluate the effectiveness and feasibility of using mineral nitrogen when inoculating soybeans on leached chernozem of the southern forest-steppe zone of Bashkortostan;

- to determine the contribution of various elements of the crop structure to the formation of the productivity of an early maturing soybean variety, to determine the factors limiting the soybean yield under varying hydrothermal conditions in the soil and climatic conditions of the Bashkir Cis-Urals.

MATERIAL AND METHODS

Soybean varieties with a good record of growth in Bashkortostan (SibNIIK 315 and Omskaya 4) were selected as the objects of the study. The effectiveness of 10 strains of *Br. japonicum* nodule bacteria was tested on them. Collection strains of *Br. japonicum* nodule bacteria were obtained from the All-Russian Research Institute of Agricultural Microbiology (St. Petersburg – Pushkin). These are standard strains 626a and 634b; strains participating in the Geographic Network of Experiments with Nitragin 640b, 605d, 635b, 402, BD32, MID10, 10k, 71t, 645d, 607d, 611d, D2, E109, M8.

The SibNIIK 315 variety, bred at the Siberian Research Institute of Fodder Crops, has been

included in the State Register since 1991 for the Volga-Vyatka, Middle Volga, Ural, West Siberian, and East Siberian regions. The growing season from germination to maturity is 92–105 days. It has demonstrated high adaptability to various growing conditions. Plants are of intermediate growth type, 70–85 cm tall, with a compressed bush shape. 1000-seed weight is 160–180 g. The seed protein content is 35–40%, and the oil content is 17–20% [1, 2].

The Omskaya 4 variety was developed at the Omsk Agricultural Research Center and has been included in the State Register for the West Siberian region since 1993. It is a middle-early variety. The bush form is semi-compressed, the plant height is 65–80 cm, and the height of the lower pod attachment is 13–16 cm. The weight of 1000 seeds is 168–180 g. The protein content in the seeds is 38.6–40.2%, and the fat content is 19.5–21.6%.

Sowing was carried out in the second ten-day period of May manually (plot area 4 m²) in four replicates with randomization according to the following general scheme: Option 1 - control, without fertilization and inoculation; Option 2 - with the use of mineral nitrogen at a dose of 60 kg / ha (N₆₀) without inoculation; Option 3 - inoculation with the standard strain 626a; Option 4 - inoculation with the standard strain 634b; Options 5-12 - inoculation with strains of nodule bacteria undergoing testing in the Geographic network of experiments with nitragin.

Agrochemical analysis showed sufficient provision of the soil with nutrients: easily hydrolyzed nitrogen - 14.76 mg / kg of soil (high), mobile phosphorus P₂O₅ - 7.49 mg / 100 g (average), potassium - 26.81 mg / 100 g (very high), humus - 5.07% (high) and leached chernozem.

Before sowing, the seeds were treated with rhizotorphin obtained from the All-Russian Research Institute of Agricultural Microbiology. In the uninoculated variants, no nodules formed because there were no spontaneous races of soybean nodule bacteria in the soil.

During the growing season, the following were determined: the weight of leaves, stems, roots, and nodules; the number of leaves, internodes, and nodules; the total and individual chlorophyll *a* and *b* content in leaves; plant length; and the height of attachment of the lower pod. After harvesting, the number and weight of pods and seeds were counted; the content of protein, oil, nitrogen, phosphorus, and potassium in seeds was determined using an IK-4250 infrared analyzer. The results were processed using dispersion and correlation analysis.

RESULTS AND DISCUSSION

Soybean in Bashkiria is an introduced crop, and there are no spontaneous races or strains of *Br. japonicum* nodule bacteria for it in the soil. A number of studies have reported the positive impact of inoculation on the productivity and quality of soybean seeds [3–6]. For soybean, as for many other legumes, there are numerous factors that limit successful symbiosis. These include acidic soils, a deficiency of micronutrients, particularly molybdenum, an excess of mineral nitrogen, the effects of pesticides used to protect crops, and unfavorable weather and climatic conditions. The variety specificity of rhizobacteria is also important. Numerous studies demonstrate the need to select strains of nodule bacteria for varieties and soils in different regions [7–12]. The results of determining the influence of the tested strains of nodule bacteria on the yield and chemical composition of soybean seeds are presented in Figs. 1 and 2. The variants are arranged in descending order of protein yield per hectare, as a more general indicator that takes into account both the amount of accumulated nitrogen and the size of the resulting yield.

The studied varieties differed in their response to inoculation with 10 strains of nodule bacteria. For example, the Omskaya 4 soybean variety, in a control variant without nodule bacteria, had lower yield and seed protein content compared to the SibNIIK 315 variety. However, inoculation with all strains of nodule bacteria significantly increased yield and, consequently, increased nitrogen removal by the seeds. Mean-

while, four strains inoculated with the SibNIIK 315 variety contributed to a decrease in yield and protein yield per hectare. The application of mineral nitrogen at a rate of 60 kg/ha also negatively impacted the yield of the SibNIIK 315 variety in nitrogen-rich soil.

Two groups of strains were identified: the effective ones, which significantly increased seed yield compared to the control and the variant with mineral nitrogen, and the ineffective ones, which did not increase or even reduced soybean productivity (see Fig. 1, 2). It turned out that both partners are responsible for the effectiveness of the symbiosis. For example, some of the best (634b, 640b, 626a, 402, and 635b) and worst (10k, BD32, and 605d) strains were common to both varieties, and some strains (MID10 and 71t) were effective in symbiosis with the Omskaya 4 variety, while on the SibNIIK 315 variety they reduced yield and protein yield per hectare.

Despite the ambiguous effects of different strains of nodule bacteria on seed yield formation, provision of fixed nitrogen in any form—mineral or symbiotic—led to an increase in seed protein content. Inoculation with even the least effective strain increased seed protein content and 1,000-kernel weight not only with the control but also with mineral nitrogen. It should be noted that, of all the variants, strain 402 contributed to the greatest increase in seed protein content in both varieties, while strain 605d contributed to the smallest.

As shown in the table, in the SibNIIK 315 variety, inoculation with most strains of nodule bacteria reduced or did not increase the indicators of seed weight, the number of seeds and pods on the plants compared to the control (only 2 strains - 634b and 640b - caused a significant increase in the weight and number of seeds), but had a positive effect on the number of seeds in a pod (within the experimental error) and on the weight of 1000 seeds (a significant increase in 6 out of 10 variants).

The Omskaya 4 variety responded better to inoculation: most strains contributed to an increase in the weight and number of seeds per

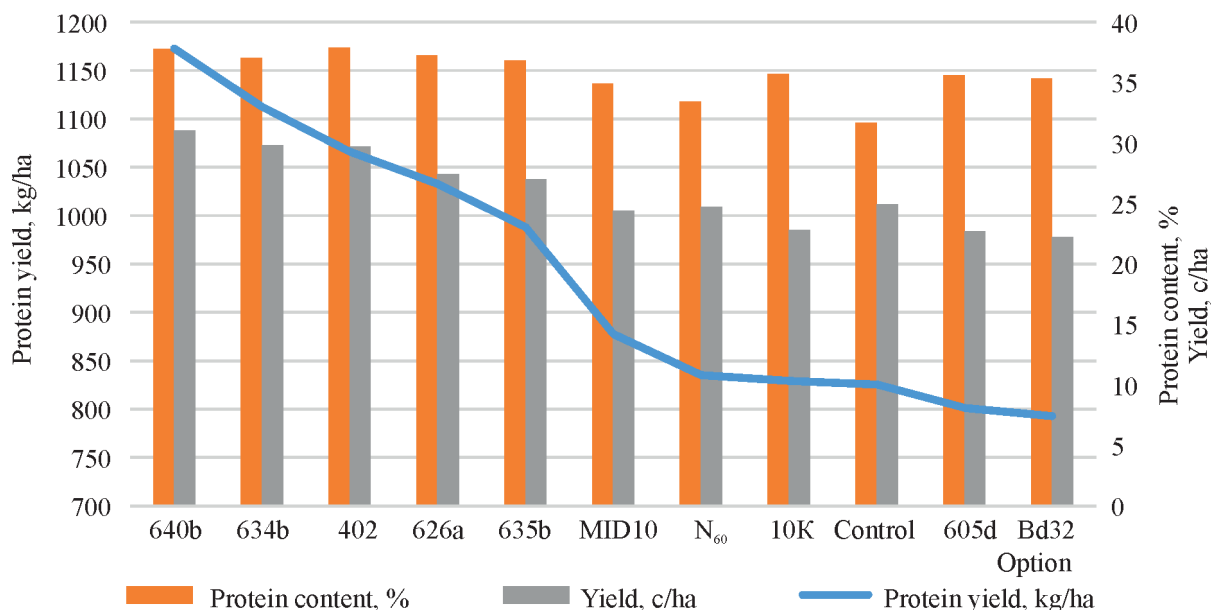


Рис. 1. Влияние различных штаммов клубеньковых бактерий на продуктивность, содержание и выход белка в урожае семян сои сорта СибНИИК 315

Fig. 1. Influence of different strains of nodule bacteria on the productivity, content and yield of protein in the harvest of soybean seeds of SibNIIC 315 variety

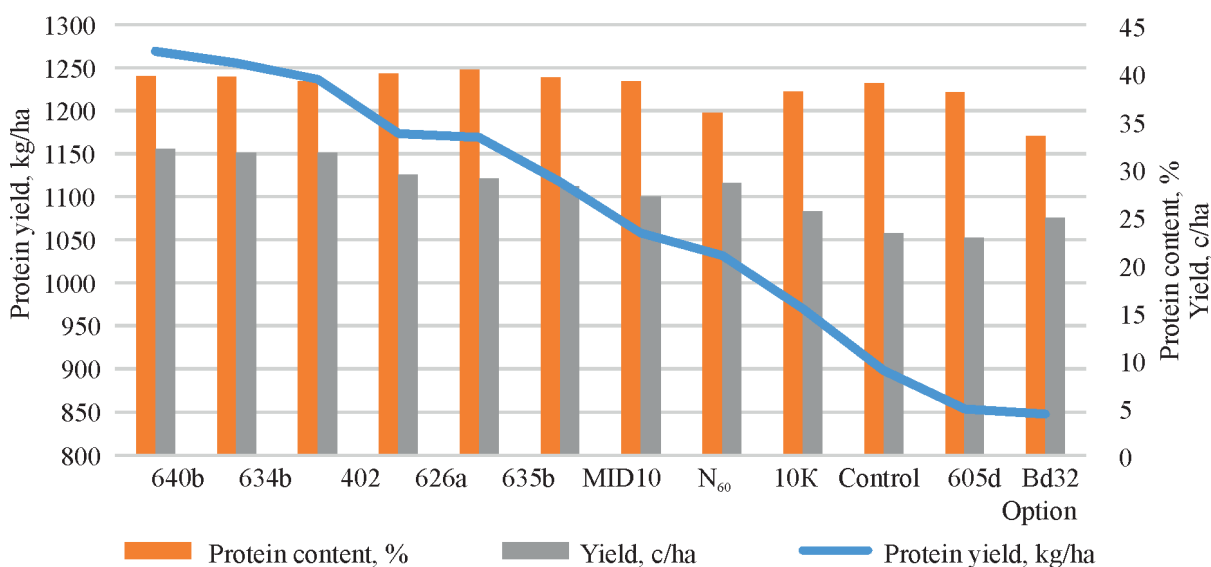


Рис. 2. Влияние различных штаммов клубеньковых бактерий на продуктивность, содержание и выход белка в урожае семян сои сорта Омская 4

Fig. 2. Effect of different strains of nodule bacteria on the productivity, content and yield of protein in the harvest of soybean seeds of Omskaya 4 variety

plant, with a significant increase in weight observed in three variants, the number of seeds per plant in 6 variants, the number of seeds per pod in 7 variants, and the weight of 1000 seeds in 8 variants compared to the control.

Analysis of soybean productivity elements shows that plants more effectively used the po-

tential of symbiosis to form the traits that are laid down at later stages (the number of seeds in a pod, the weight of 1000 seeds, the protein content in them) and significantly less effectively for the traits that are laid down at early stages of development (the number of pods and seeds per plant).

Влияние различных штаммов *Br. japonicum* на показатели структуры урожая сои
Effect of different strains of *Br. japonicum* on soybean crop structure

No.	Option	Seed weight, g/plant	Number of seeds, pcs./plant	Number of beans, pcs./plant	Number of seeds per pod, pcs.	Weight of 1000 seeds, g
<i>SibNIUK 315</i>						
1	Control	6,49	45,7	23,25	1,96	141,9
2	N ₆₀	5,82	41,82	22,10	1,90	139,2
3	626a	6,70	40,7	20,82	1,95	157,0
4	634b	7,92*	49,8*	24,97	2,0	158,5*
5	635b	6,64	40,72	20,67	1,97	162,7*
6	640b	8,27*	51,55*	25,37	2,03	161,3*
7	605d	5,26	37,00	18,77	1,98	141,4
8	402	7,00	43,35	21,80	2,0	161,4*
9	BD32	5,67	38,52	19,35	2,0	146,8
10	MID10	6,50	42,20	22,10	1,97	154,3*
11	10k	5,39	36,27	18,42	1,97	148,3
12	71t	5,29	35,37	17,60	2,0	150,6
	Average	6,42	41,92	21,27	1,98	151,9
	s _d	1,47	8,75	4,5	0,11	11,86
<i>Omskaya 4</i>						
1	Control	5,88	43,22	21,92	1,97	135,5
2	N ₆₀	6,30	45,10	21,70	2,07*	140,0
3	626a	7,82*	48,90*	23,57	2,06	160,5*
4	634b	8,34*	53,95*	25,67	2,10*	153,2
5	635b	6,87	43,40	20,47	2,13*	158,6*
6	640b	7,71	48,25*	22,95	2,11*	160,0*
7	605d	5,64	34,95	18,60	2,03	148,2
8	402	7,29	45,87*	21,60	2,13*	159,0*
9	BD32	6,30	41,37	19,80	2,08*	153,8*
10	MID10	8,19*	50,87*	23,77	2,14*	161,1*
11	10k	6,77	43,72	21,42	2,04	154,4*
12	71t	7,57	47,25*	22,85	2,06	158,5*
	Average	7,05	45,92	22,03	2,08	153,6
	s _d	1,90	2,02	5,61	0,1	9,65

*The differences are significant at $p = 0,05$.

s_d – standard deviation.

As a rule, application of mineral nitrogen at a dose of 60 kg/ha (N₆₀) decreased (for the SibNIUK 315 variety) or slightly increased (for the Omskaya 4 variety) the yield structure parameters, which is sometimes observed in rich chernozem soils. This indicates that, under these conditions, inoculation with some strains was

more effective than the application of nitrogen fertilizers at a dose of 60 kg/ha.

The correlation analysis of productivity factors revealed a close relationship between the number of pods and seeds per plant and the seed weight per plant ($r = 0.85–0.99$ at $p = 0.01$). These factors directly influence the yield and

are formed at relatively early stages of soybean development—in May and June. For example, the number of pods is determined at stage IV of organogenesis and corresponds to the branching phase, when generative buds are formed [13]. In the early stages of root infection and nodule development, when the symbiotic apparatus is just beginning to form and bacteria are not yet able to assimilate molecular nitrogen, temporary inhibition of young plants is observed. Subsequently, the additional nitrogen provides a growth and development advantage. If a plant is inoculated with an ineffective strain of nodule bacteria, the bacteria can also parasitize the host. Therefore, inoculation with an effective strain is crucial for the development of the key productivity factors that determine crop yield.

High positive correlation coefficients were found between the thousand-seed weight and protein content ($r = 0.89–0.94$ at $p = 0.01$), and high negative ones were found between the thousand-seed weight and oil content ($r = -0.89... -0.99$ at $p = 0.01$). These indices are formed at later stages, during grain filling, when the symbiotic apparatus is well developed. There is a high negative correlation between the protein and oil content in seeds ($r = -0.89... -0.99$ at $p = 0.01$). Negative correlations between protein and oil content in soybean seeds were noted in the work of Yu.Yu. Pomorova et al. [13].

The formation of soybean crop is closely linked to agroclimatic conditions [14, 15], especially for the continental climate of the Southern Urals.

CONCLUSION

Thus, selecting effective strains of *Br. japonicum* nodule bacteria for soybean inoculation is essential for its cultivation to produce high-protein yields. The most versatile and effective bacterial strains in the Republic of Bashkortostan are strains 634b and 640b. From the earliest stages of plant development, they promote the formation of the largest number of beans and seeds per plant, which are highly correlated with produc-

tivity. Some strains (605d, BD32, 10k) can also reduce plant productivity by inefficiently using the resources of the phytosymbiont. Inoculation with all strains increased seed protein content by 3.2–6.9%.

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Дата поступления статьи / Received by the editors 05.07.2025
Дата принятия к публикации / Accepted for publication 05.08.2025
Дата публикации / Published 15.10.2025



Особенности морфогенеза сортов ежевики садовой на этапе собственно микроразмножения *in vitro*

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Ежевика является ценной ягодной культурой. В настоящее время с появлением новых сортов возрос интерес к ней не только у садоводов-любителей, но и производителей. Ягоды и посадочный материал этой культуры в основном поступали и поступают в Россию из ближнего и дальнего зарубежья. Массовое размножение качественного посадочного материала ежевики необходимо для закладки насаждений и изучения новых сортов, что требует разработки современных технологий размножения методом культуры тканей *in vitro*. Целью исследований было изучение морфогенетического потенциала на 10 современных сортах ежевики садовой на этапе собственно микроразмножения. Для этого использовали среду DKW (Driver, Kuniyuki, 1984) в нашей модификации с содержанием различных регуляторов роста – цитокинина 6-бензиламинопурина (БАП) в концентрации 2,5 и 3,0 мкМ и ауксина индол-3-масляная кислота (ИМК) 0,25 и 0,3 мкМ, и без ауксина. Установлен оптимальный состав регуляторов роста (3 мкМ БАП без добавления ауксина). Проведено ранжирование сортов по основным показателям: коэффициент размножения, доля побегов, пригодных для укоренения, корнеобразование, развитие базального каллуса и витрификации побегов. Сорта ежевики были разбиты на группы с высоким, средним и низким уровнем по основным показателям. Показан разнонаправленный характер ответных реакций изученных сортов ежевики на условия культивирования. Установлено статистически значимое влияние сорта по всем изученным показателям морфогенеза. По наибольшему коэффициенту размножения выделилась группа сортов Chester, Black Satin, Brzezina и Von (12,5–9,5 шт./эксплант). По выходу побегов, пригодных для укоренения, отмечены наилучшие сорта Heaven Can Wait, Black Diamond, Black Satin, Bestberry (69,2–49,3%). В характере и направленности морфогенеза ключевую роль играет сорт, а среда лишь позволяет раскрыть его потенциал.

Ключевые слова: ежевика, клональное микроразмножение, *in vitro*, питательная среда, регенерация, регуляторы роста, *Rubus* L.

Features of morphogenesis of garden blackberry varieties at the stage of actual micropropagation *in vitro*

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Blackberries are a valuable berry crop. Currently, with the emergence of new varieties, interest in it has increased not only among amateur gardeners, but also among producers. Berries and planting material of this crop have mainly come and are coming to Russia from near and far abroad. Mass reproduction of high-quality planting material of blackberries is necessary for laying out plantings and studying new varieties, which requires the development of modern reproduction technologies using the *in vitro* tissue culture method. The purpose of the research was to study the morphogenetic potential of 10 modern varieties of garden blackberries at the stage of actual micropropagation. For this purpose, the DKW medium (Driver, Kuniyuki, 1984) was used in our modification containing various growth regulators – cytokinin 6-benzylaminopurine (BAP) in a concentration of 2.5 and 3.0 μM and auxin indolyl-3-butyric acid (IBA) 0.25 and 0.3 μM and without auxin. The optimal composition of

growth regulators (3 μ M BAP without adding auxin) was established. The varieties were ranked by the main indicators: multiplication coefficient, proportion of shoots suitable for rooting, root formation, development of basal callus and vitrification of shoots. Blackberry varieties were divided into groups with high, medium and low levels of the main indicators. The multidirectional nature of the responses of the studied blackberry varieties to the cultivation conditions was shown. A statistically significant effect of the variety on all the studied morphogenesis indicators was established. The group of varieties Chester, Black Satin, Brzezina and Von stood out by the highest reproduction coefficient (12.5–9.5 pcs./explant). In terms of the yield of shoots suitable for rooting, the best varieties are Heaven Can Wait, Black Diamond, Black Satin, Bestberry (69.2–49.3%). The variety plays a key role in the nature and direction of morphogenesis, and the medium only allows its potential to be revealed.

Keywords: blackberry, micropropagation, *in vitro*, nutrient medium, regeneration, growth regulators, *Rubus* L.

Для цитирования: Гусев Д.А., Плаксина Т.В., Блинова Г.Н. Особенности морфогенеза сортов ежевики садовой на этапе собственно микроразмножения *in vitro* // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 9. С. 14–22. <https://doi.org/10.26898/0370-8799-2025-9-2>

For citation: Gusev D.A., Plaksina T.V., Blinova G.N. Features of morphogenesis of garden blackberry varieties at the stage of actual micropropagation *in vitro*. *Sibirskii vestnik sel'skokhozyaistvennoi nauki* = *Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 9, pp. 14–22. <https://doi.org/10.26898/0370-8799-2025-9-2>

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

Благодарность

Работа выполнена при поддержке бюджетного финансирования НИР по теме 0534-2024-0003 «Использование генетических и биотехнологических методов исследований в селекции растений».

Acknowledgments

The work was carried out with the support of budget funding for research on the topic 0534-2024-0003 "The use of genetic and biotechnological research methods in plant breeding".

INTRODUCTION

Blackberries are closely related to raspberries and belong to the same genus, *Rubus* L., in the Rosaceae family, but to the subspecies *Eubatus* focke. Wild blackberries are common in Asia, Europe, and North America and include approximately 200 species. More than 50 species of blackberries grow in Russia.

Cultivated blackberry varieties originate from three European and 10 American species. The first cultivated blackberry varieties appeared in the mid-19th century in America. In our country, I.V. Michurin was one of the first to breed this crop. Between 1904 and 1908, he created the varieties Izobilnaya, Krasnaya, Texas, Enorm, and Urania 1.

The recent emergence of a wide variety of new blackberry varieties has generated significant interest among amateur gardeners and agricultural producers of various types, producing planting

stock and fresh berries. Modern blackberry varieties boast excellent flavor and transportability, with later flowering and ripening compared to raspberries, expanding the range of fresh berry consumption. Blackberries are more productive than raspberries, and their berries and leaves are no less medicinal than those of raspberries. Based on their growth habit, blackberries are divided into two groups: upright (brambleberry), or blackberry proper, and creeping, or spreading (dewberry). Upright blackberries form root suckers, like raspberries, which can be used for propagation. Spreading blackberries, however, propagate only by layering apical buds. There are also intermediate forms of semi-spreading blackberries.

It should be noted that modern blackberry varieties are complex hybrids, as evidenced by scientific publications and patents^{1–3}.

¹Nikitochkina T.D., Nikitochkin D.N. Raspberry, blackberry: A guide for amateur gardeners. Moscow: Niola-Press Publishing House; UNION-public Publishing House, 2007, pp. 113–117.

²Clark J.S., Moore J.N. "Natchez" Thornless Blackberry // HortScience, 2008, vol. 6, N 43, pp. 1897–1899.

³Clark J.S., Moore J.N. US Plant Patent. N 17,162 P3 (24 October 2006).

Currently, due to the sanctions imposed on our country, access to imported seedlings is limited. According to various estimates, Russia's dependence on imported fruit and berry seedlings ranges from 40 to 50% [1]. Consequently, there is a shortage of high-quality planting material for a number of berry crops.

Modern *in vitro* culture technologies for producing planting material for various garden plants are widely used worldwide. Leaders in this field include Brazil, Germany, Israel, India, Italy, the Netherlands, Poland, and the United States [2, 3]. In our country, this trend is also gaining popularity, as evidenced by the latest data from the Association of Planting Material Producers of Russia⁴.

In vitro micropropagation guarantees the production of healthy planting material for horticultural crops that meets the highest quality standards, which is becoming especially important in light of the latest requirements for the planting material⁵. In accordance with modern trends in blackberry breeding, the department of the M.A. Lisavenko Scientific Research Institute of Siberian Horticulture (NISS) of the Federal Altai Scientific Centre of Agro-Biotechnologies has amassed a collection of various varieties in recent years [4]. It is necessary to obtain a sufficient quantity of the planting material to fully study them in the conditions of southern Western Siberia. For rapid replication, it was decided to use the *in vitro* micropropagation method.

The purpose of the research is to evaluate the regenerative potential of blackberry varieties under *in vitro* culture conditions at the stage of micropropagation itself.

The objectives of the research included:

- optimization of the hormonal composition

of the nutrient medium at the stage of micropropagation itself and identification of the optimal nutrient medium;

- evaluation of the morphogenesis intensity for the studied blackberry varieties using the ranking method.

MATERIAL AND METHODS

The work was carried out over a period of two years (2023–2024) in the laboratory of biotechnology and cytology of the NISS department using the generally accepted methods^{6, 7} [5].

The research objects were 10 varieties of blackberries: Bestberry, Black Diamond, Black Satin, Brzezina, Chester, Heaven Can Wait, Loch-Tay, Natchez, Ouachita, Von.

Driver and Kuniyuki's DKW⁸ medium, modified in our own way [6], supplemented with iron chelate at a double concentration and bacteriological agar (0.7%), was used as the mineral base of the nutrient medium. This medium has not yet found widespread use in *in vitro* culture for fruit and berry crops. There are some examples of its use in clonal micropropagation of raspberries [7, 8]. In most cases, when micropropagating blackberries, it is customary to use a medium according to the Murashige and Skoog formula [9–11]. As a result of the previous studies, for the final stage of optimizing the concentrations, combinations, and ratios of growth regulators (GRs) in the nutrient medium, cytokinin 6-benzylaminopurine (BAP) 2.5 and 3.0 μM and auxin indolyl-3-butyric acid (IBA) 0.25 and 0.3 μM , respectively, as well as the variants without the addition of IBA were used.

A glass bottle (type II-100-2, height 105 mm, diameter 50 mm) with 20 ml of nutrient medium was used as a culture vessel.

⁴Catalogue "Nurseries of Russia" 2024. Moscow: Association of the planting material producers, 2024, 307 p.

⁵Egorov E.A., Shadrina Zh.A., Kuznetsova A.P., Efimova I.L., Kochyan G.A. et al. Organization of technological processes for the production of the planting material for fruit crops / Under the general editorship of Academician of the Russian Academy of Sciences E.A. Egorov. Krasnodar: FSBSI NCFSCHVW, 2019, 243 p.

⁶Solovykh N.V. The use of biotechnological methods in working with berry crops: Methodological recommendations. Michurinsk: Publishing House of the Michurinsk State Agrarian University, ARRIGBFP named after I.V. Michurin, 2009, 47 p.

⁷Plaksina T.V., Gusev D.A. Micropropagation of regular and everbearing raspberry varieties. Methodological recommendations. Barnaul, 2023, 27 p.

⁸Driver J.A., Kuniyuki A.H. *In vitro* propagation of paradox walnut rootstock // HortScience. 1984. vol. 19, N 4, pp. 507–509.

The cultivation conditions were according to the methods (see footnotes 6, 7). White LED lamps were used as a light source (Jazzway 6500K).

The experimental design included three explants per replicate, five replicates per treatment. Microshoots 10–13 mm long were used as the explants. The passage duration was 60 days. The results were obtained from a single subculture. A stable, long-term *in vitro* blackberry culture was used for the experiment.

The record elements characterizing the intensity of morphogenesis, manifested in the form of organogenesis (formation of new shoots, roots) or histogenesis (formation of the callus tissue) are the following: multiplication coefficient (number of microshoots per explant, pcs./ explant) (MC); proportion of the shoots ≥ 13 mm (%); presence of roots (%); degree of callus development (0 points – no callus, 1 point – 0–5 mm, 2 points – 5–10 mm, 3 points – 10 mm or more); presence of vitrification (%).

Statistical processing of the data was carried out according to generally accepted methods⁹.

The ranking of varieties according to the indicators of the recording elements was carried out by dividing the entire range of the variation of values into three equal intervals (high, medium, low).

RESULTS AND DISCUSSION

It is believed that *in vitro* tissue culture allows for the propagation of virtually any plant thanks

to controlled conditions, using the balanced nutrient media with essential nutrients and a wide range of different GRs. Micropropagation techniques have been developed for over 2,400 plant species to date. However, each species, and even cultivar, requires optimization of the *in vitro* culture conditions [3, 8, 12]. The emergence of new hybrids and varieties with complex genetic origins, as well as the preservation of the old varieties of various agricultural crops with valuable traits in their genomes, often lead to difficulties in cloning them *in vitro*. Therefore, scientists are constantly working to optimize the existing methods and technologies to meet modern plant propagation requirements.

The results of the final stage of optimization of the composition of the nutrient medium for all varieties are presented in Table 1.

A medium with 3.0 μM BAP without the addition of IBA was identified as optimal due to its high MC (7.65 pcs/explant), indicating that the balance and composition of the GR had been achieved. Researchers working with garden blackberry varieties reached a similar conclusion that the presence of cytokinin alone in the medium is sufficient for blackberry propagation of the Natchez, Black Magic, Osage [13], Triple Crown [8], Karaka Black [14], Ebony, Tupy [15] varieties and the wild species of the Peruvian Highlands [16].

Based on the data obtained from cultivating blackberries on an optimal nutrient medium, the varieties were ranked into groups according to

Табл. 1. Показатели роста и развития сортов ежевики на изученных средах

Table 1. Growth and development indicators of blackberry varieties on the studied mediums

Medium		Reproduction rate, pcs/ operation.	Proportion of shoots >13 mm, %	Rooting, %	Callus formation, score	Vitrification, %
BAP, μM	IBA, μM					
2,5	0,00	6,53	39,5	32,0	1,02	4,4
2,5	0,25	5,56	38,4	28,0	1,05	11,9
3,0	0,00	7,65	38,3	27,3	1,11	9,6
3,0	0,30	6,50	42,7	27,3	1,11	14,1
LSD ₀₅		1,10	$F\phi < Ft$	$F\phi < Ft$	$F\phi < Ft$	6,3

⁹Dospekhov B.A. Methods of field experiment. Moscow: Kolos, 1986, 502 p.

Табл. 2. Ранжирование сортов ежевики по коэффициенту размножения на среде с 3 мкМ БАП

Table 2. Ranking of blackberry varieties by multiplication coefficient on a medium with 3 μ M BAP

Ranking (range, pcs/explant)	Variety	Reproduction rate, pcs/explant
High ($\geq 9,5-12,5$)	Chester	12,5
	Black Satin	10,5
	Brzezina	10,4
	Von	9,5
Middle ($\geq 6,5-< 9,5$)	Loch-Tay	8,8
	Black Diamond	7,3
Low ($3,5-< 6,5$)	Bestberry	5,4
	Natchez	4,9
	Heaven Can Wait	3,7
	Ouachita	3,5

Табл. 3. Ранжирование сортов ежевики по доле побегов ≥ 13 мм (%) на среде с 3 мкМ БАП

Table 3. Ranking of blackberry varieties by the proportion of shoots ≥ 13 mm (%) on a medium with 3 μ M BAP

Ranking (range, %)	Variety	Proportion of shoots ≥ 13 mm, %
High ($\geq 48,0-69,2$)	Heaven Can Wait	69,2
	Black Diamond	53,8
	Black Satin	50,9
	Bestberry	49,3
Middle ($\geq 26,9-< 48,0$)	Von	44,6
	Chester	43,3
	Natchez	32,3
Low ($5,7-< 26,9$)	Loch-Tay	23,1
	Ouachita	22,2
	Brzezina	5,7

Табл. 4. Ранжирование сортов ежевики по укоренению на среде с 3 мкМ БАП

Table 4. Ranking of blackberry varieties by rooting on a medium with 3 μ M BAP

Ranking (range, %)	Variety	Rooting, %
High ($\geq 66,7-100$)	Ouachita	100,0
Middle ($\geq 33,3-< 66,7$)	Chester	40,0
	Heaven Can Wait	40,0
	Black Diamond	33,3
Low ($0,0 - <33,3$)	Brzezina	26,7
	Von	13,3
	Natchez	13,3
	Loch-Tay	6,7
	Bestberry	0,0
	Black Satin	0,0

Табл. 5. Ранжирование сортов ежевики по каллусообразованию на среде с 3 мкМ БАП

Table 5. Ranking of blackberry varieties by callus formation on a medium with 3 μ M BAP

Ranking (range, score)	Variety	Callus formation, score
High ($\geq 1,4-2,0$)	Black Diamond	2,0
	Von	1,9
	Heaven Can Wait	1,8
	Chester	1,7
Middle ($\geq 0,7-< 1,4$)	Bestberry	1,3
	Loch-Tay	1,2
	Black Satin	1,0
Low ($0,0-< 0,7$)	Brzezina	0,1
	Natchez	0,1
	Ouachita	0,0

high, medium and low values of the indicator (see Tables 2–5).

Based on MC, the Chester, Black Satin, Brzezina, and Von varieties can be distinguished as having a high value of 9.5–12.5 shoots per explant, while the Ouachita and Heaven Can Wait varieties have a low value (3.5 and 3.7, respectively). However, a high or low MC does not necessarily mean that a variety will produce a high yield of shoots suitable for rooting (≥ 13 mm in length). The Brzezina variety, with an MC of 10.4, had the lowest yield of shoots suitable for rooting (5.7%) among the studied varieties. Meanwhile, the Heaven Can Wait cultivar, with a low MC (3.7), was the leader in terms of shoot yield suitable for rooting (69.2%). Some cultivars had both high MC and shoot yield suitable for rooting (Black Satin), or low levels of both (Ouachita). The Chester cultivar, with the highest MC (12.5), fell into the group of cultivars with average values for shoot yield suitable for rooting. The Black Diamond cultivar, with an average MC, had a high shoot yield suitable for rooting (53.8%) (see Tables 2 and 3).

We hypothesize that the observed high variability in blackberry cultivars in terms of MC parameters and shoot yield suitable for rooting is related to cultivar specificity in endogenous auxin synthesis in apical meristems. Auxins are antagonists of cytokinins, so the cultivars with increased

auxin synthesis suppress the action of exogenous cytokinin, leading to a decrease in MC. High levels of endogenous auxins can also stimulate spontaneous root formation. For example, the Ouachita cultivar (100%), which we previously noted as having low MC and a low yield of shoots suitable for rooting, emerged as the leader in spontaneous root formation (see Table 4).

The Chester, Heaven Can Wait, and Black Diamond cultivars demonstrated average spontaneous rooting capacity (33.3–40.0%), although we previously noted their high rooting efficiency (Chester) and high yield of shoots suitable for rooting (Heaven Can Wait and Black Diamond). This response of the explants of these cultivars indicates a balance between the synthesis of endogenous auxins and exogenous cytokinin (BAP), which together produce a high morphogenetic response. The remaining cultivars had low rooting capacity (6.7–26.7%) or did not form roots at all (Bestberry and Black Satin).

The study did not aim to obtain roots from explants at the propagation stage itself, but the data on this indicator are valuable when working with the varieties at the subsequent stage of rhizogenesis *in vitro*.

Callus formation is undesirable during the micropropagation stage itself, but even on a nutrient medium optimized for key growth parameters, strong varietal specificity in the degree of basal callus development is evident. A group of varieties with low or no callus formation is distinguished – Brzezina, Natchez and Ouachita. For the remaining varieties, basal callus formation was between 1.0 and 2.0 points. The response of the Chester, Heaven Can Wait, Von, and Black Diamond varieties was high, ranging from 1.7 to 2.0 points (see Table 5).

When culturing explants *in vitro*, undesirable physiological effects such as vitrification or tissue hyperhydration may occur, possibly due to the attracting effect of endogenous auxins, which promote water absorption into tissue. This reaction was not characteristic of most blackberry varieties studied. Only two varieties (Chester and Brzezina) showed signs of vitrification (26.7%).

Calculation of the correlation coefficient between the data points revealed a high correlation between MC and vitrification, the proportion of shoots >13 mm, and callus formation. Thus, the varieties with high MC are also characterized

Табл. 6. Сила корреляционных связей между элементами учета на среде с 3 мкМ БАП (по шкале Чеддока)

Table 6. The strength of correlations between the record elements on the medium with 3 μM BAP (according to the Chaddock scale)

Strength of correlation	Parameter 1	Parameter 2	Correlation coefficient ±
Very high (0,90–1,00)	–	–	–
High (0,70–0,90)	Reproduction rate	Vitrification	0,77
	Proportion of shoots >13 mm	Callus formation	0,75
Middle (0,50–0,70)	–	–	–
Low (0,30–0,50)	Proportion of shoots >13 mm	Vitrification	–0,38
	Reproduction rate	Rooting	–0,38
Very low (0,00–0,30)	» »	Callus formation	0,23
	Rooting	Vitrification	0,09
	Callus formation	»	–0,12
	Proportion of shoots >13 mm	Rooting	–0,19
	Reproduction rate	Proportion of shoots >13 mm	–0,20
	Rooting	Callus formation	–0,28

Note. «–» – absence of correlation pairs in this gradation.

by vitrification (Chester and Brzezina), while the varieties with a high yield of shoots suitable for rooting are characterized by callus formation (Black Diamond and Heaven Can Wait) (see Table 6).

Stimulation of shoot growth by elongation and basal callus formation may be facilitated by high levels of endogenous auxin production in these varieties, which also confirms our previously proposed hypothesis regarding the link between high endogenous auxin concentrations and the characteristics of morphogenetic processes in blackberry varieties. The remaining factors are linked by weak and very weak positive and negative correlations, so they are not significant and can be ignored.

CONCLUSIONS

1. At the stage of micropropagation of garden blackberry varieties itself, the optimal nutrient medium is one containing cytokinin BAP at a concentration of 3.0 μM without the addition of auxins.

2. The highest morphogenetic response was observed in blackberry varieties: by multiplication coefficient – Chester, Black Satin, Brzezina, Von; by the yield of shoots suitable for rooting – Heaven Can Wait, Black Diamond, Black Satin, Bestberry; by spontaneous rooting – Ouachita. Overall, the analysis showed that blackberries in *in vitro* culture are characterized by a wide variation in morphogenetic responses, which is possibly due to the complex genetic origin of the varieties and the different types of bush growth *in vivo*, but this feature of the crop does not impede the use of the *in vitro* culture method for mass propagation.

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Дата поступления статьи / Received by the editors 15.05.2025
Дата принятия к публикации / Accepted for publication 10.07.2025
Дата публикации / Published 15.10.2025

Сравнительные экспериментальные исследования сортов картофеля при воспроизводстве мини-клубней в условиях контролируемой среды

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Воспроизводство высокопродуктивного посадочного материала картофеля в условиях контролируемой среды способствует снижению затрат на культивирование в открытом грунте, формирует необходимые условия для хорошей приживаемости, роста и развития, увеличения массы и числа мини-клубней, продления эффекта предотвращения повторного заражения. Объектами исследования являлись сорта картофеля селекции Сибирского федерального научного центра агробиотехнологий РАН: Любава, Танай, Кузнечанка, Тулеевский, Кемеровчанин. В качестве селекционного стандарта использован сорт Невский. Воспроизводство мини-клубней картофеля проводили на специальных агробиологических установках, оснащенных двухъярусными стеллажами, а также системами контроля светового и теплового режимов, времени и объема полива, состава и концентрации питательной среды. Выявлено, что все изучаемые сорта картофеля являются пригодными для воспроизводства в контролируемых условиях и получения качественного посадочного материала для открытого грунта. С помощью фенологических наблюдений установлен факт идентичности процесса воспроизводства картофеля в условиях контролируемой среды. При этом общие показатели роста, продолжительности вегетационного периода и урожайности сортов имели различные фактические значения. На основании экспериментальных данных определена длительность вегетационного периода в контролируемых условиях воспроизводства: у сорта Любава она составляет 55 сут, у сортов Кемеровчанин, Танай, Кузнечанка, Тулеевский, Невский – от 60 до 65 сут. Высота растений в зависимости от сорта доходила до 30–70 см. Статистические показатели количества клубней в зависимости от сорта варьировали в интервале от 2 до 5 шт., средний фракционный состав мини-клубней составлял 3–5 см.

Ключевые слова: безвирусный картофель, рост и развитие, мини-клубни, продуктивность, фракционный состав, агробиологические установки, контролируемая среда

Comparative experimental studies of potato varieties in the reproduction of mini-tubers in controlled environment conditions

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Reproduction of highly productive potato planting material in a controlled environment creates the necessary conditions for good survival, growth and development, increasing the mass and number of mini-tubers, prolonging the effect of preventing re-infection, and helps reduce the costs of cultivation in open ground. The objects of the study were potato varieties bred by the Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences: Lyubava, Tanai, Kuznechanka, Tuleevsky, Kemerovchanin. The Nevsky variety was taken as the breeding standard. The reproduction of mini-potato tubers was carried out on special agrobiological installations equipped with two-tiered racks, as well as the systems for controlling light and heat conditions, time and volume of irrigation, composition and concentration of the nutrient medium. It was found that all the studied potato varieties are suitable for reproduction under controlled conditions and obtaining high-quality planting material for open ground. Using phenological observations, the fact of the identity of the process of

potato reproduction under controlled environmental conditions was established. At the same time, the overall growth rates, duration of the growing season and the yield of varieties had different actual values. Based on experimental data, the duration of the growing season under controlled reproduction conditions was determined: for the Lyubava variety it is 55 days, for the Kemerovchanin, Tanai, Kuznechanka, Tuleevsky, Nevsky varieties – from 60 to 65 days. The height of plants, depending on the variety, reached 30–70 cm. Statistical indicators of the number of tubers, depending on the variety, varied in the range from 2 to 5 pieces, the average fractional composition of mini-tubers was 3–5 cm.

Keywords: virus-free potato, growth and development, mini-tubers, productivity, fractional composition, agrobiological installations, controlled environment

Для цитирования: Сухопаров А.А., Лебедев А.Н., Тамиров К.С., Федорова О.В. Сравнительные экспериментальные исследования сортов картофеля при воспроизводстве мини-клубней в условиях контролируемой среды // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 9. С. 23–32. <https://doi.org/10.26898/0370-8799-2025-9-3>

For citation: Sukhoparov A.A., Lebedev A.N., Temirov K.S., Fedorova O.V. Comparative experimental studies of potato varieties in the reproduction of mini-tubers in controlled environment conditions. *Sibirskii vestnik sel'skokhozyaistvennoi nauki* = *Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 9, pp. 23–32. <https://doi.org/10.26898/0370-8799-2025-9-3>

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

One of the elements of ensuring food security is the intensification of technological aspects of the reproduction of highly productive varieties of crop plants (in particular, potatoes) for cultivation in open ground [1]. To ensure a stable and sustainable supply of high-quality planting material to agro-industrial enterprises in the Russian Federation, the concept for the development of the agro-industrial complex envisages an increase in potato yields through the use of highly productive varieties and the use of modern technologies for the reproduction of high-quality seed material in a controlled environment [2].

Potatoes are a valuable food, forage, and industrial crop. Under *ex vitro* conditions, potatoes reproduce vegetatively and are therefore susceptible to viral, bacterial, and fungal diseases [3]. The importance of providing agro-industrial enterprises with high-quality potato planting material is a pressing scientific and practical issue. Globally, potato production is carried out using virus-free technology. A highly productive method for reproducing high-quality potato planting material is the apical meristem method, which ensures the formation of plants unaffected by pathogenic viral and bacterial flora [4].

Thus, the reproduction of potato seed mate-

rial should be carried out under controlled external and internal environments, allowing for accelerated reproduction of virus-free seed material with its subsequent inclusion in the reproduction process [5, 6].

The unique feature of potato seed production under controlled *in vitro* conditions is the complete absence of viral and bacterial flora. This is due to the absence of infections in the original tuber material, which ensures the production of healthy seed material [7].

The stage of growing meristematic potato plants under controlled conditions using biological systems involves maintaining the necessary external and internal environmental parameters to ensure sustainable plant development. These parameters include: illumination, humidity, external and internal temperature (specifically, air and nutrient substrate temperature), nutrient medium composition (balanced in essential nutrients), and its delivery schedule [8].

Improving the methodology for reproducing potato minitubers with the highest profitability requires a scientifically sound approach to developing and maintaining plant reproduction conditions. Furthermore, the quality of planting material, among other factors, is determined by planting density, which is not reflected in the op-

timality of research by leading scientists [9, 10].

In global practice, to obtain a sufficient quantity of high-quality potato seed material free from viral infection, biotechnological methods of improvement based on the elimination of viruses in *in vitro* culture are generally used [11, 12]. However, these methods do not result in high potato productivity. Comparative studies indicate that potato reproduction in agrobiological facilities allows for several times the multiplication rate and yield compared to other reproduction methods [13]. This is a consequence of the high biological adaptation of microplants to the microclimate under extreme conditions, particularly to open ground and greenhouse microclimates [14].

Thus, the purpose of the study is to evaluate the morphological characteristics of mini-tubers and the productivity of potatoes of different maturity groups during reproduction in biological installations with a controlled environment.

The scientific novelty is represented by the regime and technological parameters of reproduction of mini-tubers in a controlled environment of biological installations, as well as their influence on the morphological characteristics of different potato varieties.

MATERIAL AND METHODS

The experiment was carried out within the framework of the state assignment No. FNU-UU-2022-0006 in the laboratory for the automation of microclonal propagation of the Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences (SFSCA RAS) from 2023 to 2025.

The object of the study is the process of reproduction of potato mini-tubers in a controlled environment in agrobiological installations.

The following varieties bred by the Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences (SFSCA RAS) were used for the experiment: Lyubava, Tanai, Kuznechanka, Tulevsky, and Kem-

erovchanin¹. These varieties were selected based on the need for seed production in the Siberian Federal District as part of the project to establish a potato breeding and seed center. The Nevsky variety was chosen as the breeding standard.

The reproduction of mini-tubers was carried out in special agrobiological installations equipped with two-tiered racks, as well as the systems for controlling the time and volume of irrigation, the composition and concentration of the nutrient medium, and light and heat conditions (see Fig. 1).

Microplants were removed from the test tubes 10–12 hours before planting and placed in distilled water. After the roots were cleared of the nutrient medium, the plants were planted in an adaptation chamber (one plant per substrate volume of at least 7 dm³). Substrate composition: high-moor sphagnum peat of low decomposition, limestone (dolomite) flour, complex mineral fertilizer with the necessary set of macro- and microelements, including N_{total} – 150 мг/л, Ca – 120, Mg – 30, P₂O₅ – 150, K₂O – 250 мг/л, pH from 5,5 to 6,6. To form a sufficient density, the plants were placed sequentially in two rows and two tiers [15].

The lighting regime was provided by LED phytolamps on a 16-hour on/8-hour off cycle. The lamps' specific characteristics were selected to provide the optimal luminous flux recommended for potato propagation. The phytolamps were positioned 65 cm above the plants, with the option of additional adjustment. The lamps emitted direct, non-polarized light with an efficiency of 227.5 PPD. The photometric characteristics of the phytolamps are shown in Figure 2.

In agrobiological installations, the temperature was maintained at 20 ± 2 °C with a relative air humidity of 60–65%.

The total sample size was 340 plants, which ensures a reliable probability of the study with a significance level of $p = 0.05$. During the growing season, phenological observations were carried out according to the established methodology².

¹Agricultural crop varieties bred at the SFSCA: a textbook / compiled by N. I. Kashevarov, R. I. Polyudina, N. A. Lapshinov, N. V. Pakul, V. P. Danilov. Novosibirsk: Zolotoy Kolos, 2019, 112 p.

²Guidelines for maintaining and studying the world potato collection / compiled by S.D. Kiru, L.I. Kostina, E.V. Truskinov, N.M. Zoteeva, E.V. Rogozina, L.V. Koroleva, V.E. Fomina, S.V. Palekha, O.S. Kosareva, D.A. Kirillov. St. Petersburg, 2010, 28 p.



Рис. 1. Общий вид агробиологической установки с контролируемой средой

Fig. 1. General view of the agrobiological installation with controlled environment

For morphological analysis using the Bernoulli scheme, at least 16 control potato plants were assessed for plant height, number, weight, and fractional composition of minitubers. Fractional composition was determined using a special technical device.

In accordance with GOST 33996–2016³, mini-tubers of 9 to 60 mm sizes were used as the planting material. Using a small size fraction (less than 9 mm) during subsequent cultivation results in significant sparse seedlings, a high incidence of shoot failure, stunted growth, and reduced productivity. Therefore, mini-tubers were sorted by size fraction from 10 to 50 mm with a 10 mm gradient.

The vegetation period of the plants was assessed using hyperspectral analysis.

Statistical processing of the research results was carried out in the Mathcad environment in the following sequence:

1. Estimation of mathematical expectation:

$$m(x) = \frac{\sum_{i=1}^n x_i}{n},$$

where x_i – value of a random variable;
 n – number of observations.

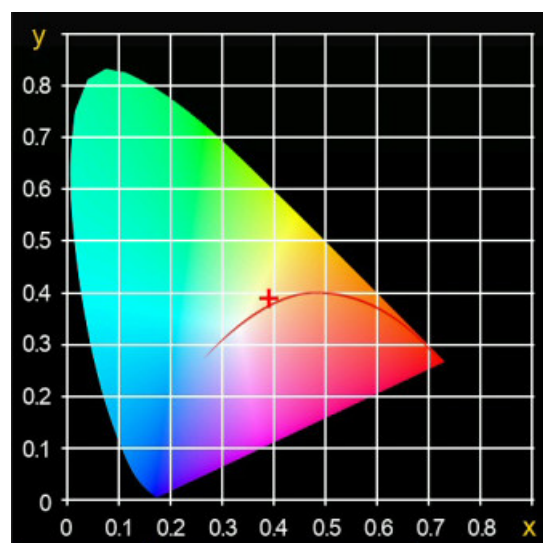


Рис. 2. Фотометрическая характеристика фитоламп

Fig. 2. Photometric characteristics of the grow lamps

2. Estimation of variance:

$$D(x) = \frac{1}{n-1} \sum_{i=1}^n (x_i - m(x))^2.$$

3. Estimation of the standard deviation:

$$\sigma(x) = \sqrt{D(x)}.$$

³GOST 33996–2016 Seed potatoes. Specifications and methods for determining quality. Moscow: Standartinform,

4. Asymmetry coefficient:

$$G(x) = \frac{\sqrt{n(n-1)}}{n-2} \cdot \frac{\sum_{i=1}^n (x_i - m(x))^3}{\sigma(x)^3}.$$

5. Excess coefficient:

$$E(x) = \left(\frac{n-1}{(n-2)(n-3)} \right) \left((n-1) \cdot \frac{\sum_{i=1}^n (x_i - m(x))^4}{D(x)^4} - 3n + 3 \right).$$

6. Variation coefficient:

$$V = \frac{\sigma(x)}{m(x)}.$$

7. Expected value estimation error:

$$M = \frac{\sigma(x)}{\sqrt{n}}.$$

8. Asymmetry standard error:

$$\Delta G = \sqrt{\frac{6n(n-1)}{(n-2)(n+1)(n+3)}}.$$

9. Excess standard error:

$$\Delta E = \sqrt{\frac{24(n-1)^2}{(n-3)(n-2)(n+3)(n+5)}}.$$

The scattering field of a random variable was found according to the rule $\pm 3\sigma$. The correspondence of the empirical distribution to the expected theoretical distribution was established using the Pearson criterion:

$$\chi^2 = \sum_{i=1}^k \frac{(m_i - np_i)^2}{np_i},$$

where m_i – empirical frequencies by intervals; np_i – theoretical frequencies by intervals; k – number of intervals.

Since the reproduction process in the experiment was carried out in an isolated volume with high air humidity, the collection and placement of tubers for storage were accompanied by two- and three-day drying at a temperature of 20 ± 2 °C with the tubers placed in a single layer on gauze or filter paper. After drying, the mini-tubers were placed in a container with filter paper placed at the top and bottom to control humidity. The container was designed with a ventilation system. The mini-tubers were stored at a temperature of 3 to 6°C.

RESULTS AND DISCUSSION

Phenological observations of growth and development revealed that plants responded differently to artificial growing conditions depending on the variety. The early-maturing Lyubava variety had a shorter flowering period (12 days) and growing season (55 days) compared to middle-early varieties, surpassing them by an average of 3-5 and 5-7 days, respectively. Within the group of middle-early varieties, no significant differences were found in flowering time or overall vegetation (60–62 days). For the remaining varieties, the time from transplantation to technical maturity was 60–65 days. Plant height at harvest averaged between 30 (Tuleevsky) and 57 cm (Lyubava) (see Fig. 3).

Analysis of plant height distribution density functions revealed significant differences between varieties. For example, the Kuznechanka and Tanai varieties are characterized by the shortest plant heights (distribution peaks in the 30–40 cm range), indicating their dwarfism. The Lyubava variety occupies an intermediate position, demonstrating a distribution peak at 50 cm. The tallest plants are the Nevsky, Tuleevsky, and Kemerovchanin varieties, with peaks at 60 cm.

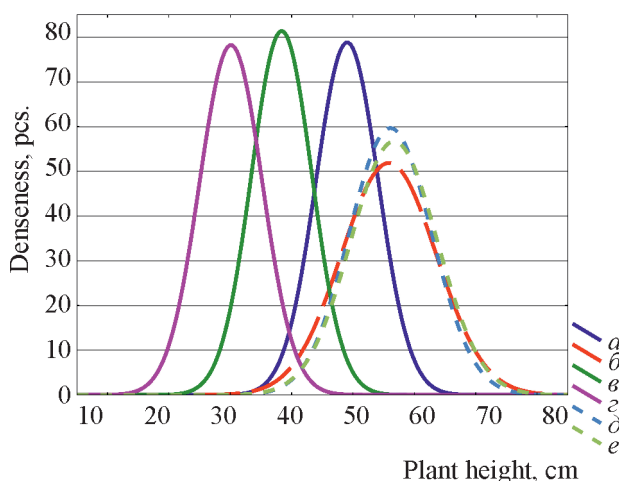


Рис. 3. Функции плотности распределения высоты растений:

a – Любава; *б* – Невский; *в* – Танай; *г* – Кузнечанка; *д* – Тулеевский; *е* – Кемеровчанин

Fig. 3. Density functions of plant height distribution:

a – Lyubava; *б* – Nevsky; *в* – Tanai; *г* – Kuznechanka; *д* – Tuleevsky; *е* – Kemerovchanin

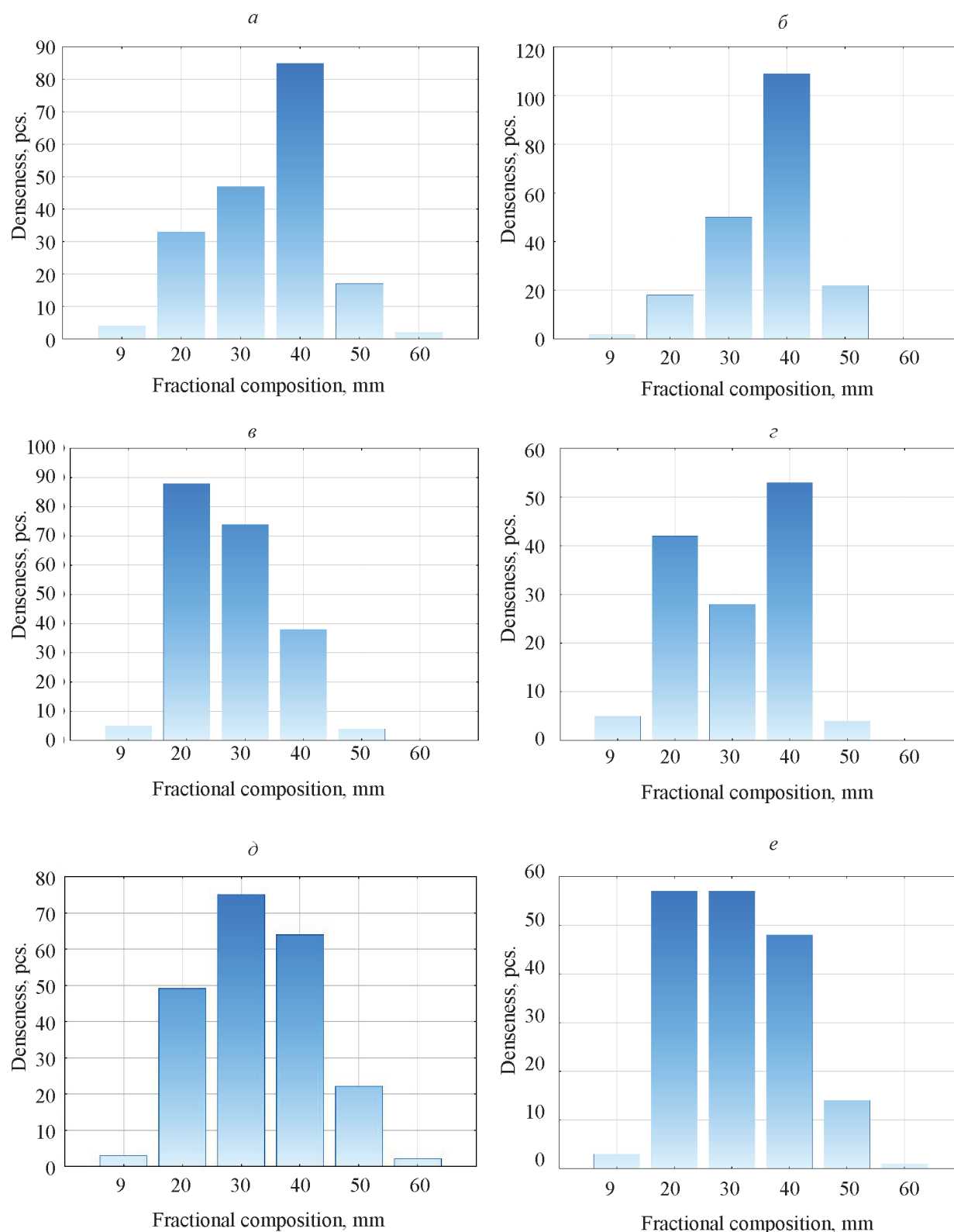


Рис. 4. Гистограммы распределения фракционного состава картофеля:

a – Любава; *б* – Nevский; *в* – Танай; *г* – Кузнецанка; *д* – Тулеевский; *е* – Кемеровчанин

Fig. 4. Histograms of the distribution of the fractional composition of potatoes:

a – Lyubava; *б* – Nevsky; *в* – Tanai; *г* – Kuznechanka; *д* – Tuleevsky; *е* – Kemerovchanin

However, the latter have a wider curve, reflecting their high growth variability. Thus, the data obtained allow us to distinguish varieties based on morphological characteristics, which can be taken into account when choosing agricultural practices, such as planting pattern, watering rates, and care requirements.

Based on the analysis of the fractional composition of mini-tubers, it was found that among the studied varieties, the Tuleevsky variety produced the most non-standard tubers (5 pieces), the Kemerovchanin variety had 4 pieces, and the Nevsky variety had 2 mini-tubers of the 50–60 mm fraction. Histograms of the distribution of varieties depending on the fractional composition of tubers are presented in Fig. 4.

It was found that the largest number of mini-tubers in all varieties falls on the 20–30 and 30–40 mm fractions.

The Lyubava variety exhibits a uniform distribution, with a predominance of the 30–40 mm fraction and a significant presence of minitubers of the 20–30 and 40–50 mm fractions. The Nevsky variety exhibits high uniformity—the majority of minitubers are in the 30–40 mm range, making it particularly suitable for industrial processing. The Tanai variety, on the other hand, has a predominance of small fractions (20–30 mm), which may be due to the variety's biological characteristics and makes it suitable for seed propagation.

The Kuznechanka variety exhibited two distinct peaks—in the 20–30 and 30–40 mm fractions—indicating a good level of uniformity. Tuleevsky variety tubers exhibited a distribution with a concentration in the 20–40 mm range. The Kemerovchanin variety is characterized by the presence of mini-tubers in the 20–50 mm fractions, with the main clusters in the 20–30 and 30–40 mm zones.

Thus, all the studied varieties have an acceptable fractional composition.

Analysis of the elements of the crop structure showed that within the framework of the study, the weight of one mini-tuber varied on average from 16.65 (Kemerovochanin) to 32.04 g (Lyubava), while exceeding the standard by 2.11 g. Tubers of the Tuleevsky, Tanai and Kuznechanka varieties had an average weight of 22–23 g (see Fig. 5).

According to the data in Figure 5, potato varieties vary significantly in mini-tuber weight. The Tanai, Kuznetchanka, Kemerovchanin, and Tuleevsky varieties are characterized by the smallest mini-tuber weights, with peaks in the 15–25 g range. The Lyubava and Nevsky varieties exhibit moderate weights (30–35 g).

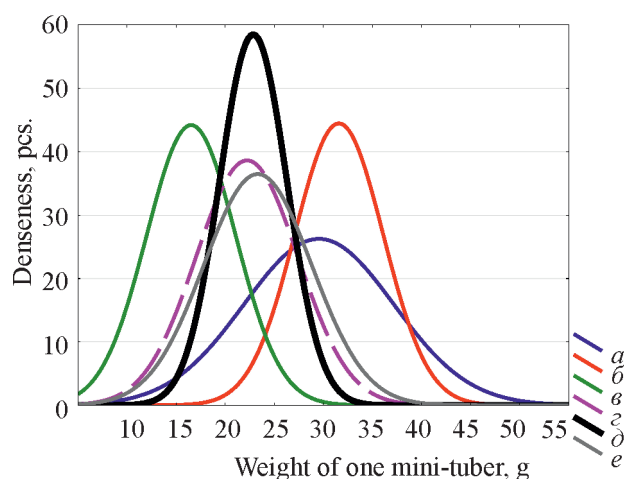


Рис. 5. Функции плотности распределения массы одного мини-клубня:

a – Любава; б – Невский; в – Танай; з – Кузнечанка; д – Тулеевский; е – Кемеровчанин

Fig. 5. Density distribution functions of the mass of one mini-tuber:

a – Lyubava; б – Nevsky; в – Tanai; з – Kuznechanka; д – Tuleevsky; е – Kemerovchanin

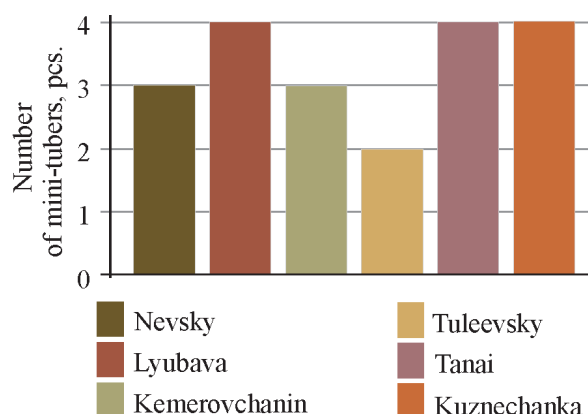


Рис. 6. Гистограмма распределения количества мини-клубней картофеля на одном растении (усредненные значения)

Fig. 6. Histogram of the distribution of the number of potato mini-tubers on one plant (average values)

It was also found that the Lyubava, Tanai, and Kuznechanka varieties produced the highest number of minitubers per plant (4 each), indicating their high generative activity. The Nevsky and Kemerovchanin varieties yielded approximately three minitubers per plant, which can be considered average productivity. The Tuleevsky variety produced the lowest number—less than three tubers per plant (see Fig. 6). These data should be considered when selecting varieties for seed and planting material production in resource-limited environments.

CONCLUSIONS

1. The potato varieties studied were found to be suitable for cultivation in controlled-environment agrobiological facilities and for producing virus-free planting material. Both early- and mid-season varieties developed robust foliage and a well-developed root system.

2. During the experiment, plant heights ranged from 30.5 cm (Tuleevsky) to 56.8 cm (Lyubava). The average number of minitubers per plant was highest for the Tanai variety (4), while the lowest was for the Tuleevsky variety (2). The Lyubava variety stood out for its tuber weight (32.04 g on average).

3. Statistical findings show homogeneity of the fractional composition of potatoes, which confirms the need for further research to assess the influence of individual factors on increasing productivity in a controlled environment.

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Дата поступления статьи / Received by the editors 21.03.2025
Дата принятия к публикации / Accepted for publication 26.06.2025
Дата публикации / Published 15.10.2025



Оценка кукурузы на устойчивость к восточному кукурузному мотыльку *Ostrinia furnacalis* (Guenee, 1854) в условиях юга Дальнего Востока

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В последнее время в Приморском крае значительно возросло производство кукурузы на зерно. При ее выращивании сельхозпроизводителями отмечена высокая вредоносность восточного кукурузного мотылька *Ostrinia furnacalis* (Guenee, 1854). Этот вредитель является многоядным, но больше всего вредит кукурузе (*Zea mays* L.). Гусеницы питаются внутри растения, что создает проблему защиты культуры инсектицидами. В связи с этим один из радикальных мер борьбы с *Ostrinia furnacalis* Гн. – создание устойчивых сортов, линий и гибридов кукурузы. Устойчивые сорта способны сдерживать численность вредителя и сохранять продуктивность даже при значительном их повреждении. В задачу данного исследования входило установить истинную устойчивость образцов на искусственном фоне заселения растений кукурузы яйцами фитофага, так как в селекции оценка *Zea mays* L. на устойчивость к вредителям осуществляется с использованием провокационных и искусственных фонов. Проведена оценка девяти перспективных селекционных образцов кукурузы на устойчивость их к *Ostrinia furnacalis* (Guenee, 1854): 3015, 3016, 3019, 3092, 3147, 3195, 3271, 3274, 3278. Данные образцы ранее были выделены из селекционного питомника *Zea mays* L. как устойчивые на естественном фоне заселения вредителем. Исследовали две составляющие устойчивости кукурузы к восточному кукурузному мотыльку: антибиоз растений и выносливость их к наносимым повреждениям. Дана характеристика каждому показателю устойчивости растений культуры к вредителю. В результате проведенных исследований выделены две линии кукурузы (3147 и 3271), обладающие средней стеблевой устойчивостью (2,1 и 2,9 балла соответственно) и высокой толерантностью. Также обнаружено пять выносливых образцов *Zea mays* L. Изученный материал рекомендуется для включения в селекционный процесс.

Ключевые слова: кукуруза, устойчивость, поврежденность, толерантность, вредитель, образец

Evaluation of corn resistance to the Asian corn borer *Ostrinia furnacalis* (Guenee, 1854) in the conditions of the southern Far East

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Recently, the production of grain corn has increased significantly in the Primorsky Territory. When growing corn, agricultural producers have noted the high harmfulness of the Asian corn borer *Ostrinia furnacalis* (Guenee, 1854). This pest is polyphagous but causes the most damage to corn plants (*Zea mays* L.). The caterpillars feed inside the plant, which creates the problem of protecting the crop

with insecticides. In this regard, one of the radical measures to combat *Ostrinia furnacalis* Gn. is the creation of resistant varieties, lines and hybrids of corn. Resistant varieties are able to contain the pest population and maintain productivity even when they are significantly damaged. The objective of this study was to establish the true resistance of the specimen against an artificial background of colonization of corn plants with phytophage eggs, since in selection the assessment of *Zea mays* L. for resistance to pests is carried out using provocative and artificial backgrounds. Evaluation of nine promising breeding samples of corn was carried out for their resistance to *Ostrinia furnacalis* (Guenee, 1854): 3015, 3016, 3019, 3092, 3147, 3195, 3271, 3274, 3278. These samples were previously isolated from the *Zea mays* L. breeding nursery as resistant to natural pest infestation. Two components of corn resistance to the Asian corn borer were studied: plant antibiosis and their tolerance to damage. Each indicator of plant resistance to the pest is characterized. As a result of the studies, two lines of corn (3147 and 3271) with average stem resistance (2.1 and 2.9 points, respectively) and high tolerance were identified. Five hardy samples of *Zea mays* L. were also found. The studied material is recommended for inclusion in the selection process.

Keywords: corn, resistance, damage, tolerance, pest, specimen

Для цитирования: Ластушкина Е.Н., Теличко О.Н. Оценка кукурузы на устойчивость к восточному кукурузному мотыльку *Ostrinia furnacalis* (Guenee, 1854) в условиях юга Дальнего Востока // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 9. С. 33–40. <https://doi.org/10.26898/0370-8799-2025-9-4>

For citation: Lastushkina E.N., Telichko O.N. Evaluation of corn resistance to the Asian corn borer *Ostrinia furnacalis* (Guenee, 1854) in the conditions of the southern Far East. *Sibirskii vestnik sel'skhoz'yastvennoi nauki* = *Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 9, pp. 33–40. <https://doi.org/10.26898/0370-8799-2025-9-4>

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

In the Primorsky Territory, significant acreage is devoted to corn (*Zea mays* L.). Interest in this crop is growing, and it is cultivated for grain and silage. Farmers have noted significant damage from the European corn borer in corn crops. Favorable weather conditions add to the development and reproduction of the pest. In the Russian Far East, including the Primorsky Territory, the Asian corn borer *Ostrinia furnacalis* (Guenee, 1854), a single-generation pest, is common [1, 2]. Corn borer caterpillars (with five instars) overwinter inside the stalks of corn plants cause damage to the plant. Pupation occurs in May–June. The moths emerge in late June or early July, and their flight can continue until late August. The caterpillars, feeding inside the stalk, can cause significant crop losses [3]. Broken panicles, stalks, and peduncles complicate harvesting. The higher the number of corn borer caterpillars in corn crops, the greater the crop damage and yield losses [4].

It is also important to note that by penetrating the stalk and cob, the caterpillars of the corn borer open the gates for fungal and bacterial infections [5]. Damage to the cobs of *Zea mays* L. by caterpillars can cause both direct harm in a form of gnawing out the kernels and contribute to the spread of mold fungi containing mycotoxins harmful to animal and human health. In addition, damage to corn by caterpillars can lead to the development and spread of such dangerous diseases as stem rot, fusarium ear blight, and corn smut [6]. As a result, the affected cobs become unsuitable for use, and the plant itself dies.

Damage by pests is one of the main reasons for low corn yields [3, 5, 7]. The most important reserve for increasing yields is protection from pests [8]. Mandatory measures for effective protection include the introduction of high-yielding, tolerant and resistant *Zea mays* L. hybrids into production [9–11]. Resistant varieties help control and even suppress the number of phytophages (stem antibiosis) when they feed on plants, as well as maintain yield (hardiness) even when se-

verely damaged by pests. The development and introduction of pathogen- and pest-resistant varieties into production is the most cost-effective and safe method of monitoring the phytosanitary condition of crops [12–14].

The first stage of breeding for corn resistance to pests is the evaluation of breeding and collection material for damage by the European corn borer under natural conditions [15–17]. Subsequent breeding work to develop new varieties of *Zea mays* L. must be carried out using provocative and artificial backgrounds. Plant immunity to pests consists of three factors, i.e., the reaction that plants evoke in the insect: the attractiveness or rejection (antixenosis) of plants by the pest, the antibiotic effect of the host plant on the phytophage, and tolerance of the damaged plants.

MATERIAL AND METHODS

Nine promising corn breeding samples were evaluated for their resistance to *Ostrinia furnacalis* (Guenée, 1854): 3015, 3016, 3019, 3092, 3147, 3195, 3271, 3274, 3278. The standard is the Slavyanka hybrid population. The studies were conducted in the experimental fields of the Laboratory of Selection and Primary Seed Production of Corn of the Federal Scientific Center of Agricultural Biotechnology of the Far East named after A.K. Chaiki against the background of artificial colonization of plants with a phytophage using the methods of VIR and VIZR¹⁻³.

Two components of sample resistance to the phytophage were studied: antibiosis and tolerance (hardiness). Antibiosis is the ability of corn plants of a particular variety, line, or hybrid to control pest populations. Tolerance is the ability of the host plant to maintain its productivity despite significant damage by the phytophage.

Before harvesting, the following damage was recorded on the sample plants: the number of

tunnels in the stem, broken panicles and stems, and damage to the ear and peduncle. Next, the corn's stem resistance to the Asian corn borer was assessed using a four-point scale according to I.D. Shapiro's method (see footnote 3). The following indicators were then determined (%): pest infestation, average number of tunnels per plant, number of plants with broken panicles and stems, and damaged ears and peduncles.

To determine the resistance of the samples to the pest, a scale of overall plant damage (in points) was used. According to this scale, the samples are classified as essentially resistant (1.0–2.0 points), moderately resistant (2.1–3.5 points), insufficiently resistant (3.6–5.0 points), and non-resistant (over 5.0 points).

RESULTS AND DISCUSSION

In 2022 and 2023, an experiment with artificial inoculation of corn samples to determine the resistance of corn samples to *Ostrinia furnacalis* (Guenée, 1854) was conducted. These samples had previously been studied in a natural environment. To confirm their resistance, the selected lines must be tested under artificial inoculation conditions. In this case, the eggs of the Asian corn borer were inoculated into a leaf funnel during the 6th and 7th leaf stages of *Zea mays* L. The hatched caterpillars feed on young leaves and pollen, then penetrate the panicle, stem, and ear of corn.

One of the main indicators of corn resistance to the moth is the varying degrees of damage to the stems and cobs of the crop by caterpillars of different ages (antibiosis of stems and cobs) against an artificial background of colonization.

Let's examine each indicator of stem resistance. It is known that damage to corn leaves by caterpillars delays flowering, while damage to the panicle impairs pollination. The most dan-

¹Osmolovskiy G.E. Identification of agricultural pests and signaling the timing of their control. Moscow: Rosselkhoz Publishing House, 1964, pp. 102–105.

²Shapiro I.D., Pereverzev D.S., Chumakov M.A. Harmfulness of the stem borer on corn crops in the Krasnodar Territory // Bulletin of VIZR, 1979, N 46, pp. 45–49.

³Shapiro I.D., Vilkovala N.A., Slepian E.I. Immunity of plants to pests and diseases. L.: Agropromizdat, 192 p.

gerous damage is to the stem, cob, and peduncle. Having penetrated the stem, the caterpillar chews through the contents of the stem, disrupting the flow of nutrients. This damage leads to significant yield losses during harvesting (see Fig. 1).

During the study period, the tested samples were distributed as follows. The most resistant sample (0–2.0 points) was line 3274 (1.9 points) (see Fig. 2). Moderately resistant (2.1–3.5 points) included Slavyanka, 3015, 3092, 3147, 3195, 3271, and weakly resistant (3.6–5.0 points) included lines 3016 and 3019. Sample 3278 turned out to be unstable (over 5.0 points).

The average “tunnel length per plant” determines the ultimate survival rate of the pest and the corn's stem resistance to *Ostrinia furnacalis* Gn. The higher the value, the less resistant the sample. Over the study period, its value ranged from 3.2 (line 3271) to 10.4 cm (line 3092) (see Fig. 2). For the Slavyanka standard, this value was 7.8 cm. Almost all samples, based on average tunnel length per plant, showed greater resistance than the standard.

Previous research by scientists has shown that the most valuable varieties are those with high antibiotic resistance, meaning they are not only

less susceptible to damage but also suppress pest populations. One important indicator of stem resistance is the average number of caterpillars per plant. The higher the number of corn borer caterpillars per plant, the greater the corn damage and yield losses. Lines 3274 and 3271 demonstrated the lowest values for this trait. The highest number of caterpillars (0.7 specimens/plant) was found in Slavyanka and line 3019 (see Fig. 2).

According to our data, the Slavyanka sample exhibited minimal stem breakage (11.9%) and no ear damage (see Fig. 3). The other samples had higher values for this parameter than the control. Low ear damage was also noted – 4.3% for lines 3092 and 3147. Ear peduncle damage was unaffected (0%) for samples 3092 and 3271.

Taking into account all the indicators of stem resistance, it can be concluded that the maximum strength of the stem and stalk of the cob to fracture is characterized by lines 3274, 3271 and 3147.

The research revealed that line 3274 exhibited the highest stem resistance, 3147 and 3271 had intermediate resistance, and 3019 had the lowest (see table). Of particular interest is studying the tolerance of corn to damage by the Asian



Рис. 1. Гусеница *Ostrinia furnacalis* (Guenee, 1854) (а) и ее место внедрения в стебель кукурузы (б)
Fig. 1. A caterpillar of *Ostrinia furnacalis* (Guenee, 1854) (a) and the place where it penetrated the corn stalk (b)

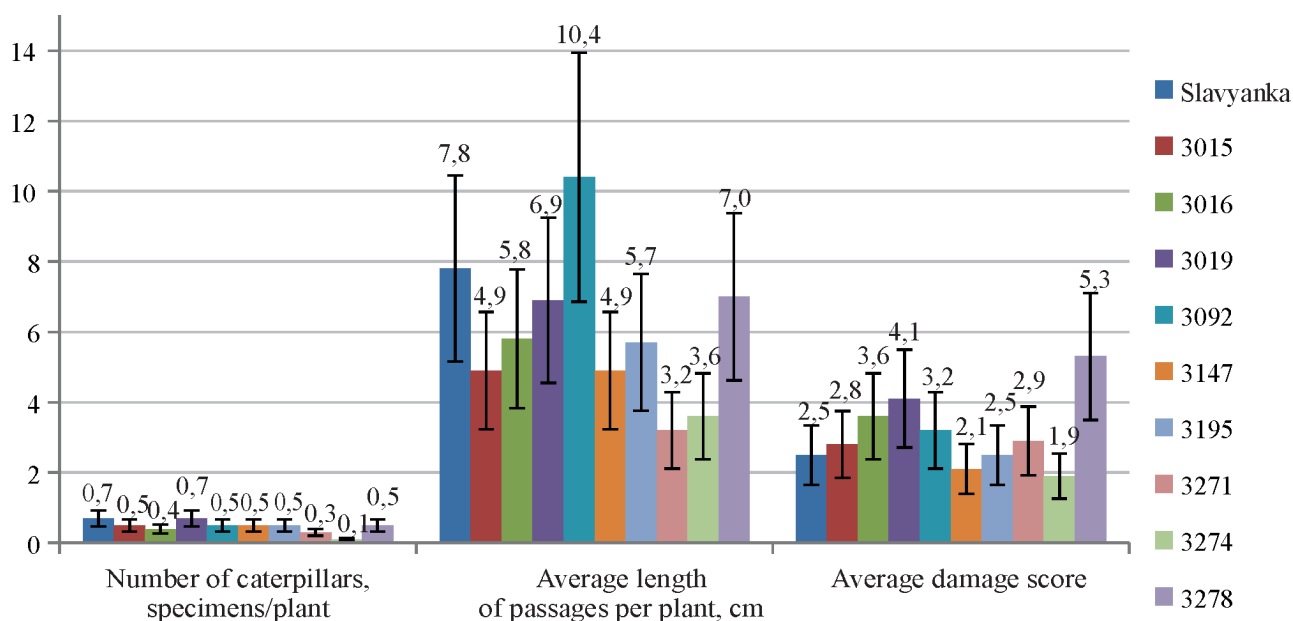


Рис. 2. Вредоносность восточного кукурузного мотылька в опыте с искусственным заселением кукурузы (2022, 2023 гг.)

Fig. 2. Harmfulness of the Asian corn borer in the experiment with the artificial colonization of corn plants with the pest (2022, 2023)

corn borer, i.e., how damage by the pest affects crop yield and what yield losses the studied genotypes incur when damaged by the phytophage. It has previously been established that tolerance can be demonstrated even in corn plants severely damaged by pests (see table). Some genotypes

demonstrate good tolerance. No productivity reduction (0%) was observed in lines 3016, 3147, and 3271. Noteworthy are samples 3015, 3092, 3195, and 3278, which experienced a yield reduction of less than 10%. Line 3274 stands out for its stem resistance (1.9 points), while the yield reduction was 17.3%.

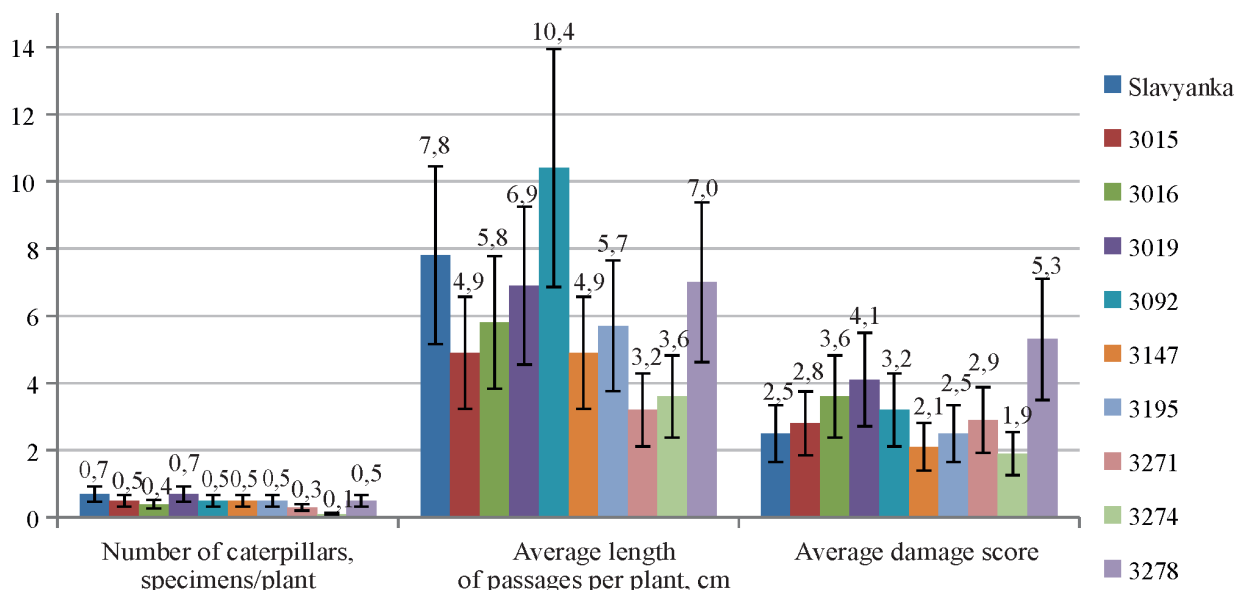


Рис. 3. Средние показатели поврежденности образцов кукурузы в опыте с искусственным заселением (2022, 2023 гг.), %

Fig. 3. Average parameters of the damage caused to the studied corn specimens in the experiment with the artificial colonization (2022, 2023), %

Показатели устойчивости кукурузы в опыте с искусственным заселением
Parameters of corn resistance in the experiment with the artificial colonization

Sample	Stem stability, points			Production loss, %		
	2022	2023	Average for 2 years	2022	2023	Average for 2 years
Slavyanka (standard)	1,9 ± 0,64	3,0 ± 1,02	2,5 ± 0,85	21,9 ± 7,46	16,8 ± 5,72	19,4 ± 6,61
Line: 3015	1,7 ± 0,57	3,8 ± 1,29	2,8 ± 0,95	0 ± 0	6,12 ± 2,08	3,1 ± 1,05
3016	4,1 ± 1,39	3,1 ± 1,05	3,6 ± 1,22	0 ± 0	0 ± 0	0 ± 0
3019	3,7 ± 1,26	4,5 ± 1,53	4,1 ± 1,39	0 ± 0	32,4 ± 11,04	16,2 ± 5,52
3092	2,0 ± 0,68	4,4 ± 1,5	3,2 ± 1,09	12,9 ± 4,39	0 ± 0	6,5 ± 2,21
3147	2,1 ± 0,71	2,1 ± 0,71	2,1 ± 0,71	0 ± 0	0 ± 0	0 ± 0
3195	2,1 ± 0,71	2,9 ± 0,98	2,5 ± 0,85	19,6 ± 6,68	0 ± 0	9,8 ± 3,34
3271	2,9 ± 0,98	2,9 ± 0,98	2,9 ± 0,98	0 ± 0	0 ± 0	0 ± 0
3274	1,6 ± 0,54	2,2 ± 0,75	1,9 ± 0,64	18,6 ± 9,75	15,9 ± 16,67	17,3 ± 13,23
3278	4,0 ± 1,36	6,5 ± 2,21	5,25 ± 1,79	0 ± 0	12,5 ± 4,26	6,3 ± 2,14

CONCLUSIONS

1. The Asian corn borer *Ostrinia furnacalis* (Guenee, 1854) causes significant damage to corn in the Far East. The development of new varieties and hybrids of *Zea mays* L. resistant to this pest will help reduce the damage caused by this phytophage and increase the quality and yield of the crop.

2. During the study period, several samples with stem resistance and tolerance emerged in self-pollinated maize lines exposed to *Ostrinia furnacalis* Gn. We believe lines 3147 and 3271 deserve special attention, as they exhibit moderate stem resistance (2.1 and 2.9 points) but high tolerance (0%). Line 3274 demonstrated stem resistance (1.9 damage points), but suffered high yield losses (17.3%).

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Дата поступления статьи / Received by the editors 28.05.2025
Дата принятия к публикации / Accepted for publication 17.07.2025
Дата публикации / Published 15.10.2025



Полиморфизм микросателлитов и воспроизводительные способности полутонкорунных овец в Приполярье

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Изучены микросателлитные профили и воспроизводительные признаки полутонкорунных овец печорской популяции. Цель исследования – выявление возможных взаимосвязей STR-маркеров с генами или их комплексами, контролирующими генетическую изменчивость признаков приспособленности полутонкорунных овец в условиях Приполярья. Генетические анализы выполнены с использованием набора реагентов COrDIS Sheep по 12 локусам и маркеру пола AMEL. Результаты генотипирования обработаны в программах Structure Version 2.3.4 и GenAlEx 6.5. Весь массив генотипированных овец с учетом породности разделен на две группы. К первой отнесены помеси ‘печорская породная группа × ромни-марш’, ко второй – помеси ‘печорская породная группа × ромни-марш × куйбышевская порода’. Массив данных в программе Structure Version 2.3.4 подразделили на четыре кластера при пороге вероятности $\geq 0,75$. Животных, вероятность членства которых в одном кластере не достигла порогового уровня, объединили в нулевой (сборный) кластер. Генетическая дистанция между первой и второй группами составила 0,015. Первая группа представлена полилокусными генотипами, отнесенными к трем кластерам, вторая группа – полилокусными генотипами, разделенными на пять кластеров. Минимальные генетические дистанции по Райту и Нею (несмещенная оценка) установили между нулевым и первым кластерами. Величина данных показателей для первого и второго кластеров составила: $F_{ST} = 0,047$, $uD_N = 0,354$. Между первым и третьим, третьим и четвертым кластерами генетические дистанции были максимальными. Внутри первой и второй групп достоверных различий по показателям фертильности между особями разных кластеров не установлено. Различия особей второй группы четвертого кластера с особями первой группы первого кластера по возрасту первого окота, молочности, темпу размножения и интенсивности роста ягнят до отъема были достоверными соответственно при $p \leq 0,001$, $p \leq 0,01$, $p \leq 0,01$, $p \leq 0,05$. Несмотря на невысокую генетическую дистанцию между первой и второй группами по микросателлитам, разница между ними по среднему возрасту первого ягнения, темпу размножения и интенсивности роста приплода до отбивки была достоверной при $p \leq 0,05$, $p \leq 0,01$ и $p \leq 0,05$. Выявлено, что скрещивание овец печорской популяции с куйбышевской породой оказало отрицательный эффект на некоторые показатели фертильности овец и интенсивность роста приплода в подсосный период. Для получения более определенных выводов о взаимосвязи полиморфизма микросателлитов с селективными признаками необходимо увеличение численности выборок.

Ключевые слова: овцы, микросателлиты, кластер, генетические дистанции, темп размножения, приспособленность

Microsatellite polymorphism and reproductive performance of semi-fine-wool sheep in the Near Arctic

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Microsatellite profiles and some reproductive traits of semi-fine-wool sheep of the Pechora population were studied. The purpose of the study was to identify possible relationships between STR markers and genes or their complexes that control genetic variability of adaptability traits in semi-fine-wool sheep in the Near Arctic. Genetic analyses were performed using the COReDIS Sheep reagent kit for 12 loci and the AMEL sex marker. The genotyping results were processed in the Structure Version 2.3.4 and GenAEx 6.5 programs. The entire array of the genotyped sheep was divided into two groups by breed. The first group included crossbreeds of the 'Pechora breed group × Romney Marsh', the second group included three-breed crossbreeds of the 'Pechora breed group × Romney Marsh × Kuibyshev breed'. The data array in the Structure Version 2.3.4 program was divided into four clusters with a probability threshold of ≥ 0.75 . Animals whose probability of membership in one cluster did not reach the threshold level were combined into a "zero" (composite) cluster. The genetic distance between groups 1 and 2 was 0.015. The first group is represented by polylocus genotypes assigned to three clusters; the second group is represented by polylocus genotypes assigned to five clusters. The minimum genetic distances according to Wright and Nei (unbiased estimate) were established between the zero and first clusters. The value of these indicators for the first and second clusters was $F_{ST} = 0.047$, $uD_N = 0.354$. Between the first and third clusters, the third and fourth clusters genetic distances were maximum. Within groups 1 and 2, no reliable differences in fertility indicators between individuals of different clusters were found. Differences between the individuals of the second group of the fourth cluster and the individuals of the first group of the first cluster in the age of first lambing, milk production, reproduction rate and intensity of lamb growth before weaning were reliable at $p \leq 0.001$, $p \leq 0.01$, $p \leq 0.01$, $p \leq 0.05$, respectively. Despite the low genetic distance between the first and second groups by microsatellites, the difference between them in the average age of first lambing, reproduction rate and intensity of offspring growth before weaning was reliable at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.05$, respectively. Crossbreeding of the Pechora population sheep with the Kuibyshev breed had a negative effect on some indices of sheep fertility and the intensity of offspring growth during the suckling period. To obtain more definite conclusions on the relationship between microsatellite polymorphism and some selective traits of sheep, it is necessary to increase the number of samples.

Keywords: sheep, microsatellites, cluster, genetic distances, reproduction rate, adaptability

Для цитирования: Матюков В.С., Лейченко А.С., Жариков Я.А., Канева Л.А. Полиморфизм микросателлитов и воспроизводительные способности полутонкорунных овец в Приполярье // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 9. С. 41–52. <https://doi.org/10.26898/0370-8799-2025-9-5>

For citation: Matyukov V.S., Leichenko A.S., Zharikov Ya.A., Kaneva L.A. Microsatellite polymorphism and reproductive performance of semi-fine-wool sheep in the Near Arctic. *Sibirskii vestnik sel'skokhozyaistvennoi nauki* = *Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 9, pp. 41–52. <https://doi.org/10.26898/0370-8799-2025-9-5>

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

Благодарность

Работа выполнена в рамках государственного задания Министерства науки и высшего образования Российской Федерации № 02106411598-8-4.4.4.

Acknowledgements

The work was completed within of the State assignment of the Ministry of Education and Science of Russia No. 02106411598-8-4.4.4.

INTRODUCTION

Identification of quantitative trait loci (QTL) and candidate genes creates the preconditions for increasing the efficiency of selection and successful acclimatization of animals to new environmental conditions [1]. The main methods for searching and identifying selectively important genes are genome-wide association studies of DNA molecular structure with target traits (Genome Wide Association Study, GWAS) and linkage disequilibrium analysis (Linkage Disequilibrium, LD).

The successful use of these methods and SNP polymorphism (Single Nucleotide Polymorphism) has allowed us to accumulate a sufficient amount of information and create a database of QTL and genes that control the variability of many quantitative and binary traits in sheep^{1,2} [2–4]. Advances in sequencing technology and the use of single-nucleotide polymorphisms in DNA have essentially replaced other methods and types of molecular markers in the study of the mechanisms of genetic control of quantitative variation. However, there remain many areas in this field where the use of other molecular markers and genetic analysis methods remains relevant.

Of particular interest in this regard are microsatellites [5], which, due to their high polymorphism, productivity, and availability of analysis, are widely used in the practice of genotyping breeding animals when assessing the accuracy of their pedigrees. To date, a vast and diverse body of material has been accumulated that can be used to analyze the associations of STR markers with target traits.

Previously, using microsatellites, we conducted a search for markers of the lost gene pool of the aboriginal northern short-tailed sheep [6],

and investigated the relationship between heterozygosity at STR loci and fertility of sheep [7].

The purpose of this study is to further analyze the possible association of microsatellite polymorphism with genetic variability of some reproductive traits of semi-fine wool sheep in the Subpolar zone.

MATERIAL AND METHODS

Microsatellite polymorphism was studied in crossbred Pechora semi-fine-wool sheep of the Romney Marsh type. The history of the herd's creation is described in detail in [6]. The genetic and population characteristics of the sheep sample were obtained by genotyping 48 ewes for 12 STR loci. The total number of ewes used to characterize clusters and breed groups based on productivity traits was 45 heads. Three ewes characterized only by their first lambing were excluded from the analysis. The total number of lambings recorded, excluding the first, was 101 ($\sum n_i$). Information on the origin, age, lambing date, fertility, and other biologically and economically valuable traits of the animals was obtained from livestock and breeding records for 2010–2020.

DNA was extracted from ear tissue removed during animal tagging and placed in 96% rectified ethyl alcohol. The tests were performed in 2020–2022 by the OOO “GORDIZ laboratory”³ using the COrDIS Sheep⁴ reagent kit, recommended by the International Society of Animal Genetics, by 12 loci (McM042, INRA006, McM527, ETH152, CSRD247, OarFCB20, INRA172, INRA063, MAF065, MAF214, INRA005, INRA023) and the gender marker AMEL.

The genotyped flock included crossbred Pechora breed group sheep and their cross-

¹Animal QTL Database. URL: <https://www.animalgenome.org/cgi-bin/QTLdb/index>.

²Certificate of State Registration of Database No. 2020620869. Database for Storage and Quick Access to the Results of Genome-Wide and Regional Association Studies / Shashkova T.I., Aulchenko Yu.S.; Copyright Holder: Novosibirsk State University; Application No. 2020620713; Submission Date: May 12, 2020; State Registration Date: May 28, 2020.

³gordiz.ru

⁴COrDIS Sheep. A reagent kit for multiplex analysis of 12 microsatellite markers and the ovine amelogenin locus. User manual. URL: <https://gordiz.ru/wp-content/uploads/2021/05/instrukciya-cordis-sheep-140521.pdf>.

es of varying bloodlines with Romney Marsh rams (first group) and Kuibyshev rams (second group). The studied samples also included animals related to the extinct northern aboriginal short-tailed sheep. The contributions of ancestral breeds to the phenotypes of individual animals or the averages across groups of different breeds (bloodlines) were expressed as percentages.

Structure Version 2.3.4⁵ and GenAlEx 6.5⁶ programs were used to process the results of sheep genotyping by STR loci. The probabilistic statistical models embedded in the Structure Version 2.3.4 made it possible to calculate the probabilities of individual genotypes belonging to independent, mixed, or crossbred genetically differentiated groups of animals, to analyze the genetic heterogeneity of the population with weak linkage and correlation of genes of marker loci, to analyze small samples and samples containing genotypes with dominant, recessive, and null alleles [8, 9].

Using the Structure Version 2.3.4, we calculated the posterior probability of assigning individual multi-locus STR genotypes to different groups (clusters) without introducing prior information on the genealogical classification of individuals. The analysis was conducted by dividing the ewe population genotyped for STR loci into two ($k = 2$) and four ($k = 4$) clusters according to the estimated number of ancestral breeds. To determine an individual's membership in the corresponding group (cluster), a threshold probability value in fractions of unity (Q) was selected, which was ≥ 0.75 , as well as the number of clusters (k). The optimal division of the entire dataset into clusters was determined based on the presence of the maximum number of individuals whose membership in their own cluster reached or exceeded the threshold probability, as well as on the correspondence between the number of clusters and the number of ancestral breeds involved in the crossbreeding.

In the GenAlEx 6.5 program, the Hardy–Weinberg genetic equilibrium was assessed for all groups and the following parameters were calculated: N_a – average number of alleles per locus; N_e – average effective number of alleles per locus; I_{Sh} – Shannon index; H_o – average observed (actual) heterozygosity rate; H_e – estimate of the average expected heterozygosity per locus; uH_e – unbiased estimate of the mean expected heterozygosity per locus; F_{IS} – fixation index (inbreeding); F_{ST} – Wright's genetic distance; D_N – genetic distance according to Nei.

Statistical data processing and graph construction were performed in Microsoft Excel.

The sheep breeds were designated by the first letters of their names: N – northern aboriginal, P – Pechora breed group, RM – Romney Marsh, K – Kuibyshev. The pedigree of the crossbreeds was expressed through the contribution of each breed to the genotype (blood content in percent), designated by numbers before the breed abbreviation. The number of animals recorded was indicated N , number of lambings – n_i . In genotyped ewes that lambed, fertility (Π_o), starting from the second lambing, was assessed by the number of live lambs per lambing. Milk production was calculated based on the litter size increase during the first 20 days of the suckling period.

For each lambing, the survival rate of the offspring was determined using the formula

$$B_{\Pi} = \Pi_B / \Pi_o,$$

where B_{Π} – number of surviving lambs at weaning (at 3 months of age), fractions of a unit; Π_B – surviving offspring to weaning, heads.

The complex indicator, designated as the “reproduction rate” (TP), was calculated using the formula

$$TP = \Pi_B / B_{\Pi},$$

where Π_B – average number of lambs produced from one ewe per lambing, at weaning; B_{Π} – age of first lambing of an ewe, years.

⁵Pritchard J.K., Wen X., Falush D. Documentation for structure software: Version 2.3. URL: <http://pritch.bsd.uchicago.edu/structure.html>.

⁶Peakall R., Smouse P.E. GenAlEx 6.5: genetic analysis in Excel. Population genetic software for teaching and research an update // *Bioinformatics*, 2012, N 28 (19), pp. 2537–2539.

The designations of statistical indicators are given according to the textbook by P.F. Rokitsky⁷.

RESULTS AND DISCUSSION

This study presents the results of genetic-population characteristics and cluster analysis of the genetic structure of a crossbred herd of semi-fine-wool sheep of the Pechora population.

From the data presented in Fig. 1, the difference in the distribution of average probabilities of membership of individuals in the corresponding clusters for the first and second groups is evident at $k = 2$.

The high probability of the genetic component of the first cluster in the first group is due to the crossing of ewes of the Pechora breed group with rams of the Romney Marsh breed, and its decrease in the second group is due to the crossing of sheep of the first group with rams of the Kuibyshev breed. The significant proportion of the second cluster component in the second group is apparently explained by the similarity (possibly kinship) of the ancestral aboriginal allele pools of Pechora and Kuibyshev sheep. The influence of Kuibyshev rams on the formation of the first group's allele pool has been excluded chronologically, by genealogical records, and by examining the accuracy of the pedigrees using microsatellites.

At $k = 4$, the number of individuals whose individual probabilities of membership in their own clusters reached or exceeded the threshold was distributed as follows. The first cluster included 16 individuals (11 in the first group, five in the second), and the second cluster included four individuals (one in the first group, three in the second). Eight animals each were assigned to clusters three and four. Among the eight individuals in the first group of cluster zero, the proportion of the genetic component characteristic of clusters three and four ranged from 22 to 44%.

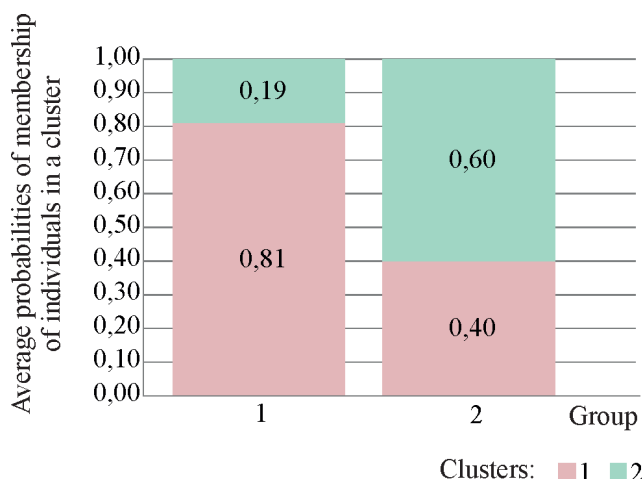


Рис. 1. Распределение средних вероятностей членства особей в кластерах с учетом группы по признаку породности ($k = 2$)

Fig. 1. Distribution of average estimates of the probability of membership of the individuals in clusters in groups of different breeds ($k = 2$)

For 12 individuals, the probability of membership in any of the clusters did not reach the threshold values. Of these, ten animals were in the first group and were descended from six rams of different bloodlines of the Pechora and Romney Marsh breed groups.

All 16 individuals from the first cluster were descended from six rams, three of which were purebred Kuibyshev breed sires and fathers of individuals of the second group, and the remaining three were crossbred sires of the Pechora breed group $\times$ Romney Marsh with Romney Marsh bloodline higher than 50% and fathers of ewes of the first group.

Three ewes of the second group of the second cluster are descended from two half-blooded Kuibyshev rams, one ewe of the first group of the second cluster is descended from a second-generation Romney Marsh ram.

All ewes in the third cluster were descended from a single purebred Kuibyshev ram No. 401. The fourth cluster included ewes that were daughters of a purebred Kuibyshev ram No. 95.

⁷Rokitsky P.F. Introduction to statistical genetics: textbook. Minsk, 1978, 448 p.

Analysis of the distribution of average probabilities of individuals' membership in clusters in the first group showed that the shares of the first and second clusters were 0.59 and 0.23, respectively (a total of 0.82), the share of the third cluster was 0.03, and the fourth was 0.15 (a total of 0.18) (see Fig. 2). In the structure of the second group, the shares of the first and second clusters were present with probabilities of 0.22 and 0.15 (a total of 0.37), and the third and fourth were 0.32 and 0.30 (a total of 0.62).

According to pedigree records, the breed composition of the animals in the first group was as follows: Northern Short-Tailed Coarse-Wool Sheep – 3%, Pechora Breed Group – 37%, Romney Marsh – 60% (see Fig. 3). The breed composition of the second group was as follows: Northern Aboriginal Sheep – 0.5%, Pechora Breed Group – 23.5%, Romney Marsh – 29.8%, Kuibyshev – 46.2%.

From the data provided, it is evident that in the first group, the average total genetic contribution of the Romney Marsh breed and the Pechora breed group calculated from the pedi-

grees was 97%. In the second group of ewes, the contribution of these breeds decreased to 53.8%, and the hereditary traits of the Kuibyshev breed amounted to 46.2%. Comparing the average contributions of different breeds to the gene pool of the first group according to the genealogy with the distribution of the shares of each of the four clusters in it, it can be assumed that the allele pool of STR loci typical for the Romney Marsh breed is concentrated in the first cluster, and that typical for the Pechora breed group is concentrated in the second.

A test of the observed genotype distribution's compliance with the expected Hardy–Weinberg law, with the exception of the INRA005 locus, did not reveal a significant imbalance in the overall sample. For the INRA005 locus genotypes, the imbalance was due to an excess frequency of the INRA005^{129/137} genotype, which occurred in the sample with a frequency of 0.02 (in a single copy) with a theoretical probability of 0.0002, which took the χ^2 value beyond the threshold value.

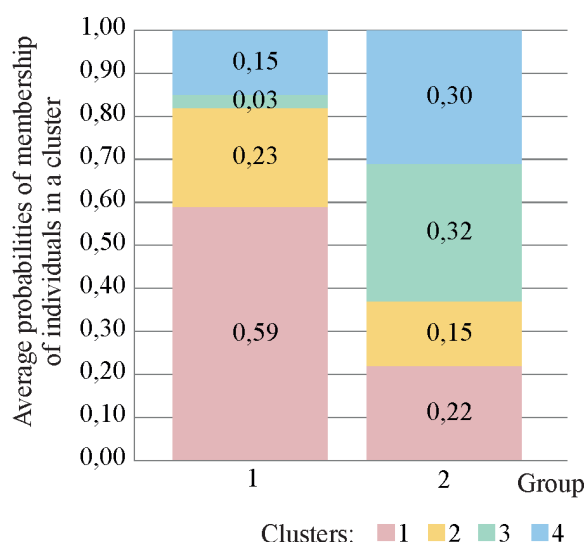


Рис. 2. Распределение средних вероятностей членства особей в кластерах с учетом группы по признаку породности ($k = 4$)

Fig. 2. Distribution of average estimates of the probability of membership of the individuals in clusters in groups of different breeds ($k = 4$)

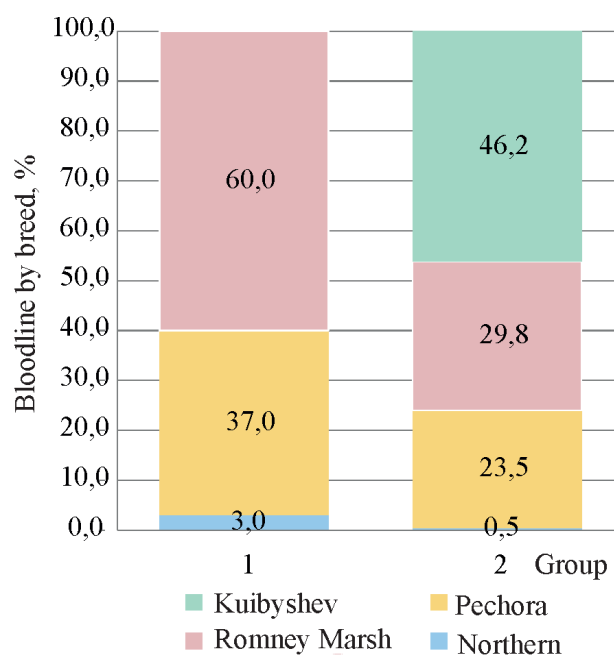


Рис. 3. Средняя кровность овец в группах разной породности

Fig. 3. Average bloodlines of sheep in groups of different breeds

Inbreeding coefficients for the null cluster and for the genotyped array as a whole were positive, with absolute values close to zero. Excess heterozygotes were detected within other clusters, reaching their maximum in the third and fourth clusters (-0.201 and -0.226 , respectively) (see Table 1). In terms of the number of effective alleles and Shannon index values, individuals grouped in the third and fourth clusters were inferior to those in other groups, including the smallest sample in the second cluster. The minimum genetic distances according to Wright (F_{ST}) and Nei (uD_N , unbiased estimator) were found between the zero and first clusters: $F_{ST} = 0.036$, $uD_N = 0.166$ (see Table 2). The genetic distances between the first and second clusters were as follows: $F_{ST} = 0.047$, $uD_N = 0.354$. The genetic distances between the first and third, as well as the third and fourth clusters were maxi-

mum: respectively, $F_{ST} = 0.130$ and $uD_N = 0.539$, $F_{ST} = 0.125$ and $uD_N = 0.473$.

Based on the results of the study, it can be concluded that cluster analysis of the sheep population genotyped at 12 polymorphic loci of microsatellites made it possible to identify subgroups within groups of different breeds that are more homogeneous in genealogy (at the level of half-sibs), alleles and genotypes of microsatellites, genetically differentiated from each other at the level of interbreed differences [10]. Genetic distance estimates obtained by different methods were positively correlated with each other when pairwise comparing clusters. The sample and rank correlation coefficients were highly significant, positive, and close to unity, respectively $r = 0,989 \pm 0,049$ and $rs = 0,976 \pm 0,077$. Thus, a similar ranking of the estimates of genetic distances between groups obtained by different methods is shown.

Табл. 1. Характеристика кластеров и популяции в целом по генетическому разнообразию

Table 1. Characteristics of clusters and the population as a whole by genetic diversity

Cluster	Number of heads	Statistics	N_a	N_e	I_{Sh}	H_o	H_e	uH_e	F_{IS}
0	12	$\bar{X}$	5,500	3,668	1,437	0,712	0,716	0,745	0,011
		$\pm Sx$	0,399	0,233	0,058	0,042	0,016	0,017	0,051
1	16	$\bar{X}$	5,333	3,303	1,328	0,765	0,674	0,694	$-0,134$
		$\pm Sx$	0,355	0,258	0,070	0,042	0,030	0,031	0,032
2	4	$\bar{X}$	3,417	2,768	1,055	0,708	0,599	0,685	$-0,192$
		$\pm Sx$	0,336	0,266	0,100	0,068	0,039	0,045	0,091
3	8	$\bar{X}$	4,500	2,929	1,191	0,740	0,622	0,663	$-0,201$
		$\pm Sx$	0,469	0,291	0,097	0,039	0,037	0,040	0,037
4	8	$\bar{X}$	4,333	2,830	1,166	0,760	0,623	0,665	$-0,226$
		$\pm Sx$	0,284	0,229	0,074	0,050	0,027	0,029	0,071
Population	48	$\bar{X}$	7,000	4,279	1,607	0,742	0,754	0,762	0,019
		$\pm Sx$	0,628	0,317	0,069	0,032	0,016	0,016	0,030

Табл. 2. Генетические дистанции между кластерами

Table 2. Genetic distances between clusters

Cluster	0	1	2	3	4
0		0,166	0,203	0,354	0,319
1	0,036		0,335	0,539	0,388
2	0,047	0,078		0,346	0,382
3	0,082	0,130	0,090		0,473
4	0,074	0,094	0,097	0,125	

Note. Above the diagonal – uD_N , under the diagonal – F_{ST} .

According to the selection traits, the minimum average age of first lambing was observed in individuals of the first group of the first cluster (576.1 ± 27.3), while the maximum was observed in ewes of the second group of the fourth cluster (807.4 ± 11.8) (see Table 3). The differences between individuals of the second group of the fourth cluster and individuals of the first group of the first cluster in terms of age at first lambing, milk production, reproduction rate, and growth intensity of lambs before weaning were significant, respectively, at $p \leq 0,001$, $p \leq 0,01$, $p \leq 0,01$, $p \leq 0,05$.

No significant differences were found between the individuals from different clusters within groups in terms of fertility, milk production, and lamb yield at weaning. However, individuals from the first cluster assigned to the first group had the highest milk production, repro-

ductive rate, and average daily live weight gain of lambs before weaning. In terms of selection indicators, they were insignificantly superior to their counterparts from the second cluster.

The lowest milk production rates, reproduction rate, and average daily growth rate of offspring before weaning were recorded in ewes of the second group of the fourth cluster (see Table 3). The difference between animals of the first and second groups in the average age at first lambing, reproduction rate, and intensity of offspring growth before weaning is significant, respectively, at $p \leq 0,05$, $p \leq 0,01$, $p \leq 0,05$. The assignment of individuals to the corresponding clusters in the first group and the average indicators characterizing their reproductive abilities showed that individuals in cluster 0, which were more likely to retain the genetic makeup of the northern short-tailed sheep, were inferior to in-

Табл. 3. Воспроизводительные признаки овцематок разных групп и кластеров
Table 3. Reproductive characteristics of ewes of different breed groups and clusters

Group, cluster, number of ewes (N), number of lambings (n_i)	Statistics	Age of first lambing, years	Number of live lambs per lamb- ing, heads	Milk yield, kg	Number of lambs at weaning, heads	Reproduc- tion rate	Daily gain in live weight of lambs at weaning, g
Cluster 0 ($N = 10$, $\sum n_i = 23$)	$\bar{X}$	677,3	1,2	20,6	1,04	0,568	173,8
	$\pm Sx$	19,5	0,1	1,9	0,08	0,047	16,1
Cluster 1 ($N = 11$, $\sum n_i = 22$)	$\bar{X}$	576,1	1,1	22,5	1,05	0,706	182,7
	$\pm Sx$	27,3	0,1	1,4	0,08	0,066	12,5
For the first group ($\sum \sum n_i = 45$)	$\bar{X}$	627,8	1,2	21,5	1,04	0,635	178,2
	$\pm Sx$	18,1	0,1	1,2	0,05	0,041	10,2
Cluster 1 ($N = 5$, $\sum n_i = 9$)	$\bar{X}$	641,1	1,0	19,5	0,89	0,556	142,1
	$\pm Sx$	56,8	0,0	3,2	0,11	0,084	34,1
Cluster 2 ($N = 3$, $\sum n_i = 8$)	$\bar{X}$	670,6	1,0	21,0	1,06	0,545	163,9
	$\pm Sx$	5,7	0,0	1,8	0,06	0,005	15,3
Cluster 3 ($N = 8$, $\sum n_i = 25$)	$\bar{X}$	634,0	1,1	19,3	0,92	0,573	154,4
	$\pm Sx$	31,5	0,1	1,7	0,08	0,055	14,8
Cluster 4 ($N = 8$, $\sum n_i = 14$)	$\bar{X}$	807,4	1,1	17,0	1,00	0,453	133,8
	$\pm Sx$	11,8	0,1	1,8	0,15	0,066	21,6
For the second group ($\sum \sum n_i = 56$)	$\bar{X}$	683,7	1,1	19,0	0,95	0,536	148,6
	$\pm Sx$	19,3	0,03	1,04	0,05	0,032	10,2

dividuals in cluster 1 in terms of productive offspring, milk production, and reproductive rate. No significant differences in selective traits were found within the groups between individuals assigned to different clusters based on multi locus STR genotypes.

When planning the experiment, we assumed that using Structure Version 2.3.4 and microsatellites, we would be able to divide the dataset into clusters, each of which would group individuals more similar in terms of STR alleles, genotypes, and genealogy. Between clusters, differentiation by microsatellites and genealogy was expected to be greater than intracluster heterogeneity, which would allow us to identify the relationship between microsatellite polymorphism, genealogy, and quantitative trait variability. In the study, the cluster structure of the groups of different breeds clearly differentiated the second group into four clusters, with a high probability of membership in individual clusters for the progeny of purebred and crossbred Kuibyshev rams. The first cluster was common to both the first and second groups, although the groups were formed from individuals of different breeds. Specifically, the animals of the first group of the first and second clusters are descended from crossbred Pechora rams with Romney Marsh, while the animals of the second group of the same clusters are descended from crossbreeds of Pechora × Romney Marsh with half-bred and purebred Kuibyshev rams.

Thus, when working with crossbred offspring obtained from related breeds, using STR polymorphism at 12 loci for genetic analysis, it was not possible to simultaneously clearly separate the dataset into clusters based on markers, genealogy, and polygenic traits. In this regard, the non-significant but significant differences in milk production, reproductive rate, survival, and offspring growth rate between ewes of the first and second groups (of different breeds) assigned to the same (first) cluster are indicative.

We have previously suggested that the level of heterozygosity at STR loci may be associated

with the fertility of ewes [7]. One of the probable versions of the mechanisms determining such relationships is the correlation of the level of heterozygosity at a number of marker loci with polymorphic genetic systems that control the variability of quantitative traits. At the same time, the "neutrality" of markers does not theoretically exclude their connection with the genetic variability of selective traits by the type of true genetic linkage disequilibrium in the case of localization of the marker and the candidate gene in the same linkage group.

The effect of such linkage depends on its tightness, the balance of the gene complex or chromosome, and interallelic and/or interlocus gene interactions. Even in purebred breeding, the contributions of individual genes, their complexes, and various chromosomes to the variability of selective traits vary widely across different breeds. In crossbred populations, such variability is apparently easier to detect, analyze, and utilize in practical marker-associated selection. However, in the study, the use of microsatellite polymorphism to group animals into clusters failed to establish any association between markers and selective traits.

CONCLUSION

1. Microsatellite genotyping of a controlled sheep sample and data processing in Structure Version 2.3.4 at $k = 4$ allowed us to detail the genetic structure of the crossbred sheep flock. Cluster analysis revealed a higher level of consolidation in the first group compared to the second, which was expected, as the formation of the STR allele pool in the second group was additionally influenced by crossbreeding with Kuibyshev rams.

2. Unlike the first group, represented by multilocus genotypes of clusters zero and one, and a single individual of the second cluster, the second group additionally included multilocus genotypes assigned to clusters three and four. The descendants of two purebred Kuibyshev rams, No. 401 and 95, respectively, were grouped into

these clusters using Structure Version 2.3.4 and microsatellite analysis. Pairwise comparison of these clusters revealed maximum genetic distances. Thus, F_{ST} and uD_N between the first and third clusters were 0.130 and 0.539, respectively, and between the third and fourth – 0.125 and 0.473. The minimum genetic distances for F_{ST} and DN values were established between the zero and first clusters (0.036 and 0.166), as well as between the first and second (0.047 and 0.203). The range of F_{ST} values from minimum to maximum exceeded the limits of variation of interbreed genetic distances [13], while the genetic distance between the first and second breed groups was 0.015, i.e., it was significantly lower than the minimum genetic distances established between individual clusters.

3. Within groups of different breeds, no significant differences in productivity indicators were found between individuals belonging to different clusters. No correlations were found between genetic distances between individuals assigned to different clusters and their differentiation in indicators characterizing certain selective traits.

4. With a minimum genetic distance, the first group, compared with the second, had better indicators for the age of the first lambing of ewes (627.8 ± 18.1 and 683.7 ± 19.3), the number of lambs obtained in one lambing (1.2 ± 0.10 and 1.1 ± 0.03), milk yield (21.5 ± 1.18 and 19.0 ± 1.39), the yield of lambs at weaning (1.04 ± 0.05 and 0.95 ± 0.05), the rate of reproduction (0.635 ± 0.041 and 0.536 ± 0.032), the increase in live weight of lambs up to 3 months of age (178.2 ± 10.2 and 148.6 ± 10.2). The difference between the animals of the first and second groups in the average age of first lambing, the rate of reproduction and the intensity of the offspring growth before weaning is reliable at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.05$, respectively. From the data presented, it is clear that crossing the Pechora population of sheep with the Kuibyshev breed did not have a positive effect on productivity indicators.

5. In terms of age at first lambing, milk production, reproduction rate and growth intensity of lambs before weaning, the best indicators were shown by the animals of the first cluster of the first group (576.1 ± 27.3 ; 22.5 ± 1.43 ; 0.706 ± 0.066 ; 182.7 ± 12.5 , respectively). The worst indicators for these traits were shown by the animals assigned to the fourth cluster of the second group (807.4 ± 11.8 ; 17.0 ± 1.77 ; 0.453 ± 0.066 ; 133.8 ± 21.6 , respectively). The differences between the individuals of the second group of the fourth cluster and the individuals of the first group of the first cluster for the specified characteristics were significant at $p \leq 0.001$, $p \leq 0.01$, $p \leq 0.01$, $p \leq 0.05$, respectively. The animals of these clusters did not differ significantly in terms of average fertility and the yield of lambs per lambing at weaning.

6. Apparently, the statistically insufficient number of surviving herds of the formally extinct Pechora population of semi-fine-wool Romney Marsh sheep prevented the collection of objective data on the presence or absence of associations between microsatellite polymorphism and genetic variability of some selectively significant traits. Therefore, future research requires the use of new bioinformatics methods, expansion of the breed composition, and an increase in the reference population size, which will provide more reliable data on the relationship between the level of genetic diversity at STR markers and selectively significant traits.

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Дата поступления статьи / Received by the editors 04.03.2025
Дата принятия к публикации / Accepted for publication 28.05.2025
Дата публикации / Published 15.10.2025

Регулирование окислительного стресса как основа здоровья и продуктивности животных

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Изложены результаты собственных исследований и обзор литературных источников по проблемам адаптации животных к факторам внешней среды, особенно к интенсивным методам разведения животных, с позиций работы митохондрий, свободнорадикального окисления тканей и энергетического обмена. Базируясь на фундаментальных исследованиях о состоянии биофизического потенциала живой системы, показано влияние перекисного окисления липидов на состояние здоровья, продуктивность, жизнеспособность животных и роль антиоксидантов в их проявлении. Снижение прироста, возникающее у поросят при отъеме от матерей, связанное с перекисным окислением липидов, можно устранять с помощью различных видов антиоксидантов. Разработаны дозы ультрафиолетового облучения свиней в условиях промышленной технологии, позволяющие регулировать уровень свободнорадикального окисления тканей и усиливать их антиоксидантную активность, улучшать плодовитость свиноматок, жизнеспособность и интенсивность роста приплода. Впервые обнаружены резкие различия наиболее распространенных пород свиней по уровню свободнорадикального окисления их тканей, связанные с различным содержанием жирных кислот и холестерина во внутримышечном жире и сале. Показана зависимость качества мясных продуктов от состава их жирных кислот. Такие антиоксиданты, как каталаза и тиоловые соединения, содержащиеся в крови хряков и свиноматок, способны противодействовать разрушающему воздействию активных форм кислорода при оплодотворении, влияют на плодовитость, массу гнезда при опоросе. Впервые в противоположность сложившемуся стереотипу о вредности НЖК, в частности сала свиней, экспериментальным путем доказано, что жир, содержащий больше НЖК, но меньше ПНЖК, особенно линолевой жирной кислоты и холестерина, при включении в корм животных положительно влияет на продуктивность и сердечно-сосудистую систему, снижает атерогенный индекс. Предложено ввести специальный раздел животноводства «Энергобиотест», изучающий соотношение окислительных и антиоксидантных реакций в организме, проводящий разработку технологий гармонизации жизненных процессов и улучшения качества продукции животноводства.

Ключевые слова: свиньи, жир, митохондрия, окислительный стресс, УФ-облучение, каталаза, жирные кислоты, антиоксиданты, тиоловые соединения

Regulation of oxidative stress as the foundation for animal health and productivity

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The article presents the results of the authors' own research and a review of literature sources on the issues of animal adaptation to environmental factors, particularly intensive animal farming methods, from the perspective of mitochondrial function, tissue free-radical oxidation, and energy metabolism. Based on fundamental studies of the biophysical potential state of living systems, the influence of lipid peroxidation on health status, productivity, and viability of animals is demonstrated, along with the role of antioxidants in their manifestation. The decrease in growth that occurs in piglets at weaning, associated with lipid peroxidation, can be eliminated with the help of various types of antioxidants. Doses of ultraviolet irradiation of pigs under the conditions of industrial technology have been developed, which make it possible to regulate the level of free-radical oxidation of tissues and enhance their antioxidant activity, allowing to improve the fertility of sows, the viability and intensity of growth of

the offspring. For the first time, sharp differences in the most common breeds of pigs in the level of free-radical oxidation of their tissues have been found, associated with different content of fatty acids and cholesterol in intramuscular fat and lard. The dependence of the quality of meat products on the composition of their fatty acids has been shown. Antioxidants such as catalase and thiol compounds contained in the blood of boars and sows are able to counteract the destructive effect of reactive oxygen species during fertilization, affect fertility and the litter weight during farrowing. For the first time, in contrast to the stereotype about the harmfulness of EFAs and, in particular, pork lard, it has been experimentally proven that fat containing more EFAs, but less PUFAs, especially linoleic fatty acid and cholesterol, when included in animal feed, has a positive effect on productivity and the cardiovascular system, and reduces the atherogenic index. It has been proposed to introduce a special section of animal husbandry, "Energobiotest", which studies the ratio of oxidative and antioxidant reactions in the body, develops technologies for harmonizing life processes and improving the quality of livestock products.

Keywords: pigs, fat, mitochondria, oxidative stress, UV- irradiation, catalase, fatty acids, antioxidants, thiol compounds

Для цитирования: Бекенёв В.А., Захаренко А.М. Регулирование окислительного стресса как основа здоровья и продуктивности животных // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 9. С. 53–67. <https://doi.org/10.26898/0370-8799-2025-9-6>

For citation: Bekenev V.A., Zakharenko A.M. Regulation of oxidative stress as the foundation for animal health and productivity. *Sibirskii vestnik sel'skhozaystvennoi nayki* = *Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 9, pp. 53–67. <https://doi.org/10.26898/0370-8799-2025-9-6>

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

The viability of all living organisms, including the productivity of animals, depends on mitochondria, the main function of which is the breakdown of glucose and fatty acids in food with the help of oxygen and the production of energy by synthesizing adenosine triphosphate (ATP).

Under normal conditions, mitochondria produce enough energy to support the health of the entire body. However, their mechanisms are tuned to respond to the environment. Free radicals, depending on conditions, can either stimulate or suppress cell division, genomic activity, and stimulate the expression of various genes [1]. Without suitable conditions, mitochondria do not generate ATP in quantities sufficient for cellular function. These factors include dietary factors, particularly overeating, nutrient deficiencies, altered microbiomes, lack of exercise, chronic stress, toxins, environmental changes, circadian rhythm disruptions, inconsistency in

temperature and light conditions, and others. In many cases, this leads to a destructive imbalance called oxidative stress, during which mitochondria produce and release large quantities of free radicals that cannot be neutralized by antioxidants, triggering a chain reaction of damage. It is believed that almost all diseases are caused by energy-related metabolic disturbances [2].

Free radicals, also known as reactive oxygen species (ROS), cause lipid peroxidation [3]. They normally act as signaling molecules. When free radical levels get out of control, oxidative stress occurs, triggering a chain reaction of damage. Free radicals are implicated in the aging process, as well as cancer, heart disease, stroke, arthritis, and possibly allergies, among many other diseases. They also play a key role in mammalian reproductive function, including follicle development and the maturation of oocytes and sperm¹.

¹Barron Jon. All Rights Reserved // A Step-by-Step Guide to Optimum Health and Relief from Catastrophic Illness. www.jonbarron.org. 2002.

The formation of free radicals depends on many factors, including feed composition, living conditions, and the genetic characteristics of animals [4]. Oxidative stress, which occurs in the blood serum, ovaries, and eggs, is caused by animal stress and causes significant harm to oocyte development [5]. Sperm cells, which are characterized by an extremely high metabolic rate, produce especially large quantities of free radicals [6].

Thus, oxidative stress is a product of mitochondria and affects the production of energy for all vital functions, the biophysical potential of the body, health, its adaptation to various environmental factors, reproductive function, and the quality of livestock products.

The purpose of this work is to review our own research and published materials of other scientists on these issues in order to create a general theory of oxidative stress regulation by various factors and, on this basis, further technological development of specific methods for increasing animal productivity and improving product quality.

The objectives of the work are to consider:

- general problems and the role of oxidative stress in the reproduction of farm animals;
- the influence of thiol compounds and catalase on the reproductive function of sows and boars;
- the effects of ultraviolet irradiation on lipid peroxidation, antioxidant activity of blood and productivity of sows;
- состояние липидного обмена, интенсивность роста и жизнеспособность поросят под влиянием антиоксидантов;
- the influence of fatty acid composition and oxidative properties of meat and fat of pigs of different breeds, fats with different levels of SFA and PUFA in feed rations on biochemical parameters and the atherogenic index of consumers of products.

In the creation of new selective forms of animals with high productivity, improved quality of livestock products, and enhanced reproductive

qualities, it is proposed to develop and use the methods for regulating the functioning of mitochondria aimed at normalizing oxidative stress, creating the biophysical potential for high productivity of animals, improving reproduction and the quality of livestock products, taking into account environmental factors and animal husbandry technology. It is proposed to introduce a special section of animal husbandry that studies the above phenomena in different species and breeds of animals, aimed at developing technologies for harmonizing their life processes.

*General issues of the role of mitochondria
and oxidative stress in the reproduction
of farm animals*

With the intensification of livestock farming, especially with industrial farming, all vital energy is focused on achieving maximum productivity. At the same time, animals are deprived of a close connection with their natural environment. They experience stress from physical inactivity, overcrowding, the operation of machinery, and other factors. As a result, the lifespan and economic use of particularly highly productive animals are declining. Extending the productive lifespan of animals has become a critical task for increasing the economic efficiency of livestock farming by creating optimal conditions for realizing the already-developed genetic potential.

Highly productive animals experience metabolic (oxidative) stress, which is characterized by increased production of free radicals, accompanied by a number of disturbances in the functioning of biological membranes and cells and the redox balance [7, 8]. Damage and dysfunction of the antioxidant system occur, including chronic pain and lameness. Researchers [9] noted increased levels of free radicals—reactive oxygen species (ROS) and malondialdehyde (MDA)—in the spinal cord of dairy cows with chronic inflammatory lameness. Lameness had higher ROS (350.5 ± 75.22 fluorescence/mg protein) compared to non-lame cows (152.5 ± 28.62 fluorescence/mg protein) ($p < 0.05$). Increased animal productivity is accompanied by a decline in their reproductive function. In many farms in

the Russian Federation, the productive life of dairy cows has been reduced to 2–3 lactations, calving periods for beef cows to 2.7 [10, 11], and sows to 3–4 farrowings² [12]. As a result, there is a temporary extinction of sexual dominance, the effectiveness of artificial insemination decreases, the duration of the service period increases, and the duration of productive use decreases.

Moving away from animal husbandry to sociology, it turns out that similar problems are being identified. Despite the world's population being over 8 billion, birth rates are declining in most countries. Interestingly, the most fertile countries are poor ones, especially in Africa, but even there, population growth is slowing. As family income is increasing, the number of children is decreasing, and life expectancy is also increasing. In high-income countries, people have become less physically active, have become heavier, and have fewer children. It is known that 10–15% of married couples in modern economically developed countries are infertile.

Studies³ [13] have shown that mitochondria produce an important 24-amino acid peptide, humanin, which is encoded by the 16S rRNA gene in the mitochondrial genome. It circulates throughout the body and is directly connected to the hypothalamus, the center for controlling energy metabolism, which influences sexual and reproductive behavior, and protects cells from oxidative stress.

In metabolic syndrome, the number of mitochondria in cells increases. These mitochondria, which contain their own genetic material, transmit a signal to the brain's pituitary gland indicating that the body is either overloaded or underloaded with energy. When there is an excess of nutrients, this signal forces the body to activate endocrine organs, including sex hormones, to reduce their functions for the sake of the organism's survival. When there is a deficiency, the

signal forces the organism to increase activity and reproduce faster for the sake of the species' survival. It can be assumed that humanin is the link that ensures the constant viability of a living system, depending on environmental conditions.

Neutralization of free radicals in the body is carried out by enzymatic and non-enzymatic mechanisms, collectively referred to as antioxidant protection.

There are specific enzymatic scavengers of reactive oxygen species – antioxidants such as glutathione peroxidase (GPx), catalase (CAT), superoxide dismutase, glutathione peroxidase (GPx1) and others, which convert them into harmless molecules and are of great importance in the development of follicles and the process of oocyte maturation [4, 14].

The role of thiol compounds and catalase in reproduction

Thiol compounds, which contain sulfhydryl groups (SH groups) characterized by high reactivity, play a leading role in the molecular mechanisms of antioxidant protection and in bringing the concentration of free radicals to a physiologically necessary level [15, 16]. Certain relationships between CAT and SH groups in the blood lead to improved sperm capacitation and, thus, to better fertilization of eggs [17]. Excessive oxidative stress, which is a key sign of poor energy, damages the sensitive membranes of sperm, disrupts their development, and leads to a decrease in sperm quality [2].

Based on this, in the 90s of the 20th century we studied the oxidative status of the blood of sows, blood and sperm of boars for antioxidant activity (thiol compounds - SH-groups, catalase activity)⁴. Table 1 shows that in the blood of sows there is a clear negative correlation ($r = -0.55$) between the activity of CAT and lipid peroxidation (MDA) and an insignificant one between the MDA and SH groups, i.e. catalase

²Bekenev V.A. Technology for pig breeding and keeping: a tutorial. St. Petersburg: Lan, 2012, pp. 184–205.

³Barzilai Nir, Cohen Pinchas. Mitochondrial Booster for Longer Healthspans and Longer Life. A Special Report by the Transformatonal Technology AlertTeam. Mauldin economics // BULL or BUST, 2016, Navigating the High-Speed Train Wreck.

⁴Patent A01K 67/02 (Russian Federation). 2137363 C 1. Method for increasing the fertility of pigs based on a biochemical indicator / Bekenev V.A., Nikiforova N.G., Kharchenko P.G.; published 09.20.1999.

is more active than thiol compounds in neutralizing free radicals.

A significant increase in multiple pregnancy and litter weight at farrowing was revealed in paired combinations where the sows had a high level of SH groups and the boars had a high catalase activity in the blood, especially when these indicators were combined in the sow and the boar (see Table 2, Fig. 1).

There is also a high correlation between the intensity of peroxidation processes and the an-

tioxidant activity (AOA) of sperm. Since SH groups affect the penetration of sperm into the glycoprotein membrane of the egg plasma membrane [16], it can be assumed that a sufficient amount of SH groups in the blood of sows facilitates the penetration of sperm into it. As a result, fertility and the number of piglets born increase. However, during the formation of the zygote, free radicals in the female reproductive tract are believed to be neutralized [6], and AOA maintains its high status, achieved as a result of enhanced metabolism.

Табл. 1. Взаимосвязь показателей антиокислительного статуса крови и репродукции свиней (23 хряка, 48 гнезд)

Table 1. Relationship between blood antioxidant status parameters and reproductive performance in pigs (23 boars, 48 litters)

Indicator	MDA	DA	SH	CAT	Total lip-ids	Prolifica-cy	Litter weight	Weak piglets	Still-born
<i>Boar blood</i>									
MDA	—								
DA	0,34	—							
SH	0,29	0,09	—						
CAT	−0,72	−0,34	0,05	—					
Total lipids	−0,52	−0,19	−0,41	0,43	—				
Prolificacy	−0,17*	0,08	0,17*	0,29**	0,04	—			
Litter weigh	−0,11	0,17*	0,21*	0,24*	−0,03	0,93***	—		
Weak piglets	−0,19*	−0,03	−0,14	0,15	0,14	0,40***	0,14		
Stillborn	0,13	0,27**	−0,01	−0,14	0,07	−0,15	0,10	0,03	—
<i>Blood of sows</i>									
MDA	—								
DA	0,61***	—							
SH	−0,15	0,02	—						
CAT	−0,55***	0,06	0,13	—					
Total lipids	0,19	0,08	0,13	−0,03	—				
Prolificacy	0,05	−0,04	0,11	0,07	0,04	—			
Litter weigh	−0,04	−0,14	0,17*	0,12	0,07	0,92***			
Weak piglets	0,07	0,21*	−0,11	0,02	−0,14	0,40***	0,14	—	
Stillborn	0,01	−0,03	0,21*	−0,02	−0,14	−0,15	0,10	0,03	

The degree of reliability of the correlation coefficients:

* $p < 0,05$.

** $p < 0,01$.

*** $p < 0,001$.

*The effect of ultraviolet irradiation
on lipid peroxidation, blood antioxidant
activity and productivity of sows*

Lipid metabolism parameters and productivity of sows were studied in the OOO “Kudryashovskoye”, Novosibirsk Region, from 1977 to 1980. They were irradiated with ultraviolet rays from LE-30-1 lamps from the 32nd to the 110th

day of gestation during two reproductive cycles. Irradiation doses were as follows for each group: Group 1 – 70–80 mEhr/m², Group 2 – 95–105 mEhr/m², and Group 3 – 120–130 mEhr/m² per day. Pigs in Group 4 were not irradiated and served as a control.

It was found that UV irradiation of sows and piglets, depending on its dose, promotes an in-

Табл. 2. Многоплодие свиной в зависимости от уровня каталазы в крови хряков и SH-групп в крови маток

Table 2. Fecundity in pigs depending on the level of catalase in boars' blood and SH-groups in sows' blood

Catalase levels in boar blood	Level of SH groups in the blood of ewes	Number of farrowings	Live piglets born, heads	<i>p</i>	Nest weight at farrowing, kg	<i>p</i>
High (H)	High (H)	15	10,9 ± 0,52	–	14,6 ± 0,59	–
High (H)	Low (L)	13	9,9 ± 0,72	Unreliable	12,9 ± 1,06	Unreliable
Low (L)	High (H)	4	9,5 ± 2,53	»	12,7 ± 3,09	»
Low (L)	Low (L)	16	8,1 ± 0,79	< 0,01	11,1 ± 0,92	< 0,01

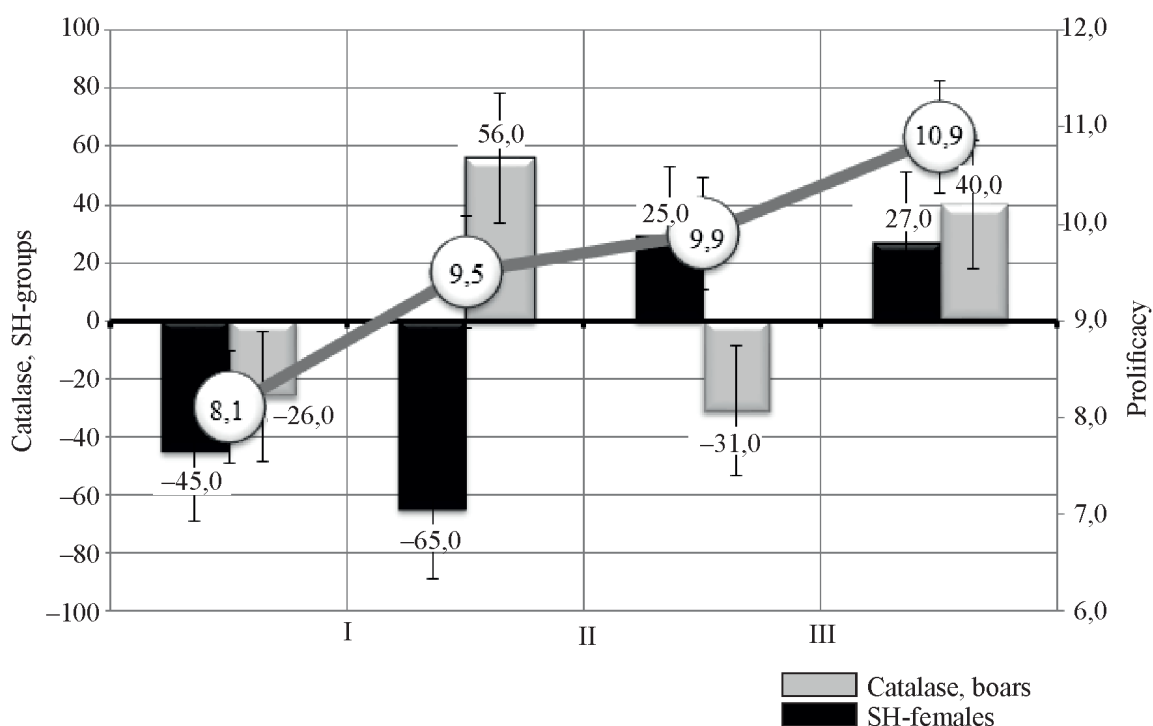


Рис. 1. Зависимость многоплодия свиной от уровня каталазы и SH-групп в крови хряков и маток, % от среднего

Fig. 1. Dependence of pig fecundity on the level of catalase and SH-groups in the blood of boars and sows, % of the average

crease in the antioxidant activity of cell membrane lipids by 36–51% in pregnant sows, by 14–29% in lactating sows, and a decrease in the concentration of total lipids by 3.8–15.1% (see Table 3).

The greatest increase in antioxidant activity was observed in animals that received a higher radiation dose⁵⁻⁷. At the same time, vitamin D levels in the blood of lactating sows, a powerful modulator of mitochondrial function and oxidative stress, increased to 6.8–7.5 IU compared to 6.0 IU in the control group, or a 17–25% increase. Vitamin D is better absorbed and more freely penetrates the cell's mitochondria when it is obtained by the body not from food, but through UV irradiation of the body's surface, causing an electronically excited state of the body's cells, "in which portions of energy are released, equivalent to quanta of a part of the elec-

tromagnetic spectrum from the UV to the near IR range" [18].

These changes in blood under the influence of irradiation were accompanied by an increase in the productivity of sows (see footnote 7). Thus, in the 2nd and 3rd groups, 0.7–1.0 more viable piglets were born from each sow than in the control group. The yield of piglets at weaning was also higher by 0.5–1.8 heads, and the live weight of each piglet was greater by 0.2–0.3 kg. It should be noted that the culling rate among sows that were irradiated was 7–27% lower than in the control group, and their conception rate after weaning was 10–15% higher.

Thus, in the animals exposed to ultraviolet radiation in industrial conditions, the antioxidant activity of cell membrane lipids increases, the AOA/LPO index increases, and at the same time, the productivity and adaptive properties

Табл. 3. Липидный обмен в эритроцитарных мембранах у свиноматок

Table 3. Lipid metabolism in erythrocyte membranes of sows

Group	Antioxidant activity, h-ml/g	Peroxidation, c.u.	Total lipids	Total cholesterol	Free cholesterol	Cholesterol esterification, %
			mg%			
In pregnant sows in the first irradiation cycle						
1st	323,2 ± 30,7	0,195 ± 0,087	247 ± 20	81,0 ± 3,7	47,2 ± 1,9	41,8 ± 1,7
2nd	307,2 ± 42,9	0,134 ± 0,034	280 ± 7	74,0 ± 5,5	41,8 ± 3,1	43,5 ± 1,1
3rd	340,0 ± 37,9	0,156 ± 0,036	275 ± 5	77,0 ± 5,0	41,8 ± 2,1	45,7 ± 1,7
4th	225,0 ± 72,6	0,127 ± 0,056	291 ± 27	73,0 ± 4,5	45,0 ± 1,9	38,4 ± 2,9
In lactating sows after the first cycle of irradiation						
1st	170,0 ± 4,7	0,085 ± 0,016	207 ± 4	77,5 ± 2,4	49,7 ± 1,5	35,9 ± 0,2
2nd	174,0 ± 11,6	0,134 ± 0,049	210 ± 4	62,0 ± 1,2	36,0 ± 0,0	42,0 ± 1,0
3rd	193,0 ± 7,9*	0,151 ± 0,031	207 ± 4	66,6 ± 3,6	35,0 ± 1,8	47,5 ± 2,8
4th	149,0 ± 16,2	0,142 ± 0,032	240 ± 13	76,3 ± 1,3	46,2 ± 3,8	39,5 ± 2,0
In pregnant sows in the second cycle of irradiation						
2nd	246,2 ± 2,8**	0,182 ± 0,039	203 ± 3	61,7 ± 9,6	35,5 ± 3,5	42,5 ± 1,3
4th	209,6 ± 6,4	0,194 ± 0,038	216 ± 8	81,0 ± 7,7	39,5 ± 3,0	46,5 ± 1,6

⁵Bekenev V.A., Khasnulin V.I. Lipid peroxidation and antioxidant activity in pigs under the influence of ultraviolet irradiation // Siberian Herald of Agricultural Science, 1981, N 1, pp. 82–86.

⁶Bekenev V.A., Khasnulin V.I. Biological mechanisms of adaptation of piglets to industrial technology conditions // Agricultural Biology, 1982, vol. 17, N 1, pp. 113–116.

⁷Bekenev V.A., Chastikin A.G. Ultraviolet irradiation of pigs at a pig farm // Pig breeding, 1978, N 8, pp. 22–23.

of pigs improve. The experimentally obtained optimal doses of UV irradiation are included in the information and technical reference book on the best available technologies "Intensive pig breeding" ITS 41-2023, which is a standardization document approved by Order No. 533 of the Ministry of Industry and Trade of the Russian Federation dated February 17, 2023.

Lipid metabolism, growth rate and viability of piglets under the influence of antioxidants

One of the factors that has a significant negative impact on mitochondrial function and ATP generation in modern pig farming is stress, which reduces animal viability and productivity, disrupts reproductive function, and reduces product quality. In weaned piglets, stress is caused by weaning, mixing different litters, the process of transporting piglets to another location, changing habitat and living conditions, and partial changes in feeding quality.

In 1980–1982, we studied viability, growth rate, antioxidant activity (AOA), and lipid peroxidation (LPO) in the blood and liver of piglets after weaning under the influence of feed additives: vitamin E, ascorbic acid, chlorpromazine, as well as an insufficiently studied but promising adaptogen – Eleutherococcus extract, including against the background of ultraviolet (UV) irradiation.

Significant differences in the activity of endogenous antioxidants of erythrocyte membrane lipids were observed in piglets of different groups. Thus, AOA increased under the influence of all studied factors, especially with the addition of Eleutherococcus alone to the feed and in combination with chlorpromazine and UV irradiation ($p < 0.001$). Moreover, in animals supplemented with eleutherococcus and chlorpromazine, lipid peroxidation increased ($p < 0.001$), while exposure to UV irradiation decreased it ($p < 0.001$). The AOA/LPO ratio was higher than the control

in almost all experimental groups of piglets, but was highest in the groups treated with UV irradiation. Eleutherococcus increased the total lipid content in erythrocyte membranes ($p < 0.05$).

Eleutherococcus extract, combined with vitamin E as supplements, as well as in combination with ascorbic acid, induced an even greater increase in the antioxidant activity of red blood cell lipids ($p < 0.001$). Despite the increase in lipid peroxidation, antioxidant accumulation processes prevailed over free-radical reactions, as evidenced by the increase in the AOA/LPO index under the influence of the combination of preparations (see Table 4).

Thus, the use of preventive anti-stress and tranquilizing drugs during weaning of piglets allows, due to the normalization of antioxidant activity and erythrocyte lipid peroxidation, to improve their growth during the growing period by 4.8–24.6%, and to increase survival by 5.0–5.1%⁸.

At the same time, a number of studies have shown that increased peroxidation (free radical) oxidation of lipids is necessary for the body to switch metabolic processes to a new, higher energy level^{9, 10}. In this case, endogenous antioxidants, acting as "traps" for lipid peroxidation products, prevent the damaging effects of increased free-radical oxidation. As a result of the superiority of enzymatic oxidation over free-radical oxidation, energy products (fats, carbohydrates) are used for their intended purpose—for animal growth and development, which contributes to increased adaptive resilience and viability in piglets.

*Fatty acid composition
and oxidative properties of meat
and fat of pigs of different breeds*

To substantiate the positive and negative qualities of saturated and polyunsaturated fatty acids, their impact on the health of consumers of

⁸A.c. № 1239918, A 61 K 31/00 Method for preventing stress in piglets/ Bekenev V.A. DSP. No. 2825611/30-15; applied 28.09.79; published 28.09.80.

⁹Voskresensky O.N. The importance of the systematic nature of biological inhibition of lipid peroxidation in atherogenesis // Bioantioxidants, Moscow, 1975, pp. 121–125.

¹⁰Kaznacheev V.P., Khasnulin V.I. The state of adaptive mechanisms and metabolic processes in the builders of the Baikal-Amur Mainline // Man on the BAM. Novosibirsk, 1979, pp. 3–8.

Табл. 4. Состояние липидного обмена, интенсивность роста и жизнеспособность поросят под влиянием антистрессовых добавок

Table 4. Lipid metabolism status, growth rate, and viability of piglets under the influence of anti-stress supplements

Indicator	Group			
	1st (Eleutherococcus 6 ml + vitamin E 20 mg)	2nd (Eleutherococcus 3 ml + vitamin E 20 mg + vitamin C 500 mg)	3rd (Eleuthero-coccus 6 ml)	4th (control)
Number of animals	26	26	26	26
Live weight, kg: at the beginning of the ex- periment	5,7 ± 0,10	5,71 ± 0,11	5,72 ± 0,10	5,71 ± 0,08
at the end of the experiment	36,1 ± 0,10***	37,5 ± 0,56***	34,6 ± 0,57*	32,6 ± 0,80
Average daily gain, g	395	412	375	349
Viability, %	100	100	88,5	96,1
AOA blood, h.ml/g	156,3 ± 27,5***	97,7 ± 16,3***	79,0 ± 26,6*	8,3 ± 8,3
LPO, c.u.	280 ± 120	390 ± 70*	220 ± 220	200 ± 50
AOA/ LPO Index	0,56 ± 0,03***	0,25 ± 0,02***	0,36 ± 0,03***	0,04 ± 0,01
Total lipids, mg %	263,3 ± 26,1	266,7 ± 31,8	285,0 ± 15,0	218,0 ± 30,6
Piglet growth, % to the control	113,2	118,0	107,4	100,0
Viability, %	100	100	88,5	96,1

The difference with the control is significant at

* $p < 0,05$.

** $p < 0,01$.

*** $p < 0,001$.

products with a certain ratio of these fatty acids in the diet, pigs and quails were taken as model objects, which, according to a number of scientists, are closer to humans in their anatomical and physiological characteristics [19].

The studies were conducted at the OOO “Chistogorsky” in the Kemerovo Region from 2018 to 2023. The longissimus dorsi muscle of the Kemerovo pigs contained slightly higher levels of SFAs and MUFAs, but significantly lower (almost 2 times) PUFAs, at 6.92% and 12.84%, respectively, than that of the Pietrain animals. The subcutaneous fat of the Kemerovo pigs contained significantly more SFAs (41.56%) and slightly more monounsaturated fatty acids (MUFAs), but significantly lower levels of PUFAs (15.18%) than that of the Pietrain animals (see Table 5).

High levels of PUFAs, especially linoleic acid, contribute to rapid oxidation of products due to high metabolic activity (high productiv-

ity) in animals, posing a risk of cardiovascular, oncological, and other diseases in consumers and negatively impacting the health of the animals themselves. Polyunsaturated fatty acids, found in cell membranes, are particularly vulnerable to lipid hydroperoxides due to the multiple unsaturated points found in their structure [20, 21].

The fat of these two pig breeds, which differ significantly in fatty acid composition and cholesterol levels, was taken for introduction into the diet of quails, which serve as a model object.

Three groups of 60 randomly selected quail chicks were formed immediately after hatching. The quail were fed fat at a rate of 3.0–3.5% of their dietary weight: sunflower oil in the first control group, subcutaneous fat from the Kemerovo pigs in the second experimental group, and the Pietrain pig fat in the third experimental group.

The live weight of quails in the 1st control group at 60 days of age was 204.3 g, in the 2nd experimental group – 213.5 g, in the 3rd experimental group – 208.7 g. In the 2nd experimental group, whose diet included fat of the Kemerovo breed, it was 4.5% higher ($p < 0,1$).

Birds in the 2nd experimental group at 60 days of age tended to outperform those in the first control group in terms of live weight and body weight gain. Feed consumption per unit of gain was 8.2, 7.53, and 7.99 kg, respectively, with feed consumption in the 2nd experimental group being 8.2% lower.

In our studies, quails from the 3rd experimental group received pork fat with a high concentration of PUFAs, especially linoleic fatty acid, which are the main source of lipid peroxidation. Feed costs per 10 eggs were 0.525; 0.412 and 0.507 kg, respectively. The average egg weight was highest in hens from the 2nd experimental group – 11.38 ± 0.16 g versus 11.23 ± 0.18 g ($p < 0.01$) in the control and 10.65 ± 0.09 g in the 3rd experimental group.

In 10 birds from each group, slaughtered at 8 and 23 weeks of age, blood serum was tested for

the content of total cholesterol, HDL and LDL, triglycerides, total protein, albumin, glucose, antioxidants, aspartate aminotransferase (AST), the initial level of lipid peroxidation products (LPO) in low-density lipoproteins (LDL) and oxidative resistance of LDL.

It is known that when consuming PUFAs, a high concentration of lipid peroxidation products appears in the blood and tissues, in particular malondialdehyde, which destabilizes cell membranes, causing atherosclerotic changes that deepen under stressful conditions, when the balance between the formation and capture of free radicals is disrupted [22–24] (see Table 6).

The LDL level at 23 weeks of age was highest in quails fed with fat from the Pietrain pigs, which is characterized by an increased content of PUFA and cholesterol (44.9 mg/l versus 29.0 mg/dl in the control group and 28.6 mg/dl in the 2nd experimental group).

It is important to note that the atherogenic index (AI) (the ratio (TC-HDL)/HDL), which characterizes the risk of developing coronary heart disease, was correspondingly the highest ($p < 0.01$) in quails with elevated LDL levels

Табл. 5. Жирные кислоты подкожного жира свиней разных пород, %

Table 5. Fatty acid composition of subcutaneous fat in different pig breeds, %

Fatty acid	Pig breed			
	Kemerovo	Pietrain	Kemerovo	Pietrain
	Longissimus dorsi muscle		Subcutaneous fat	
Palmitic C16 : 0	27,02 ± 0,90	23,54 ± 1,12	25,62 ± 1,96	23 ± 0,59
Stearic C18 : 0	12,82 ± 0,24	12,50 ± 0,46	13,72 ± 0,67	13,34 ± 0,95
EFA sum	39,84	36,04	41,56	38,28
Palmitoleic C16 : 1	4,26 ± 0,21	2,86 ± 0,27	2,36 ± 0,32	2,08 ± 0,2
Oleic C18 : 1	36,22 ± 0,56	31,82 ± 1,17	34,78 ± 1,42	33 ± 0,91
Gondoinic C20 : 1	0,74 ± 0,07	1,0 ± 0,22	0,3	0,3
Total MUFA	41,22	35,68	43,1	41,7
Linoleic C18 : 2 (ω-6)	6,74 ± 0,69	12,42 ± 0,95	15,08 ± 1,61	19,22 ± 1,6
α-Linolenic C18 : 3n3	0	0	0	0
Eicosapentaenoic C20 : 5	0,08 ± 0,03	0,2 ± 0,06	0	0
Docosahexaenic C22 : 6	0,10 ± 0,05	0,22 ± 0,04	0	0
Total PUFA	6,92	12,84	15,18	19,42

receiving the Pietrain pig fat as a feed additive (0.93 versus 0.57 and 0.69 in other groups) (see Table 6, Fig. 2).

For the first time, experimental evidence has been obtained that fats containing more SFAs but less cholesterol and linoleic fatty acid, the main structural unit of omega-6 PUFAs, are more beneficial in animal nutrition. The importance of the presence of certain metals, such as magnesium, which exists in a complex with ATP, should also be considered [25].

Contrary to the prevailing international concept of Ancel Keys [26, 27], based on limiting the consumption of fats, especially those containing a lot of saturated fatty acids, we have experimentally proven that fat rich in saturated fatty acids, but containing less PUFA, especially linoleic fatty acid and cholesterol, is not only not harmful when included in animal feed, but also has a positive effect on their productivity, reduces the atherogenic index, and likely reduces the risk of cardiovascular diseases. This changes the established scientific concepts in medicine and animal husbandry, explains scientific facts and

experimental data that previously found no scientific explanation.

This is confirmed by a recent study conducted by American scientists from various universities, which showed that mortality in humans is associated with high blood levels of linoleic fatty acid, the main component of PUFAs. A high omega-6/omega-3 ratio in the blood increases the overall risk of death by 26%, cancer by 14%, and the risk of death from cardiovascular disease by 31% [28].

Thus, mitochondrial function is a vital component influencing a wide variety of aspects of life, the health of organisms, and the productivity of farm animals, as it supplies energy for the creation and expression of the body's biophysical potential. Regulating oxidative stress can be used to enhance the reproductive performance of animals through the use of thiol compounds and catalase. Exposure of animals to ultraviolet radiation increases the antioxidant activity of cell membrane lipids. It should be used in specific doses to improve animal productivity, especially on industrial farms. Antioxidants such

Табл. 6. Биохимические показатели крови перепелок

Table 6. Blood biochemical parameters of quails

Test	Group		
	1st control	2nd experimental	3rd experimental
Triglycerides, mg/dL	90,0 ± 9,23	123,7 ± 11,39*	107,8 ± 12,02
Total cholesterol, mg/dL	128,7 ± 12,97	130,4 ± 10,22	137,7 ± 15,38
Antioxidant activity, mmol/l	2,3 ± 0,07	2,2 ± 0,09	2,2 ± 0,06
Lipid peroxidation (0 min), nmol MDA/mg protein	1,1 ± 0,2	1,7 ± 0,31	1,9 ± 0,23*
Lipid peroxidation (30 min), nmol MDA/mg protein	3,8 ± 0,39	4,5 ± 0,53	3,8 ± 0,45
High-density lipoproteins, mg/dL	81,7 ± 7,42	77,1 ± 4,81	71,2 ± 6,7
Low-density lipoproteins, mg/dL	29,0 ± 5,51	28,6 ± 4,81	44,9 ± 9,01
Atherogenic index, y.e.d.	0,57 ± 0,06	0,69 ± 0,69	0,93 ± 0,10**
Total protein, g/l	24,3 ± 3,01	25,3 ± 2,31	25,4 ± 2,12
Albumins, g/l	9,2 ± 0,95	9,7 ± 0,48	9,8 ± 0,76
Aspartate aminotransferase, U/L	147,3 ± 29,37	221,9 ± 14,96*	205,8 ± 31,93
Glucose, mmol/l	10,0 ± 1,32	9,2 ± 0,88	10,5 ± 0,93

*The difference compared to the control is significant at $p < 0,05$; **at $p < 0,01$.

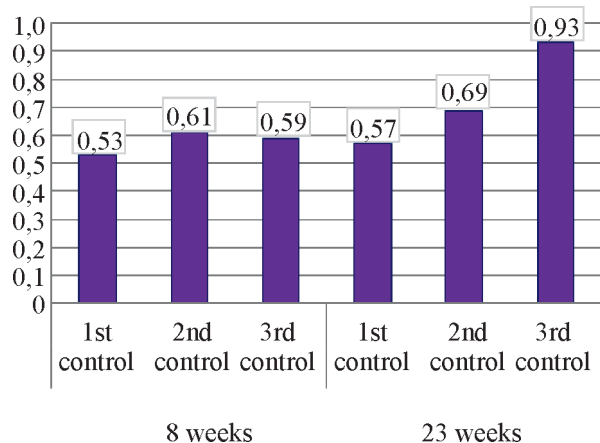


Рис. 2. Атерогенный индекс у перепелок разных групп с возрастом

Fig. 2. Atherogenic index in quails of different groups by age

as vitamin E, ascorbic acid, chlorpromazine, and eleutherococcus extract, including those used in conjunction with ultraviolet radiation, increase antioxidant activity and lipid peroxidation in the blood and liver of piglets, thereby promoting their vitality and growth. The health of agricultural consumers depends significantly on the ratio of saturated and polyunsaturated fatty acids in meat and lard, as well as their oxidative properties. This should be taken into account when developing new animal breeds, feeding conditions, and housing. Fat, including lard from pigs, which contains more SFAs but less cholesterol and linoleic acid, is more beneficial in animal nutrition, reduces the atherogenic index, and lowers the risk of cardiovascular disease, which is likely applicable to human nutrition as well.

Based on this, we propose, along with the selection and feeding of farm animals, to introduce a special section of animal husbandry, “Energiobiotest,” which studies the aforementioned phenomena in different species and breeds of animals from theoretical and applied positions, including the composition of fatty acids in body tissues and consumed feed, the amount of ATP obtained from food, the ratio of oxidative and antioxidant reactions in the body, the atherogenic index, behavioral reactions and stresses that affect the antioxidant activity of body tissues, the development of technologies for the harmoniza-

tion of life processes and improving the quality of the resulting products.

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Дата поступления статьи / Received by the editors 09.04.2025
Дата принятия к публикации / Accepted for publication 28.05.2025
Дата публикации / Published 15.10.2025

Ассоциации живой массы и генотипического разнообразия популяций оленей чукотской и эвенской пород Крайнего Северо-Востока России

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Представлены результаты исследования ассоциаций живой массы и генотипических признаков в сельскохозяйственных популяциях домашних северных оленей Магаданской области и Чукотского автономного округа. Исследования проведены в 2020–2022 гг. на базе четырех сельскохозяйственных предприятий Чукотки и Магаданской области. В работе использована зоотехническая информация из годовых отчетов сельхозпредприятий Чукотского автономного округа и Северо-Эвенского района Магаданской области. Для изучения взята живая масса реализованных на мясо животных, рассчитанная как среднеарифметическая за 10 лет по каждой половозрастной группе. Материалом для генетических исследований служили образцы ткани (ушные выщипы) оленей разных половозрастных групп. В молекулярно-генетических исследованиях использовано 925 проб. Индивидуальное генотипирование животных осуществляли с применением ISSR-PCR-метода. Зависимость между полиморфизмом ISSR-маркеров и продуктивными признаками оленей чукотской и эвенской пород ранее не изучали. Чукотские популяции оленей уступали эвенским по среднему числу аллелей на локус на 12%, числу действующих эффективных аллелей на локус на 11,0%. Значения коэффициента корреляции между показателями живой массы и генетического разнообразия в популяциях чукотской и эвенской пород по всем половозрастным группам оленей оказались соответственно равны: для среднего числа аллелей на локус $r = 0,347$ и $0,336$, числа эффективных аллелей $r = 0,534$ и $0,546$, теоретической гетерозиготности $0,570$ и $0,538$ соответственно. Полученные данные позволяют констатировать зависимость живой массы оленей от генотипического разнообразия в популяциях чукотской и эвенской пород.

Ключевые слова: северное оленеводство, чукотская порода, эвенская порода, живая масса, генетическое разнообразие

Associations of live weight and genotypic diversity of deer populations of the Chukchi and Even breeds of the Far North-East of Russia

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The results of the study of associations of live weight and genotypic traits in agricultural populations of domestic reindeer in the Magadan region and the Chukotka Autonomous District are presented. The studies were conducted between 2020 and 2022 at four agricultural enterprises in Chukotka and the Magadan region. The study utilized zootechnical data from the annual reports of agricultural enterprises in the Chukotka Autonomous District and the Severo-Evensky District of the Magadan region. The study utilized the live weight of animals sold for meat, calculated as the 10-year arithmetic mean for each sex and age group. The material for genetic studies consisted of tissue samples (ear notches) from reindeer of different sex and age groups. A total of 925 samples were used in the molecular genetic studies. Individual genotyping of the animals was performed using the ISSR-PCR method. The relationship between ISSR marker polymorphism and productive traits in the Chukchi and Even reindeer breeds had not been studied prior to this research. Chukotka reindeer populations

exhibited 12% lower average number of alleles per locus and 11.0% lower number of effective alleles per locus compared to Even breeds. The values of the correlation coefficient between the live weight and genetic diversity indicators in the populations of the Chukotka and Even breeds for all age and sex groups of reindeer were respectively equal to: for the average number of alleles per locus $r = 0.347$ and 336, the number of effective alleles $r = 0.534$ and 0.546; theoretical heterozygosity 0.570 and 0.538, respectively. The obtained data allow us to state the dependence of the live weight of reindeer on the genotypic diversity in the populations of the Chukchi and Even breeds.

Keywords: reindeer husbandry, Chukchi breed, Even breed, live weight, genetic diversity

Для цитирования: Брызгалов Г.Я., Витомскова Е.А., Гинтер Е.В. Ассоциации живой массы и генотипического разнообразия популяций оленей чукотской и эвенской пород Крайнего Северо-Востока России // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 9. С. 68–74. <https://doi.org/10.26898/0370-8799-2025-9-7>

For citation: Bryzgalov G.Y., Vitomskova E.A., Ginter E.V. Associations of live weight and genotypic diversity of deer populations of the Chukchi and Even breeds of the Far North-East of Russia. *Sibirskii vestnik sel'skhoz'yastvennoi nauki* = *Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 9, pp. 68–74. <https://doi.org/10.26898/0370-8799-2025-9-7>

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

In the far northeast of the Russian Federation, the Chukchi and Even breeds of reindeer retain their economic importance as a breeding species. The Chukchi breed is the most numerous one. Due to the restructuring of reindeer herding farms engaged in breeding the Even breed in the post-Soviet period, the population of these animals has significantly decreased.

Reindeer herding farms are taking the necessary measures to increase their herd size, but it is nevertheless declining. Selective breeding work with domestic reindeer on farms is carried out using traditional methods based on mass selection by phenotype [1–5].

To accelerate selection and breeding efforts, it is necessary to create herds with the desired productivity level, adapted to specific breeding regions and industrial technologies. Traditionally, such work takes a long time and is sometimes ineffective. The effectiveness of this approach is complicated by the fact that the predicted productivity of highly specialized breeds is realized under specific housing and feeding conditions. The development of molecular genetics, particularly the advent of the polymerase chain reaction (PCR), which allows for the amplification of large numbers of specific DNA regions and subsequent analysis of polymorphisms within

these regions in different individuals, has fundamentally changed the possibilities for genotyping animals and identifying key genes whose polymorphisms significantly contribute to the development of economically valuable traits. It is necessary to conduct research aimed at developing more effective methods that incorporate advances in molecular genetics in order to improve the breeding methods [6–13].

The purpose of the work is to study the associations of live weight and genotypic traits in agricultural populations of domestic reindeer in the Magadan Region and the Chukotka Autonomous Okrug.

MATERIAL AND METHODS

The research was conducted in 2020–2022 at four agricultural enterprises in Chukotka and the Magadan Region: AE “Vozrozhdenie”, “Amgue-ma”, “Ostrovnoye”, and the MUAЕ “Irbychan” (see the figure).

The study utilized zootechnical information from annual reports of agricultural enterprises in the Chukotka Autonomous Okrug and the Severo-Evensky District of the Magadan Region. The live weight of animals sold for meat was calculated as the arithmetic mean over 10 years for each age and sex group. On average, approximately 3,500 animals were sold per farm annually. All



Чукотская порода оленей СПХ «Амгуэма»
Chukchi breed of deer of the AE "Amguema"

carcasses were weighed, and farms maintained individual records. To compensate for seasonal and annual fluctuations in live weight, data on reindeer sales in the fourth quarter of each year during periods of stable industry development were used.

The nomenclature of age and sex groups adopted in reindeer herding: does – females over two years old, calves – males and females 5–6 months old, bull calves – males from one to two years old, bulls – males over three years old.

The genetic studies were conducted using tissue samples (ear notches) from reindeer of different age and sex groups. A total of 925 samples were used in the molecular genetic studies. Individual genotyping of animals was performed using the ISSR-PCR method. The relationship between the ISSR marker polymorphism and performance traits in reindeer of the Chukotka and Even breeds has not been previously studied.

The existing nomenclature of age and sex groups of animals in northern reindeer herding was adopted. Data processing was performed using the generally accepted methods of variation statistics*.

RESULTS AND DISCUSSION

To study associations between genetic diversity and live weight, data from Table 1 were used. Individuals belonging to the Chukotka

breed from the “Vozrozhdenie” and “Amguema” farms were classified as highly productive populations meeting the requirements of the Elite quality class. Animals from the “Ostrovnoye” farm population were classified as having an average live weight across all age and sex groups. Live weight differences in favor of deer from the “Vozrozhdenie” and “Amguema” farms compared to deer from the “Ostrovnoye” farm were 32.0% for does, 27.4% for calves, 17.6% for bull calves, and 16.5% for bulls, with an average of 23.2% across all age and sex groups. High-yielding deer populations surpassed less productive ones in the average number of alleles per locus by 2.0% and the number of active effective alleles per locus by 17.6%.

The heterozygosity rate in the deer populations from the “Vozrozhdenie” and “Amguema” farms exceeds that of the “Ostrovnoye” population by 2.1 and 3.2%, respectively. The most significant difference between the populations, which differ in live weight, was determined by the polymorphic information content (*PIG*) index at 64.2%.

The homozygosity coefficient, reflecting the genetic uniformity of populations, in the “Vozrozhdenie” and “Amguema” farms was 18.2 and 26.8% lower, respectively, than the population from the “Ostrovnoye” ($p < 0,01$).

In populations with the highest live weight of age-sex groups of deer from the “Vozrozhdenie” and “Amguema” farms, the most significant indicators of genetic diversity were also found: the average number of alleles per locus is 8.57/8.71, the number of effective alleles per locus is 7.57/8.15, the expected heterozygosity is 0.868/0.877, the *PIG* index is 0.248/0.374, respectively. In the population from the “Ostrovnoye” farm with low live weight of deer, less significant indicators were found: the average number of alleles per locus is 8.47, the number of effective alleles per locus is 6.68, the expected heterozygosity is 0.850, the *PIG* index is 0.151.

*Biganova S.G. Biometrics. St. Petersburg: Lan, 2024, 132 p.

Табл. 1. Показатели живой массы и генотипического разнообразия в популяциях оленей чукотской и эвенской пород

Table 1. Live weight and genotypic diversity indicators in deer populations of the Chukchi and Even breeds

Age and gender group	Populations of the Chukchi breed			Average	Populations of the Even breed		Average	Differ- ence
	Vozrozh- denie	Amgue- ma	Ostrovnoe		Pa- renskaya	Gizhi- ginskaya		
Live weight, kg								
Does	105,1	101,6	77,8	94,8	89,5	91,4	90,4	4,4
Calves	60,4	53,1	44,5	52,6	50,8	52,3	51,5	1,1
Bull calves	85,4	87,6	73,5	82,2	75,9	76,1	76,0	0,1
Bulls	131,7	132,3	111,3	125,1	112,7	113,6	113,2	0,5
Genetic diversity								
Average number of alleles per locus	8,57	8,71	8,47	8,58	9,95	9,56	9,75	1,17
Effective alleles per locus	7,57	8,15	6,68	7,46	8,49	8,28	8,38	0,92
Homozygosity coefficient	0,132	0,123	0,156	0,135	0,120	0,110	0,115	0,020
Heterozygosity	0,868	0,877	0,850	0,865	0,880	0,880	0,880	0,015
PIG (proportion of heterozygotes)	0,248	0,374	0,151	0,257	—	—	—	—

Even reindeer from the Parenskaya and Gizhiginskaya populations differ insignificantly in live weight: does by 2.1%, calves by 2.9%, bull calves by 0.3%, and bulls by 0.8% (an average of 1.4% across all age and sex groups) in favor of the Gizhiginskaya population. In terms of genetic diversity, both Even breed populations also differ insignificantly: the number of effective alleles per locus is 2.5%, and the expected heterozygosity value is the same in both populations – 0,880.

The homozygosity coefficient, reflecting the genetic uniformity of populations, in the Parenskaya and Gizhiginskaya populations was approximately at the same level – 0.120 and 0.110, respectively (see Table 1).

The correlation coefficient between live weight and genetic diversity in the Chukchi breed populations across all age and sex groups of reindeer was found to be equal: for the average number of alleles per locus, $r = 0.347$, the number of effective alleles – $r = 0.534$, and theoretical heterozygosity – 0.570. The most significant correlation was found between live weight

and the proportion of heterozygous variants in the population – $r = 0.646$. In the age and sex groups of reindeer, the highest correlation coefficient between live weight and genetic diversity indicators of the Chukotka breed is found in the group of bull calves ($r = 0.597–0.809$) (see Table 2). Live weight in Chukotka bull calves is the most stable indicator in comparison with other age and sex groups, since the does are lactating, the bulls are after the estrus, and the calves are growing, and therefore more dependent on environmental conditions.

The values of the correlation coefficient between the live weight and genetic diversity indicators in the Even breed populations for all age and sex groups of deer were equal, respectively: for the average number of alleles per locus $r = 0.336$, the number of effective alleles – $r = 0.546$, theoretical heterozygosity – 0.538. In the age and sex groups of deer, the highest correlation coefficient between live weight and the genetic diversity indicators of the Even breed was found in the group of bull calves ($r = 0.534–0.812$) (see Table 2).

Табл. 2. Коэффициенты корреляции показателей генотипического разнообразия и живой массы в популяциях оленей чукотской и эвенской пород

Table 2. Correlation coefficients of genotypic diversity and live weight in deer populations of the Chukchi and Even breeds

An indicator of genetic diversity that correlates with live weight of deer	Chukchi breed				Even breed			
	Does	Calves	Bull calves	Bulls	Does	Calves	Bull calves	Bulls
Average number of alleles per locus (N_a)	0,301	0,298	0,597	0,193	0,325	0,275	0,534	0,211
Effective alleles per locus (N_e)	0,522	0,478	0,780	0,358	0,487	0,469	0,882	0,349
Homozygosity coefficient (C_a)	–0,556	–0,521	–0,809	–0,396	–0,498	–0,436	–0,831	–0,376
Expected heterozygosity (H_e)	0,556	0,521	0,809	0,396	0,508	0,502	0,812	0,332
Proportion of heterozygotes (PIG)	0,731	0,511	0,741	0,602	–	–	–	–

CONCLUSIONS

1. The most significant differences in live weight were between the most highly productive populations (“Vozrozhdenie” and “Amguema”) and the less productive (“Ostrovnoye”) for the Chukotka breed of deer, which amounted to 32.0% for females, 27.4% for calves, 17.6% for bull calves, and 16.5% for males, with an average of 23.2% for all age and sex groups.

2. The homozygosity coefficient in the more productive populations from the “Vozrozhdenie” and “Amguema” farms was 18.2% and 26.8% lower, respectively, than in the low-productivity population from the “Ostrovnoye” farm. In the Even breed populations, where productivity was virtually identical, the homozygosity indices were approximately the same.

3. The correlation coefficients between live weight and genetic diversity in the populations of the Chukotka and Even breeds for all age and sex groups of reindeer were equal: for the average number of alleles per locus $r = 0.347/0.336$, the number of effective alleles $r = 0.534/0.546$, and the expected heterozygosity $r = 0.570/0.538$, respectively. Our data are consistent with the data of other researchers [15].

4. The data obtained allow us to establish a relationship between live weight and genotypic diversity in the Chukchi and Even breed populations. It is necessary to monitor the genetic structure of Chukchi and Even breed reindeer populations in the Far Northeast of the Russian Federation.

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Дата поступления статьи / Received by the editors 24.02.2025
Дата принятия к публикации / Accepted for publication 28.03.2025
Дата публикации / Published 15.10.2025

Оптимизация белкового питания коров на раздое

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Задачей кормления жвачных животных является создание оптимальных условий для работы рубцовой микрофлоры, резервом повышения продуктивных качеств – применение защищенного (транзитного) белка, что минимизирует нагрузку на печень. С целью оптимизации белкового питания молочных коров организован опыт по применению белковых кормовых добавок. В период раздоя на коровах красной степной породы сформированы три группы (контрольная и две опытные) по 50 гол. в каждой. На фоне хозяйственного рациона (контроль) дополнительно применены в 1-й опытной – дрожжи кормовые в количестве 1 кг/гол. в сутки, во 2-й опытной – высокобелковый концентрат Кауфит 60 в количестве 850 г/гол. в сутки. Добавка Кауфит 60 представляет собой смесь растительных, животных и синтетических компонентов с содержанием сырого протеина 60%. В ходе проведенных исследований установлено: дополнительное применение дрожжей способствовало увеличению в рационе сырого протеина на 7%, переваримого – на 5%, соотношение рубцовой и кишечной фракций составило 65/35. Применение белковой добавки Кауфит 60 способствовало увеличению сырого протеина на 13%, переваримого – на 15%, увеличение количества транзитного белка в рационе составило 40%, соотношение РП/НРП составило 60/40. Отмечено увеличение валового надоя по опытным группам от 6 до 13%. Баланс энергии и протеина в кормах в группе с применением Кауфит 60 способствовал достоверному повышению жирности и уровня белка на 0,1 и 0,2% соответственно, уровень мочевины в молоке был в пределах физиологического норматива. Применение белковых кормовых добавок в опытных группах привело к увеличению кормовых затрат, при этом увеличение выручки от реализации молока составило от 6 до 13%, прибыли – от 2 до 8%.

Ключевые слова: коровы, раздой, белковая добавка, удой, качество молока, затраты корма

Optimization of protein nutrition while increasing the milking capacity of cows

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The task of feeding ruminants is to create optimal conditions for the work of rumen microflora, a reserve for increasing productive qualities is the use of protected (transit) protein, which minimizes the load on the liver. In order to optimize protein nutrition of dairy cows, an experiment was organized on the use of protein feed additives. During the period of increasing the milking capacity of cows, three groups (control and two experimental) of 50 heads each were formed from the cows of the Red Steppe breed. Against the background of the farm diet (control), in the 1st experimental group, feed yeast was additionally used in the amount of 1 kg/head/day, and in the 2nd experimental group, high-protein concentrate Kaufit 60 was used in the amount of 850 g/head/day. The supplement Kaufit 60 is a mixture of plant, animal and synthetic components with a crude protein content of 60%. The studies showed that additional use of yeast contributed to an increase in crude protein in the diet by 7%, digestible protein by 5%, and the ratio of rumen and intestinal fractions was 65/35. The use of the protein supplement Kaufit 60 contributed to an increase in crude protein by 13%, digestible protein by 15%, the increase in the amount of transit protein in the diet was 40%, the SP/NSP ratio was 60/40. An increase in gross milk yield in experimental groups from 6 to 13% was noted. The balance of energy and protein in the feed in the group using Kaufit 60 contributed

to a reliable increase in fat content and protein levels by 0.1 and 0.2%, respectively, the level of urea in milk was within the physiological norm. The use of protein feed additives in experimental groups led to an increase in feed costs, while the increase in revenue from milk sales amounted to 6 to 13%, and profit from 2 to 8%.

Keywords: cows, increasing the milking capacity of cows, protein supplement, milk yield, milk quality, feed costs

Для цитирования: Кузнецов Д.В. Оптимизация белкового питания коров на раздое // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 9. С. 75–81. <https://doi.org/10.26898/0370-8799-2025-9-8>

For citation: Kuznetsov D.V. Optimization of protein nutrition while increasing the milking capacity of cows. *Sibirskii vestnik sel'skokhozyaistvennoi nauki* = *Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 9, pp. 75–81. <https://doi.org/10.26898/0370-8799-2025-9-8>

Конфликт интересов

Автор заявляет об отсутствии конфликта интересов.

Conflict of interest

The author declares no conflict of interest.

INTRODUCTION

Protein metabolism in ruminants is unique, due to the physiological structure of their digestive tract. The amount of protein reaching the small intestine is not equal to the amount found in the feed. This is because the forestomach microflora (bacteria and protozoa), acting on the feed with their enzymes, breaks down the feed proteins, and in doing so, rapidly multiplies. Intensive reproduction produces a significant amount of high-quality bacterial protein, which is absorbed by the cow's body in the small intestine. The bacteria feed not only on feed protein but also on nitrogen compounds (non-protein nitrogen), which require sufficient energy to digest [1–3].

An important nutritional goal is to create optimal conditions for the functioning of rumen microflora, and a reserve for improving productivity is the use of protected (transit) protein [4–6], which minimizes the load on the liver. High-yielding cows often lack microbial protein; in this case, transit protein compensates for the animal's protein requirement.

The purpose of the research is to optimize protein nutrition and its impact on the performance of lactating dairy cows. To achieve this goal, the following objectives were set:

- assessment of nutritional value and provision of the diet with complete protein;
- record of milk productivity and milk quality composition;
- economic efficiency of the research conducted.

MATERIAL AND METHODS

The research was conducted in 2023 on the Red Steppe dairy cows at a livestock complex in the Altai Territory. We would like to express our sincere gratitude to A.I. Tokarev, Director of the OOO “Mustang-Siberia”, and A.M. Bulgakov, Scientific Consultant, Doctor of Science in Agriculture, for their assistance in conducting the research.

During the milking period, three groups of 50 cows were formed using the analog method. The control group received a basic diet (BD), consisting of succulent and bulky roughage. Deficiencies were balanced using a concentrated feed (a grain mixture). The feed included the energy supplement Laktoneo, the vitamin and mineral premix Kaufit Immunofertil, and the buffer mixture Rumenbuffer. In addition to the main diet, the first experimental group received feed yeast at a daily rate of 1,000 g/head. Cows in the second group received the protein feed supplement Kaufit 60 at a daily rate of 850 g/head. The high-protein supplement Kaufit 60 is a blend of plant (rapeseed, sunflower, and soybean meal, corn gluten, and distillers grains), animal (poultry blood and meat), and synthetic (lysine and methionine) components. The supplement contains 60% crude protein and increased amounts of essential amino acids (lysine – 1.8%, methionine – 0.3%).

The duration of the record period was 30 days (see Table 1). Cows were selected into groups based on the day of lactation and lactation num-

ber. The average day of lactation by group at the beginning of the record period was 60–62 days, the proportion of cows in lactations 1–3 was 80–82%, 4–6 lactations – 14–15%, 7 and older – 4–5%.

A comparative analysis of the diets was conducted based on the content of key nutrients and the qualitative composition of protein. To assess milk productivity, gross milk yield over the experimental period and average daily milk yield per head were taken into account. At the end of the experiment, milk was analyzed for protein, fat, and urea content in each group of 10 heads. An economic assessment was conducted taking into account gross milk yield for basic fat content, feed costs, and revenue from milk sales. Based on the data obtained, profit margins were determined by group. Data analysis was processed using the method of variation statistics*.

RESULTS AND DISCUSSION

A mixed feed was used to feed the cows during the milking period. The composition and nutritional value of the rations by group are presented in Table 2.

The control group diet contained 218 MJ of FE, 1 kg of dry matter contained 138 g of crude protein, including 97 g of digestible protein, 42 g of crude fat, 199 g of crude fiber, and 884 g of transit protein. The energy-protein ratio was 8.9, with 1.1 EFU per kg of dry matter. The ratio of rumen (RP) to intestinal protein was 68/32.

The dry matter content in the experimental groups' diets was 4–5% higher due to the addition of protein feed additives. The main differences were in the levels of protein and its fractions. For example, the diet in the first experimental group had 7% more crude protein per 1 kg of dry matter, 5% more digestible protein, and 20% more transit protein compared to the control. The rumen-to-intestinal protein ratio was 65/35. In the diet of the 2nd experimental group, crude protein was 13% higher, digestible protein was 15% higher, and transit protein was 40%. The RP/NRP ratio was 60/40. The ratio of the sum of sugars and starch to digestible protein in the experimental groups was within 2.0–2.1/1, the crude fat content was 40–43 g per 1 kg of DM, and crude fiber was at the level of 192–201 g/kg of DM.

The daily milk yield during the experimental period (see Table 3) in the control group was 26.8 kg, in the 1st and 2nd experimental groups this indicator was higher by 6 and 10%, respectively. The fat content of milk in the control and the 1st experimental groups was $3.90 \pm 0.04\%$, in the 2nd experimental group it was significantly higher – $4.0 \pm 0.02\%$, $p \leq 0.05$. The protein level in milk in the control group was $3.1 \pm 0.04\%$, in the 1st experimental group – $3.2 \pm 0.06\%$ (the result is not statistically significant), in the 2nd experimental group – $3.3 \pm 0.05\%$, $p \leq 0.05$. The urea level in the control group was $20 \pm 1.9 \text{ mg}\%$, in the 1st experimental group – $37 \pm 4.7 \text{ mg}\%$, $p \leq 0.01$, in the 2nd – $25 \pm 1.3 \text{ mg}\%$, $p \leq 0.05$ (standard value 20–25 mg%).

A significant excess of urea in the milk of cows in the first experimental group indicates an excess of urea in the body, which is confirmed by the results of other researchers [7–10]. Optimal energy concentration and an increase in transit protein in the diet of the second experimental group create favorable conditions for the functioning of rumen microflora, promote the intensive production of volatile fatty acids, in particular acetic acid [11–15], thereby increasing the fat content of milk.

Табл. 1. Схема опыта

Table 1. Experimental scheme

Group	Record period, days	Number of cows, heads	Feeding conditions
Control	30	50	BD
1st experimental	30	50	BD + feeding yeast 1000 g/head
2nd experimental	30	50	BD + Kaufit 60 850 g/head

*Korosteleva N.I., Kondrashkova I.S., Rudishina N.M., Kamardina I.A. Biometrics in animal husbandry. Textbook, Barnaul, 2009, 210 p.

Табл. 2. Состав и питательная ценность рационов кормления по группам

Table 2. Composition and nutritional value of feeding rations by groups

Indicator	Group		
	Control	1st experimental	2nd experimental
<i>Diet composition</i>			
Corn silage, kg	26	26	26
Alfalfa haylage, kg	13	13	13
Hay, kg	2	2	2
Mixture of grains, kg	8	8	8
Feeding yeast, kg		1,00	
Kaufit 60, кг			0,85
Lactoneo, kg	0,25	0,25	0,25
Rumenbuffer, kg	0,1	0,1	0,1
Premix Kaufit Immunofertil, kg	0,1	0,1	0,1
<i>Nutritional value of feeding rations</i>			
ME, MJ	218	221	226
EFU	21,8	22,1	22,6
Dry matter (DM), kg	19,8	20,68	21,72
Crude protein, g	2734	3062	3245
Digestible protein, g	1930	2122	2321
RP, g	1850	2000	1960
NRP, g	884	1062	1285
Crude fat, g	827	830	890
Crude fiber, g	3950	3971	4170
Sugar, g	648	651	725
Starch, g	3730	3732	3894
Ratios:			
EFU / in 1 kg DM	1,1	1,1	1,1
EPR	8,9	9,6	10,3
Crude protein, g in 1 kg DM	138	148	157
Digestible protein, g in 1 kg DM	97	103	112
RP / NRP	68/32	65/35	60/40
Sugars + starch, g / digestible protein, g	2,3/1	2,1/1	2,0/1
Crude fat, g / in 1 kg DM	42	40	43
Crude fiber, g / in 1 kg DM	199	192	201

The level of milk productivity, the amount of milk fat and protein content by groups are presented in Table 4.

The gross milk yield during the experimental period in the control group was 804 kg/head, in the 1st experimental group it was 45 kg higher, in the 2nd – 81 kg. The amount of milk fat in the control was 31.4 kg, in the 1st and 2nd experimental groups as a result of increased milk yield and increased milk fat content it was recorded to be higher by 6 and 13%, respectively, and milk protein – by 9 and 17%.

The economic evaluation of the studies conducted is reflected in Table 5.

Gross milk yield in the control group, when converted to basic fat content, was 922 kg, while in the 1st and 2nd experimental groups it was 6 and 13% higher. Feed costs per 1 kg of milk in the control group were 7.84 rubles, while in the experimental groups they were higher by 0.76 and 0.95 rubles. The revenue from milk sales in the 1st and 2nd experimental groups increased by 6 and 13%, respectively, and the profit (the difference between feed costs and revenue from milk sales) by 2 and 8%, respectively.

Табл. 3. Величина удоя и качественный состав молока**Table 3.** Milk yield and quality composition of milk

Indicator	Group		
	Control	1st experimental	2nd experimental
Average daily milk yield per head, kg	26,8	28,3	29,5
Fat, %	3,90 ± 0,04	3,90 ± 0,09	4,00 ± 0,02*
Protein, %	3,10 ± 0,04	3,20 ± 0,06	3,3 ± 0,05*
Urea, mg%	20 ± 1,9	37 ± 4,7**	25 ± 1,3*

* $p \leq 0,05$.** $p \leq 0,01$.**Табл. 4.** Уровень молочной продуктивности**Table 4.** Milk productivity level

Indicator	Group		
	Control	1st experimental	2nd experimental
Milk yield during the experimental period, kg/head	804	849	885
Amount of milk fat, kg	31,4	33,1	35,4
Milk protein content, kg	24,9	27,6	29,2

Табл. 5. Экономические показатели проведенных исследований, затраты корма на единицу продукции**Table 5.** Economic indicators of the conducted research, feed costs per unit of production

Indicator	Group		
	Control	1st experimental	2nd experimental
Gross milk yield of basic fat content is 3.4% per 1 head/kg	922	974	1041
Feed costs per head, roubles	7 230	8 370	9 150
Feed costs per 1 kg of milk of basic fat content, roubles	7,84	8,59	8,79
Revenue from milk sales per head, roubles	29 512	31 163	33 318
Profit per head, roubles	22 282	22 793	24 168

CONCLUSIONS

1. The additional use of protein feed additives (feed yeast and the high-protein feed additive Kaufit 60) during the milking period contributed to an increase in the crude protein content of the diet by 7 and 13%, respectively, and digestible protein by 5 and 15%. The increase in the intestinal protein fraction ranged from 20 to 45%. The ratio of rumen and transit protein (RP/NRP) fractions in the experimental groups changed towards an increase in the proportion of transit protein (35–40%, compared to 32% in the control group).

2. Gross milk yield increased by 6% and 13% in the first and second experimental groups, respectively. In the second experimental group, a significant increase in milk fat content of 0.1% and milk protein content of 0.2% was observed.

3. The additional use of protein feed additives resulted in an increase in feed costs per kg of milk from 0.76 to 0.95 rubles. Meanwhile, the milk sales revenue in the experimental groups increased by 6% and 13%, respectively, while the profit (the difference between feed costs and milk sales revenue) was higher by 2% and 8%.

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Дата поступления статьи / Received by the editors 23.04.2025
 Дата принятия к публикации / Accepted for publication 06.06.2025
 Дата публикации / Published 15.10.2025

Паразитофауна монгольской степной антилопы (дзерен) на территории Забайкальского края

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В статье изложены результаты паразитологических исследований монгольской степной антилопы, или дзерена (*Procapra gutturosa*), на территории Забайкальского края с целью определения качественного и количественного состава паразитов как одного из сдерживающих факторов увеличения популяции этих животных. Крупномасштабных исследований паразитозов и паразитоценозов у дзеренов, обитающих в Забайкальском крае, до настоящего времени не проводилось. В ходе исследования установлена зараженность дзерена 20 видами паразитов – гельминты, паразитические простейшие, насекомые. Анализ паразитофауны популяции монгольской степной антилопы на территории Забайкальского края показал, что у животных наиболее широко представлены гельминты желудочно-кишечного тракта – нематоды семейства Trichostrongylidae и цестоды семейства Anoplocephalidae. Установлено участие дзерена в роли промежуточного хозяина в жизненном цикле ленточных гельминтов *Echinococcus granulosus* и *Taenia hydatigena*, а также простейших рода *Sarcocystis*, имеющих не только ветеринарное, но и эпидемиологическое значение и представляющих угрозу для здоровья человека. Зарегистрировано паразитирование в желчных протоках печени одного дзерена трематоды *Dicrocoelium lanceatum* в количестве 7 экз. Необычность данного факта заключается в том, что Забайкальский край считается благополучным по дикроцелиозу, и случаев заболевания этой инвазией среди сельскохозяйственных животных здесь не зафиксировано. У одной особи (ЭИ = 3,8%) в носовой полости найдены личинки носоглоточного овода *Oestrus ovis*, который также поражает овец. На пищеводе и гортани у двух дзеренов обнаружены цисты саркоцист (8 экз./гол.), видовую принадлежность которых установить не удалось. У 18 животных (ЭИ = 21,4%) отмечены ооцисты эймерий. Установлено одновременное заражение животных несколькими видами паразитов, в том числе разных таксономических групп (гельминты, простейшие, насекомые), что указывает на существование паразитоценозов в популяции дзерена.

Ключевые слова: монгольская степная антилопа, паразиты, паразитоценозы, Забайкальский край

Parasite fauna of the Mongolian steppe antelope (dzeren) in the Transbaikal Territory

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The article presents the results of parasitological studies of the Mongolian steppe antelope, or dzeren (*Procapra gutturosa*), in the Trans-Baikal Territory with the aim of determining the qualitative and quantitative composition of parasites as one of the factors limiting the increase in the population of these animals. Large-scale studies of parasitoses and parasitocenoses in dzerens living in the Trans-Baikal Territory have not been conducted to date. During the study, the dzeren was found to be infected with 20 types of parasites in the specified area – helminths, parasitic protozoa, insects. Analysis of the parasite fauna of the Mongolian steppe antelope population in the Trans-Baikal Territory showed that the animals are most widely represented by gastrointestinal tract helminths – nematodes of the Trichostrongylidae family and cestodes of the Anoplocephalidae family. The participation of

the dzeren as an intermediate host in the life cycle of tapeworms *Echinococcus granulosus* and *Taenia hydatigena*, as well as protozoa of the genus *Sarcocystis*, which have not only veterinary but also epidemiological significance and pose a threat to human health, has been established. Parasitism of the trematode *Dicrocoelium lanceatum* in the bile ducts of the liver of one dzeren in the amount of 7 specimens was recorded. The unusual thing about this fact is that the Transbaikal Territory is considered to be free of dicrocoeliosis, and no cases of this invasion among farm animals have been recorded here. In one dzeren (EI = 3.8%), larvae of the nasopharyngeal gadfly *Oestrus ovis*, which also attacks sheep, were found in the nasal cavity. Sarcocyst cysts (8 specimens/head) were found on the esophagus and larynx of two dzerens, the species of which could not be determined. Eimeria oocysts were detected in 18 animals (EI = 21.4%). Simultaneous infection of the dzeren with several types of parasites, including different taxonomic groups (helminths, protozoa, insects) has been established, which indicates the existence of parasitocenoses in the dzeren population.

Keywords: Mongolian steppe antelope, parasites, parasitocenoses, Trans-Baikal Territory

Для цитирования: Третьяков А.М., Боярова Л.И., Дашиинимаев Б.Ц. Паразитофауна монгольской степной антилопы (дзерен) на территории Забайкальского края // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 9. С. 82–89. <https://doi.org/10.26898/0370-8799-2025-9-9>

For citation: Tretyakov A.M., Boyarova L.I., Dashinimaev B.Ts. Parasite fauna of the Mongolian steppe antelope (dzeren) in the Transbaikal Territory. *Sibirskii vestnik sel'skokhozyaistvennoi nauki* = *Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 9, pp. 82–89. <https://doi.org/10.26898/0370-8799-2025-9-9>

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

The Mongolian steppe antelope, or dzeren (*Procapra gutturosa*), is an even-toed ungulate of the family Bovidae. This species was first described to European science in 1777 by P.S. Pallas, based on a specimen collected near the village of Mangut (now part of the Kyrinsky District of the Trans-Baikal Territory), where dzerens were then permanent residents. In the Chita region, they were exterminated in the 1970s, resulting in the species being listed in the Red Data Book of the Russian Federation. In 1992, a small group of antelopes appeared in the Daursky State Nature Biosphere Reserve (near Lake Barun-Torey, Ononsky District, Trans-Baikal Territory).

The first modern mass migration of Mongolian gazelles from Mongolia to the Trans-Baikal Territory occurred in the winter of 2000/01. This was caused by deep snow cover and unusually low temperatures (down to -47°C) in the ani-

mals' habitat in Mongolia. To ensure more reliable protection and conservation of the dzeren, the "Dzeren Valley" state nature reserve was established as a subdivision of the Daursky Nature Reserve in 2011 by a Russian Government decree. In the winter of 2023/2024, the dzeren population in the Trans-Baikal Territory exceeded 450,000 individuals. Within the Daursky Nature Reserve, it was approximately 30,000¹ [1].

Thus, a large concentration of animals is observed in a limited area, which can lead to an increased incidence and spread of various diseases, including parasitic ones. As animal numbers increase, so does their parasite infestation [2–5]. According to several authors, many species of parasitic pathogens are highly virulent and often cause severe illnesses, sometimes fatal. For example, in the Belovezhskaya Pushcha (Belarus), bison die-offs were reported due to monieziaosis and dictyocaulosis. The mortality rate of bison in the Oksky State Nature Biosphere Reserve

¹Kirilyuk V.E. and Lushchekina A.A. Current status of gazelle (*Procapra gutturosa*: Bovidae) in Russia // Nature Conservation Research Reserved science, 2017, vol. 2, Appendix 1, pp. 81–99.

nursery (Ryazan Oblast) from parasitic infestations ranged from 2.0 to 10.2% of the total population from 1960 to 2013, averaging 5.9% per year. The mortality rate of calves under one year old reached 53.9%, including helminthiasis – 8,2%² [6, 7].

In natural biocenoses, wild ruminants can act as reservoirs for helminths, facilitating their spread among domestic ungulates. In anthropogenic agrobiocenoses bordering natural forest and steppe zones, reverse circulation of parasites is observed³ [2, 8–12]. For example, in the Kaliningrad region, the circulation of helminths of domestic and wild ruminants in mixed diffuse natural foci has been recorded⁴.

Mongolian steppe antelopes, the main population of which is located in the Daurisky Nature Reserve, are characterized by two genera of helminths belonging to the class of nematodes – *Nematodirus* spp. and *Trichostrongylus* spp., which can be transmitted to farm and wild ruminants [11].

Given the similar susceptibility of domestic and wild ruminants to various parasite species and significant differences in their immunity at the population level, a detailed study of the characteristics of parasitic systems and the likelihood of their phase changes due to environmental and anthropogenic factors is necessary. Unexplained cases of mass mortality of wild fauna, and sometimes even domestic animals, up to date, may be due to variability in parasitic systems (increased helminth virulence, decreased population immunity) (see footnote 3) [4, 11].

Detailed studies of parasitoses and parasitocenoses in dzerens living in the Trans-Baikal Territory have not been conducted to date, which was the reason for carrying out work on this topic.

The purpose of the study is to examine the parasite fauna of the Mongolian steppe antelope in the Trans-Baikal Territory.

The research objectives are:

- 1) to study the species composition of zoo-parasites of the Mongolian steppe antelope living in the Trans-Baikal Territory;
- 2) to determine the extent of infestation of the dzeren population by different taxonomic groups of parasites;
- 3) formulate the basic principles of prevention of parasitic diseases.

MATERIAL AND METHODS

The study was conducted from 2020 to 2025 in the Trans-Baikal Territory. The research sample consisted of the carcasses of Mongolian gazelles that died from hypothermia, malnutrition, or were killed by predators and were found in the Borzinsky, Ononsky, Akshinsky, and Dul'durginsky municipal districts ($n = 26$). Laboratory studies were conducted at the Research Institute of Veterinary Science of Eastern Siberia.

Animal carcasses were subjected to a complete necropsy for helminthological examination⁵. Pathological material was examined using conventional ovo- and larvoscopy, as well as compression methods. Fecal samples were analyzed using the Darling method and sequential fecal washing. Infection prevalence was assessed using the following parameters such as prevalence of infestation (PE, %) and infection intensity (II). Microscopy and photography of the slides were performed using a Zeiss Axio Imager M2 microscope (Carl Zeiss Microscopy GmbH, Germany).

RESULTS AND DISCUSSION

As shown in the table, 20 species of parasites were found in the Mongolian steppe antelope

²Tsibizova E.L., Aksenova P.V., Ermakov A.M. Dynamics and mortality reasons Bison Bonasus in the Oka State Biosphere Reserve Bison Nursery // Veterinary Medicine, 2015, N 6, pp. 13–17.

³Lunitsyn V.G., Mikhailov V.I., Tishkov M.Yu., Shmakova O.N., Anchin A.V. Helminth fauna of wild and domestic artiodactyls of the Saylyugemsky National Park // Bulletin of Altai State Agricultural University, 2017, N 4, pp. 131–134.

⁴Efremov A.Yu. Ecological and biocenological aspects of helminths of ruminants in the Kaliningrad region // International Bulletin of Veterinary Medicine, 2016, N 2, pp. 25–30.

⁵Skryabin K.I. Method of complete helminthological dissections of vertebrates, including humans. Moscow, 1928, 46 p.

living in the Trans-Baikal Territory, including 17 species of helminths, 2 species of protozoa and 1 species of parasitic insects.

The highest prevalence of invasion (from 73.0 to 53.8%) was recorded for nematodirois caused by *N. spathiger*, *N. helvetianus*, *N. oiratianus*, *N. abnormalis*, *N. longissimespiculata*. Nematodirus were found throughout the entire length of the small intestine, with infestation rates ranging from 1 to 141 specimens per head. In addition to nematodirus, representatives of the suborder Rhabditata were also found in the small intestine – *S. papillosus* (see Fig. 1). All ruminant farm animals are susceptible to nematodirois and strongyloidiasis. In this case, the Mongolian gazelle's infection likely originated

from these parasites, as the Mongolian steppe antelope's habitat overlaps with the grazing areas of farm animals (cattle, sheep, and goats).

In the large intestine, the whipworm *T. ovis* (PE = 7.7%) and two species of cestodes – *M. benedeni* (PE = 7.7%) and *S. globipunctata* (PE = 3.8%) – were noted (see Fig. 2, 3). Potential exchange of these helminths between dzerens and wild ungulates (elk, roe deer, red deer) is possible.

S. labiato-papillosa was detected in the abdominal and thoracic cavities of 16 dzerens (PE = 61.5%, II = 5–23 specimens/head). This species of helminth also infects cattle. *E. granulosus* larvae were detected in the lung and liver parenchyma of 26.9% of the examined antelopes,

Паразитофауна монгольской степной антилопы (n = 26)
Parasite fauna of the Mongolian steppe antelope (n = 26)

Variety	Infected animals, heads	PE, %	II, specimens/head
<i>Moniezia benedeni</i> Moniez, 1879	2	7,7	1–5
<i>Stilezia globipunctata</i> Rivolta, 1874	1	3,8	2
<i>Cysticercus tenuicollis</i> Rudolphi, 1810	12	46,2	2–10
<i>Echinococcus granulosus larva</i> Batsch, 1786	7	26,9	1–3
<i>Setaria labiato-papillosa</i> Alessandrini, 1839	16	61,5	5–23
<i>Strogylodes papillosus</i> Wedl, 1856	5	19,2	7–19
<i>Teladorsagia circumcincta</i> Stadelman, 1894; Andreeva & Satubaldin, 1954	7	26,9	7–32
<i>Marchallagia marchalli</i> Ransom, 1907	10	38,5	11–20
<i>Nematodirus spathiger</i> Railliet, 1896	19	73,1	1–137
<i>Nematodirus helvetianus</i> May, 1920	14	53,8	2–86
<i>Nematodirus abnormalis</i> May, 1920	15	57,7	3–31
<i>Nematodirus oiratianus</i> Rajevskaja, 1929	17	65,4	1–117
<i>Nematodirella longissimespiculata</i> Romanovitsch, 1915	16	61,5	11–141
<i>Trichostrongylus axei</i> Cobbord, 1879	3	11,5	10–46
<i>Trichostrongylus colubriformis</i> Giles, 1892	4	15,4	7–19
<i>Trichocephalus ovis</i> Abildgaard, 1755	2	7,7	3–82
<i>Dicrocoelium lanceatum</i> Stiles et Hassall, 1896	1	3,9	7
<i>Sarcocystis</i> spp.	2	7,6	8 cysts
<i>Oestrus ovis</i> Linnaeus, 1758	1	3,8	16
<i>Eimeria</i> spp.	18	21,4	< 50 oocysts in the microscope's field of view



Рис. 1. Яйца *S. papillosus*. Увел. 400

Fig. 1. *S. papillosus* eggs. Magn. 400

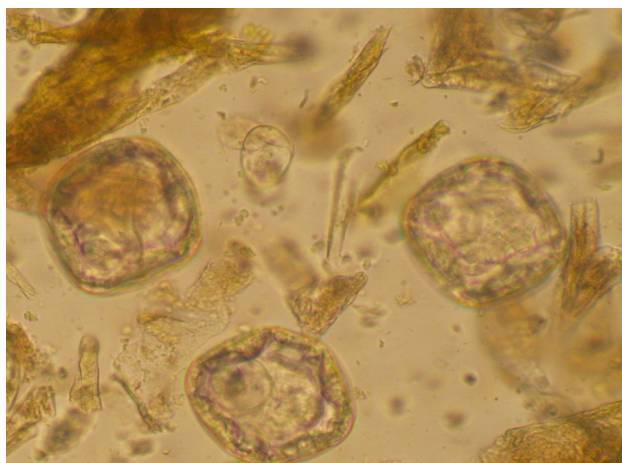


Рис. 2. Яйца *M. benedeni*. Увел. 400

Fig. 2. *M. benedeni* eggs. Magn. 400



Рис. 3. Сколекс *S. globipunctata*. Увел. 400

Fig. 3. Scolex of *S. globipunctata*. Magn. 400

indicating that dzerens participate in the biological life cycle of echinococci. Thin-walled, clear fluid-filled blisters the size of a chicken egg were found on the serous membranes of the abdominal organs and the mesentery of 12 individuals (PE = 46.2%). These blisters were subsequently identified as *C. tenuicollis*. The number of blisters in one animal ranged from two to ten. Sources of dzeren infection with larval echinococcosis and cysticercosis are carnivores (foxes, wolves, dogs), whose intestines harbor the adult stage of these helminths.

Visual examination of the abomasum mucus membrane revealed small white-yellow nematodes identified as *T. circumcincta* (PE = 26,9%), *M. marchalli* (PE = 38,5%), *T. colubriformis* (PE = 15,4%), *T. axei* (PE = 11,5%).

The study revealed an interesting finding: seven *D. lanceatum* trematodes were found parasitizing the liver bile ducts of a single dzeren. This is unusual because the Transbaikal Territory is free of dicrocoeliosis, and no cases of this infection have been recorded among farm animals. The animal most likely became infected in Mongolia, where this infection is widespread.

One individual (PE = 3.8%) was found to have larvae of the nasopharyngeal botfly *O. ovis* in its nasal cavity, which also infects sheep.

Eight cysts of the genus *Sarcocystis* were found on the esophagus and larynx of two dzerens, the species of which could not be determined.

Eimeria oocysts (more than 50 oocysts per microscopic field) were found in the feces of 18 animals (PE = 21.4%). The oocysts are elliptical, colorless, and have a polar cap measuring $25 \times 17 \mu\text{m}$ at the pole.

The study established that parasitoses are widespread in the Mongolian steppe antelope population in the Trans-Baikal Territory, which is consistent with the data of I.I. Tsepilova et al. [11]. 17 species of parasitic helminths, 2 species of protozoa, and 1 species of insects were found in the Mongolian gazelle. Domestic ruminants can also be infected with most of these species

when grazing in the same area (see Fig. 4). In addition, the results obtained coincide with the conclusions of O.D. Kirillova [1] that most parasitic diseases of wild animals can affect many species of farm animals.

The highest prevalence of infestation in Mongolian steppe antelope was recorded for nematodiosis. Of the 26 animals examined, nematodiosis was detected in 19 individuals. Most of the animals examined had mixed infestations. Simultaneous parasitism in the gastrointestinal tract by nematodes, cestodes, and parasitic protozoa (associative disease or parasitocenosis) was observed, as well as the simultaneous parasitism of several taxonomic groups of parasites, which aggravates the pathological process and can cause mass mortality.



Рис. 4. Обитание дзерена на территории выпаса крупного рогатого скота

Fig. 4. Habitat of the dzeren in the territory of cattle grazing

CONCLUSION

Analysis of the parasite fauna of the Mongolian steppe antelope population in the Trans-Baikal Territory showed that these animals have the most widely represented fauna of helminths of the gastrointestinal tract (nematodes of the Trichostrongylidae family and cestodes of the Anoplocephalidae family). Research results have demonstrated the role of the Mongolian gazelle as an intermediate host in the life cycle of the tapeworms *Echinococcus granulosus* and *Taenia hydatigena*, as well as protozoans of the genus *Sarcocystis*, which are of not only veterinary but also epidemiological significance and pose a threat to human health. There is a potential for helminth exchange between Mongolian gazelles and wild ungulates (elk, roe deer, red deer), as well as cattle, sheep, and goats.

Simultaneous infection of the Mongolian gazelle with several types of parasites, including those from different taxonomic groups (helminths, protozoa, insects), has been established, which indicates the existence of parasitocenoses in the population.

Thus, given the high level of parasite infestation of the Mongolian steppe antelope, there is a need to develop and implement preventive veterinary measures, including general economic, biotechnical and special measures, taking into account all components of the parasitocenoses that have formed in the population of these animals.

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Дата поступления статьи / Received by the editors 10.04.2025
Дата принятия к публикации / Accepted for publication 12.05.2025
Дата публикации / Published 15.09.2025



<https://doi.org/10.26898/0370-8799-2025-9-10>

УДК 631.354.2-047.44(571.13)

Тип статьи: оригинальная

Type of article: original

Анализ оснащённости сельскохозяйственных организаций Омской области зерноуборочными комбайнами

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Для оценки качественного и количественного состава парка зерноуборочных комбайнов в Омской области проведены исследования, позволяющие установить количество зерноуборочных комбайнов (ЗУК), их марочный состав, энергетические характеристики. Анализ этих данных позволил установить обеспеченность сельскохозяйственных товаропроизводителей комбайнами, возрастной состав парка машин, энергообеспеченность посевных площадей, факторы, влияющие на темпы обновления парка машин. Установлено, что снизилось количество основных сельскохозяйственных машин, кроме зерноуборочных комбайнов (+1,0%). В парке доминируют зерноуборочные комбайны заводов «Ростсельмаш» (42,9%) и «Енисей» (26,8%). Более 60% зерноуборочных комбайнов имеют год выпуска старше 10 лет. Нагрузка посевных площадей на один комбайн в Омской области на 64% больше, чем в среднем по России, энергообеспеченность является самой низкой в Сибирском федеральном округе. Снижение уровня механизации сельскохозяйственного производства ведет к потере не менее 10–20% урожая сельскохозяйственных культур. Повышенная нагрузка на комбайны в отдельных хозяйствах превосходит норматив в 5–7 раз. Для повышения темпов обновления парка машин требуется реализация системных мер, в том числе: развитие рынка аутсорсинга услуг по выполнению технологических операций, развитие рынка аренды сельскохозяйственной техники, совершенствование программ государственной поддержки сельских товаропроизводителей. Для обновления парка комбайнов в Омской области и доведения уровня нагрузки до общероссийских показателей требуется пополнение парка не менее, чем на 1,5 тыс. машин. Стоимость программы модернизации составит порядка 30 млрд р.

Ключевые слова: зерноуборочный комбайн, марочный состав, парк машин, энергообеспеченность, рынок сельскохозяйственных машин

Analysis of the availability of grain harvesters in the agricultural organizations of the Omsk region

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To assess the qualitative and quantitative composition of the fleet of grain harvesters in the Omsk region, studies were conducted to determine the number of grain harvesters, their grade composition and energy characteristics. Analysis of these data allowed determining the provision of agricultural producers with combines, the age composition of the machine fleet, energy supply of the sown areas, and the factors affecting the rate of renewal of the machine fleet. It was established that the number of main agricultural machines, except for grain harvesters, decreased (+1.0%). The fleet is dominated by grain harvesters from the “Rostselmash” (42.9%) and “Yenisei” plants (26.8%). More than 60% of grain harvesters are older than 10 years. The crop area load per combine harvester in the Omsk re-

gion is 64% higher than the Russian average, and energy supply is the lowest in the Siberian Federal District. A decrease in the level of mechanization of agricultural production leads to a loss of at least 10–20% of agricultural crop yields. The increased load on combines in some farms exceeds the standard by 5–7 times. To increase the rate of renewal of the machinery fleet, it is necessary to implement systemic measures, including: developing a market for outsourcing services for the performance of technological operations, developing a market for the rental of agricultural machinery, and improving state support programs for rural producers. To upgrade the combine harvester fleet in the Omsk region and bring its utilization rate up to national standards, at least 1,500 additional machines are needed. The modernization program will cost approximately 30 billion rubles.

Keywords: grain harvester, grade composition, equipment fleet, energy supply, agricultural machinery market

Для цитирования: Помогаев В.М., Ревякин П.И. Анализ оснащенности сельскохозяйственных организаций Омской области зерноуборочными комбайнами // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 9. С. 90–98. <https://doi.org/10.26898/0370-8799-2025-9-10>

For citation: Pomogaev V.M., Revyakin P.I. Analysis of the availability of grain harvesters in the agricultural organizations of the Omsk region. *Sibirskii vestnik sel'skokhozyaistvennoi nauki* = *Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 9, pp. 90–98. <https://doi.org/10.26898/0370-8799-2025-9-10>

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Agriculture is a strategic sector of the economy, ensuring Russia's food security. Crop production in general, and grain cultivation in particular, form the raw material base for many sub-sectors and provide the basic food products for humanity. Availability of agricultural machinery plays a key role in the development of the grain products sub-complex of the agro-industrial complex [1]. The most complex and expensive type of agricultural machinery is the combine harvester. Traditionally, in Russia, the load per combine harvester exceeds established international standards by at least four times [2].

The Omsk region is considered a high-risk agricultural zone, and the problem of agricultural machinery availability is exacerbated by fluctuations in the timing of agricultural work due to adverse weather conditions [3]. An analysis of the availability of tractors and combines at agricultural organizations allows for the timely identification of negative trends and the development of measures aimed at accelerating the pace of replenishment of the machinery fleet and the introduction of new maintenance and repair technologies.

The purpose of the study is to analyze and evaluate the availability of grain harvesters to agricultural producers in the Omsk region and to identify the factors influencing changes in the rate of replenishment of the machine fleet.

MATERIAL AND METHODS

This article was prepared using data from the Federal State Statistics Service and the Omsk regional office of Rosstat, scientific research materials, and data from agricultural machinery manufacturers and dealers. The data was analyzed using statistical methods, patterns and trends were identified analytically, and the research results were visualized graphically.

RESULTS AND DISCUSSION

In the 2020s, the agricultural machinery market in Russia showed positive dynamics, growing at an average annual rate of at least 7% [4]. In 2023, sales of grain harvesters increased by 8.9% compared to 2022, reaching almost 6,000 units. The AO “Rostselmash” holds a dominant position in the market. “John Deere Rus”, “CLAAS”, “Bryanskseilmash”, and “Gomselmash” are also considered key manufacturers. However, the share of grain harvesters older than 10 years is 45.95% [5].

Data from the Federal State Statistics Service indicate that the Omsk Region is seeing a decline in the number of agricultural machinery¹ (see Fig. 1).

At the same time, the number of grain harvesters has increased by 1.0% over the past five years.

The brand composition of grain harvesters in farms of the Omsk region is as follows (see Fig. 2).

“Rostselmash” combine harvesters account for the largest share of the grain harvesting fleet, accounting for 2,071 units (42.9%). “Yenisei” combines (“Krasnoyarsk Combine Plant”) rate the second accounting for 1,294 units (26.8%). “GS Polesie” combines (“Gomselmash” holding) account for a significant share of the fleet's brand structure, accounting for 564 units (11.7%). Foreign brands such as “John Deere Rus”, “CLAAS”, “New Holland”, “Case”, and others are present in significantly smaller numbers, and their combined share does not exceed 10%.

Analysis of the years of production of grain harvesters shows that the fleet of these machines is quite old (see Fig. 3).

Analyzing the presented data, we can conclude that more than 60% of grain harvesters are older than 10 years. This figure is almost 14% higher than the Russian average. The largest number of machines (1,607 units, or 32%) were manufactured between 2010 and 2019. More than 1,400 combine harvesters (28.2%) were manufactured between 2000 and 2009, while 743 units (14.9%) were manufactured between 1990 and 1999. This fleet of machines is significantly outdated and requires substantial maintenance and repair (M&R) expenses.

Over the past five years, the peak of grain harvester fleet renewal occurred in 2021 (see Fig. 4).

The growth dynamics of the end of the last decade ended in 2021, after which there was a sharp decline in fleet renewal, and in 2023 it amounted to only 69 units.

The largest number of combines are equipped with the engines ranging from 200 to 299 hp (2,087 units, or 41.8%) and the engines ranging from 100 to 199 hp (1,897 units, or 38.0%). In the former case, these are typically combines no older than 5–10 years with a throughput of 7 to

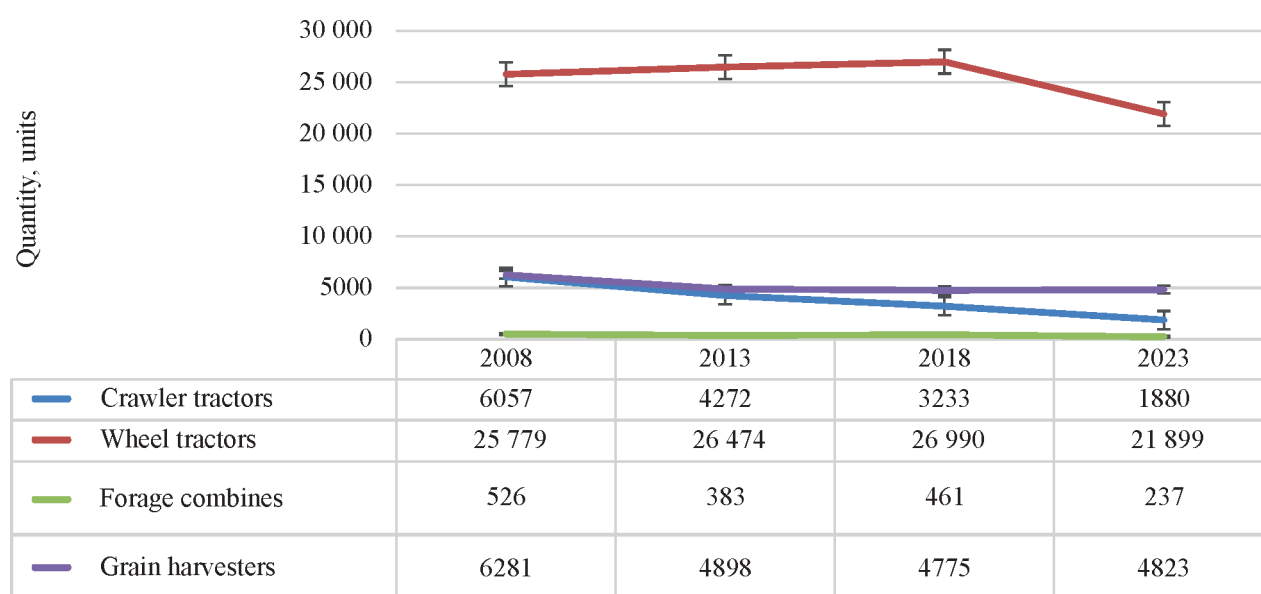


Рис. 1. Динамика численности парка сельскохозяйственных машин

Fig. 1. Dynamics of the agricultural machinery fleet number

¹URL: https://rosstat.gov.ru/enterprise_economy

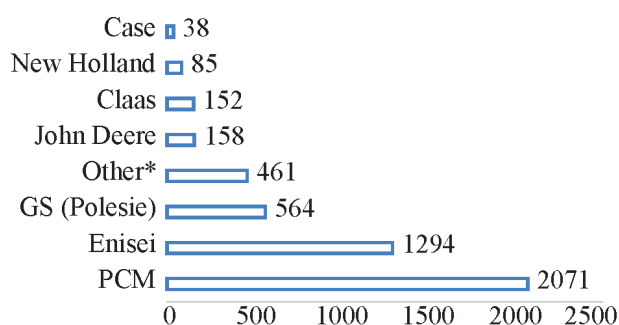


Рис. 2. Марочный состав парка зерноуборочных комбайнов Омской области по состоянию на 2023 г., ед. (*группа включает марки комбайнов, общее количество которых не превышает 30 ед.)

Fig. 2. Brand composition of the fleet of grain harvesting combines in the Omsk region as of 2023, units (*the group includes brands of combines, the total number of which does not exceed 30 units)

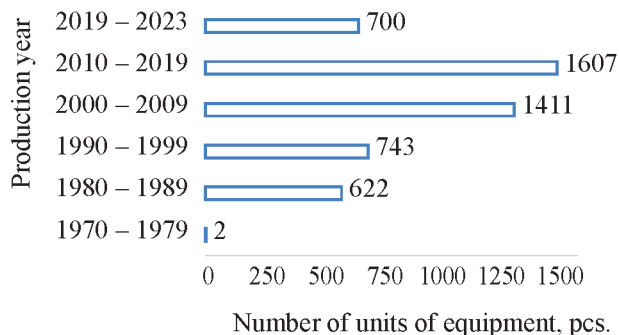


Рис. 3. Численный состав парка комбайнов Омской области в разрезе по интервалам годов выпуска по состоянию на 2023 г.

Fig. 3. The number of combine harvesters in the Omsk region broken down by production year intervals as of 2023

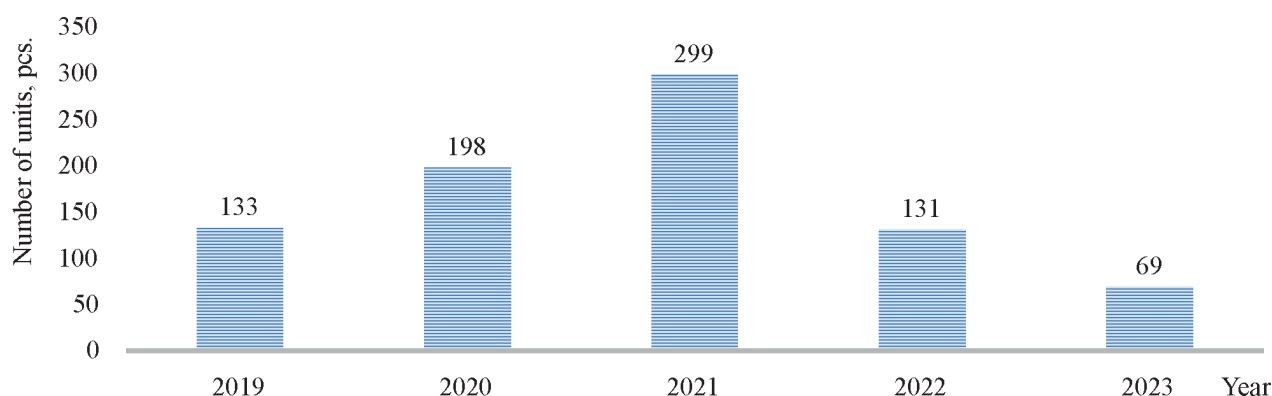


Рис. 4. Обновление парка зерноуборочных комбайнов, ед.

Fig. 4. Updating the fleet of grain harvesters, units

12 kg/s (classes 7–11), which fully corresponds to the productivity of agricultural crops in the Omsk region [6]. In the second case, these are typically the combines over 10 years old with a throughput of 5–7 kg/s (classes 5–7) for harvesting grain crops with a potential yield of 20–25 c/ha. Fifteen percent of combines have a power rating of 300 to 399 hp. This group primarily includes early-model foreign-brand combines, RSM combines (“Akros” and “Don”), and combines from the “Bryanskselmash” plant.

The fleet of combine harvesters in the Omsk region is equipped mainly with SMD engines (1,458 units, or 36%) and YaMZ engines (1,934 units, or 48%).

Combines manufactured before 2010 are equipped with SMD engines, further highlighting the age distribution of the fleet. Foreign-made engines, such as “Cummins” (80 units), “RG60***” (61 units), “QSL8.9-C360” (36 units), “OM473” (4 units), and “OM460” (9 units), are present in small quantities.

An important indicator is the level of availability of grain harvesting combines at agricultural enterprises (see Fig. 5). The harvesting load per combine varies by year both across Russia as a whole and in the Omsk Region, but the trend line indicates that the number of crops per combine will increase over the years. At the same time, the energy supply of agricultural or-

ganizations in the Omsk Region tends to remain in the range of 133–135 hp per 100 hectares of crops. This indicates that, despite the increase in harvesting load per combine, there has been no qualitative change in the fleet (the appearance of more productive machines).

The data also shows that the crop area utilization per combine harvester in the Omsk Region is 64% higher than the Russian average. Furthermore, the energy supply to agricultural organizations in the Omsk Region is the lowest in the Siberian Federal District².

Thus, on average in Russia in 2023 this indicator was 203 hp per 100 hectares of sown area, on average in the Siberian Federal District – 172 hp per 100 hectares of sown area, in the Omsk Region – 135 hp per 100 hectares of sown area.

The presence and condition of headers significantly impacts combine harvester performance. Research has shown that in the Omsk Region, there are over 11,000 mounted headers for grain, legume, and grass crops, and approximately 300 trailed headers. The percentage of headers that have reached their depreciation period is 49% and 30%, respectively.

It is clear that the problem of ensuring the reliability of grain harvesters remains extremely acute for the Omsk Region [7]. A decrease in the level of mechanization of agricultural production leads to a loss of 30% of agricultural crop yields [8]. Particularly significant losses are caused by the failure to comply with agronomic deadlines for spring sowing and harvesting, as well as violations of cultivation technology [9]. The extension of harvesting periods due to a shortage of grain harvesters leads to the fact that in addition to significant losses during harvesting, the grown crop is not harvested before snowfall and autumn inclement weather.

The Omsk Region, like many regions of Russia, is experiencing increased load on grain harvesters due to a shortage of equipment. On some farms, this figure exceeds the standard by 5–7 times. This results in rapid wear and tear and frequent failures. According to various sources, on average, over 15% of grain harvesters nationwide are idle during the autumn fieldwork period, with yield losses due to downtime in the Siberian region alone reaching 15 million tons³.

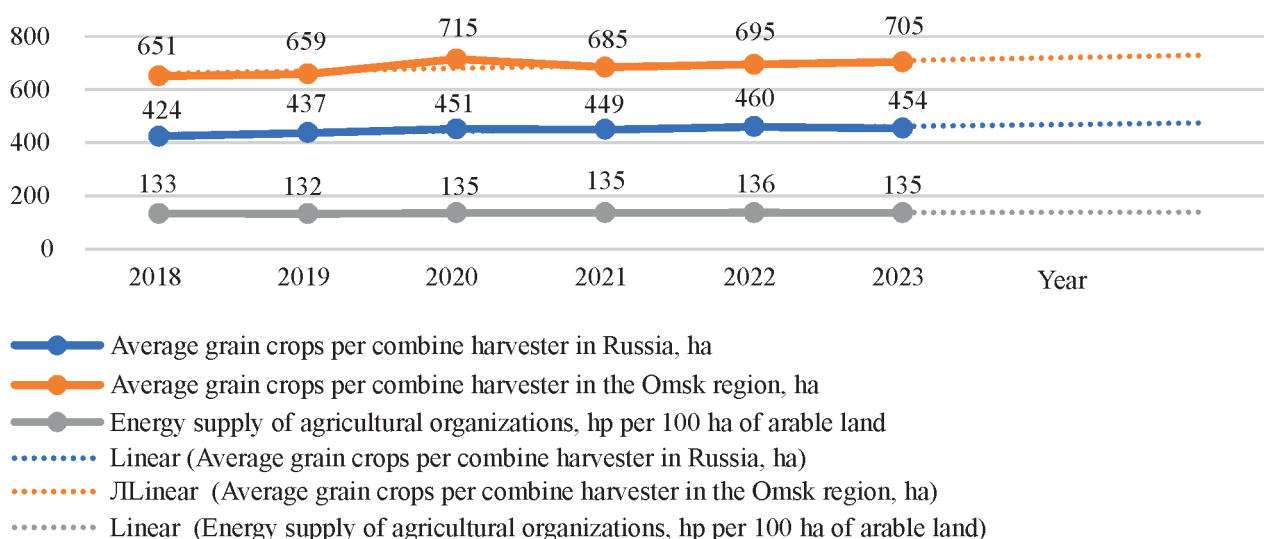


Рис. 5. Обеспеченность сельскохозяйственных товаропроизводителей зерноуборочными комбайнами
Fig. 5. Provision of agricultural producers with grain harvesting combines

²Омский областной статистический ежегодник «2024». Омск: Омскстат, 2024 163 p.

³Subochev S.V. Evaluation of the efficiency of grain harvesters based on the main reliability indicators in Siberian conditions: Candidate's thesis in Engineering: 05.20.03 / S.V. Subochev, Novosibirsk, 2015, 130 p.

Rational selection of combine harvester fleets is crucial for the efficient organization of agricultural production. The Omsk Agricultural Research Center has developed recommendations for the Omsk Region on selecting combine harvester classes and brands based on average long-term yields and natural and climatic conditions [3] (see the table).

Compliance with scientifically based recommendations will help reduce the load on combines, reduce the number of machine operators and increase cost recovery.

The condition of the grain harvester fleet and the quality of service indicate that the workload will only increase in the foreseeable future, the fleet will age, and the quality of maintenance and repairs will decline. At the same time, the grain harvester fleet has been replenished with modern, high-tech machines over the past 10 years, allowing us to consider implementing modern methods of monitoring the technical condition of the machines using digital, intelligent technologies [10].

Analysis of scientific research and the conditions for modernizing the material and technical base of agricultural producers in the Omsk region made it possible to identify a number of factors influencing the process of updating the fleet of grain harvesters (see Fig. 6) [11]. Economic, cost, natural, climatic and management factors were identified.

Economic factors are related to the payback period of the machines and the specific nature of their use. Sixty percent of the grain harvester fleet in the Omsk Region is beyond its depreciation period, with some units having around 3,000 operating hours. The remaining service life of the machines largely explains this age distribution.

Cost is also a limiting factor. It is noted that in 2023, compared to 2022, prices for agricultural machinery increased by 30–50%; a combine harvester that cost 12 million rubles now costs 19 million rubles⁴.

The natural and climatic conditions of farming in the Omsk region are a slowing factor. The quality and quantity of harvested produce, as well as pricing, fluctuate greatly from year to year. Temperatures during the harvest period range from 10–15°C, with humidity reaching 65–75%. Prolonged autumn precipitation significantly slows the harvesting process, with grain moisture levels varying from 14 to 28%, and straw moisture levels from 8 to 36%. For example, on average, over the past 10 years, every third day in the south of Western Siberia has been rainy⁵. In the fall of 2021, the cost of one ton of wheat in the Siberian Federal District was about 14,000 rubles, while in the fall of 2024 it was approximately 11,800 rubles⁶. Such conditions create significant risks in the fleet renewal program.

Рекомендации по формированию рационального парка зерноуборочных комбайнов Recommendations for the formation of a rational park of grain harvesting combines

Indicator	Natural climatic zone			
	Steppe zone	Southern forest-steppe zone	Northern forest-steppe zone	Northern zone
Grain and leguminous crop yields (average for the period 2020–2025), c/ha	15,1	17,9	15,6	15,7
Combine class: 5–7 kg/s, %	50	60	60	70
7–10 kg/s, %	30	25	30	30
10 and more kg/s, %	20	15	10	–

⁴URL: <https://www.rbc.ru/business/10/04/2023/6432867b9a7947d31bb90d6f>

⁵ Report on climate features in the Russian Federation for 2022. Moscow: Roshydromet, 2023, 104 p.

⁶URL: <https://agro-bursa.ru/prices/wheat/>

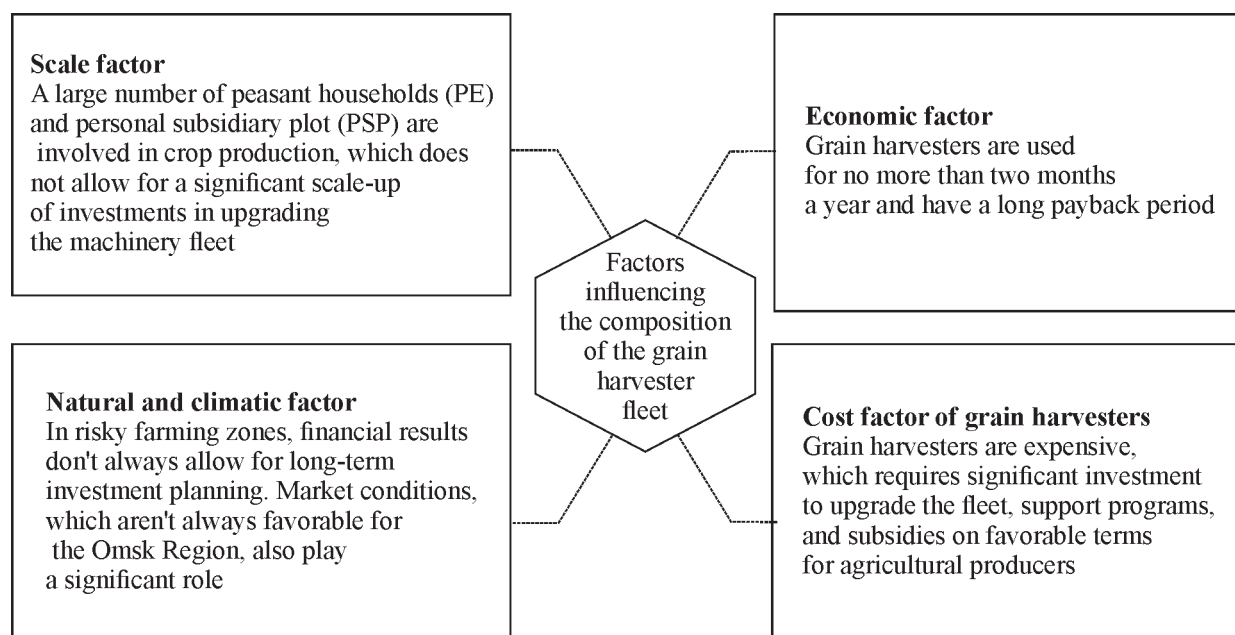


Рис. 6. Факторы, влияющие на обновление парка зерноуборочных комбайнов

Fig. 6. Factors influencing the renewal of the grain harvesting combines fleet

In the Omsk region, there are approximately 400 agricultural enterprises of various ownership types, including 1,850 peasant farms, and over 234,000 private household plots. Each enterprise has an average land area of 6,000 hectares, while each peasant farm has approximately 1,000 hectares⁷. Clearly, such a scale of operation, especially for peasant farms and private household plots, is not conducive to the systematic renewal of machinery.

CONCLUSION

The conducted research allowed us to assess the condition of the grain harvester fleet in the Omsk Region. The data shows that the number of wheeled tractors has decreased by 17.3%, forage harvesters by 38.1%, and grain harvesters by 1.5%. Rostselmash brand grain harvesters dominate the fleet (42.9%). More than 60% of grain harvesters are older than 10 years, and the renewal rate is negative. The largest number of combine harvesters are equipped with YaMZ (48%) and SMD (36%) engines, with power rat-

ings ranging from 200 to 299 hp (41.8%) and 100 to 199 hp (38%). The crop area load per combine harvester in the Omsk Region is 64% higher than the Russian average, while energy supply is the lowest in the Siberian Federal District. The load on grain harvesters exceeds the standard by 5–7 times. This results in rapid wear, frequent failures, and crop yield losses of at least 10-20%.

Analysis of the modernization conditions for the material and technical base of agricultural enterprises in the Omsk Region revealed several factors influencing the renewal of grain harvester fleets. The most important factors hindering the renewal of grain harvester fleets are economic, cost, natural and climatic, and management factors. These factors can be mitigated by the following measures: development of the outsourcing market for services for the implementation of technological operations in agriculture (such as machine and tractor stations), development of the agricultural machinery rental market, improvement of state support programs for rural

⁷URL: https://omsk.aif.ru/celhoz/omskaya_oblast_voshla_v_top_regionov_po_razmeru_selhozugodiy

producers in terms of purchasing agricultural machinery and reducing the risks of late loan and lease payments (for example, in the event of an emergency, the introduction of credit holidays or reimbursement of part of the payments).

To upgrade the grain harvester fleet in the Omsk Region and bring its utilization rate up to national standards, the fleet will need to be replenished with at least 1,500 machines. The cost of such a modernization program will be approximately 30 billion rubles.

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ИНФОРМАЦИЯ ОБ АВТОРАХ

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Дата поступления статьи / Received by the editors 09.08.2025
Дата принятия к публикации / Accepted for publication 02.09.2025
Дата публикации / Published 15.10.2025

Рекуператор теплоты отработавших газов двигателя трактора МТЗ-82

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Изложены краткие результаты исследования по разработке газожидкостного теплообменного аппарата, или рекуператора теплоты отработавших газов двигателя внутреннего сгорания, на примере дизельного двигателя Д-242 трактора МТЗ-82. Для реализации цели и задач исследования создана экспериментальная установка, где в качестве силового агрегата использован указанный двигатель. Проведен факторный эксперимент по изучению теплового состояния двигателя на различных режимах работы, который выявил некоторые противоречия в тепловом балансе работающего двигателя. В зависимости от режима работы и температуры окружающей среды в течение 15 мин работы двигателя масло в поддоне нагревалось до 62 °С, температура охлаждающей жидкости достигала максимального значения в 86 °С, температура отработавших газов – 330 °С. Формально по температуре охлаждающей жидкости двигатель достигал оптимального эксплуатационного диапазона температур (85–90 °С), однако при более детальном рассмотрении становится понятно, что масло не достигало оптимальной температуры. Это свидетельствует, что в узлах трения температурный фон по-прежнему оставался пониженным, следовательно, сохранялись потери на трение и высокая вероятность задигов. Разработанный рекуператор предназначен для отбора части бросовой теплоты двигателя, рассеиваемой в атмосферу с отработавшими газами, с целью ее дальнейшего использования в узлах и агрегатах машины для поддержания заданного температурного режима, включая и двигатель машины. В перспективе рекуперированную теплоту возможно использовать для выработки холода и электричества с целью обеспечения данными ресурсами необходимых технологических операций, выполняемых машинно-тракторным агрегатом.

Ключевые слова: рекуператор, двигатель внутреннего сгорания, прогрев, бросовая теплота, отработавшие газы

Exhaust gas heat recuperator for the MTZ-82 tractor engine

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Brief results of the study on the development of a gas-liquid heat exchange apparatus or exhaust gas heat recuperator for the D-242 diesel engine of the MTZ-82 tractor are presented. To achieve the goals and objectives of the study, an experimental setup was created, utilizing the specified engine as the power unit. A factorial experiment was conducted to study the thermal state of the engine under various operating modes, which revealed certain contradictions in the heat balance of the operating engine. Depending on the operating mode and ambient temperature, within 15 minutes of engine operation, the oil in the sump heated up to 62°C, while the coolant temperature reached a maximum value of 86°C, and the exhaust gas temperature reached 330°C. Formally, based on the coolant temperature, the engine reached the optimal operational temperature range (85–90°C). However, upon closer examination, it becomes clear that the oil had not yet reached its optimal temperature. This indicates that the temperature conditions in the friction units remained low, consequently, friction losses persisted, along with a high risk of scuffing. The developed recuperator is designed to capture a portion of the waste heat from the engine, which is dissipated into the atmosphere with the exhaust gases, for its

subsequent use in the components and assemblies of the machine to maintain the specified temperature regime, including the machine's engine. Looking ahead, the recuperated heat could potentially be utilized for generating cooling and electricity to provide these resources for necessary technological operations performed by the machine-tractor unit.

Keywords: recuperator, internal combustion engine, heating, waste heat, exhaust gases

Для цитирования: Иванников А.Б., Жолудев В.Л., Дусантаев А.И., Зайналов З.К. Рекуператор теплоты отработавших газов двигателя трактора МТЗ-82 // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 9. С. 99–108. <https://doi.org/10.26898/0370-8799-2025-9-11>

For citation: Ivannikov A.B., Zholudev V. L., Dusantaev A.I., Zainalov Z. K. Exhaust gas heat recuperator for the MTZ-82 tractor engine. *Sibirskii vestnik sel'skhoz'yastvennoi nauki* = *Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 9, pp. 99–108. <https://doi.org/10.26898/0370-8799-2025-9-11>

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

Благодарность

Авторы выражают благодарность инженерам лаборатории технического сервиса МТП СибИМЭ СФНЦА РАН А.А. Монозон и О.М. Петрушкоу за помощь в проведении исследования и участии в подготовке статьи.

Acknowledgements

The authors express gratitude to the engineers of the Laboratory of Technical Service of Machine and Tractor Fleet of the Siberian Research Institute of Mechanization and Electrification of Agriculture SFSCA RAS Monoszon A.A. and Petrushkov O.M. for assistance in conducting the research and participation in the preparation of the article.

INTRODUCTION

Operating the machinery and tractor fleet (MTF) in the agro-industrial complex in today's environment requires new approaches from business entities that not only enable efficient use of available resources but also create working conditions that prioritize resource-saving technologies. Implementing such a policy in business management can yield significant economic benefits and increase labor productivity. One area for implementing resource-saving approaches and technologies in MTF use may be the climatic conditions of the Russian Federation, particularly in the Northwestern, Ural, Siberian, and Far Eastern Federal Districts. The climate features primarily include lower ambient temperatures throughout the year. For example, the average annual temperature in the Novosibirsk region is 0.2°C ¹, And the only month without frost is July. Low temperatures negatively impact technical systems, which in turn leads to a decrease in the reliability and durability of the MTF² [1–3]. Work in this direction is largely as-

sociated with the development of technical solutions for the thermal preparation of an internal combustion engine (ICE) for start-up [4–7] and with the development of systems for the utilization of waste heat from ICEs, which make it possible to use the utilized heat to maintain an optimal temperature regime in the main units and assemblies of the MTF [8–10]. Recovered heat can also be used to support various technological operations in the machine-tractor unit [11]. Recycling waste heat will make it possible to partially solve one of the serious problems – the low efficiency of heat released from combustion of fuel in the internal combustion engine.

Recycling of waste heat means directing the heat dissipated into the atmosphere with exhaust gases (EG), the cooling system and the lubrication system of the internal combustion engine to ensure specified temperature conditions in the units and assemblies of the self-propelled vehicle itself or supplying this heat to a trailer unit to ensure any technological processes.

The purpose of the study is to justify and develop an exhaust gas heat recuperator for the

¹FSBI "West Siberian Administration for Hydrometeorology and Environmental Monitoring" Official observation data. Official forecasts.URL: <http://www.meteo-nso.ru/pages/46>

²Koch P.I. Climate and reliability of machines. Moscow: Mechanical Engineering, 1981, 175 p.

waste heat recovery system of internal combustion engines.

The research objectives are:

- to study the thermal state of the D-242 engine in various operating modes;
- to justify the technical solution for the exhaust gas heat recuperator of the D-242 engine of the MTZ-82 tractor and to manufacture a prototype of the recuperator.

MATERIAL AND METHODS

Experimental studies were conducted in 2023 and 2024. The study of the thermal state of the D-242 engine was carried out on an experimental setup (see Fig. 1), including a KI-1363V GOSNITI run-in and brake stand, a D-242 diesel engine, control and measuring instruments (CMI) and the recording equipment.

The KI-1363V GOSNITI test rig was installed indoors, and the engine was installed outdoors. The engine and the rig were connected via a cardan shaft through a hole in the wall. A control panel, including the CMI and equipment, as well as controls for the rig and engine, was created to manage the experimental setup. A computer was used to record the test parameters.

Temperature measurements were taken at the intake manifold (air temperature), exhaust manifold (exhaust gas temperature), cylinder head (coolant temperature), and crankcase (oil temperature). The experiments were conducted on days when the ambient temperature matched the experimental design.

When planning the factorial experiment and processing its results, we were guided by the standard methods³. A second-degree polynomial was used as a mathematical model.

The ambient temperature at the engine muffler inlet was selected as the response. The a priori ranking was used as the primary method for determining the significance of the determining factors. Information on the determining factors and their levels of variation is summarized in the table.

When substantiating the technical solution for the exhaust gas heat recuperator of internal combustion engines, standard methods for performing thermal calculations of heat exchangers were used as initial methods⁴. However, standard methods were not fully suitable for the study's purposes, as they are primarily used for calculating stationary devices with pre-determined

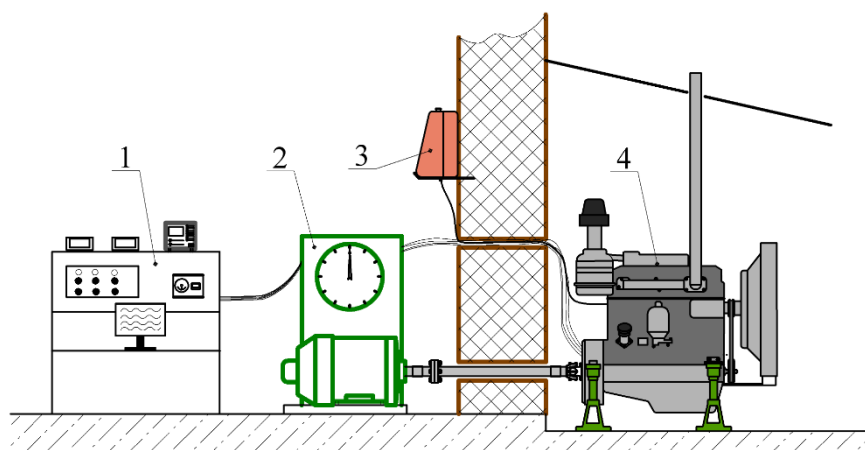


Рис. 1. Экспериментальная установка: 1 – пульт управления установкой; 2 – обкаточно-тормозной стенд; 3 – топливный бак; 4 – дизель Д-242

Fig. 1. Experimental installation: 1 – control panel of the installation; 2 – running-in and braking stand; 3 – fuel tank; 4 – diesel engine D-242

³Berikashvili, V.Sh., Oskin S.P. Statistical data processing, experimental design and random processes: textbook for universities; 2nd ed., corrected and enlarged. Moscow: Yurait, 2022, 164 p.

⁴Bazhan P.I., Kanevets G.E., Seliverstov V.M. Handbook of heat exchangers. Moscow: Mechanical Engineering, 1989, 368 p.

Определяющие факторов и уровни их варьирования
Determining factors and the levels of their variation

The determining factor	Factor	Level of variation		
		low	null	high
Engine load level N , % (kW)	X_1	50 (22,8)	65 (29,8)	80 (36,4)
Operating time τ , min	X_2	15	22,5	30
Ambient temperature t_{OC} , °C	X_3	–30	–15	0

physical parameters of the coolants. Some of the most important parameters are the coolant flow rate and temperature.

The temperature and velocity of exhaust gases are directly proportional to the amount of fuel burned per unit of time and, accordingly, to the engine crankshaft speed, which introduces certain difficulties into the calculations. This and other difficulties were taken into account when substantiating the technical solution, and a number of features and assumptions were incorporated into the recuperator calculation methodology:

- the recuperator must be placed on the exhaust line, for example in the muffler or instead of it, as a result of which the overall dimensions of the recuperator can be similar to the dimensions of the muffler;
- in case of replacing the standard muffler with a recuperator, it is necessary to provide for its performance as a muffler;
- it is advisable to determine the capacity of the recuperator by the total capacity of the heat consumers in the maximum heat consumption mode;
- considering that the temperature, exhaust gas velocity, fuel and air mass flow rates of the engine constantly fluctuate, it is advisable to use average values of these parameters in calculations, obtained depending on the time of year and engine operating modes;
- when developing a recuperator, it is necessary to provide a mechanism that allows for automatic influence on the heat transfer process by reducing (increasing) the amount of exhaust gases involved in heat exchange;

– provide for the possibility of technical maintenance of the recuperator (cleaning from carbon deposits, its assembly and disassembly).

The work uses methods and techniques based on the application of general scientific research methods.

RESULTS AND DISCUSSION

Analysis of the study results confirms the presence of significant thermal and kinetic energy in the exhaust gases. For example, when the experimental setup was operating at 80% (37 kW) of its rated engine power and an ambient temperature of –30°C, the exhaust gas flow temperature exceeded 200°C by the eighth minute of operation. Meanwhile, the oil in the engine sump only warmed up to –13°C, and the engine coolant temperature reached 8°C (see Fig. 2).

The maximum exhaust gas temperature reached 290°C by the 15th minute of engine operation, while the oil had reached 50°C and the coolant 72°C. This indicates that, despite the simultaneous release of a large amount of heat from the exhaust gases into the atmosphere, the engine did not warm up to operating temperature (85–90°C).

When the ambient temperature rises to 0°C, with the same load and operating time, the engine's thermal state changes significantly (see Fig. 3). Thus, the maximum exhaust gas temperature was recorded at 330°C by the 12th minute of engine operation. By this time, the oil in the engine sump had warmed up to 60°C, and the engine coolant temperature had reached 76°C. The oil temperature by the 15th minute of engine operation had not changed significantly,

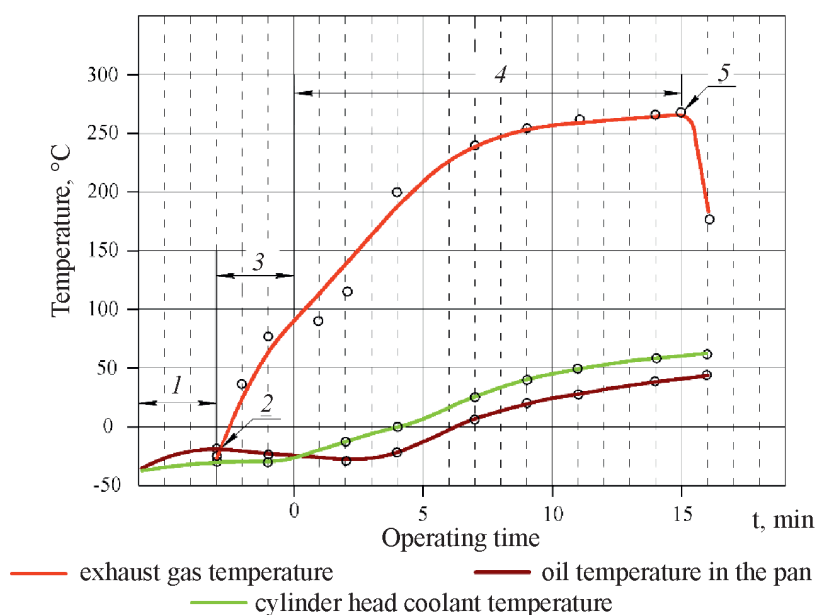


Рис. 2. Зависимость температуры отработавших газов, охлаждающей жидкости и масла от степени загрузки двигателя (80%), температуры окружающей среды (-30°C) и времени работы (15 мин):

1 – предпусковой разогрев; 2 – запуск двигателя; 3 – послепусковой прогрев; 4 – работа двигателя под нагрузкой; 5 – остановка двигателя

Fig. 2. Dependence of exhaust gas, coolant and oil temperature on engine load (80%), ambient temperature (minus 30°C) and operation time (15 min.):

1 – pre-start warm-up; 2 – engine start; 3 – post-start warm-up; 4 – engine operation under load; 5 – engine stop

remaining at 62°C , while the coolant temperature had reached 86°C .

Formally, the engine coolant temperature has reached its optimal operating range, but a closer analysis reveals that the oil temperature has not yet reached its optimal temperature. This means that the temperature in the friction units remains low, resulting in continued friction losses and a high risk of scuffing. It should also be noted that, under normal operating conditions, a car or tractor engine rarely operates for long periods at high loads, except during certain technical operations.

The experimental results demonstrate that achieving the optimal operating temperature for the D-242 engine at low ambient temperatures is not always possible. During engine operation, the exhaust gas temperature at the muffler inlet

reaches 330°C or more, confirming the feasibility of further research into the recycling of internal combustion engine waste heat and paving the way for the development of an exhaust gas heat recovery system using the D-242 engine as an example.

It is known that there are no commercially available recuperators for exhaust gas heat recovery and recycling systems from internal combustion engines. This is primarily due to the lack of ready-made solutions for equipping vehicles with such systems, even in regions with harsh climates. However, researchers are working in this direction [12]⁵.

The closest technical solution, which was used as a prototype, is a gas-liquid shell-and-tube heat exchanger, developed earlier with the participation of one of the authors of the article⁶.

⁵Patent No. 52108 U1 Russian Federation, IPC F01N 5/02. Exhaust Gas Heat Recycler / Davydenko D.V., Matievsky G.D., Sheptunov V.M., Zakharov G.O.; applicant Sibenergoprom LLC; No. 2005131820/22; declared 13.10.2005; published 10.03.2006.

⁶Patent No. 2523454 C1 Russian Federation, IPC F28D 7/00, F28F 27/00. Gas-liquid shell-and-tube heat exchanger with an automatic heat exchange process control system / Krokhta G.M., Ivannikov A.B.; applicant Novosibirsk State Agrarian University; No. 2013100549/06; declared 09.01.2013; published 20.07.2014.

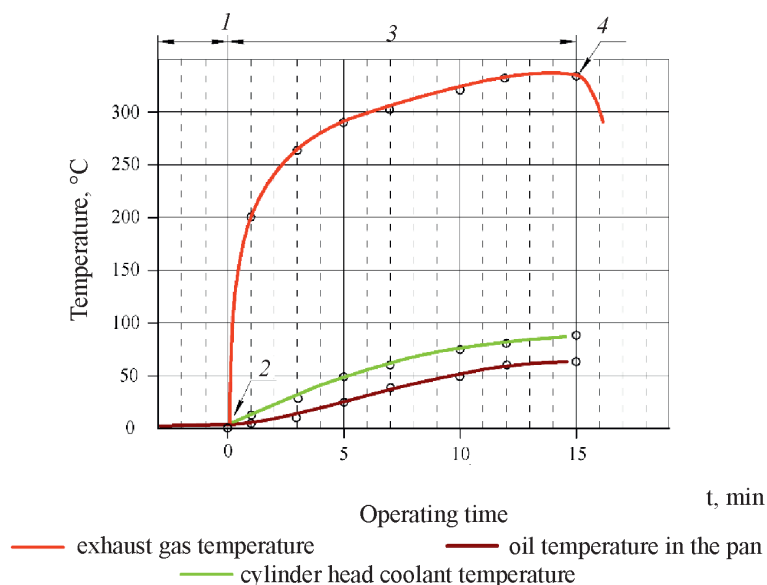


Рис. 3. Зависимость температуры отработавших газов, охлаждающей жидкости и масла от степени загрузки двигателя (80%), температуры окружающей среды (0 °C) и времени работы (15 мин):

1 – предпусковой разогрев; 2 – запуск двигателя; 3 – запуск двигателя под нагрузкой; 4 – остановка двигателя

Fig. 3. Dependence of exhaust gas, coolant and oil temperature on engine load (80%), ambient temperature (0 °C) and operation time (15 min.)

1 – pre-start warm-up; 2 – engine start; 3 – engine operation under load; 4 – engine stop

The described heat exchanger has a single-module design with individual elements of the damper control mechanism located inside the housing.

The prototype's drawbacks include the placement of the gas damper inside the heat exchanger, which complicates the design of the thermostat and damper drive mechanism. This also means that, regardless of the operating mode, the damper shaft bushing will be constantly washed by exhaust gases and contaminated with soot and other combustion products, potentially causing jamming. Another drawback is the use of a single pipe for supplying exhaust gases to the heat exchanger and subsequently exhausting them to the atmosphere. This design allows the heat exchanger to be used as a muffler only when the gas valve is closed, i.e. when the exhaust gases pass through the intertube space during heat exchange, and when the gas valve opens according to the operating algorithm, the central pipe of the heat exchanger turns into a straight-through exhaust pipe, which can lead to acoustic pollution of the environment.

To justify the technical solution, a design was chosen that could effectively serve as an exhaust gas heat recuperator and exhaust system muffler during engine operation in various modes. Based on the design of the D-242 engine exhaust system of the MTZ-82 tractor and the placement of the standard muffler, a two-module recuperator configuration with a heat exchange module and a sound attenuation module for the tractor's exhaust system was adopted. The functional diagram is shown in Fig. 4.

The proposed recuperator utilizes standard muffler components as the attenuation module, and the heat exchange (recuperation) module is also housed within the standard muffler housing. The heat exchange module is a multi-pass shell-and-tube heat exchanger. To simplify the manufacture of the heat exchange module, a finned coil, for example, through which the heat transfer fluid of the heat recovery circuit will circulate, can be integrated into the standard muffler.

One of the main components of the recuperator, which regulates the heat exchange process between the exhaust gases and the heat transfer

fluid of the waste heat recovery circuit, is the gas damper, which controls the volume of hot exhaust gases entering the intertube space of the heat exchange module. The gas damper's operating algorithm depends on the temperature of the waste heat recovery circuit's heat transfer fluid at the recuperator outlet and can be programmed based on the objectives of the waste heat recovery system installed on the vehicle.

The recuperator operates as follows (see Fig. 4). Initially, before starting the internal combustion engine, the gas valve is positioned to close the exhaust gas supply pipe to the heat exchange module. After starting the internal combustion engine, a signal from the coolant temperature sensor is sent to the gas valve actuator control unit, where a command for further action is

generated in accordance with the operating algorithm. The operating algorithm may be as follows. If, after starting the internal combustion engine, the temperature of the heated coolant at the outlet of the recuperator is below 70°C , the command to open the gas damper is given, and the exhaust gases enter the heat exchange module. Heat exchange between the exhaust gases and the heated coolant begins. If, after starting the internal combustion engine, the temperature of the heated coolant is above 70°C , the command to open the gas damper is not given, and the exhaust gases enter the exhaust sound attenuation module of the internal combustion engine. When the heated coolant cools to 70°C due to heat exchange, the control unit commands the damper actuator to close the exhaust gas sup-

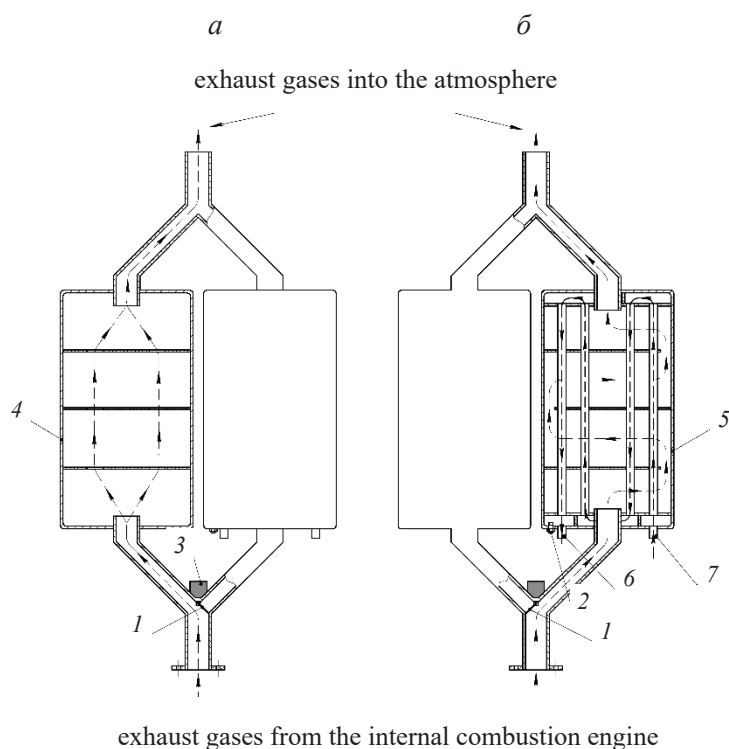


Рис. 4. Функциональная схема работы рекуператора: *a* – режим глушения звука; *б* – режим рекуперации:

1 – газовая заслонка; 2 – температурный датчик теплоносителя утилизационного контура; 3 – механизм привода газовой заслонки с блоком управления; 4 – модуль глушения звука; 5 – модуль теплообмена; 6 – отвод теплоносителя утилизационного контура из рекуператора; 7 – подвод теплоносителя утилизационного контура в рекуператор

Fig. 4. Functional scheme of the recuperator operation: *a* – mute mode; *б* – recuperation mode:

1 – gas flap; 2 – temperature sensor of the heat carrier of the utilization circuit; 3 – gas flap drive mechanism with control unit; 4 – sound attenuation module; 5 – heat exchange module; 6 – utilization circuit heat carrier withdrawal from the recuperator; 7 – utilization circuit heat carrier supply to the recuperator

ply pipe to the sound attenuation module. This redirects the exhaust gases back to the heat exchange module, and heating of the waste heat recovery circuit coolant resumes. This operating algorithm automatically maintains the coolant temperature of the waste heat recovery circuit at the recuperator outlet at the set point of 70°C.

Based on the results of the study, an application was prepared and patent No. 2822779 was issued for "Exhaust Gas Heat Recuperator for Internal Combustion Engines," confirming the scientific novelty of the research. One of the results of the completed study is an experimental recuperator prototype, which was manufactured and mounted on the engine of the experimental setup (see Fig. 5).

Testing of the experimental recuperator is planned for 2025 as part of a stationary experimental installation and in 2026 as part of a mobile installation.

CONCLUSIONS

1. A study of the thermal state of the D-242 engine in various modes showed that under conditions of low ambient temperatures (from 0 °C and below) it is not always possible to achieve the optimal operating temperature of the engine (85–90 °C), while the temperature of the exhaust gases reaches high values (330 °C and more), which indicates a significant amount of waste heat from the engine dissipated into the atmosphere with the exhaust gases.

2. The proposed recuperator has a two-module system and can effectively perform the functions of a muffler and a heat exchanger, allowing for the secondary use of a significant portion of the heat dissipated with the exhaust gases of the internal combustion engine.

3. Recycling the heat from exhaust gases of internal combustion engines will increase the efficiency of heat released from combustion of fuel in the engine.



Рис. 5. Экспериментальный рекуператор:

a – общий вид; *б* – в защитном кожухе

Fig. 5. Experimental recuperator:

a – general view; *б* – in a protective casing

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Дата поступления статьи / Received by the editors 09.04.2025
Дата принятия к публикации / Accepted for publication 28.05.2025
Дата публикации / Published 15.10.2025



Гранулометрический состав как фактор зимней миграции влаги в почвах

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В статье на основе обзора опубликованных данных уточнено влияние гранулометрического состава на зимнюю миграцию влаги в почвах степных и лесостепных районов Сибири, установлены количественные пропорциональности между параметрами среды и криогенной аккумуляцией влаги в почвах с разным гранулометрическим составом в целях прогнозирования этого элемента водного режима почв. Гранулометрическим составом предопределяются водоотдача почв и объем подвижной влаги при влажности ниже уровня наименьшей влагоемкости. Тяжелые по гранулометрическому составу почвы (тяжелосуглинистые и легкосуглинистые) отличаются низкой водоотдачей (коэффициент водоотдачи 0,06). Это обусловлено высокой обводненностью микропор трудноподвижной влагой и повышенной гидроадсорбционной способностью высокоиллистых почв (более 15% массы). Содержание подвижной влаги при влажности ниже уровня наименьшей влагоемкости остается высоким. Поэтому в тяжелых почвах при близком залегании грунтовых вод объем намерзания не превышает 50 мм, при глубоком залегании он достигает 25 мм. Под такими почвами при перераспределении части грунтовых вод в слой криогенной аккумуляции падение их уровня за октябрь – март может составлять 0,9 м, а мощность слоя намерзания достигает 1,1 м. Легкие (песчаные и супесчаные) почвы характеризуются преобладанием крупных и средних пор, а также малой гидроадсорбционной способностью (2–3% массы). Поэтому легкие почвы отличаются большой водоотдачей (коэффициент водоотдачи может достигать 0,5). Содержание способной к передвижению влаги в легких почвах при влажности ниже уровня наименьшей влагоемкости невелико, поскольку влага в средних и крупных порах находится в основном в разобленном состоянии. По этой причине в легких почвах при близком залегании грунтовых вод намерзает до 100 мм, при глубоком – менее 10 мм влаги. Из-за большой водоотдачи падение уровня грунтовых вод в легких почвах в октябре – марте едва достигает 0,2 м, вертикальная мощность слоя намерзания составляет не более 0,5 м.

Ключевые слова: гранулометрический состав, структура общей пористости, почвенная влага, водоотдача почв, уровень грунтовых вод, слой криогенной аккумуляции влаги

Granulometric composition as a factor of winter moisture migration in soils

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Based on a review of published data, the article refines the understanding of the influence of granulometric composition on winter moisture migration in soils of the steppe and forest-steppe regions of Siberia. It establishes quantitative proportionalities between environmental parameters and the cryogenic accumulation of moisture in soils with different granulometric compositions for the pur-

pose of forecasting this element of the soil water regime. The particle size distribution predetermines the water yield of soils and the volume of mobile moisture at humidity levels below the field capacity. Soils with a heavy particle size distribution (heavy loamy and light clayey) are characterized by low water yield (the water storage coefficient is 0.06). This is due to the high water content of micropores with difficult-to-move moisture and the increased hydro-adsorption capacity of highly silty soils (more than 15% of the mass). The content of mobile moisture remains high even at humidity levels below the field capacity. Therefore, in heavy soils with shallow groundwater, the freezing accumulation does not exceed 50 mm, while with deep groundwater, it reaches 25 mm. Under such soils, during the redistribution of part of the groundwater into the cryogenic accumulation layer, their level may drop by 0.9 m from October to March, and the thickness of the freezing layer can reach 1.1 m. Light (sandy and sandy loam) soils are characterized by the predominance of large and medium pores, as well as low hydro-adsorption capacity (2–3% of the mass). Therefore, light soils are characterized by high water storage (the water storage coefficient can reach up to 0.5). The content of moisture capable of movement at humidity levels below the field capacity is low in light soils, since moisture in medium and large pores is predominantly in a disconnected state. For this reason, in light soils with shallow groundwater, up to 100 mm of moisture can freeze, while with deep groundwater, less than 10 mm freezes. Due to the high water storage, the drop in groundwater level in light soils from October to March barely reaches 0.2 m, and the vertical thickness of the freezing layer does not exceed 0.5 m.

Keywords: granulometric composition, structure of total porosity, soil moisture, soil water loss, groundwater level, cryogenic moisture accumulation layer

Для цитирования: Кравцов Ю.В. Гранулометрический состав как фактор зимней миграции влаги в почвах // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 9. С. 109–116. <https://doi.org/10.26898/0370-8799-2025-9-12>

For citation: Kravtsov Yu.V. Granulometric composition as a factor of winter moisture migration in soils. *Sibirskii vestnik sel'skookhozyaistvennoi nauki* = *Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 9, pp. 109–116. <https://doi.org/10.26898/0370-8799-2025-9-12>

Конфликт интересов

Автор заявляет об отсутствии конфликта интересов.

Conflict of interest

The author declares no conflict of interest.

Благодарность

Исследование выполнено за счет гранта Российского научного фонда № 24-26-00104 (<https://rscf.ru/project/24-26-00104/>).

Acknowledgements

The research was carried out at the expense of the grant from the Russian Science Foundation No. 24-26-00104 (<https://rscf.ru/project/24-26-00104/>).

INTRODUCTION

The particle size distribution and other physical properties of soils in the southern regions of Siberia were extensively studied in the second half of the 20th century¹⁻⁴. However, the study of changes in the moisture profile of soil layers in southern Siberia during the winter period was less extensive^{5, 6}.

Factors of winter moisture migration include soil freezing, high soil moisture, and granulometric composition [1]. Studying the factors of cryogenic moisture migration is important for establishing quantitative relationships between environmental parameters and moisture freezing [2], which will allow predicting the parameters of this element of the soil water regime.

¹Agrophysical characteristics of soils in Western Siberia / ed. V.P. Panfilov. Novosibirsk: Nauka, 1976, 544 p.

²Soil-physical conditions of land reclamation in Western Siberia / ed. V.P. Panfilov. Novosibirsk: Nauka, 1977, 88 p.

³Physics of Soils of Western Siberia / eds. V.P. Panfilov, R.V. Kovalev. Novosibirsk: Nauka, 1971, 140 p.

⁴Chernozems: Properties and Irrigation Features. Novosibirsk: Nauka, 1988, 254 p.

⁵Kulikov A.I., Panfilov V.P., Dugarov V.I. Physical properties and regimes of meadow-chernozem permafrost soils of Buryatia. Novosibirsk: Nauka, 1986, 136 p.

⁶Panfilov V.P. Physical properties and water regime of soils of the Kulunda steppe. Novosibirsk: Nauka, 1973, 260 p.

The article presents a review of the previously published data, based on which the influence of particle size distribution on winter moisture migration in soils of southern Siberia was determined.

MATERIAL AND METHODS

The work is based on the published results of observations of moisture freezing in southern chernozems, meadow-chernozem and chernozem-meadow soils of the Ishim steppe [1], meadow-chernozem permafrost soils of the Eravninskaya forest-steppe (island forest-steppe in the south of Transbaikalia), chestnut and meadow-chestnut soils of the Kulunda steppe (see footnotes 5, 6), meadow-chernozem soils of the Baraba forest-steppe⁷.

Moisture freezing observations were conducted using a uniform methodology. The volume of winter moisture accumulation and the location of the freezing layer were determined by comparing soil moisture profiles in the second and third ten-day periods of October, as well as in the third ten-day period of March. Soil and rock samples for moisture determination were collected by hand drilling to the groundwater table and processed using the thermostat-weight method. Groundwater levels were measured in the drilled boreholes.

To support this review, similarities in the parameters of the leading factors of cryogenic moisture accumulation in soils in southern Siberia are presented. Winter weather conditions are based on the data from the "Weather and Climate" website⁸. Положение грунтовых вод установлено по [3, 4]. Formulas for the proportionality of the volume of moisture freezing to environmental parameters in soils with different granulometric compositions were obtained in the Microsoft Excel program.

RESULTS AND DISCUSSION

The location of the studied areas in the Siberian steppe and forest-steppe predetermines the similarity of their climate. Long (4–6 months) and cold (January temperatures of $-17... -25^{\circ}\text{C}$) winters are typical for the south of Siberia. During the cold season of the year in the south of Western Siberia, 90–110 mm of precipitation falls and a small snow cover accumulates (up to 0.5 m) [5]. In the Trans-Baikal forest-steppe, up to 20 mm of precipitation falls during the winter, and snow cover may not form [6]. In the south of Siberia, severe frosts (down to $-20... -30^{\circ}\text{C}$) are frequent in October – early November [7].

As a result of the above factors, soil freezing in the region begins in October–November, and thawing begins in the third ten-day period of March [8]. Deep penetration of 0°C (up to 2.5 m) is observed in the soils of southern Western Siberia. In the Trans-Baikal forest-steppe, the seasonally thawing layer (up to 3 m thick) freezes throughout the winter. The amount of frozen moisture depends on the autumn soil moisture, which is related to the groundwater level. In the south of Western Siberia, groundwater levels at 2–5 meters are due to the weak dissection of the earth's surface and the shallow location of aquicludes. In the Trans-Baikal forest-steppe, perched water forms at depths of 2–3 meters on the roof of permanently frozen soils in summer. Thus, due to climatic conditions, the depth and duration of seasonal soil freezing in southern Siberia are comparable, while subsoil moisture levels are elevated. Despite similar underlying conditions, another factor affecting frost migration of soil moisture in the region—the particle size distribution of soils and rocks—is different.

In the Ishim Steppe, lacustrine accumulation of sedimentary material predominated during the Neogene and most of the Anthropogene.

⁷*Srebryanskaya G.A.* Phenomena of seasonal freezing and thawing of soils of Central Baraba // Transactions of the V.V. Dokuchaev Soil Institute: collection of articles. Moscow: Publishing house of the USSR Academy of Sciences, 1954, vol. 42, part 2, pp. 172–232.

⁸Weather and climate [Electronic resource]. URL: <http://www.pogodaiklimat.ru/history/29638.htm> (date of reference: 23.08.2024).

In the Middle and Upper Pleistocene, the land surface was covered by a mantle of loess-like deposits (1–10 m thick), largely composed of the products of wind-driven redistribution of older sediments. Consequently, the soil texture of the Ishim Steppe is represented by silty- clayey light clays and heavy loams (see Table 1). The total porosity of soils present in the Ishim steppe decreases from 50–55% in the arable layer to 45–47% at a depth of more than 1 m (see Table 2). The high silt concentration is associated with the predominance of micropores in the porosity structure (up to 60–65% of the pore volume) and a large total surface area of the solid phase.

The heavy particle size distribution and the predominance of micropores in the porosity structure result in significant hydrosorption capacity and water saturation of the pores of the Ishim soils. Maximum hygroscopicity in the soil

reaches 15% of the mass, and in the subsoil, 24–30% (see footnote 1). At the same time, sluggish water almost completely fills the micropores. The water content of pores in the 0–1 m layer at a moisture content at the level of the lowest water capacity is 60–70% of their volume. The water content of pores in the 1–2 m layer at a moisture content corresponding to the capillary water capacity reaches 77% (see footnote 2). High water content of the pore space is the cause of low reserve water capacity (less than 25% of the soil volume at the moisture content of the capillary water capacity) and soil water loss.

The water-loss coefficient at full moisture capacity reaches 0.06. This is the main reason why, with high subsoil moisture, the volume of moisture frozen in them is comparatively small, while the thickness of the cryogenic moisture accumulation layer and the drop in groundwater

Табл. 1. Гранулометрический состав почв южных районов Сибири

Table 1. Granulometric composition of soils in the southern regions of Siberia

Depth, m	Losses from HCl treatment, %	Proportion of particles of a certain size, %						
		1–0,25 mm	0,25–0,05 mm	0,05–0,01 mm	0,01–0,005 mm	0,005–0,001 mm	< 0,001 mm	< 0,01 mm
<i>Ishim steppe. Southern chernozem (see footnote 4)</i>								
0–0,2	5,3	0,0	4,7	28,0	10,9	16,8	34,3	62,0
0,2–0,5	13,4	0,0	4,5	22,4	12,4	12,9	34,4	59,7
0,5–0,7	15,9	0,0	4,3	21,8	9,1	12,9	36,0	58,0
0,7–0,9	18,1	0,0	1,0	22,8	11,5	12,6	34,0	58,1
1,3–1,5	11,2	0,6	18,7	16,5	8,2	12,6	32,2	53,0
<i>Kulunda steppe. Chestnut soil (see footnote 3)</i>								
0–0,2	1,2	29,6	44,6	7,1	1,6	3,7	12,2	17,5
0,2–0,4	1,4	29,7	42,9	6,0	2,0	3,0	15,0	20,0
0,4–0,6	1,1	28,3	47,5	6,6	0,9	2,2	13,4	16,5
0,6–0,8	5,7	14,9	55,0	7,6	0,9	2,4	13,5	16,8
1,0–1,4	5,3	32,1	43,3	5,0	0,7	1,8	11,8	14,3
1,6–2,0	2,5	45,9	41,1	1,3	0,3	1,2	7,7	9,2
<i>Eravskaya forest-steppe. Meadow-chestnut permafrost soil (see footnote 5)</i>								
0–0,2	7,1	24,2	17,3	11,6	9,8	9,1	20,9	39,8
0,35–0,45	7,5	31,6	12,6	6,2	3,1	10,3	28,7	42,1
0,7–0,8	16,7	28,6	18,6	6,3	3,2	5,3	21,3	29,8
1,2–1,3	6,2	52,4	19,6	8,6	2,0	1,1	10,1	13,2
1,5–1,6	3,2	63,1	20,3	4,3	1,1	0,2	7,8	9,1
<i>Baraba forest-steppe. Meadow-chernozem soil (see footnote 1)</i>								
0–0,25	4,2	0,8	7,2	32,7	13,4	14,4	27,3	55,1
0,25–0,40	3,4	1,2	8,7	21,6	7,1	16,8	44,5	68,4
0,40–0,55	6,8	1,1	8,9	21,0	6,0	16,0	47,0	69,1
0,55–0,80	23,4	1,6	12,3	18,2	8,9	12,6	46,4	67,9
0,8–1,1	22,5	0,2	1,7	23,5	11,7	13,0	49,9	74,6
1,1–1,5	19,0	0,0	0,6	23,5	11,3	15,8	48,3	75,8

Табл. 2. Состав пор в почвах южных районов Сибири

Table 2. Pore composition in soils in the southern regions of Siberia

Depth, m	Total porosity, %	Pore content, % of total porosity		
		> 60 microns	3–60 microns	< 3 microns
Ishim steppe. Southern chernozem (see footnote 4)				
0–0,15	55,3	15,4	20,2	64,4
0,59–0,69	48,5	19,9	16,4	65,7
1,48–1,58	45,4	8,7	23,1	62,2
Kulunda steppe. Chestnut soil (see footnote 6)				
0–0,18	47,2	47,3	24,1	28,6
0,18–0,30	39,4	26,4	35,9	38,0
0,30–0,70	37,6	27,0	41,1	31,9
1,0–1,3	36,5	36,1	36,7	27,2
Eravskaya forest-steppe. Meadow-chestnut permafrost soil (see footnote 5)				
0,05–0,15	55,2	30,9	21,6	47,5
0,3–0,4	44,0	34,3	8,4	57,3
0,55–0,65	47,2	26,9	14,3	59,6
1,2–1,3	35,3	44,4	7,9	47,7

levels during the winter season are significant. If groundwater levels are greater than 4 m deep in autumn, 15–30 mm of moisture accumulates in the seasonally frozen layer, and the freezing layer is observed at a depth of 0.8–1.8 m. As a result, the groundwater level drops by 0.3–0.5 m. If the groundwater level is above 4 m in October, the moisture increase in the freezing layer reaches 30–50 mm, and this layer is observed in the depth range from 0.4–0.8 to 1.7 m. The drop in the groundwater level reaches 0.9 m.

The Kulunda Steppe is considered an area of accumulation of river and lake sediments throughout virtually the entire anthropogenic period. For this reason, the texture of the chestnut soils in this area is silty-clayey sandy loam (see Table 1). The sandy loam parent material is underlain by sandy deposits at a depth of 1.4 m (see footnote 6). The grain size distribution of meadow chestnut soils located in negative relief forms (on the slopes of lake basins, in ravines) with a shallow groundwater table (2–3 m) is light loamy and sandy loam. The physical and hydro-physical properties of automorphic and semihydromorphic soils are similar (see footnote 1).

Total porosity in these soils decreases from

47% in the 0–0.2 m layer to 35–37% in the parent material. Medium and large pores predominate in the porosity structure (see Table 2). These pores are connected by narrow channels at the junctions of solid particles. This is primarily responsible for the discrete moisture state in the soils. The low content of silt particles results in a low water absorption capacity of the soils. Maximum hygroscopicity reaches 2–3% of the soil mass. Pore water content in the 0–1 m layer at the lowest moisture capacity reaches 40%, while in the 1–2 m layer at the capillary moisture capacity it reaches 50–53%. Therefore, sandy loam soils are characterized by high reserve water capacity (up to 40% of the soil volume at capillary moisture capacity) and water yield. The water yield coefficient reaches 0.5.

When groundwater levels are less than 4 m deep, the high-water yield of the soil layers results in large freezing depths of moisture – from 32 to 100 mm⁹. Due to the high-water yield of the rocks, moisture entering the frost accumulation layer from the groundwater causes a drop in the groundwater level of only 0.1–0.2 m. For this reason, the vertical thickness of the frost accumulation layer is small – up to 0.5 m. In the

⁹Senkov A.A. Water regime of hydromorphic and semi-hydromorphic soils of Kulunda during freezing // On the soils of Siberia: for the XI Int. Congress of Soil Scientists: collection of articles. Novosibirsk: Science, 1978, pp. 187–191.

case of deep groundwater levels, moisture in sandy loam soils is dispersed, so the volume of its winter migration is small – less than 10 mm (see footnote 6).

Based on observations in the Ishim and Kulunda steppes, a connection was established between the autumn position of groundwater and the increase in moisture in the seasonally freezing layer (see the figure).

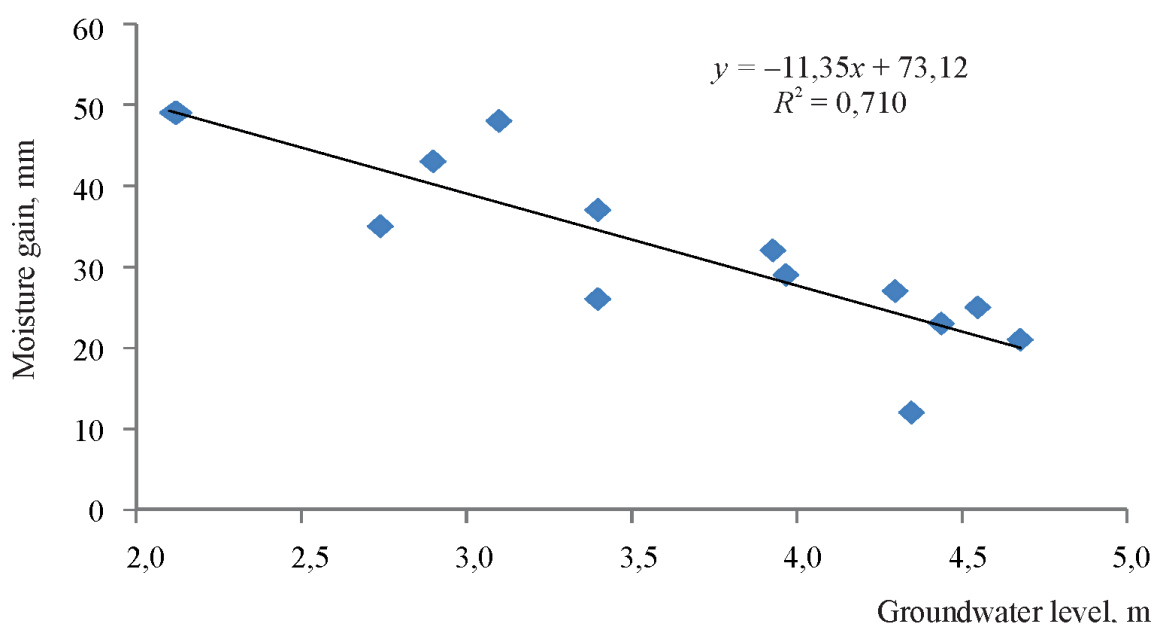
The following proportionality has been established for the soils of Kulunda:

$$Y = -0,2597x + 128,61,$$

where Y – moisture increase in the cryogenic accumulation layer, mm; x – groundwater level in October, cm; R^2 – approximation reliability value ($R^2 = 0,8467$).

The decrease in moisture content in the non-freezing soils of southern Western Siberia during winter is weak, but the drop in groundwater levels is quite pronounced over the same period. The drop in groundwater levels can be used to predict the amount of moisture freezing in the soils of the Ishim Steppe (a) and Kulunda (6):

$$a) Y = 1,6586x + 6,6272;$$



Пропорциональная зависимость уровня грунтовых вод в октябре и прибавки влаги в слое намерзания в III декаде марта на территории Ишимской степи

Proportional dependence of the groundwater level in October and the increase in moisture in the freezing layer in the third ten-day period of March in the Ishim steppe

$$6) Y = 3,8077x + 11,085,$$

where Y – volume of moisture freezing, mm; x – drop in groundwater levels in October – March, cm; R^2 – approximation reliability value ($R^2 = 0,7463$ – for the Ishim steppe, $R^2 = 0,8954$ – for the Kulunda steppe).

The Yeravskaya forest-steppe is home to a variety of anthropogenic rocks, resulting in a layered structure. The top meter is composed of medium loams with a clay particle concentration of up to 29% (see Table 1). With a high clay content, micropores predominate in the porosity structure (see Table 2). Since large pores account for 26–34% of the soil volume, aeration porosity at the lowest moisture capacity reaches 16–22%. Sandy-gravelly deposits are found starting at a depth of 1 m. Aeration porosity, with the lowest water holding capacity, is 18–24%, resulting in significant water capacity and water yield from soils and subsurface rocks. Due to the large moisture resources in the suprapermfrost perched water, the volume of frozen water in the top meter of soil reaches 80 mm.

Meadow-chnozem soils of the Baraba forest-steppe are characterized by a heavy loamy

and light clayey texture (see Table 1). Micropores predominate in the porosity structure, which determines the high hydroadsorption capacity of the soils (maximum hygroscopicity of 7–13% of the mass) and high-water content of the pore space with moisture at the level of capillary water capacity (80–90%) (see Table 2). Therefore, the reserve water capacity and water yield of soils and rocks can be estimated as low. In meadow-chnozem soils, moisture freezes to a volume of 20–40 mm [1].

CONCLUSIONS

1. The soils of southern Siberia develop under similar hydrological and climatic conditions. The region is characterized by long (4–6 months) and cold winters (January temperatures range from –17 to –25°C) and thin snow cover (up to 0.5 m). The prevalence of lowland plains in the south of Western Siberia and the presence of permafrost in the forest-steppe of Transbaikalia result in groundwater levels close to the surface (2–5 m). These similarities suggest that the primary cause of differences in cryogenic moisture accumulation is the specific granulometric composition of soils and rocks.

2. Soils with heavy textures are characterized by high hydrosorption capacity (over 15%) and high-water content in their pore space (up to 77% at capillary capacity). Water yield from such soils is low (with a loss of 6 mm of moisture, the groundwater level drops by 0.1 m). Therefore, when groundwater levels are less than 4 m deep in autumn, the volume of frozen soil moisture is relatively small (less than 50 mm). Due to the movement of some groundwater toward the freezing layer, the groundwater level drops to 0.9 m. When groundwater levels are deep, only soil moisture is involved in winter migration, with the volume of frozen soil moisture reaching up to 25 mm.

3. With a light texture, soils have low hydrosorption capacity and pore water content (2–3% by weight and 53% by capillary capacity, respectively). Such soils are characterized by high

water yield—the water yield coefficient reaches 0.5. When groundwater levels are close to the surface, the freezing depth increases to 100 mm. Under such conditions, the drop in groundwater level due to partial movement toward the freezing front is small (up to 0.2 m). With deep groundwater levels and low soil moisture, the cryogenic moisture accumulation is less than 10 mm.

4. Proportionality formulas have been established to predict winter changes in the moisture profile of soils of different particle sizes. The key parameter for the forecast is the groundwater level in October.

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Дата поступления статьи / Received by the editors 12.03.2025
Дата принятия к публикации / Accepted for publication 16.04.2025
Дата публикации / Published 15.10.2025

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- reject the article due to its inconsistency to the journal’s goals, lack of originality and little scientific significance.

Correspondence with the authors of the manuscript is maintained through a key contact mentioned in the manuscript.

All scientific articles submitted to the editorial board of the journal “Siberian Herald of Agricultural Science” undergo obligatory double-blind reviewing (author and reviewer do not know about each other). Manuscripts are sent in accordance with their research profile for reviewing to the members of the Editorial Board.

In controversial cases, the editor may involve several specialists in the review process, as well as the Editor-in-Chief. If the reviewer’s opinion is positive, the article is submitted to the editor for preparation for publication.

In case a decision is made to have the manuscript revised, reviewer’s comments and remarks are passed to the author. The latter is given two months to make amendments. If, within this period, the author has not notified the editors about the actions planned, the article is removed from the publication waiting list.

In case there is a decision to reject the article, the notification with the editorial decision is sent to the author.

The designated author (contact author) is sent the final version of the manuscript accepted for publication, which he/she must check.

REVERSAL OF EDITOR/ REVIEWER’S DECISION

In case the author does not agree with the conclusions of the reviewer and/or editor, they can dispute the decision made. In order to do this, the author should:

- amend the manuscript in compliance with the comments substantiated by reviewers and editors;
- clearly outline their stance on the issue under question.

The editors facilitate the second submission of manuscripts that could potentially be accepted but were rejected due to the need of significant amendments or collection of the additional data, and are ready to clearly explain what must be rectified in the manuscript for it to be accepted for publication.

ACTIONS OF THE EDITORIAL BOARD IN CASE OF PLAGIARISM AND DATA FALSIFICATION DETECTION

The Editorial Board of the “Siberian Herald of Agricultural Science” follows the conventional ethical principles for scientific periodicals and guidelines of the “Publication Ethics Code” developed and approved of by the Committee on Publication Ethics (COPE) and demands that all those involved in the publishing process should obey these principles.

ERRORS RECTIFICATION AND ARTICLE WITHDRAWAL

In case of error detection that affect understanding of an article but do not distort the results of research, they can be rectified by replacing the pdf-file of an article. In case of error detection that distort the results of research or in case of plagiarism or misconduct of the author (authors) connected with data falsification, the article can be withdrawn. The withdrawal can be initiated by the editors, the author, organization or private individual. Such article is marked with the note “Article withdrawn”, the page of the article gives the reason for withdrawal. Information about the article withdrawal is sent to data bases where the journal is indexed.

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