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

SIBERIAN HERALD OF AGRICULTURAL SCIENCE

No 12
Volume 55
DECEMBER 2025

SIBERIAN HERALD OF AGRICULTURAL SCIENCE
Volume 55 No 12 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. 12 (325)
DOI: 10.26898

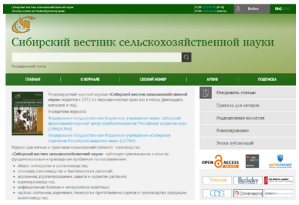
2025
December

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.

Acting Editor-in-Chief – Tatyana A. Lombanina, Head of the "Agronauka" Publishing House of the Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences, Novosibirsk, Russia

Editorial board:

Vladimir V. Azarenko	Dr. Sci. in Engineering, Cor. Mem. of the Nat. Acad. Sci. of Belarus, Minsk, Belarus
Victor V. Alt	Acad. of Russ. Acad. Sci., Dr. Sci. in Engineering, Novosibirsk, Russia
Olga S. Afanasenko	Acad. of Russ. Acad. Sci., Dr. Sci. in Biology, Saint-Petersburg, Russia
Gennady P. Gamzikov	Acad. of Russ. Acad. Sci., Dr. Sci. in Biology, Novosibirsk, Russia
Kirill S. Golokhvast	Cor. Mem. of Russ. Acad. Edu., Dr. Sci. in Biology, Novosibirsk, Russia
Nikolay P. Goncharov	Acad. of Russ. Acad. Sci., Dr. Sci. in Biology, Novosibirsk, Russia
Mikhail I. Gulyukin	Acad. of Russ. Acad. Sci., Dr. Sci. in Veterinary Medicine, Moscow, Russia
Valery N. Delyagin	Dr. Sci. in Engineering, Novosibirsk, Russia
Seyed Ali Johari	Associate Professor, PhD, Sanandaj, Iran
Irina M. Donnik	Acad. of Russ. Acad. Sci., Dr. Sci. in Biology, Moscow, Russia
Asankadyr T. Zhunushov	Dr. Sci. in Veterinary Medicine, Acad. of the Nat. Acad. Sci. Rep. of Kyrgyzstan, Bishkek, Kyrgyzstan
Nikolay M. Ivanov	Cor. Mem. of Russ. Acad. Sci., Dr. Sci. in Engineering, Novosibirsk, Russia
Andrey Yu. Izmailov	Acad. of Russ. Acad. Sci., Dr. Sci. in Engineering, Moscow, Russia
Nikolay I. Kashevarov	Acad. of Russ. Acad. Sci., Dr. Sci. in Agriculture, Novosibirsk, Russia
Valery I. Kiryushin	Acad. of Russ. Acad. Sci., Dr. Sci. in Biology, Moscow, Russia
Akhylbek K. Kurishbaev	Dr. Sci. in Agriculture, Acad. of Nat. Acad. Sci. Rep. of Kazakhstan, For. Mem. of the Russ. Acad. Sci., Alma-Ata, Kazakhstan
Sergey N. Mager	Dr. Sci. in Biology, Novosibirsk, Russia
Muhammad A. Nawaz	Professor, PhD, Tomsk, Russia
Askar M. Nametov	Dr. Sci. in Veterinary Medicine, Cor. Mem. of the Nat. Acad. Sci. Rep. of Kazakhstan, Uralsk, Kazakhstan
Vasil S. Nikolov	Dr. Sci. in Veterinary Medicine, Sofia, Bulgaria
Sergey P. Ozornin	Dr. Sci. in Engineering, Chita, Russia
Valery L. Petukhov	Dr. Sci. in Biology, Novosibirsk, Russia
Revmira I. Polyudina	Dr. Sci. in Agriculture, Novosibirsk, Russia
Amonullo F. Salimzoda	Dr. Sci. in Agriculture, Cor. Mem. of the Acad.of Agr. Sci. of Tajikistan, Dushanbe, Tajikistan
Marina I. Selionova	Dr. Sci. in Biology, Moscow, Russia
Vladimir A. Soloshenko	Acad. of Russ. Acad. Sci., Dr. Sci. in Agriculture, Novosibirsk, Russia
Nikolay A. Surin	Acad. of Russ. Acad. Sci., Dr. Sci. in Agriculture, Krasnoyarsk, Russia
Aristidis M. Tsatsakis	Dr. Sci. in Biology, For. Mem. of the Russ. Acad. Sci., Crete, Greece
Alexander A. Shpedt	Dr. Sci. in Agriculture, Krasnoyarsk, Russia
Sezai Ercisli	Professor, PhD, Erzurum, Turkey
Seung H. Yang	Professor, PhD, Gwangju, Korea



www. sibvest.elpub.ru

Editors *Evgeniy V. Egorov, Evgeniya M. Isaevich, Galina N. Yagupova.* Corrector *Valentina E. Selyanina.*
Desktop Publisher *Natalya Yu. Borisko.* Translator *Marina Sh. Gatsenko.*
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 19.12.2025. Format 60 ×84 1/8. Paper type. No. 1. Offset printing. Printer's sheet 18,25.
Publisher's signature 18,25. Circulation 500 copies. The price is free.

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

© Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences, 2025
© Siberian Branch of the Russian Academy of Sciences, 2025

СОДЕРЖАНИЕ

ЗЕМЛЕДЕЛИЕ И ХИМИЗАЦИЯ

Оленин О.А., Зудилин С.Н., Сафин Х.М. Комплексное применение органических удобрений и биопрепаратов в зернопаровом севообороте в условиях органического земледелия **5**

Савельева Д.А., Каличкин В.К., Сайнакова А.Б. Геоинформационное моделирование весенне-талой эрозии почв в подтаежной зоне Западной Сибири на основе USLE **15**

Воронин А.Н., Котяк П.А. Изменение фотосинтетической активности многолетних трав в зависимости от обработки почвы и удобрений **28**

РАСТЕНИЕВОДСТВО И СЕЛЕКЦИЯ

Любимова Н.А., Рабинович Г.Ю. Апробация биопрепарата с наночастицами оксида железа на семенах льна различной скороспелости **36**

CONTENTS

AGRICULTURE AND CHEMICALIZATION

Olenin O.A., Zudilin S.N., Safin Kh.M. Integrated application of organic fertilizers and biopreparations in grain-fallow crop rotation under organic farming conditions **5**

Savel'eva D.A., Kalichkin V.K., Saynakova A.B. Geoinformation modeling of spring-thaw soil erosion in the subtaiga zone of Western Siberia based on USLE **15**

Voronin A.N., Kotyak P.A. Changes in photosynthetic activity of perennial grasses depending on soil treatment and fertilizers **28**

PLANT GROWING AND BREEDING

Lyubimova N.A., Rabinovich G.Yu. Testing of a biopreparation with iron oxide nanoparticles on flax seeds of varying prematurity **36**

Раченко А.М., Раченко М.А., Мокшонова И.М., Раченко Д.М. Сравнительная оценка клоновых подвоев яблони различного происхождения для использования в Иркутской области

47 **Rachenko A.M., Rachenko M.A., Mokshonova I.M., Rachenko D.M.** Comparative evaluation of clonal apple rootstocks of various origin for use in the Irkutsk region

Хасбиуллина О.И., Гайнатулина В.В., Хасбиуллин Р.А. Семеноводство картофеля в Камчатском крае: оценка и отбор отечественных сортов

56 **Khasbiullina O.I., Gainatulina V.V., Khasbiullin R.A.** Seed potato production in the Kamchatka Territory: evaluation and selection of domestic varieties

ЗАЩИТА РАСТЕНИЙ

PLANT PROTECTION

Басай З.В., Мороховец В.Н., Мороховец Т.В., Вострикова С.С., Маркова Е.С. Щетинники зеленый и сизый в агроценозах Приморского края и поиск эффективных почвенных гербицидов для борьбы с ними в посевах сои

66 **Basai Z.V., Morokhovets V.N., Morokhovets T.V., Vostrikova S.S., Markova E.S.** Green bristle-grass and yellow foxtail in the agrocenoses of the Primorsky Territory and the search for effective soil herbicides to control them in soybean crops

ЗООТЕХНИЯ И ВЕТЕРИНАРИЯ

ZOOTECHNICS AND VETERINARY MEDICINE

Авадани Д.А., Гончаренко Г.М., Хорошилова Т.С., Гришина Н.Б., Халина О.Л. Полиморфизм генов *CSN3*, *BLG*, *TNF-α-824*, *Pit-1*, *SCD1* и их влияние на молочную продуктивность коров черно-пестрой породы

75 **Avadani D.A., Goncharenko G.M., Khoroshilova T.S., Grishina N.B., Khalina O.L.** Polymorphism of the *CSN3*, *BLG*, *TNF-α-824*, *Pit-1*, *SCD1* genes and their influence on milk productivity of cows of the Black-and-White breed

Безбородова Н.А., Соколова О.В., Мартынов Н.А., Зверев А.В., Романов Е.В., Юсупова Ч.Р. Молекулярно-генетический мониторинг наследственных аномалий у крупного рогатого скота: гипотрихоз, идиопатическая эпилепсия и дилютор-фенотип (обзор)

86 **Bezborodova N.A., Sokolova O.V., Martynov N.A., Zverev A.V., Romanov E.V., Yusupova Ch.R.** Molecular genetic monitoring of hereditary abnormalities in cattle: hypotrichosis, idiopathic epilepsy and dilutor phenotype (review)

Новикова Н.Н., Власенко В.С. Иммунный статус голштинизированных коров с разным уровнем молочной продуктивности **94** **Novikova N.N., Vlasenko V.S.** Immune status of Holsteinized cows with different levels of milk productivity

Савельева Л.Н., Бондарчук М.Л., Некрасова О.С., Базарон Б.З., Дашинимаев Б.Ц. Эффективность нового средства природного происхождения при лечении желудочно-кишечных болезней телят, сопровождающихся диареей **103** **Savelyeva L.N., Bondarchuk M.L., Nekrasova O.S., Bazaron B.Z., Dashinimaev B.Ts.** Efficacy of a new natural remedy in the treatment of calves with gastrointestinal diseases accompanied by diarrhea

Пономарева Е.Н., Ширина Ю.М., Григорьев В.А., Сорокина М.Н., Файзулина Д.Р., Ковалева А.В., Мазанко М.С. Влияние использования в кормах про- и пребиотиков на физиологические показатели личинок тиляпии **111** **Ponomareva E.N., Shirina Yu.M., Grigoriev V.A., Sorokina M.N., Faizulina D.R., Kovaleva A.V., Mazanko M.S.** The effect of using pro- and prebiotics in feed on the physiological parameters of tilapia larvae

ИЗ ИСТОРИИ СЕЛЬСКОХОЗЯЙСТВЕННОЙ НАУКИ

FROM THE HISTORY OF AGRICULTURAL SCIENCE

Данилова А.А., Ткаченко Г.И., Колбин С.А. Полвека изучения плодородия черноземов Сибири (к 45-летию со дня образования лаборатории плодородия почв СибНИИ кормов СФНЦА РАН) **120** **Danilova A.A., Tkachenko G.I., Kolbin S.A**. Half a century of studying Siberian chernozem fertility (on the 45th anniversary of the foundation of the Soil Fertility Laboratory of the Siberian Research Institute of Fodder Crops SFSCA RAS)

ПАМЯТИ УЧЕНОГО

IN COMMEMORATION OF SCIENTIST

Александр Семенович Донченко **129** **Alexandr Semenovich Donchenko**

https://doi.org/10.26898/0370-8799-2025-12-1
УДК 631.58:632.931.1
Тип статьи: оригинальная
Type of article: original

Комплексное применение органических удобрений и биопрепаратов в зернопаровом севообороте в условиях органического земледелия

(✉)**Оленин О.А.[1], Зудилин С.Н.[1], Сафин Х.М.[2]**
[1]*Самарский государственный аграрный университет*
Самарская область, п.г.т. Усть-Кинельский, Россия
[2]*Академия наук Республики Башкортостан*
Уфа, Россия
(✉)e-mail: agrotonik63@mail.ru

На современном этапе в Российской Федерации на законодательном уровне закреплен стратегический курс развития АПК, ориентированный на активное применение системы органического земледелия. В связи с этим целью исследования стала оценка влияния органических удобрений и биопрепаратов в органической системе земледелия на показатели фитосанитарного состояния и урожайность культур зернопарового севооборота в условиях лесостепи Заволжья в сравнении с минеральными удобрениями и пестицидами в традиционной системе земледелия. Исследованы различные способы внесения биопрепаратов, а также многокомпонентных органических удобрений на основе диатомита и цеолита при использовании органической системы земледелия. Изучено влияние органических удобрений и биопрепаратов на распространенность поражения корневыми гнилями и бурой листовой ржавчиной и урожайность культур зернопарового севооборота в сравнении с минеральными удобрениями и пестицидами. Полученные результаты показали, что совместное применение дражирования семян и биопрепаратов по вегетации сокращает распространенность корневых гнилей в среднем на 44,6% по озимой ржи, 49,4% по твердой яровой пшенице, 50,5% по ячменю по сравнению с контролем. Снижение распространенности бурой листовой ржавчины достигало 46,4% по озимой ржи и 57,8% по твердой яровой пшенице. Наибольшую прибавку урожайности обеспечили применение органического удобрения, состоящего из диатомита, древесной золы и органического калия, и проведение предпосевного дражирования семян. В среднем по препаратам при двукратной обработке за вегетацию биопрепарат давал прибавку урожайности 8,2–54,4% по отношению к контролю и 2,5–24,7% по отношению к пестицидам. Среди сельхозкультур наиболее отзывчивыми на биопрепарат оказались твердая яровая пшеница и нут: превышение показателей контроля на 54,4 и 47,6% (0,62 и 0,50 т/га), пестицидов – соответственно на 20,2 и 24,7% (0,23 и 0,26 т/га). Таким образом, комплексное применение в системе органического земледелия многокомпонентных полифункциональных органических удобрений и биопрепаратов с функциями биозащиты обеспечивает агрономический эффект, не уступающий по эффективности комплексному применению синтетических химических минеральных удобрений и пестицидов.

Ключевые слова: органическая система земледелия, органические удобрения и биопрепараты, зернопаровой севооборот, корневые гнили, бурая листовая ржавчина, урожайность

Integrated application of organic fertilizers and biopreparations in grain-fallow crop rotation under organic farming conditions

(✉)**Olenin O.A.[1], Zudilin S.N.[1], Safin Kh.M.[2]**
[1]*Samara State Agrarian University*
Ust-Kinelsky, Samara region, Russia

[2]*Academy of Sciences of the Republic of Bashkortostan*
Ufa, Russia
(✉)e-mail: agrotonik63@mail.ru

At the present stage, the strategic course for the development of the agro-industrial complex, focused on the active application of the organic farming system, has been enshrine at the statutory level in the Russian Federation. In this regard, the purpose of the study was to assess the influence of organic fertilizers and biopreparations in the organic farming system on the phytosanitary conditions and crop yields of grain-fallow crop rotation in the forest-steppe conditions of the Trans-Volga region in comparison with mineral fertilizers and pesticides in the traditional farming system. Various methods of introducing biopreparations, as well as multi-component organic fertilizers based on diatomite and zeolite, were studied when using an organic farming system. The influence of organic fertilizers and biopreparations on the prevalence of root rot and brown leaf rust and the yield of grain-fallow crop rotation was studied in comparison with mineral fertilizers and pesticides. The obtained results showed that the combined use of seed pelleting and biopreparations during vegetation reduces the prevalence of root rot by an average of 44.6% for winter rye, 49.4% for hard spring wheat, and 50.5% for barley compared to the control. The reduction in the prevalence of brown leaf rust reached 46.4% for winter rye and 57.8% for hard spring wheat. The greatest increase in yield was achieved by using organic fertilizer consisting of diatomite, wood ash and organic potassium, as well as pre-sowing seed pelleting. On average, for preparations, with two treatments during the growing season, the biopreparation gave an increase in yield of 8.2–54.4% in relation to the control and 2.5–24.7% in relation to pesticides. Among agricultural crops, hard spring wheat and chickpeas turned out to be the most responsive to the biopreparation: the control indicators were exceeded by 54.4 and 47.6% (0.62 and 0.50 t/ha), and pesticides – by 20.2 and 24.7% (0.23 and 0.26 t/ha), respectively. Thus, the integrated use of multi-component, multifunctional organic fertilizers and biopreparations with bioprotection functions in the organic farming system provides an agronomic effect that is not inferior in effectiveness to the integrated use of synthetic chemical mineral fertilizers and pesticides.

Keywords: organic farming system, organic fertilizers and biological products, grain-fallow crop rotation, root rots, brown leaf rust, yield

Для цитирования: *Оленин О.А., Зудилин С.Н., Сафин Х.М.* Комплексное применение органических удобрений и биопрепаратов в зернопаровом севообороте в условиях органического земледелия // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 12. С. 5–14. https://doi.org/10.26898/0370-8799-2025-12-1

For citation: Olenin O.A., Zudilin S.N., Safin Kh.M. Integrated application of organic fertilizers and biopreparations in grain-fallow crop rotation under organic farming conditions. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 12, pp. 5–14. https://doi.org/10.26898/0370-8799-2025-12-1

Конфликт интересов
Авторы заявляют об отсутствии конфликта интересов.
Conflict of interest
The authors declare no conflict of interest.

INTRODUCTION

In Russia, a strategic course for the development of the agro-industrial complex is recognized by law and is focused on organic farming, which is one of the basic elements of the system for preserving and increasing soil fertility, producing environmentally safe products, and decarbonizing agriculture as a whole [1, 2].

Samara State Agrarian University (SamSAU) is developing crop rotations (a set of crops and methods of their sowing) for organic farming that provide a bio-protection effect under global climate change conditions; multi-component organic fertilizers and biopreparations based on the processing of various types of organic waste and raw materials, natural minerals, as well as new methods of their application to the soil and during vegetation.

The purpose of the study is to examine the impact of organic fertilizers and biopreparations in the organic farming system on the indicators of phytosanitary condition and crop yield of grain-fallow crop rotation in the forest-steppe of Trans-Volga region, compared with mineral

fertilizers and pesticides used in the traditional farming system.

The research objectives are:

1) the development of methods for applying organic biopreparations and fertilizers based on diatomite and zeolite in an organic farming system;

2) the development of new methods of sowing crops for organic crop rotation;

3) the study of the effect of organic fertilizers and biopreparations on the prevalence of root rots and brown leaf rust, as well as the yield of crops in comparison with mineral fertilizers and pesticides.

MATERIAL AND METHODS

The objects of the study were the crops of the following plants: winter rye of the Bezenchukskaya 110 variety, spring barley of the Orlan variety, hard spring wheat of the Bezenchukskaya Stepnaya variety (originator – Samara Research Institute of Agriculture – branch of the Samara Scientific Center of the Russian Academy of Sciences); naked oats of the Bekas variety (originators – FSBSI Federal Agrarian Scientific Center of the North-East, FSBIS Samara Federal Research Center of the Russian Academy of Sciences); safflower of the Ershovsky 4 variety, chickpea of the Galileo variety, phacelia of the Anastasia variety (originator – OOO "EIE 'Pokrovskoe'").

The study was conducted at the experimental field of the SamSAU in 2017–2022. The soil is a typical medium-thick heavy loamy chernozem. Humus content is 5.3%, pH_{salt} = 6.9. In the 0–30 cm layer, the concentration of easily hydrolyzable nitrogen is 80–120 mg/kg, mobile phosphorus is 135–145 mg/kg, and mobile potassium is 150–195 mg/kg.

During the years of the study, from May to August, precipitation amounted to only 89.6% of the norm, while the average air temperature for the same period exceeded the long-term average by 9.4%. Accordingly, the trend of increasing aridity during the active growing season of field crops in the forest-steppe of the Trans-Volga region due to global climate change is confirmed.

The following indicators were studied during the experiment: the prevalence of root rot in cereal crops (methodology of the All-Russian Research Institute of Plant Protection) and brown leaf rust (Rusakov scale), yield (GOST 12041–82[1] and GOST 12037–81[2]). Methods of dispersion and correlation analysis were also used[3].

Field stationary two-factor experiment in crop rotation:

1) phacelia (green manured fallow);

2) winter rye + spring barley (spring mixed sowing);

3) winter rye;

4) safflower;

5) chickpea + hard spring wheat (cross sowing);

6) naked oats.

Seeding rates: cereal grain crops – 4.5–5.0 million viable seeds/ha (200–220 kg/ha), chickpeas – 0.80–0.90 million (200–240 kg/ha), safflower – 0.25–0.30 million (10–12 kg/ha), phacelia – 4.30–6.00 million (10–12 kg/ha). Mixed and cross sowing: rye + barley – 50% each of the standard seeding rate, chickpeas + wheat – 70% and 50% of the standard seeding rate, respectively.

There are 21 options in the field, 63 plots, with triple repetition. The total area of the field is 0.40 ha, the area of first-order plots is 189 m², second-order – 63 m² (4.5 × 14.0 m), the record area of the plots is 31.5 m². The arrangement of the plots is systematic.

Fertilizers (factor A) were applied at sowing from the seeder into the row on the seedbed, used for cereal grains, grain legumes, safflower, and mixes (fertilizers were not applied in the green manured fallow): A_1 – control; A_2 – 100 kg/ha of nitroammophoska (NPK 16:16:16); A_3 – 150 kg/ha of organo-mineral fertilizer 'di-

[1]GOST 12041–82. Agricultural crop seeds. Methods for moisture content determination. Moscow: Standartinform, 2011.

[2]GOST 12037–81. Agricultural crop seeds. Methods for determining seed purity and waste. Moscow: Standartinform, 2011.

[3]*Dospekhov B.A.* Methodology of field experiment (with the basics of statistical processing of research results). Moscow: Alliance, 2011, 350 p.

atomite + potassium humate + chicken manure extract + nitroammophoska'[4]; A_4 – 200 kg/ha of organic fertilizer 'diatomite + wood ash + organic potassium'[5]; A_5 – 100 kg/ha of a multi-component organic mixture containing trace elements, with the functions of biofertilizer, biostimulant, biofungicide, and biobactericide in the form of pre-sowing seed coating[6, 7]; A_6 – 200 kg/ha of organic fertilizer 'zeolite + effluent + potassium humate'[8]; A_7 – 200 kg/ha of organic fertilizer 'zeolite + diatomite + chicken manure + wood ash'[9].

Coating of chickpea seeds was not carried out for technological reasons: large diameter and smooth leathery seed coat.

During the growing season, foliar treatment (spraying) with the preparations (factor B) was carried out across the direction of sowing and fertilizer application: B_1 – control; B_2 – pesticides in the form of a fungicide and/or insecticide, and/or herbicide; B_3 – multicomponent biopreparation with functions of biofertilizer, biostimulator, antistress, and biofungicide/biobactericide[10].

Treatment with the preparations was carried out twice (except for the green manured fallow): cereal grains – at the tillering and stem elongation stages, chickpea – before the budding stage, safflower – at the beginning of branching and beginning of budding stages.

Pesticides were applied at the recommended rates according to the instructions, and the biopreparation – at a rate of 3.0 l/ha with a working solution volume of 150 l/ha.

Seeds were treated with a chemical seed treatment only in the variant with mineral fertilizer nitroammophoska (A_2) across all B backgrounds; in variants with organo-mineral (A_3) and organic fertilizers (A_4–A_7), biotreatment of seeds was carried out by coating the grain (A_5) or by applying fertilizers together during sowing (A_3, A_4, A_6, A_7).

Soil treatment: green manure incorporation – double disking to 6–8 and 10–12 cm (after 10–14 days), if weeds regrow – repeat disking to 6–8 cm; for spring mixed sowing – early spring harrowing, cultivation no earlier than 1–2 days before sowing; for safflower, cross sowing, naked oats and green manured fallow: primary – double disking to 6–8 and 10–12 cm (after 10–14 days), spring – early spring harrowing, cultivation no earlier than 1–2 days before sowing.

Sowing was carried out using an Amazone Primera DMC seeder (working width 4.5 m). Following sowing, rolling was done with a KKS-6 roller. For spraying, an Amazone UF 01 sprayer was used (working width 14 m), and for harvesting, a TERRION SR2010 combine harvester was used.

RESULTS AND DISCUSSION

Root rots caused by soil-borne pathogenic fungi more often affect wheat, rye, and barley, becoming a cause of deterioration in crop structure indicators and reducing crop productivity by up to 40%[11] [3, 4].

[4]Patent (RU) No. 2800714. Complex organomineral fertilizer based on diatomite / Olenin O.A., Zudilin S.N.; submitted 13.03.23; published 26.07.23, Bulletin No. 30.

[5]Patent (RU) No. 2756819. Organic complex plant nutrition with soil improver function / Olenin O.A., Zudilin S.N.; submitted 03.22.21; published 10.06.21, Bulletin No. 28.

[6]Patent (RU) No. 2782430. Method of pelleting seeds of agricultural crops / Chistov A.V., Kutuzov E.L., Kutuzov S.L., Olenin O.A., Zudilin S.N.; submitted 01.09.21; publ. 10/26/22, Bulletin. No. 30.

[7]Patent (RU) No. 2829217. Composition for pelleting seeds of grain and cereal crops / Olenin O.A., Zudilin S.N.; submitted 08.04.24; published 30.10.24, Bulletin No. 31.

[8]Patent (RU) No. 2781283. Multicomponent organic fertilizer based on nanostructured zeolite with soil improver and biostimulant functions / Olenin O.A., Zudilin S.N.; submitted 08.04.22; published 11.10.22, Bulletin No. 29.

[9]Patent (RU) No. 2805874. Complex fertilizer based on diatomite and zeolite / Olenin O.A., Zudilin S.N.; submitted 31.01.23; published 24.10.23, Bulletin No. 30.

[10]Patent (RU) No. 2830874. Complex extract from humate-containing substrates and method for its production / Olenin O.A.; submitted 03/15/24; published 11/26/24, Bulletin No. 33.

[11]*Zudilin S., Olenin O., Vasilisko A., Zudilin A.* Application of biotechnologies in production of multifunctional biopreparations for organic farming // 20th International Multidisciplinary Scientific GeoConference – SGEM 2020. Sophia, 2020, Iss. 6.2, pp. 55–64.

The main elements of integrated bioprotection in the organic farming system are the following: a) crop rotation (phytosanitary and nectar plants, enrichment with legumes (up to 25–30%), perennial grasses, mixed and joint sowings); b) seed biotreatment; c) seed coating with biotreatment; d) introducing multi-component organic fertilizers and biopreparations with bioprotection functions into the soil before and during sowing; e) treatment of crops with bioprotective biopreparations – on the leaves (ground sprayers and UAS (unmanned aircraft system)) and into the soil (multi-injector, up to a certain phase of crop growth and development); f) new crops and varieties resistant to bioprotection under extreme weather conditions and global climate changes [5–8].

The influence of fertilizers and treatments on the prevalence of root rots is presented in Table 1 (on average over two surveys in the tillering and milk ripeness phases of the grain; for winter rye – in 2017 at the tillering phase and after 30 days).

According to the obtained results, in winter rye, the greatest reduction in disease incidence was contributed by the biopreparation (B_3) and organic fertilizers with a biofungicide function (A_4 and A_5). Accordingly, the most significant decrease was noted in the variant 'seed coating + biopreparation' (A_5B_3): 44.6% higher compared to the control (A_1B_1) and 50.6% higher compared to the variant 'nitroammophoska + pesticides' (A_2B_2).

The highest effectiveness of the biopreparation and organic fertilizers was observed on barley and wheat. Thus, the most significant reduction in disease incidence was noted in variant A5B3: on barley – by 50.5% compared to the control and by 52.3% compared to variant A2B2, on wheat – by 49.4% and 57.2% respectively.

Brown leaf rust, caused by the fungus *Puccinia triticina*, primarily affects wheat, rye, triticale, and wild grasses. The occurrence of the disease is promoted by the use of susceptible varieties and fertilizers with mineral nitrogen, as well as prolonged warm weather with high humidity during the active growing period. The disease reduces yields by 10–50%, and with significant infection of crops, total loss is possible [9–11].

The influence of fertilizers and treatments on the prevalence of brown leaf rust is presented in Table 1 (on average over two surveys in the tillering (spring) and milk ripeness phases of the grain; for winter rye – not determined in 2017).

In winter rye, the greatest reduction in disease incidence was contributed by the biopreparation and organic fertilizers. Thus, the biopreparation reduced the prevalence of brown rust by 25.6% compared to the control and by 7.7% compared to pesticides.

Similar patterns were observed in wheat. For example, the biopreparation contributed to a reduction in disease incidence by 41.7% compared to the control and by 17.1% compared to pesticides. The most significant reduction in the prevalence of brown leaf rust was noted in the 'seed coating + biopreparation' treatment (A_5B_3) – 57,8%.

Thus, in cereal grain crops, the greatest reduction in the prevalence of root rots and brown leaf rust was facilitated by organic fertilizers with bioprotection functions.

Pre-sowing seed pelleting, in addition to being an innovative method of introducing organic fertilizers and biopreparations into the soil, turned out to be the most effective method of disease control in an integrated bio-protection system. When seeds are coated with a shell made of a complex organic composition containing ingredients for biofungicidal, biobactericidal, and bioinsecticidal (if necessary) protection, biopriming occurs, and microorganisms – antagonists of pathogenic microflora – immediately enter the potential rhizosphere zone of the seedlings at sowing, from where the beneficial microorganisms and their metabolites penetrate into the above-ground organs of the plants.

Multicomponent biopreparations with bioprotection functions surpass pesticides in the effectiveness of reducing the prevalence of the studied diseases. At the same time, the greatest synergistic effect of integrated bioprotection was noted when combining seed coating and the use of the biopreparation during vegetation.

Yield is the ultimate indicator of the efficiency of the main elements of the farming system, including the fertilizer system and the integrated plant protection system [12–14].

Табл. 1. Распространенность поражения корневыми гнилями и бурой листовой ржавчиной растений культур зернопарового севооборота (2017–2022 гг.), %

Table 1. The prevalence of root rot and brown leaf rust in crops of grain-fallow crop rotation (2017–2022), %

Fertilizer system (A)	Root rots						Brown leaf rust			
	Winter rye		Barley		Hard spring wheat		Winter rye		Hard spring wheat	
	average	% to the control	average	% to the control	average	% to the control	average	% to the control	average	% to the control
Protection system (*B*) *Control* (B_1)										
Control (A_1)	26,9	100,0	28,3	100,0	24,3	100,0	20,7	100,0	18,7	100,0
NAPK (A_2)	28,1	104,5	28,8	101,8	26,1	107,4	21,0	101,5	19,3	103,2
D + PH + CME + NAPK (A_3)	25,2	93,7	26,0	91,9	22,8	93,8	17,5	84,5	18,3	97,9
D + WA + OP (A_4)	24,1	85,6	26,3	92,9	22,8	93,8	17,7	85,5	18,0	96,3
Seed coating (A_5)	18,2	67,6	17,9	63,3	18,4	75,7	16,0	77,3	15,1	80,7
Z + E + PH (A_6)	27,8	103,3	28,2	99,7	25,3	104,1	17,8	86,0	19,1	102,1
Z + D + КП + WA (A_7)	24,1	89,6	26,3	92,9	22,6	93,0	17,3	83,6	17,8	95,2
Average	24,9	92,6	26,0	91,9	23,2	95,5	18,3	88,4	18,0	96,3
Pesticides (B_2)										
Control (A_1)	28,5	106,0	28,3	100,4	25,6	105,3	22,2	107,2	16,6	88,8
NAPK (A_2)	28,5	106,0	28,8	101,8	26,2	107,8	22,9	110,6	15,9	85,0
D + PH + CME + NAPK (A_3)	24,9	92,6	26,0	92,2	22,8	93,8	19,4	93,7	14,3	76,5
D + WA + OP (A_4)	24,3	90,3	26,3	88,0	22,2	91,4	20,3	98,1	15,2	81,3
Seed coating (A_5)	18,3	68,0	17,9	62,2	17,5	72,0	13,5	65,2	10,3	55,1
Z + E + PH (A_6)	28,6	106,3	28,2	98,6	24,4	100,4	18,4	88,9	13,0	69,5
Z + D + CM + WA (A_7)	26,7	99,3	26,3	88,7	22,2	91,4	17,0	82,1	13,4	71,7
Average	25,7	95,5	26,0	90,1	23,0	94,7	19,1	92,3	14,1	75,4
Biopreparation (B_3)										
Control (A_1)	26,0	96,7	24,7	87,3	21,5	88,5	16,1	77,8	11,9	63,6
NAPK (A_2)	25,2	93,7	25,8	91,2	22,5	92,6	17,1	82,6	11,7	62,6
D + PH + CME + NAPK (A_3)	22,8	84,8	23,3	82,3	19,6	80,7	16,0	77,3	9,7	51,9
D + WA + OP (A_4)	22,4	83,3	22,5	79,5	18,3	75,3	15,7	75,9	10,3	55,1
Seed coating (A_5)	14,9	55,4	14,0	49,5	12,3	50,6	11,1	53,6	7,9	42,2
Z + E + PH (A_6)	23,0	85,5	21,3	75,3	17,0	70,0	16,4	79,2	11,6	62,0
Z + D + CM + WA (A_7)	23,1	85,9	20,7	73,1	16,1	66,3	15,7	75,9	13,3	71,1
Average	22,5	83,6	21,8	77,0	18,2	74,9	15,4	74,4	10,9	58,3

Note. In tables 1, 2: NAPK – nitroammophoska; D + PH + CME + NAPK – diatomite + potassium humate + chicken manure extract + nitroammophoska; D + WA + OP – diatomite + wood ash + organic potassium; Z + E + ГК – zeolite + Effluent + potassium humate; Z + D + CM + WA – zeolite + diatomite + chicken manure + wood ash.

The influence of fertilizers and treatments on the yield of crops in the grain-fallow crop rotation is shown in Table 2.

According to the received data, in winter rye, the effectiveness of organic fertilizers and nitroammophoska on yield turned out to be at the same level. The greatest increase was provided by pelleting – 7.0–12.7% (0.23–0.42 t/ha) compared to the control (3.31 t/ha). The use of the biopreparation proved to be 8.2% more ef-

Табл. 2. Урожайность культур зернопарового севооборота (2017–2022 гг.), т/га
Table 2. Crop yields of the grain-fallow crop rotation (2017–2022), t/ha

Fertilizer system (A)	Barley		Winter rye		Safflower		Chickpea		Hard spring wheat		Hulless oats	
	average	% to the control	average	% to the control	average	% to the control	average	% to the control	average	% to the control	average	% to the control
Protection system (*B*) *Control* (B_1)												
Control (A_1)	1,26	100,0	3,31	100,0	1,02	100,0	1,05	100,0	1,14	100,0	2,04	100,0
NAPK (A_2)	1,36	107,9	3,48	105,1	1,09	106,9	1,19	113,3	1,33	116,7	2,22	108,8
D + PH + CME + NAPK (A_3)	1,43	113,5	3,31	100,0	1,11	108,8	1,29	122,9	1,41	123,7	2,20	107,8
D + WA + OP (A_4)	1,37	108,7	3,38	102,1	1,09	106,9	1,25	119,1	1,42	124,6	2,25	110,3
Seed coating (A_5)	1,49	118,3	3,54	107,0	1,15	112,8	–	–	1,44	126,3	2,25	110,3
Z + E + PH (A_6)	1,34	107,1	3,37	101,8	1,10	107,8	1,19	113,3	1,30	114,0	2,14	104,9
Z + D + CM + WA (A_7)	1,38	109,5	3,38	102,1	1,12	109,8	1,23	117,1	1,45	127,2	2,12	103,9
Average	1,38	109,5	3,40	102,7	1,10	107,8	1,20	114,3	1,36	119,3	2,17	106,4
Pesticides (B_2)												
Control (A_1)	1,31	104,0	3,32	100,3	1,03	101,0	1,13	107,6	1,29	113,2	2,11	103,4
NAPK (A_2)	1,45	115,1	3,44	103,9	1,08	105,9	1,25	119,1	1,55	136,0	2,22	108,8
D + PH + CME + NAPK (A_3)	1,49	118,3	3,50	105,7	1,08	105,9	1,35	128,6	1,62	142,1	2,34	114,7
D + WA + OP (A_4)	1,48	117,5	3,51	106,0	1,12	109,8	1,33	126,7	1,61	141,2	2,29	112,3
Seed coating (A_5)	1,56	123,8	3,60	108,8	1,20	117,7	–	–	1,65	144,7	2,31	113,2
Z + E + PH (A_6)	1,42	112,7	3,48	105,1	1,17	114,7	1,28	121,9	1,50	131,6	2,16	105,9
Z + D + CM + WA (A_7)	1,51	119,8	3,48	105,1	1,21	118,6	1,42	135,2	1,48	129,8	2,28	111,8
Average	1,46	115,9	3,48	105,1	1,13	110,8	1,29	122,9	1,53	134,2	2,24	109,8
Biopreparation (B_3)												
Control (A_1)	1,43	113,5	3,38	102,1	1,09	106,9	1,47	140,0	1,62	142,1	2,15	105,4
NAPK (A_2)	1,61	127,8	3,60	108,8	1,15	112,8	1,51	143,8	1,77	155,3	2,29	112,3
D + PH + CME + NAPK (A_3)	1,65	131,0	3,67	110,9	1,20	117,7	1,55	147,6	1,82	159,7	2,29	112,3
D + WA + OP (A_4)	1,67	132,5	3,53	106,7	1,16	113,7	1,57	149,5	1,79	157,0	2,33	114,2
Seed coating (A_5)	1,72	136,5	3,73	112,7	1,28	125,5	–	–	1,88	164,9	2,41	118,1
Z + E + PH (A_6)	1,55	123,0	3,53	106,7	1,22	119,6	1,54	146,7	1,71	150,0	2,26	110,8
Z + D + CM + WA (A_7)	1,63	129,4	3,65	110,3	1,25	122,6	1,63	155,2	1,76	154,4	2,30	112,7
Average	1,61	127,8	3,58	108,2	1,19	116,7	1,55	147,6	1,76	154,4	2,29	112,3
$LSD_{05total}$ (by years), t/ha	*2017* – 0,07 *2018* – 0,08 *2019* – 0,11 *2020* – 0,10 *2021* – 0,06 *2022* – 0,10		*2017* – 0,21 *2018* – 0,20 *2019* – 0,15 *2020* – 0,19 *2021* – 0,18 *2022* – 0,24		*2017* – 0,05 *2018* – 0,06 *2019* – 0,10 *2020* – 0,12 *2021* – 0,05 *2022* – 0,08		*2017* – 0,12 *2018* – 0,09 *2019* – 0,14 *2020* – 0,18 *2021* – 0,10 *2022*– 0,15		*2017* – 0,15 *2018* – 0,12 *2019* – 0,21 *2020* – 0,16 *2021* – 0,11 *2022* – 0,20		*2017* – 0,08 *2018* – 0,12 *2019* – 0,14 *2020* – 0,09 *2021* – 0,16 *2022* – 0,11	

fective than the control, and pesticides – 3.1%. The highest yield (3.73 t/ha) was observed in the variant 'seed pelleting + biopreparations' (A_5B_3) – an increase of 12.7% compared to the control and 4.3% relative to the variant 'nitroammophoska + pesticides' (A_2B_2).

For barley, the average yield in the variants with nitroammophoska was roughly at the same level as with organic fertilizers. Only seed coating had a significant advantage: for example, against the B_3 background, coating increased the yield by 8.7% (0.11 t/ha) compared to nitroammophoska. Relative to the control (A_1B_1; 1.26 t/ha), pesticides increased the yield on average by 15.9% (0.20 t/ha), and the bioproduct by 27.8% (0.35 t/ha).

In safflower, among fertilizers, the greatest increase in yield was provided by seed coating – 12.8–25.5% (0.13–0.26 t/ha) compared to the control (1.02 t/ha). When used together with a biopreparation during the growing season, the effectiveness of organic fertilizers increased significantly: for example, the highest yield was observed in the option "seed coating + biopreparation" (A_5B_3) – 1.28 t/ha. Treatment of crops with the biopreparation increased the yield by an average of 16.7% compared to the control and by 5.9% compared to pesticides.

Organic fertilizers and a biopreparation containing humic substances and a complex of microelements had a significant effect on chickpea yield. Thus, against the B_3 background, the application of nitroammophoska increased yield by an average of 43.8% compared to the control (1.05 t/ha), while organic fertilizers increased it by 46.7–55.2% (on A_7B_3 – 155.2%, or 1.63 t/ha). Compared to the control, pesticides increased chickpea yield by an average of 22.9% (0.24 t/ha), while the biopreparation increased it by 47.6% (0.50 t/ha).

On wheat, organic fertilizers in terms of yield increase were scarcely inferior to fertilizers with nitroammophoska. Thus, against the B_3 background, compared to the control (1.14 t/ha), nitroammophoska contributed to a yield increase of 55.3%, whereas pelleting – by 64.9%. For pesticide preparations, pesticides increased crop yields on average by 34.2% (0.39 t/ha) compared to the control, and biopreparations – by 54.4% (0.62 t/ha).

And only for oats, no significant differences were found in the impact on yield between mineral, organomineral and organic fertilizers, as well as between pesticides and the biopreparation.

Thus, organic fertilizers with bioprotection functions were comparable to or exceeded the options with organomineral and mineral fertilizers in terms of effectiveness on yield.

On average, the biopreparation with bioprotection functions contributed to a greater yield increase than pesticides: the excess compared to the control was 8.2–54.4%, compared to pesticides – 2.5–24.7%. Wheat and chickpeas were the most responsive to the biopreparation: the increase relative to the control (1.14 and 1.05 t/ha) was 54.4% and 47.6% (0.62 and 0.50 t/ha), respectively; the increase relative to pesticides was 20.2% and 24.7% (0.23 and 0.26 t/ha).

CONCLUSIONS

1. Multicomponent organic fertilizers based on diatomite and zeolite with bioprotection functions, when applied simultaneously with sowing, contributed to the greatest reduction in the prevalence of root rot and brown leaf rust in cereal crops. Moreover, their application in the form of pre-sowing seed coating proved to be the most effective.

2. The multicomponent biopreparation with bioprotection functions also contributed to a greater reduction in the prevalence of the studied disease complex. For example, on hard spring wheat, compared to the control, the biopreparation reduced the prevalence of brown leaf rust by an average of 41.7%, whereas pesticides reduced it by only 24.6%.

3. The strongest synergistic effect of the integrated bioprotection system was achieved with the combined use of the biopreparation and seed coating. For example, in hard spring wheat, the reduction of brown leaf rust averaged 57.8% compared to the control and 42.8% compared to the combination of pesticides and mineral fertilizer.

4. Multicomponent organic fertilizers, especially in the form of seed coating, contributed to yield increase no less than organo-mineral and mineral fertilizers. Thus, in hard spring wheat against the background of a biopreparation, the application of nitroammophoska increased yield on average by 55.3% (0.63 t/ha) compared to the control (1.14 t/ha), while coating increased it by 64.9% (0.74 t/ha).

5. The multicomponent biopreparation provided a greater yield increase than pesticides: the increase relative to the control averaged 8.5–54.4%, the increase relative to pesticides was 2.5–24.7%. For example, compared to the control, pesticides increased the yield of hard spring wheat by 34.2% (0.39 t/ha), while biopreparations increased it by 54.4% (0.62 t/ha).

6. The integrated use of multicomponent multifunctional organic fertilizers and biopreparations with bioprotection functions in the organic farming system provides an agronomic effect not inferior in effectiveness to the integrated use of synthetic chemical mineral fertilizers and pesticides.

СПИСОК ЛИТЕРАТУРЫ

1. *Кундиус В.А.* Эффективность органического сельского хозяйства в условиях научно-технологического суверенитета // Russian Journal of Management. 2023. Vol. 11. N 4. P. 125–138. DOI: 10.29039/2409-6024-2023-11-4-125-138.
2. *Мерзлая Г.Е.* Оценка продуктивности агроценозов в органическом и традиционном земледелии // Плодородие. 2020. № 6. С. 44–46.
3. *Жуковский А.Г., Крупенько Н.А., Буга С.Ф., Поплавская Н.Г., Жуковская А.А., Радивон В.А., Халаев А.Н., Жук Е.И., Радына А.А., Лешкевич В.Г., Бурнос Н.А., Крыжановская И.Н.* Корневая гниль зерновых культур и роль инфицированности семян в ее развитии // Защита растений. 2018. № 42. С. 84–95.
4. *Корчагина И.А., Юшкевич Л.В.* Особенности развития корневой гнили в агрофитоценозе пшеницы яровой при различных агротехнологиях в лесостепи Западной Сибири // Зерновое хозяйство России. 2022. Т. 14. № 6. С. 90–96. DOI: 10.31367/2079-8725-2022-83-6-90-96.
5. *Mudarisov S.G., Safin H.M., Farkhutdinov I.M., Aminov R.I.* Agrotechnical and energy assessment of strip tillage machine in field conditions // BIO Web of Conferences. 2020. Vol. 17. P. 00248. DOI: 10.1051/bioconf/20201700248.
6. *Мистратова Н.А., Ступницкий Д.Н., Яшин С.Е.* Органическое земледелие в России (обзорная статья) // Вестник Красноярского государственного аграрного университета. 2021. № 11. С. 100–107.
7. *Мазалов В.И., Кузнецов М.Н., Жук Г.П.* Использование агробиотехнологических приемов в органическом земледелии Орловской области // Зернобобовые и крупяные культуры. 2024. № 3 (51). С. 106–113. DOI: 10.24412/2309-348X-2024-3-106-113.
8. *Савенкова Е.В., Мистратова Н.А., Ступницкий Д.Н.* Фитосанитарный анализ севооборота с использованием принципов органического земледелия в условиях Красноярского края // Вестник Красноярского государственного аграрного университета. 2024. № 10. С. 68–73. DOI: 10.36718/1819-4036-2024-10-68-73.
9. *Гультяева Е.И., Шайдаюк Е.Л.* Идентификация генов устойчивости к бурой ржавчине у новых российских сортов мягкой пшеницы // Биотехнология и селекция растений. 2021. № 4 (2). С. 15–27. DOI: 10.30901/2658-6266-2021-2-02.
10. *Пономарева М.Л., Пономарев С.Н., Маннапова Г.С., Гильмуллина Л.Ф., Фомин С.И., Илалова Л.В.* Бурая ржавчина ржи: анализ многолетней динамики и источники устойчивости // Вестник Казанского государственного аграрного университета. 2019. № 3. С. 53–57. DOI: 10.12737/article_5db94fa6d589c6.74857948.
11. *Козлов А.В., Куликова А.Х., Селицкая О.В., Уромова И.П.* Устойчивость микробиологической активности дерново-подзолистой почвы в условиях применения диатомита и цеолита // Вестник Томского государственного университета. Биология. 2019. № 46. С. 26–47.
12. *Семинченко Е.В.* Урожайность севооборотов в зависимости от приемов биологизации // Аграрная наука. 2021. № 1. С. 121–124.
13. *Лукьянов В.А., Нитченко Л.Б.* Влияние севооборотов и минеральных удобрений на показатели экономико-энергетической эффективности при возделывании озимой пшеницы в ЦЧР // Зерновое хозяйство России. 2023. № 6. С. 90–98. DOI: 10.31367/2079-8725-2023-89-6-90-98.
14. *Мерзлая Г.Е., Афанасьев Р.А.* Эффективность органического земледелия // Плодородие. 2020. № 5. С. 56–60.

REFERENCES

1. Kundius V.A. Efficiency of organic agriculture in the conditions of scientific and technological sovereignty. *Russian journal of management = Russian Journal of Management*, 2023, vol. 11, no. 4, pp. 125–138. (In Russian). DOI: 10.29039/2409-6024-2023-11-4-125-138.
2. Merzlaya G.E. Productivity evaluation of agrocenoses based on the application of organic and mineral fertilizers. *Plodorodie = Plodorodie*, 2020, no. 6, pp. 44–46. (In Russian).
3. Zhukovsky A.G., Krupenko N.A., Buga S.F., Poplavskaya N.G., Zhukovskaya A.A., Radivon V.A., Khalaev A.N., Zhuk E.I., Radyna A.A., Leshkevich V.G., Burnos N.A., Kryzhanovskaya I.N. Root rot of grain crops and seed affection role in its severity. *Zashchita rasteniy = Plant Protection*, 2018, no. 42, pp. 84–95. (In Russian).

4. Korchagina I.A., Yushkevich L.V. Features of root rot development in the spring wheat agrophytocenosis under various agricultural technologies in the forest-steppe of Western Siberia. *Zernovoe khozyaistvo Rossii = Grain Economy of Russia*, 2022, vol. 14, no. 6, pp. 90–96. (In Russian). DOI: 10.31367/2079-8725-2022-83-6-90-96.
5. Mudarisov S.G., Safin H.M., Farkhutdinov I.M., Aminov R.I. Agrotechnical and energy assessment of strip tillage machine in field conditions. *BIO Web of Conference*, 2020, vol. 17, p. 00248. DOI: 10.1051/bioconf/20201700248.
6. Mistratova N.A., Stupnitskiy D.N., Yashin S.E. Organic farming in Russia (review article). *Vestnik KrasGAU = Bulletin of KrasSAU*, 2021, no. 11, pp. 100–107. (In Russian).
7. Mazalov V.I., Kuznetsov M.N., Zhuk G.P. The use of agrobiotechnological techniques in organic farming in the Orel region. *Zernobobovye i krupyanye kul'tury = Legumes and Groat Crops*, 2024, no. 3 (51), pp. 106–113. (In Russian). DOI: 10.24412/2309-348X-2024-3-106-113.
8. Savenkova E.V., Mistratova N.A., Stupnitskiy D.N. Crop rotation phytosanitary analysis using the organic farming principles in the Krasnoyarsk region conditions. *Vestnik KrasGAU = Bulletin of KrasSAU*, 2024, no. 10, pp. 68–73. (In Russian). DOI: 10.36718/1819-4036-2024-10-68-73.
9. Gultyaeva E.I., Shaidayuk E.L. Identification of leaf rust resistance genes in the new Russian varieties of common wheat. *Biotekhnologiya i selektsiya rasteniy = Plant Biotechnology and Breeding*. 2021, no. 4 (2), pp. 15–27. (In Russian). DOI: 10.30901/2658-6266-2021-2-02.
10. Ponomareva M.L., Ponomarev S.N., Mannapova G.S., Gilmullina L.F., Fomin S.I., Ilalova L.V. Brown rust of rye: analysis of long-term dynamics and sustainability sources. *Vestnik Kazanskogo gosudarstvennogo agrarnogo universiteta = Vestnik of Kazan State Agrarian University*, 2019, no. 3, pp. 53–57. (In Russian). DOI: 10.12737/article_5db94fa6d589c6.74857948.
11. Kozlov A.V., Kulikova A.Kh., Selitskaya O.V., Uromova I.P. Stability of microbiological activity of the sod-podzolic soil when applying diatomite and zeolite. *Vestnik Tomskogo gosudarstvennogo universiteta. Biologiya = Tomsk State University Journal of Biology*, 2019, no. 46, pp. 26–47. (In Russian).
12. Seminchenko E.V. Crop rotation yield depending on from the receptions of biologization. *Agrarnaya nauka = Agrarian Science*, 2021, no. 1, pp. 121–124. (In Russian).
13. Lukyanov V.A., Nitchenko L.B. The effect of crop rotations and mineral fertilizers on economic and energy efficiency indicators when cultivating winter wheat in the Central Blackearth region. *Zernovoe khozyaistvo Rossii = Grain Economy of Russia*, 2023, no. 6, pp. 90–98. (In Russian). DOI: 10.31367/2079-8725-2023-89-6-90-98.
14. Merzlaya G.E., Afanasyev R.A. Efficiency of crop production system based on the application of organic fertilizers. *Plodorodie = Plodorodie*, 2020, no. 5, pp. 56–60. (In Russian).

ИНФОРМАЦИЯ ОБ АВТОРАХ

(✉)**Оленин Олег Анатольевич,** научный сотрудник, кандидат сельскохозяйственных наук, научный сотрудник; ORCID 0000-0002-8253-1571; **адрес для переписки:** Россия, 446442, Самарская область, п.г.т. Усть-Кинельский, ул. Учебная, 2; e-mail: agrotonik63@mail.ru

Зудилин Сергей Николаевич, преподаватель, доктор сельскохозяйственных наук, профессор; ORCID 0000-0002-6113-5043

Сафин Халил Масгутович, академик-секретарь, доктор сельскохозяйственных наук, профессор; ORCID 0000-0001-8337-4371

AUTHOR INFORMATION

(✉)**Oleg A. Olenin,** Researcher, Candidate of Science in Agriculture; ORCID 0000-0002-8253-1571; **address:** 2, Uchebnaya St., Ust-Kinelsky, Samara Region, 446442, Russia; e-mail: agrotonik63@mail.ru

Sergey N. Zudilin, Lecturer, Doctor of Science in Agriculture, Professor; ORCID 0000-0002-6113-5043

Khalil M. Safin, Academic Secretary, Doctor of Science in Agriculture, Professor; ORCID 0000-0001-8337-4371

Дата поступления статьи / Received by the editors 07.08.2025
Дата принятия к публикации / Accepted for publication 30.10.2025
Дата публикации / Published 19.12.2025

https://doi.org/10.26898/0370-8799-2025-12-2
УДК 631.459.21:004.942
Тип статьи: оригинальная
Type of article: original

Геоинформационное моделирование весенneталой эрозии почв в подтаежной зоне Западной Сибири на основе USLE

(✉)**Савельева Д.А.[1], Каличкин В.К.[2], Сайнакова А.Б.[1]**
[1]*Сибирский научно-исследовательский институт сельского хозяйства и торфа – филиал Сибирского федерального научного центра агробиотехнологий Российской академии наук*
Томск, Россия
[2]*Сибирский федеральный научный центр агробиотехнологий Российской академии наук*
Новосибирская область, р.п. Краснообск, Россия
(✉)e-mail: daria.a.saveleva@yandex.ru

Представлены исследования по созданию геоинформационной модели весенneталой эрозии почв пашни на основе универсального уравнения потерь почвы Уишмейера и Смита (USLE) и проверки ее качества и точности в условиях подтаежной зоны Западной Сибири. Фактор эродирующей способности осадков *R* рассчитан на основе геоинформационной модели снежного покрова, включающей сведения о запасах воды в снеге, особенностях залегания снега на склонах разной экспозиции, характеристиках периода снеготаяния. Учтено также количество выпавших за период снеготаяния жидких осадков. Моделирование выполняли в программах QGIS, GRASS, SAGA. Качество модели оценивали с помощью общепринятых показателей – коэффициента корреляции Спирмена *r*, коэффициента детерминации R^2, средней относительной ошибки (Mean Relative Error – MRE), средней абсолютной ошибки (Mean Absolute Error – MAE), среднеквадратичной ошибки (Mean Squared Error – MSE). Сходимость модели с фактом оценивали с помощью статистики линейно-взвешенной каппы (k) в классах объема смыва, рассчитанных по методу натуральных интервалов Дженкса. Фактический смыв определяли методом учета струйчатых размывов в 2014–2023 гг. Точность модели USLE в целевых условиях не ниже, чем это описано в мировой литературе. Ошибка модели составляет в среднем 44% за 10 лет. Лучшие характеристики качества модели достигались на южных склонах при минимальном наличии промоин и минимальном увлажнении. Средние за 10 лет показатели качества модели: для южных склонов – r = 0,76…0,92, R^2 = 0,29…0,81, MRE = 0,39…0,64, MAE = 0,16…0,93, MSE = 0,07…2,66, k = 0,66…0,91; для северных склонов – r = 0,57…0,79, R^2 = 0,27…0,60, MRE = 0,43…0,45, MAE = 0,20…0,47, MSE = 0,13…1,42, k = 0,46…0,84. USLE может быть использована в качестве инструмента первичной оценки потенциала смыва почв пашни при весеннем снеготаянии в условиях подтайги Западной Сибири при использовании в расчетах *R*-фактора характеристик снежного покрова и условий снеготаяния.

Ключевые слова: весенneталая эрозия, геоинформационная модель, USLE, качество модели, Западная Сибирь

Geoinformation modeling of spring-thaw soil erosion in the subtaiga zone of Western Siberia based on USLE

(✉)**Savel'eva D.A.[1], Kalichkin V.K.[2], Saynakova A.B.[1]**
[1]*Siberian Research Institute of Agriculture and Peat - Branch of the Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences*
Tomsk, Russia
[2]*Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences*
Krasnoobsk, Novosibirsk region, Russia
(✉)e-mail: daria.a.saveleva@yandex.ru

The article presents research on the creation of a geoinformation model of spring-thaw erosion of arable soils based on the universal soil loss equation of Wischmeier and Smith (USLE) and testing its quality and accuracy in the conditions of the subtaiga zone of Western Siberia. The erosive capacity factor of precipitation *R* is calculated on the basis of a geoinformation model of snow cover, which includes information on water reserves in snow, features of snow deposition on slopes of different exposures, and characteristics of the snowmelt period. The amount of liquid precipitation that fell during

the snowmelt period was also taken into account. Modeling was performed using QGIS, GRASS, and SAGA. The quality of the model was assessed using generally accepted indicators: Spearman's correlation coefficient *r*, the coefficient of determination R^2, the mean relative error (MRE), the mean absolute error (MAE), and the mean squared error (MSE). The model convergence with the fact was assessed using the linear-weighted kappa (k) statistic in outwash volume classes calculated using the Jenks natural breaks method. The actual outwash was determined using the method of recording the flow erosion in 2014–2023. The accuracy of the USLE model under target conditions is not lower than that described in the world literature. The model error averages 44% over 10 years. The best model performance was achieved on southern slopes with minimal gullies and minimal moisture. Average 10-year model quality indicators: for southern slopes – r = 0,76…0,92, R^2 = 0,29…0,81, MRE = 0,39…0,64, MAE = 0,16…0,93, MSE = 0,07…2,66, k = 0,66…0,91; for northern slopes – r = 0,57…0,79, R^2 = 0,27…0,60, MRE = 0,43…0,45, MAE = 0,20…0,47, MSE = 0,13…1,42, k = 0,46…0,84. USLE can be used as a tool for the primary assessment of the potential for arable soil loss during spring snowmelt in the subtaiga conditions of Western Siberia when using the *R*-factor of snow cover characteristics and snowmelt conditions in the calculations.

Keywords: spring-thaw erosion, geoinformation model, USLE, model quality, Western Siberia

Для цитирования: *Савельева Д.А., Каличкин В.К., Сайнакова А.Б.* Геоинформационное моделирование весенне-талой эрозии почв в подтаежной зоне Западной Сибири на основе USLE // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 12. С. 15–27. https://doi.org/10.26898/0370-8799-2025-12-2

For citation: Savel'eva D.A., Kalichkin V.K., Saynakova A.B. Geoinformation modeling of spring-thaw soil erosion in the subtaiga zone of Western Siberia based on USLE. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 12, pp. 15–27. https://doi.org/10.26898/0370-8799-2025-12-2

Конфликт интересов
Авторы заявляют об отсутствии конфликта интересов.
Conflict of interest
The authors declare no conflict of interest.

INTRODUCTION

For drafting projects of on-farm adaptive landscape agriculture systems (ALAS), the methodology of agri-ecological land assessment is used, the formalized digital foundation of which is a software and hardware complex in the form of AgroGIS with digital maps and attribute databases. The number of electronic thematic map layers depends on the complexity of landscape-ecological conditions. By mutually overlaying thematic electronic map layers, a comprehensive map of agroecological groups and land types (mesorelief, soil-forming rocks, hydrological conditions, soil cover structures, soil properties, etc.) is formed. This map, along with its database and explanatory note, is the main document for ALAS design [1, 2].

In accordance with the ALAS formation methodology, eroded lands belong to a separate agro-ecological group and require a specialized approach in their agricultural use. For eroded lands, various options for soil protection farming systems and anti-erosion land organization are developed, taking into account the local agro-landscape conditions [3–5]. Areas similar in the intensity of erosional processes and soil cover are combined into agrolandscape strips, which in turn serve as working plots with approximately the same set of soil protection technologies, ensuring control over erosion processes [6]. As the risk of erosion increases, the use of complete fallow and arable crops is reduced or eliminated, and the role of soil conservation measures increases. The application of deep no-till soil cultivation with crop residues and straw left on the surface is of particular importance [7]. To develop and implement such systems, it is necessary to have information about permissible losses and the actual amount of soil washouts due to erosion at comparable levels of temporal and spatial resolution of assessments [8]. Currently, geographic information systems are widely used for calculating erosion-related soil losses, allowing for the processing of large volumes of data with

acceptable accuracy and spatial detail of washout estimates [9, 10].

Geoinformation modeling of the process of water erosion of the soil cover is a complex and not yet fully resolved problem; however, this modeling is one of the recognized effective tools for assessing the erosion hazard of soils. Soils are considered erosion-hazardous where combinations of natural conditions (relief, soil-forming and underlying rocks, precipitation) create the possibility of soil erosion when used for agricultural purposes[1] [11]. Erosion risk is assessed by the magnitude of a potential washout. Currently, there are a number of soil cover erosion models, one of which is the empirical USLE model (Universal Soil Loss Equation)[2]. This model is based on dividing the watershed into individual cells of a regular grid and assigning each cell a set of attributes, such as slope value, slope length, runoff erosion intensity, soil erodibility factor, and others.

At the Global Symposium on Soil Erosion, held in 2019 in Rome, USLE and its modifications were recognized as the most commonly used equations in the world for modeling soil erosion washout [12]. The main focus was on RUSLE – the revised universal soil loss equation as a model with more elaborated *P* and *R* factors. However, RUSLE still retains the basic structure of USLE, just like the equation presented in the State Standard of the USSR (GOST 17.4.4.03–86), which is currently in force on the territory of the Russian Federation. Despite the presence and recognition of ongoing problems with the use of the USLE-based approach at the level of global soil erosion monitoring, this model remains a priority, used at the international level.

The question of the applicability of the universal soil loss equation on the territory of Russia has been raised repeatedly, and the verdict of the assessment has not always been satisfactory, since for the conditions of Russia and the CIS countries, the necessary data to verify this equation are lacking, both in terms of erosion factors and in terms of the magnitude of soil loss [13]. In the literature, the description of the result of modeling soil erosion potential is most often observed without its comparison with actual washout [9, 14], which does not allow for the assessment of the quality of the output data. There are studies in which the authors state a good agreement between the model and actual data, but do not indicate the magnitude of deviations and do not provide information on the assessment of the level of agreement[3, 4]. Published results of the validation of the USLE model are rare; as an example, one can refer to the work [15]. For the territory of the subtaiga zone of Western Siberia, they are not found at all.

Within the sub-taiga of Western Siberia, the main problem is the small amount of up-to-date comprehensive information on soil erosion for most of the arable land. Here, the main soil erosion occurs during the spring snowmelt. The volume of erosion during this time can reach 80–90% of the annual volume and causes the greatest damage to the arable soil cover[5] [16]. In this regard, it is critically important to accumulate many years of continuous data on the actual washout of arable soils specifically during the snowmelt period and to use them to check the quality and accuracy of the mathematical models used, which will ultimately ensure the effectiveness of designing soil protection measures, saving time and resources.

[1] *Fetyukhin I.V., Chernenko V.V.* Factors of development, modeling and forecasting of soil erosion // International Agricultural Journal, 2018, N 1, pp. 11–13. DOI: 10.24411/2587-6740-2018-11003.

[2] *Wischmeier W.H., Smith D.D.* Predicting rainfall erosion losses: A guide to conservation planning. Washington: U.S. Government Printing Office. 1978, 58 p.

[3] *Gorbacheva E.N.* Application of the universal soil loss equation (RUSLE) in assessing the intensity of water-erosion processes based on GIS // Soil Science and Agrochemistry, 2011, N 2, pp. 42–51.

[4] *Gitas I.Z., Douros K., Minakou C., Silleos G.N., Karydas C.G.* Multi-temporal soil erosion risk assessment in N. Chalkidiki using a modified USLE raster model // EARSel eProceedings, 2009, vol. 8, N 1, pp. 40–52.

[5] *Gerasimenko V.P.* Average long-term soil loss in arable land under various natural and agricultural conditions // Eurasian Soil Science, 1995, N 5, pp. 608–616.

A significant contribution to the acquisition of information on soil washout from arable land and the characteristics of the snow cover in the study area is made by specialists such as Evseeva N.S., Kashiro M.A., Kvasnikova Z.N., and others. However, the issue of the practical application of the obtained and published data has still not been resolved.

The aim of the work is to create a geoinformation model of spring snowmelt soil erosion on arable land based on the Universal Soil Loss Equation (USLE) by Wischmeier and Smith, and to verify its quality and accuracy in the sub-taiga zone of Western Siberia.

The results of geoinformation modeling of springtime thaw soil erosion of arable land using an original approach to calculating the R-factor are considered; and, for the first time for the sub-taiga zone of Western Siberia, analysis of the convergence of actual and predicted washout data was carried out.

MATERIAL AND METHODS

Modeling and field studies were carried out in 2014–2023 in the Tomsk region on a total area of 53.4 ha at the Luchanovskaya scientific and production site of the Siberian Research Institute of Agriculture and Peat – a branch of the Siberian Federal Scientific Centre of Agro-Bio-Technologies. The lands have been under agricultural use for more than 85 years. The soils are agro-gray and agro-dark-gray, medium- and heavy-loamy. Studies were conducted on the slopes of two main exposures in the area (north and south). The average slope length is 100.2 m (31.6% of slopes are more than 120 m), and the average slope steepness is 1.36° (ranging from 0.24° to 3.87°).

The entire territory was divided into 534 survey plots with an area of 0.1 ha on the southern slopes (208 plots) and northern slopes (326). The plots are grouped into sites, which represent cascades of survey plots down the slope, 100 m wide and with a total length equal to the length of the slope. In total, 12 sites were analyzed (5 with southern exposure and 7 with northern exposure). The number of survey plots per site ranges from 37 to 48. Within all sites, the formation of temporary watercourses was observed annually during the snowmelt period. Based on this characteristic, the sites were divided into two types:

– type A – with moderate concentration of rain rills (presence of a single unbranched rain rill);

– type B – with high concentration of rain rills (presence of single or two and more branched rain rills on the site).

The calculation of the slope length and steepness factors LS, soil erodibility K, and vegetation cover factor C was carried out as in [16]. The values of the anti-erosion measures factor *P* were obtained from GOST 17.4.4.03–86. The erosive capability of precipitation factor *R* was calculated based on a snow cover geoinformation model. The model included calculations of the volume of water reserves in the snow, the snow accumulation coefficient on the slopes with different exposures, the washout intensity coefficient during snowmelt on the slopes with different exposures, and the amount of liquid precipitation that fell during the snowmelt period. For snow cover modeling, data presented in the works of N.S. Evseeva et al. [17], data from the open weather archive (https://rp5.ru), and the SRTM digital elevation model were used (http://srtm.csi.cgiar.org).

Based on the DEM, an electronic map of geomorphological phonotypes was created using a machine vision approach[6] to identify the main archetypes of terrain morphology in the area, which are associated with changes in snow cover thickness, and to create a general geomorphometric map. To obtain a power grid of the snow cover, on the basis of which an electronic

[6]*Jasiewicz J., Stepinski T.* Geomorphons – a pattern recognition approach to classification and mapping of landforms // Geomorphology, 2013, vol. 182, pp. 147–156. DOI: 10.1016/j.geomorph.2012.11.005.

map of water reserves in the snow was created, a multi-level β-spline method[7] was applied. Next, the R-factor calculation method was used, based on the modified Fourier index as in the work [16]. Modeling was carried out in the programs QGIS, GRASS, SAGA. Measurements of the actual washout volume were carried out using the method of recording for rill washes by S.S. Sobolev.

To assess the quality and accuracy of the model, the Spearman correlation coefficient, the coefficient of determination R^2, the mean relative error (Mean Relative Error – MRE), the mean absolute error (Mean Absolute Error – MAE), and the mean squared error (Mean Squared Error – MSE) were calculated.

The level of convergence between the model data and the actual data was checked using the coefficient of linear-weighted kappa (Kappa with Linear Weighting – k) based on the classification of the washout intensity in units of measurement – m³/0.1 ha (the size of one plot of record), created using the Jenks Natural Breaks method. The level of convergence (m³/ha) was also determined.

RESULTS AND DISCUSSION

As a result of the research, a long-term dataset of actual soil washout during the spring snowmelt period was obtained, and a geoinformation model of spring thaw erosion for the studied area was developed. A classification of lands was developed based on the amount of washout in cubic meters per survey plot and cubic meters per hectare. Analysis of the quality and accuracy of the obtained model was carried out. The main indicators of wash and the magnitudes of model deviations from reality are presented in Table 1.

The washout indicators from a single record plot on the southern slopes ranged from 0.01 to 2.73 m³ for the model and from 0 to 7.22 m³ according to actual measurements. On the northern slopes, the model showed washout values of 0.01–1.92 m³, while actual measurements were 0–12.05 m³. In 82.0% of cases for the southern slopes and 71.4% for the northern slopes, the sets of predicted data did not have statistically significant differences ($p > 0.05$) from the territorially corresponding sets of actual values, regardless of the magnitude of the R-factor and the condition of the arable surface.

Табл. 1. Показатели смыва и отклонений данных модели от факта (среднее за 2014–2023 гг.)
Table 1. Indicators of the outwash and deviations of the model data from the actual data (average for 2014–2023)

Indicator	Plot type	Southern slope	Northern slope
Washout from one plot, m³	A	0,28–0,82 / 0,27–0,92*	0,22–0,80 / 0,24–0,84
	B	0,35–1,79 / 0,29–0,50	0,45–1,81 / 0,32–0,56
Soil erosion, m³/ha	A	2,8–8,2 / 2,7–9,0	2,2–7,9 / 2,3–7,4
	B	3,6–17,9 / 2,8–4,8	3,4–15,0 / 3,0–5,2
Deviation of the model from the fact, %	All lands	–19,9 ± 3,65	–20,8 ± 3,65
	A	From –8,1 ± 3,84 To +9,1 ± 2,16	From –10,5 ± 2,90 To +11,1 ± 4,41
	B	–67,3 ± 7,73	–45,5 ± 5,79

*Fact / model.

[7] *Lee S., Wolberg G., Shin S.Y.* Scattered Data Interpolation with Multilevel B-Splines // IEEE transactions on visualisation and computer graphics, 1997, vol. 3, N 3, pp. 228–244. DOI: 10.1109/2945.620490.

Within the plots, the average gross soil washout on the southern slopes according to the model was 10.4–41.2 m³ along the entire slope, or 2.7–9.2 m³/ha. The actual washout here ranged from 10.4–66.3 m³, recalculated per 1 ha – 2.8–17.9 m³/ha. On the northern slopes, the model showed an average washout of 10.6–38.5 m³ along the entire slope, or 2.4–8.4 m³/ha. The actual gross washout from plots on the northern slopes was 10.0–83.3 m³, which corresponds to 2.2–18.1 m³/ha.

When moving down the slope, the absolute values of washout intensity varied on the southern slopes from 0.05 to 21.83 m³/ha according to the model and 0–47.0 m³/ha in reality, on the northern slopes – 0.08–17.77 m³/ha according to the model and 0–57.4 m³/ha in reality.

The absolute values of deviations of the model values from the actual values range from –1.2 to 11.8 m³ per one record plot, or from –4.9 to 48.9 m³/ha. On Type A plots on southern and northern slopes, the deviations of the model from the actual values are close: from –1.1 to +2.7 and from –1.2 to +3.0 m³ per one accounting plot, or from –3.7 to +9.4 and from –4.9 to +11.1 m³/ha, respectively.

Exceeding of actual values over modeled ones is mainly characteristic of arable land areas with developed erosion forms, predominantly in the lower halves of slopes. Exceeding of model data over actual values is noted on subhorizontal surfaces and, in some cases, at the foot of slopes. The deviation of model data reaches up to 78.6% (on average 8.6% for type A areas and 67.3% for type B) on southern slopes and up to 75.8% on northern slopes (on average 10.7% for type A areas and 45.5% for type B). On average, for the entire studied territory over 10 years, the model shows soil erosion amounts underestimated by 20.4 ± 3.30%.

In type A areas, at minimum *R*-factor values, the model predicted the closest washout values. No statistically significant differences were noted between the deviations of the model data from actual values for slopes of different exposures on average and for areas of type A. The average deviation from actual values on type B sites (statistically significant with $p < 0.001$) is higher on the southern slopes than on the northern slopes.

The presented diagrams illustrate the change in actual and predicted washout values when moving down the slope (see Fig. 1). The graphs reflect the impact of the most and least favorable conditions for erosion development on the slope on the amount of runoff from a single experimental plot. This combination of conditions (the magnitude of the *R*-factor, the expression of temporary watercourses on arable land and their nature, vegetation and the condition of the arable surface) corresponds to the maximum and minimum actual soil erosion. It has been shown that high values of the rainfall factor in the presence of rills on the plot cause an increase in actual erosion in the middle and lower third of the slope. The nature of the change in the model data is close to the actual one under conditions of low moisture and the absence or slight expression of rills on the site. It was also noted that even in the absence of autumn soil treatment, the difference in the model's deviation from reality increases.

The nature of the changes in the predicted washout values with movement down the slope is in good agreement with the changes in the actual values in the same direction. For southern slopes, the 10-year average Spearman correlation coefficient was $r = 0.67–0.98$ and $r = 0.27–0.93$ for northern slopes (see Table 2). The coefficient of determination R^2 varied from 0.07 to 0.93 depending on the morphometry of the slopes, the condition of the cultivated land surface, and the magnitude of the *R*-factor. On southern slopes, it was higher than on northern slopes for type A plots. Type B plots had low R^2 values. A decrease in the R-factor values determined an increase in the R^2 magnitude on both northern and southern slopes for plots of both types.

The mean relative error (MRE) ranged from 0.003 to 7.74, i.e., 0.3–774% (MAPE) of the

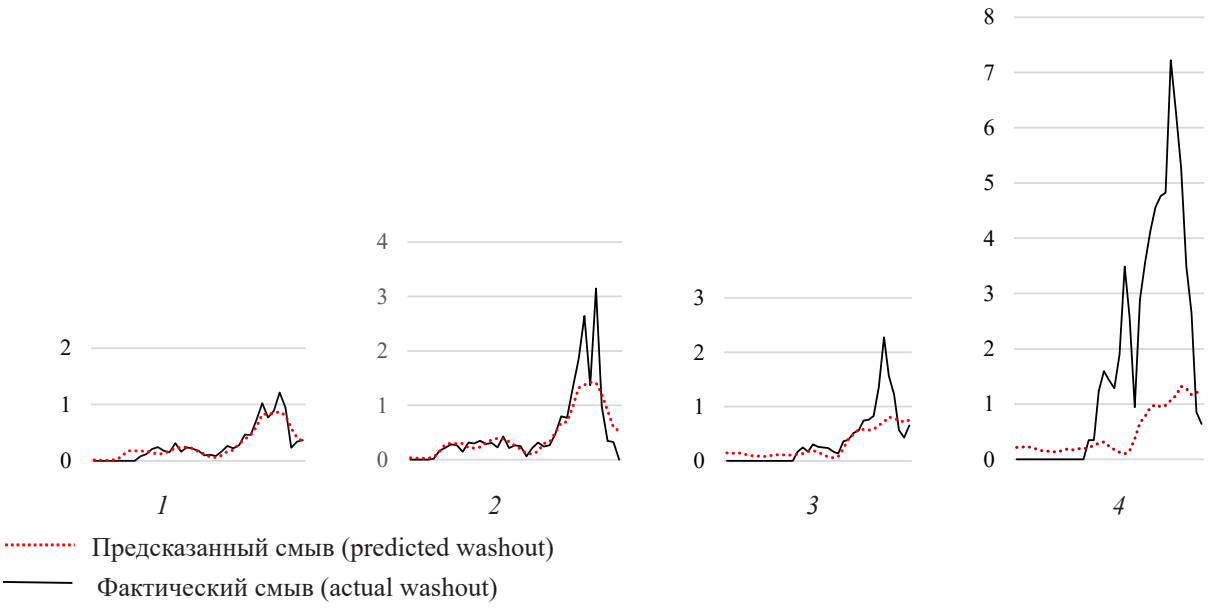


Рис. 1. Динамика объема весеннего смыва почвы при движении вниз по склону при разных сочетаниях условий:
ось *y* – м^3 на учетную делянку; ось *x* – изменение фактических и предсказанных значений при движении вниз по склону; условия: *1* – участок типа А, низкий *R*-фактор, зябь; *2* – участок типа А, высокий *R*-фактор, стерня яровых злаков; *3* – участок типа Б, низкий *R*-фактор, зябь; *4* – участок типа Б, высокий *R*-фактор, стерня яровых злаков

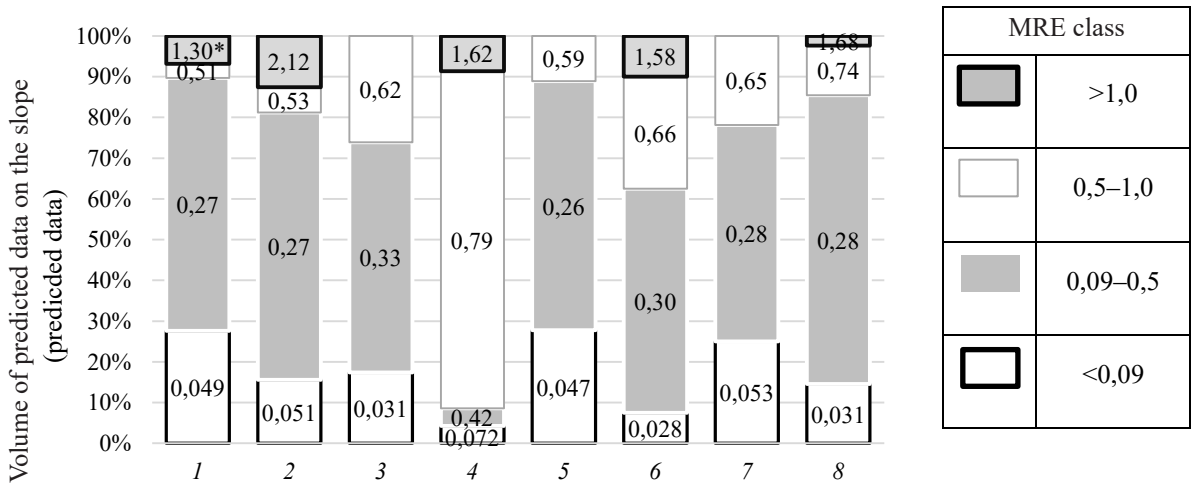
Fig. 1. Dynamics of the volume of spring soil erosion when moving down a slope under different combinations of conditions:
axis y – m^3 per plot; axis x – change in actual and predicted values when moving down the slope; conditions: *1* – type A plot, low *R*-factor, autumn plowing; *2* – type A plot, high *R*-factor, spring cereal stubble; *3* – type B plot, low R-factor, autumn plowing; *4* – type B plot, high *R*-factor, spring cereal stubble

Табл. 2. Показатели качества модели (среднее за 2014–2023 гг.) (min – max)
Table 2. Model quality indicators, (average for 2014–2023) (min – max)

Indicator	Plot type	Southern slope	Northern slope
Spearman's correlation coefficient *r*	А	0,92 (0,69–0,98)	0,79 (0,48–0,93)
	Б	0,76 (0,67–0,89)	0,57 (0,27–0,79)
R^2	А	0,81 (0,36–0,93)	0,60 (0,22–0,84)
	Б	0,29 (0,13–0,68)	0,27 (0,07–0,58)
MRE	А	0,39 (0,21–0,65)	0,45 (0,24–0,81)
	Б	0,64 (0,35–0,86)	0,43 (0,26–0,64)
MAE	А	0,16 (0,08–0,29)	0,20 (0,07–0,53)
	Б	0,93 (0,17–1,48)	0,47 (0,19–1,35)
MSE	А	0,07 (0,01–0,36)	0,13 (0,01–0,73)
	Б	2,66 (0,06–4,83)	1,42 (0,16–7,33)
Linearly weighted kappa (k)	А	0,78 (0,49–0,93)	0,67 (0,40–0,85)
	Б	0,36 (0,15–0,69)	0,49 (0,23–0,71)

output variable. Overall, for the model, it is quite high and amounted to 0.44, or 44% over 10 years. The magnitude of the error varied depending on the slope exposure and the degree of moisture (see Fig. 2). For comparison, let us consider prediction errors under conditions of minimal and maximal moisture on plots of type A and B. The MRE value increases with increasing *R*-factor values, as well as with the increased prominence of erosion forms on arable land surfaces. Under calm relief conditions, with increasing *R*-factor values, the southern slopes were characterized by a smaller increase in the number of data points with high (greater than 0.5) MRE values compared to the northern slopes. At the same time, southern slope areas with developed erosion forms showed the highest increase in the number of data points with high MRE values under unfavorable conditions, compared to the northern slopes.

The lowest mean absolute error (MAE) was observed in areas with a minimal number of water galls and rill erosion – 0.14–0.18. This error increased in the areas with pronounced rain rills – 0.44–0.93. Given the linear nature of this assessment, it can be stated that, on average, the resulting model is more accurate on 'simple' terrain, i.e., on this terrain the model is 4.13 times more accurate than under conditions with gully erosion and rills on arable land, and 1.6 times more accurate under conditions of moderate erosion concentration. The MAE maxima occurred in the years with the highest *R*-factor values. They amounted to 0.2–0.29 in sections of type A and 1.21–1.48 in type B. Under conditions of "simple" terrain and at low *R*-factor values, the



Variants of combinations of relief and moisture conditions (see the legend)
and the corresponding average MRE* values

Рис. 2. Соотношение объема предсказанных данных с разной величиной средней ошибки аппроксимации MRE в условиях минимального и максимального увлажнения на участках типов А и Б:

1 – южный склон, участки типа А, *R*-фактор минимальный; *2* – южный склон, участки типа А, *R*-фактор максимальный; *3* – южный склон, участки типа Б, *R*-фактор минимальный; *4* – южный склон, участки типа Б, *R*-фактор максимальный; *5* – северный склон, участки типа А, *R*-фактор минимальный; *6* – северный склон, участки типа А, *R*-фактор максимальный; *7* – северный склон, участки типа Б, *R*-фактор минимальный; *8* – северный склон, участки типа Б, *R*-фактор максимальный

Fig. 2. The ratio of the predicted data volume with different values of the mean approximation error MRE under conditions of minimum and maximum moisture in the areas of types A and B:

1 – southern slope, type A plots, *R*-factor is minimal; *2* – southern slope, type A plots, *R*-factor is maximal; *3* – southern slope, type B plots, *R*-factor is minimal; *4* – southern slope, type B plots, *R*-factor is maximal; *5* – northern slope, type A plots, *R*-factor is minimal; 6 – northern slope, type A plots, *R*-factor is maximal; *7* – northern slope, type B plots, *R*-factor is minimal; *8* – northern slope, type B plots, *R*-factor is maximal

model also produced fewer large errors.

The number of major errors increased against the background of fallow and fiber flax, especially in the presence of washouts. This is clearly visible from the values of the mean squared error MSE (see Table 2). The nature of the changes in the values of MAE and MSE in sections of type A and B is similar to MRE.

Analysis of the convergence of predicted and actual data in the classification calculated by the natural intervals method (0–0.32; 0.32–0.80; 0.80–1.36; 1.36–2.17; 2.17–3.20; 3.20 and above; the units of measurement (cubic meter/record plot) showed complete convergence for 72.4% of record plots in the first five classes. The volume of predicted data that deviated from the target class by one class was 21.1%, by two classes – 3.3%, by three – 2.0%. The contingency table for calculating the average coefficient of the linear-weighted kappa is presented below (see Table 3). The 10-year average for the entire territory of the k coefficient was 0.6424 ± 0.0078, which characterizes the level of convergence of the model with the actual data as stable.

Deviations in the direction of underestimating the model results relative to the fact corresponded to 16.9% of data pairs, 10.7% of data pairs – in the direction of overestimation. The number of data underestimated and overestimated by one class is close – 11.0% and 10.1%, respectively; more than one class deviated in 5.9% of data pairs in the direction of underestimation relative to the fact and in 0.5% – in the direction of overestimation. It was established that the model tends to predominantly show underestimated predicted values at high values of actual washout.

Against the background of low R-factor values in type A areas on the southern slopes, the coefficient of the linearly weighted Kappa showed a near-complete (k = 0.82–0.91) agreement of the model with the real data in the specified classification; on the northern slopes – a stable and near-complete agreement (k = 0,72–0,84). On plots of type B, under conditions of low *R*-factor values or medium *R*-factor values against the background of fallow or cereal stubble, on the southern slope k = 0.66–0.69 (stable, close to moderate emergence) was observed, on the northern slope k = 0.46–0.71 (moderate and stable emergence). The minimum coefficient values are noted in sections of type B at *R*-factor values above average regardless of the background: on the southern slope k = 0.15–0.48 (predominantly weak and satisfactory convergence), on the northern slope – k = 0.23–0.62 (predominantly moderate).

When converted to cubic meters per hectare (m³/ha), classifications for the results of ground measurements and modeling, obtained by the natural breaks method (0–0.95; 0.95–2.12; 2.12–4.50; 4.50–8.12; 8.12–13.17; 13.17 and above),

Табл. 3. Таблица сопряженности фактических и предсказанных данных смыва для 534 учетных делянок коэффициента линейно-взвешенной каппы k (среднее за 2014–2023 гг.), м³/делянку

Table 3. Contingency table of actual and predicted outwash data for 534 plots of the linear-weighted kappa coefficient k (average for 2014-2023), m³ per plot

Data	Forecasted (model)						
Actual	Class	0–0,32	0,32–0,80	0,80–1,36	1,36–2,17	2,17–3,20	>3,20
	0–0,32	2392	269	15	0	0	0
	0,32–0,80	214	915	207	14	0	0
	0,80–1,36	46	184	420	63	0	0
	1,36–2,17	27	45	157	128	2	0
	2,17–3,20	6	26	56	31	11	0
	>3,20	5	49	55	1	2	0
Kappa	$k = 0{,}6424 \pm 0{,}0078$; $k_{max} = 0{,}8512$.						$K = 6$ $N = 5340$

the linearly weighted kappa coefficient averaged $k = 0.7077 \pm 0.0055$; $k_{max} = 0.8370$. The pattern of change in the coefficient value is similar to that described above.

A common feature of all the studied accounting plots is that most of the deviations of the simulation results from the actual washout values and the increase in forecast errors are associated with the presence of rain rills on the arable land and the density of the temporary erosion network during the spring snowmelt period. It is obvious that rain rills and rill washouts, as formations whose width is less than the cell width of a digital elevation model, cannot affect the final modeling result. In the studied area, active development of temporary streams during the spring period was observed in the middle and lower thirds of the slopes. An increase in actual washout is noted here; however, the model data turned out to be lower. This was especially noticeable in the years with high levels of moisture. The influence of moisture levels on the accuracy and quality of the model is clearly visible regardless of the background, and is also statistically confirmed.

The connection with the type of vegetation and the condition of the arable surface was not always obvious. It was found that on the areas under autumn plowing, the model was consistently more accurate and had fewer errors, whereas against the background of fiber flax, black fallow, and cereal stubble, the model showed a decrease in accuracy and an increase in errors, including large errors in areas of type B. From this, it can be concluded that at the current scale, the model tends to underestimate the washout magnitude.

In the literature regarding the quality of forecasts based on USLE, authors[8] [18] point to a large variability in simulation results when using the same approach. It has been noted that the models tend to underestimate washout results, especially when using a coarse-meshed digital model, which is confirmed by the results of using new approaches in USLE-based modeling. The global experience of USLE validation shows that the average error is on average around 60%. Christine Alewell et al. noted that '...in all cases, relative errors tended to be greater for lower values of soil loss, with overestimation in the areas with low erosion rates and underestimation in the areas with high erosion rates. Although deviations from modeled and measured data may seem significant in absolute numbers, the deviation between modeled and observed erosion rates is no greater than the variability within the actual data...' [19]. We observe a similar dependence for the sub-taiga territory of Western Siberia according to the results of the present study.

The described experience of geoinformation modeling of the volumes of spring snowmelt soil washout based on the Universal Soil Loss Equation (USLE) showed that its use in the sub-taiga conditions of Western Siberia makes sense. The accuracy of the model in the target conditions is no lower than that described in the global literature, and the applied forecasting approach based on the geoinformation model of the snow cover allowed reducing the model error to an average of 44% over 10 years.

The best model quality characteristics were achieved on the southern slopes with minimal presence of rills and minimal moisture. The lowest values of mean relative error (MRE), mean absolute error (MAE), mean squared error (MSE) were noted here, and the highest values for the Spearman correlation coefficient and the coefficient of determination R^2. The convergence of the simulation data with the actual washout values was characterized as stable ($k = 0.6424 \pm 0.0078$; $k_{max} = 0.8512$) in the described classes of washout in cubic meters with plot recording, as well as when recalculating cubic meters per hectare ($k = 0{,}7077 \pm 0{,}0055$; $k_{max} = 0{,}8370$).

[8] *Borrelli P., Robinson D.A., Fleischer L.R., Lugato E., Ballabi C., Alewell C., Meusburger K., Modugno S., Schütt B., Ferro V., Bagarello V., van Oost K., Montanarella L., Panagos P.* An assessment of the global impact of 21st century land use change on soil erosion // Nature Communications, 2017, N 8 (1), pp. 1–13. DOI: 10.1038/s41467-017-02142-7.

CONCLUSIONS

1. USLE can be used as a tool for the primary assessment of the potential for arable soil erosion during spring snowmelt in the sub-taiga area of Western Siberia.

2. The accuracy of the model in the target soil and climatic conditions depends on the presence or absence, as well as the number of temporary watercourses and erosion forms on arable land smaller than the cell of the digital elevation model.

3. In the sub-taiga zone of Western Siberia, including GIS modeling data of snow water reserves in the calculation of the USLE *R*-factor allows achieving a stable level of convergence between predicted and actual data on the volume of spring snowmelt runoff from arable soils.

We believe that in the future, the accuracy of the developed geoinformation model of spring snowmelt soil erosion of arable land can be increased by using a number of topographic indices and taking into account the influence of terrain morphometry.

СПИСОК ЛИТЕРАТУРЫ

1. *Кирюшин В.И.* Методология комплексной оценки сельскохозяйственных земель // Почвоведение. 2020. № 7. С. 871–879. DOI: 10.31857/S0032180X20070060.
2. *Кирюшин В.И.* Организация территориального и внутрихозяйственного землеустройства на ландшафтно-экологической основе // Достижения науки и техники АПК. 2024. Т. 38. № 5. С. 4–9. DOI: 10.53859/02352451_2024_38_5_4.
3. *Соловьева Ю.А., Подлесных И.В., Зарудная Т.Я.* Усовершенствованная методика противоэрозионной организации территории для сельскохозяйственных угодий Центрального Черноземья // Достижения науки и техники АПК. 2019. Т. 33. № 9. С. 5–9. DOI: 10.24411/0235-2451-2019-10901.
4. *Кирюшин В.И., Дубачинская Н.Н.* Проблема освоения адаптивно-ландшафтных систем земледелия в Оренбургской области // Известия Оренбургского государственного аграрного университета. 2020. № 6 (86). С. 9–14. DOI: 10.37670/2073-0853-2020-86-6-9-14.
5. *Подлесных И.В., Соловьева Ю.А.* Новый подход в методологии формирования структуры севооборотов с учетом противоэрозионной роли сельскохозяйственных культур // Достижения науки и техники АПК. 2020. Т. 34. № 11. С. 21–25. DOI: 10.24411/0235-2451-2020-11103.
6. *Полуэктов Е.В.* Организация эрозионно опасной территории на ландшафтной основе // Экология и водное хозяйство. 2022. Т. 4. № 3. С. 46–57. DOI: 10.31774/2658-7890-2022-4-3-46-57.
7. *Кирюшин В.И., Дубачинская Н.Н., Юрова А.Ю.* Комплексная оценка сельскохозяйственных земель на примере Южного Урала // Почвоведение. 2021. № 11. С. 1363–1375. DOI: 10.31857/S0032180X21110083.
8. *Козлов Д.Н., Жидкин А.П., Лозбенев Н.И.* Цифровое картографирование эрозионных структур почвенного покрова на основе имитационной модели смыва (северная лесостепь Среднерусской возвышенности) // Бюллетень Почвенного института им. В.В. Докучаева. 2019. № 100. С. 5–35. DOI: 10.19047/0136-1694-2019-100-5-35.
9. *Мальцев К.А., Ермолаев О.П.* Потенциальные эрозионные потери почвы на пахотных землях европейской части России // Почвоведение. 2019. № 12. С. 1502–1512. DOI: 10.1134/S0032180X19120104.
10. *Смирнова М.А., Жидкин А.П., Лозбенев Н.И., Заздравных Е.А., Козлов Д.Н.* Цифровое картографирование степени эродированности почв с использованием моделей фактор-свойство и фактор-процесс-свойство (юг Среднерусской возвышенности) // Бюллетень Почвенного института им. В.В. Докучаева. 2020. № 104. С. 158–198. DOI: 10.19047/0136-1694-2020-104-158-198.
11. *Бадмаева С.Э., Бадмаева Ю.В., Лидяева Н.Е.* Эрозионные процессы на черноземах лесостепной зоны Красноярского края // Вестник Красноярского государственного аграрного университета. 2019. № 4 (145). С. 62–66.
12. *Lefèvre C., Cruse R.M., dos Anjos L.H.C., Calzolari C., Haregeweyn N.* Guest editorial-soil erosion assessment, tools and data: A special issue from the Global Symposium on soil Erosion 2019 // International Soil and Water Conservation Research. 2020. Vol. 8. № 4. P. 333–336. DOI: 10.1016/j.iswcr.2020.11.004.

13. *Сухановский Ю.П., Прущик А.В.* Моделирование водной эрозии почв: монография. Курск: Курский федеральный аграрный научный центр. 2023. 175 с.
14. *Kardhana H., Solehudin, Wijayasari W., Immaddudin F., Rohmat W.* Assessing basin-wide soil erosion in the Citarum watershed using USLE method // Results in Engineering. 2024. Vol. 22. P. 102–130. DOI: 10.1016/j.rineng.2024.102130.
15. *Li J., Xiong M., Sun R., Chen L.* Temporal variability of global potential water erosion based on an improved USLE model // International Soil and Water Conservation Research. 2024. Vol. 12. № 1. P. 1–12. DOI: 10.1016/j.iswcr.2023.03.005.
16. *Савельева Д.А., Каличкин В.К.* Внутрисезонный мониторинг водной эрозии почв пашни в подтайге Западной Сибири // Достижения науки и техники АПК. 2021. Т. 35. № 5. С. 15–21. DOI: 10.24411/0235-2451-2021-10502.
17. *Евсеева Н.С., Петров А.И., Хон А.В., Каширо М.А., Квасникова З.Н.* Водная эрозия почв от стока талых снеговых вод в агроландшафтах юго-востока Томской области // Вестник Северо-Восточного федерального университета им. М.К. Аммосова. Серия: Науки о Земле. 2024. № 4 (36). С. 104–119. DOI: 10.25587/2587-8751-2024-4-104-119.
18. *Benjamin U. Meinen, Derek T.* Robinson From hillslopes to watersheds: Variability in model outcomes with the USLE // Environmental Modelling and Software. 2021. Vol. 146. P. 105229. DOI: 10.1016/j.envsoft.2021.105229.
19. *Christine Alewell, Pasquale Borrelli, Katrin Meusburger, Panos Panagos.* Using the USLE: Chances, challenges and limitations of soil erosion modelling // International Soil and Water Conservation Research. 2019. № 7. P. 203–225. DOI: 10.1016/j.iswcr.2019.05.004.

REFERENCES

1. Kiryushin V.I. The methodology for the integrated assessment of agricultural land. *Pochvovedenie = Eurasian Soil Science*, 2020, no. 7, pp. 871–879. (In Russian.). DOI: 10.31857/S0032180X20070060.
2. Kiryushin V.I. Organization of regional and intrafarm land management on a landscape-ecological basis. *Dostizheniya nauki i tekhniki APK = Achievements of Science and Technology of AIC*, 2024, vol. 38, no. 5, pp. 4–9. (In Russian.) DOI: 10.53859/02352451_2024_38_5_4.
3. Solov'eva Yu.A., Podlesnykh I.V., Zarudnaya T.Ya. Improved techniques of anti-erosion organization of the territory for the farmland in the Central Chernozem region. *Dostizheniya nauki i tekhniki APK = Achievements of Science and Technology of AIC*, 2019, vol. 33, no. 9, pp. 5–9. (In Russian.) DOI: 10.24411/0235-2451-2019-10901.
4. Kiryushin V.I., Dubachinskaya N.N. The problem of adaptive landscape farming systems development in the Orenburg region. *Izvestiya Orenburgskogo gosudarstvennogo agrarnogo universiteta = Izvestia Orenburg State Agrarian University*, 2020, no. 6 (86), pp. 9–14. (In Russian.). DOI: 10.37670/2073-0853-2020-86-6-9-14.
5. Podlesnykh I.V., Solov'eva Yu.A. A new approach in the methodology for the formation of crop rotation structure taking into account the anti-erosion role of crops. *Dostizheniya nauki i tekhniki APK = Achievements of Science and Technology of AIC*, 2020, vol. 34, no. 11, pp. 21–25. (In Russian.). DOI: 10.24411/0235-2451-2020-11103.
6. Poluektov E.V. Organization of an erosion-prone territory on a landscape basis. *Ekologiya i vodnoe khozyaystvo = Ecology and water management*, 2022, vol. 4, no. 3, pp. 46–57. (In Russian.). DOI: 10.31774/2658-7890-2022-4-3-46-57.
7. Kiryushin V.I., Dubachinskaya N.N., Yurova A.Yu. Multifactorial assessment of agricultural land exemplified by the Southern Urals region // *Pochvovedenie = Eurasian Soil Science,* 2021, no. 11, pp. 1363–1375. (In Russian.). DOI: 10.31857/S0032180X21110083.
8. Kozlov D.N., Zhidkin A.P., Lozbenev N.I. Digital mapping of soil cover eroded patterns on the basis of soil erosion simulation model (northern forest-steppe of the Central Russian Upland). *Byulleten' Pochvennogo instituta im. V.V. Dokuchaeva = Dokuchaev Soil Bulletin*, 2019, no. 100, pp. 5–35. (In Russian.) DOI: 10.19047/0136-1694-2019-100-5-35.
9. Mal'tsev K.A., Ermolaev O.P. Potential soil loss from erosion on the arable land in the European part of Russia. *Pochvovedenie = Eurasian Soil Science,* 2019, no. 12, pp. 1502–1512. (In Russian.). DOI: 10.1134/S0032180X19120104.
10. Smirnova M.A., Zhidkin A.P., Lozbenev N.I., Zazdravnykh E.A., Kozlov D.N. Digital map-

ping of erosion degree of soils using the factor – property and factor – process – property models (the south of the Central Russian upland). *Byulleten' Pochvennogo instituta im. V.V. Dokuchaeva = Dokuchaev Soil Bulletin*, 2020, no. 104, pp. 158–198. (In Russian.). DOI: 10.19047/0136-1694-2020-104-158-198.
11. Badmaeva S.E., Badmaeva Yu.V., Lidyaeva N.E. Erosion processes on chernozyoms of forest-steppe zone of Krasnoyarsk region. *Vestnik KrasGAU = Bulletin of KrasSAU*, 2019, no. 4 (145), pp. 62–66. (In Russian.)
12. Lefèvre C., Cruse R.M., dos Anjos L.H.C., Calzolari C., Haregeweyn N. Guest editorial-soil erosion assessment, tools and data: A special issue from the Global Symposium on soil Erosion 2019. *International Soil and Water Conservation Research*, 2020, vol. 8, no. 4, pp. 333–336. DOI: 10.1016/j.iswcr.2020.11.004.
13. Sukhanovskiy Yu.P., Prushchik A.V. *Modeling of soils water erosion*. Kursk: Kursk Federal Agrarian Scientific Center, 2023, 175 p. (In Russian.)
14. Kardhana H., Solehudin, Wijayasari W., Immaddudin F., Rohmat W. Assessing basin-wide soil erosion in the Citarum watershed using USLE method. *Results in Engineering*, 2024, vol. 22, pp. 102–130. DOI: 10.1016/j.rineng.2024.102130.
15. Li J., Xiong M., Sun R., Chen L. Temporal variability of global potential water erosion based on an improved USLE model. *International Soil and Water Conservation Research*, 2024, vol. 12, no. 1, pp. 1–12. DOI: 10.1016/j.iswcr.2023.03.005.
16. Savel'eva D.A., Kalichkin V.K. Intraseasonal monitoring of water erosion of arable soils in subtaiga of Western Siberia. *Dostizheniya nauki i tekhniki APK = Achievements of Science and Technology of AIC*, 2021, vol. 35, no. 5, pp. 15–21. (In Russian.). DOI: 10.24411/0235-2451-2021-10502.
17. Evseeva N.S., Petrov A.I., Khon A.V., Kashiro M.A., Kvasnikova Z.N. Water erosion of soils from runoff of melt snow water in agrolandscapes of southeastern Tomsk Oblast. *Vestnik Severo-Vostochnogo federal'nogo universiteta im. M.K. Ammosova. Seriya: Nauki o Zemle = Vestnik of North-Eastern Federal University Series "Earth Sciences",* 2024, no. 4 (36), pp. 104–119. (In Russian.). DOI: 10.25587/2587-8751-2024-4-104-119.
18. Benjamin U. Meinen, Derek T. Robinson From hillslopes to watersheds: Variability in model outcomes with the USLE. *Environmental Modelling and Software*, 2021, vol. 146, pp. 105–229. DOI: 10.1016/j.envsoft.2021.105229.
19. Christine Alewell, Pasquale Borrelli, Katrin Meusburger, Panos Panagos Using the USLE: Chances, challenges and limitations of soil erosion modeling. *International Soil and Water Conservation Research*, 2019, no. 7, pp. 203–225. DOI: 10.1016/j.iswcr.2019.05.004.

ИНФОРМАЦИЯ ОБ АВТОРАХ

(✉)**Савельева Дарья Анатольевна**, научный сотрудник, аспирант; SPIN-код 2303-0249; **адрес для переписки**: Россия, 634050, Томск, ул. Гагарина, 3; e-mail: daria.a.saveleva@yandex.ru

Каличкин Владимир Климентьевич, руководитель СибНИИЗБиЦ СФНЦА РАН, доктор сельскохозяйственных наук, профессор; SPIN-код 1587-4615

Сайнакова Анна Борисовна, директор, кандидат сельскохозяйственных наук, SPIN-код 5268-2348

AUTHOR INFORMATION

(✉)**Darya A. Savel'eva,** Researcher, Post-graduate Student; SPIN-code 2303-0249; **address:** 3, Gagarina St., Tomsk, 634050, Russia; e-mail: daria.a.saveleva@yandex.ru

Vladimir K. Kalichkin, Head of the Siberian Research Institute of Agriculture, Biologization, and Digitalization, Doctor of Science in Agriculture, Professor; SPIN-code 1587-4615

Anna B. Sainakova, Director, Candidate od Science in Agriculture; SPIN-code 5268-2348

Дата поступления статьи / Received by the editors 29.08.2025
Дата принятия к публикации / Accepted for publication 30.09.2025
Дата публикации / Published 19.12.2025

https://doi.org/10.26898/0370-8799-2025-12-3
УДК 633.1:631.51:631.8
Тип статьи: оригинальная
Type of article: original

Изменение фотосинтетической активности многолетних трав в зависимости от обработки почвы и удобрений

(✉)**Воронин А.Н., Котяк П.А.**
Ярославский государственный аграрный университет
Ярославль, Россия
(✉)e-mail: voronin@yarcx.ru

Многолетние травы служат основным источником корма для животных. Они имеют важное агротехническое и экологическое значение. Высокие и стабильные урожаи достигаются за счет создания посевов с идеальными характеристиками листовой поверхности, высокой чистой продуктивностью фотосинтеза, максимальным фотосинтетическим потенциалом и эффективной работой ассимилирующей поверхности, что в итоге обеспечивает получение запланированного объема урожая. В статье представлены результаты исследований по изучению систем отвальной, поверхностно-отвальной и поверхностной обработки, а также систем удобрения на основе соломы как отдельно, так и в сочетании с полным минеральным удобрением. Приведены данные по площади листьев, накоплению сухого вещества, фотосинтетического потенциала и чистой продуктивности фотосинтеза, а также по урожайности многолетних трав за 2023–2024 гг. Исследования проводились на дерново-подзолистых глееватых среднесуглинистых почвах Ярославской области. За время опытов использование систем ресурсосберегающей обработки почвы способствовало снижению фотосинтетических показателей клевера лугового и тимофеевки луговой. Это можно объяснить угнетением культурных растений сорными при минимализации обработки почвы. Применение полной нормы минеральных удобрений как отдельно, так и совместно с соломой вызвало увеличение площади листьев, накопления сухого вещества и фотосинтетического потенциала означенных выше культур при максимальных значениях по фону SNPK. Наибольшая урожайность зеленой массы многолетних трав отмечалась при системе поверхностно-отвальной обработки и варианте совместного использования соломы и полной нормы минеральных удобрений. В среднем за годы исследований показатель отмечался на уровне 218–226 ц/га.

Ключевые слова: фотосинтез, площадь листовой поверхности, накопление сухого вещества, фотосинтетический потенциал, чистая продуктивность фотосинтеза, многолетние травы, урожайность

Changes in photosynthetic activity of perennial grasses depending on soil treatment and fertilizers

(✉)**Voronin A.N., Kotyak P.A.**
Yaroslavl State Agrarian University
Yaroslavl, Russia
(✉)e-mail: voronin@yarcx.ru

Perennial grasses are the main source of animal feed. They have important agronomic and ecological significance. High and stable yields are achieved by creating crops with ideal characteristics of the leaf surface, high net productivity of photosynthetic processes, maximum photosynthetic potential and efficient work of the assimilating surface, which ultimately ensures the planned harvest volume is obtained. The article presents the results of the studies of moldboard, surface-moldboard and surface cultivation systems, as well as straw-based fertilization systems both separately and in combination with complete mineral fertilization. Data are provided on the leaf area, dry matter accumulation, photosynthetic potential and net productivity of photosynthetic processes, as well as the yield of perennial grasses on average for 2023–2024. The studies were carried out on sod-podzolic gleyic medium loamy soils of the Yaroslavl region. During the experiments, the use of resource-saving soil cultivation systems contributed to a decrease in the photosynthetic indices of red clover and timothy grass. This can be explained by the suppression of cultivated plants by weeds with minimal soil cultivation. The use of a full rate of mineral fertilizers both separately and together with straw caused an increase in the

leaf area, accumulation of dry matter and photosynthetic potential of the above-mentioned crops with maximum values for the SNPK background. The highest yield of green mass of perennial grasses was noted with the surface-moldboard cultivation system in the variant of combined use of straw and a full rate of mineral fertilizers. On average, over the years of research, the indicator was noted at the level of 218–226 c/ha.

Keywords: photosynthesis, leaf area, dry matter accumulation, photosynthetic potential, net photosynthetic productivity, perennial grasses, crop yield

Для цитирования: *Воронин А.Н., Котяк П.А.* Изменение фотосинтетической активности многолетних трав в зависимости от обработки почвы и удобрений // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 12. С. 28–35. https://doi.org/10.26898/0370-8799-2025-12-3

For citation: Voronin A.N., Kotyak P.A. Changes in photosynthetic activity of perennial grasses depending on soil treatment and fertilizers. *Sibirskii ivestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 12, pp. 28–35. https://doi.org/10.26898/0370-8799-2025-12-3

Конфликт интересов
Авторы заявляют об отсутствии конфликта интересов.
Conflict of interest
The authors declare no conflict of interest.

INTRODUCTION

The main component of the assimilatory apparatus is the leaf cover. The size of the leaves is an indicator of the photosynthetic activity of plants, which varies depending on the level of moisture, the presence of minerals, and the agricultural cultivation methods used [1, 2].

The process of photosynthesis plays a key role in the life of plants, determining the yield of agricultural crops and ensuring the accumulation of a sufficient amount of nutrients [3, 4]. The efficiency of photosynthesis in plants is best assessed by the increase in their dry mass, expressed per unit leaf area over a given period of time. It is these quantities that are used to characterize the net productivity of photosynthesis (NPP) [5]. This parameter is quite variable and depends on many environmental factors, as well as on the availability of mineral nutrients for plants.

An important component of agricultural technology is soil cultivation, which affects the efficiency of photosynthesis. In the studies of T.P. Sabirova et al.[1], when using moldboard soil tillage, a mixture of vetch and oats demonstrates improved leaf area characteristics and photosynthetic activity. The highest level of NPP was observed during surface soil treatment – 4.1 g/ m^2 per day. According to E.D. Adinyaev and I.I. Tomaeva[2], compared to chisel plow treatment, moldboard plowing contributed to an increase in the photosynthetic potential of plants growing in a mixture of vetch with oats, winter rye, and on potato plantations.

B.G. Magaramov and K.U. Kurkiev[3] believe that the best photosynthetic potential of naked oats is manifested with subsurface tillage. According to A.Yu. Batrakova and A.N. Kryukov[4], the use of subsurface tillage resulted in higher leaf area values of corn plants compared to moldboard soil tillage. According to A.V. Mishchenko[5], the use of chisel soil cultivation contributes to an increase in leaf area and photosynthetic

[1]*Sabirova T.P., Shchukin S.V., Sabirov R.A., Noskova E.V.* Photosynthetic potential and productivity of the vetch-oat mixture depending on tillage and fertilizers in the North-West region // Herald of Agroindustrial complex of Upper Volga region, 2019, N 1, pp. 16–21.

[2]*Adinyaev E.D., Tomaeva I.I.* The effect of the agrobackground on soil fertility indicators and the productivity of agricultural crops in mountain farming // Proceedings of the Gorsky State Agrarian University, 2016, N 3, pp. 27–34.

[3]*Magaramov B. G., Kurkiev K. U.* Photosynthetic activity and leaf surface of oat plants with various methods of tillage// Scientific life, 2019, N 6, pp. 844–852.

[4]*Batrakova A.Yu., Kryukov A.N.* The influence of soil treatment and sowing methods on the leaf area of maize plants // Gorinsk Readings. Innovative Solutions for Agriculture: Proceedings of the International Scientific Conference, 2023, vol. 1, pp. 11–12.

[5]*Mishchenko A.V.* Dependence of the photosynthetic potential of soybeans on soil treatment and sowing method on an erosion-prone slope in the Rostov region // Actual issues in the development of agricultural sectors: theory and practice: materials of the III All-Russian (with international participation) scientific-practical conference of young agricultural scientists (Rassvet, May 14–15, 2021). Rostov-on-Don, 2021, pp. 62–67.

potential of soybeans compared to mouldboard soil tillage. Research by E.A. Bildieva et al. [6] showed that when using No-till technology, winter wheat plants develop a more advanced photosynthetic apparatus, which functions for a longer period, allowing them to create more biomass by the end of the growing season, which ultimately leads to an increase in grain yield.

Meanwhile, E.M. Titova[6] found that surface soil treatment contributed to an increase in the formation of leaf area of barley plants by 4% compared to moldboard plowing.

Fertilizers also have a significant impact on photosynthesis indicators. In the experiments of V.A. Isaichev et al.[7], the use of mineral fertilizer ensured the acceleration of plant biomass accumulation and the intensity of photosynthesis. According to D.A. Kuznetsov et al.[8], the use of nitrogen fertilizers had a significant effect on the formation of the assimilating surface of oat plants. According to E.A. Bildieva and co-authors [7], the application of high doses of fertilizers contributes to the activation of photosynthetic activity (increases the photosynthetic potential) of plants grown using no-till technology. As a result, they consume nitrogen more intensively during the reproductive period, which leads to an increase in yield. Other authors[9] share the same point of view [8–11].

At the same time, V.I. Nikitishen et al.[10] established that under the influence of increasing doses of mineral fertilizers, the NPP decreased in all crops, despite the active formation of aboveground biomass in these variants. This is probably due to the increasing expenditure of energy resources on respiration and transpiration by crops with a more developed leaf surface.

Organic fertilizers also play a significant role in the formation of photosynthetic indicators. In the experiments of A.S. Nikulina, the use of sapropel caused an increase in the leaf area and height of barley and oats [12]. According to M.R. Musaev et al.[11], the leaf area, photosynthetic potential, and NPP significantly increased with the application of manure and plowing in green manure.

In the work of I.V. Satunkin[12], the application of mineral and organic fertilizers increased the maximum leaf area of sugar beet by 12.8% compared to the control.

Thus, the question of the impact of various systems of primary soil cultivation and fertilization is very complex and insufficiently studied. Many aspects require detailed clarification. In this regard, the aim of our study was to assess the impact of different systems of soil cultivation and fertilization on the photosynthetic parameters of perennial grass crops under the conditions of the Central Non-Black Earth Zone. The objectives of the study included determining the influence of different systems of soil cultivation and fertilization on the photosynthetic activity of perennial grass crops and identifying the effect of the studied agricultural practices on the yield of perennial grasses.

MATERIAL AND METHODS

The research was carried out in 2023–2024 on sod-podzolic gleyey loamy soil in a long-

[6]*Titova E.M.* Efficiency of various barley cultivation technologies in the conditions of the Central region of Russia: abstract of the dissertation for the degree of the Candidate of Science in Agriculture. Orel, 2000, 19 p.

[7]*Isaichev V.A., Plechov D.V., Andreev N.N.* Influence of growth regulators and fertilizers on photosynthetic parameters and yield of winter wheat variety Biruza in the conditions of forest-steppe of the middle Volga region // Volga Region Farmland, 2015, N 4 (37), pp. 53–61.

[8]*Kuznetsov D.A., Ibragimova G.N., Kalinina A.D.* The effect of nitrogen fertilizer application methods on the development of leaf surface of oat plants // Agricultural Science Euro-North-East, 2019, N 20 (6), pp. 623–631.

[9]*Gnennny E.Yu., Tkachenko M.A., Mazyukina E.A.* The influence of mineral fertilizer standards on stand density and leaf area of winter wheat // Actual directions of scientific research: theory and practice: materials of the International (correspondence) scientific-practical conference (Minsk, February 9, 2022). Neftekamsk, 2022, pp. 35–38.

[10]*Nikitishen V.I., Terekhova L.M., Lichko V.I.* Formation of the assimilative apparatus and photosynthetic productivity of plants under various mineral nutrition conditions // Agricultural Chemistry, 2007, N 8, pp. 35–43.

[11]*Musayev M.R., Ramazanov A.V., Klyushin P.V., Savinova S.V.* Forage crop productivity in the Tersko-Sulak subprovince of the Republic of Dagestan with the application of various forms of fertilizers // International Journal of Applied Sciences and Technologies INTEGRAL, 2017, N 4, p. 39.

[12]*Satunkin I.V.* Influence of calculated fertilization rates and primary soil tillage depth, under different irrigation regimes, on photosynthetic activity of sugar beet / Izvestia Orenburg State Agrarian University, 2014, N 5, pp. 40–43.

term field two-factor experiment established at the experimental field of the Yaroslavl State Agricultural Academy.

The characteristics of soil conditions and the experimental scheme are given in [13].

In 2023 and 2024, research was conducted on the plantings of a clover-timothy mixture in the 1st and 2nd year of use.

The leaf area was determined by the method of punches, *dry matter* – by the thermostat-weight method with drying of plants to constant mass at a temperature of 105 °C, *photosynthetic potential* was calculated by the method of A.A. Nichiporovich, *NPP* – by the Kidd, West, and Briggs formula. *Crop yield* was determined by the continuous fractionation method taking into account moisture and contamination.

The studies were conducted on the processing options MP, SP, and ST, with the nutrient backgrounds F0, S, SNPK, and NPK. The experimental field in the crops of agricultural plants was examined.

In 2023, the average air temperature in May was 12.6 °C, which is close to the long-term average values. The total precipitation for the month was 50 mm. In June and July, the temperature was below the long-term values. The total precipitation in June amounted to 53% of the long-term average. In July, 165% of the monthly norm fell. On average, in August, the air temperature was 18.3 °C, which is 1.8 °C above the long-term average values. In August, 38 mm of precipitation fell.

In 2024, the average air temperature for May was 9.5 °C, which is 2.9 °C below the long-term average. The total precipitation for the month was 52 mm. In June, the temperature was 5.4 °C below the long-term average. The total precipitation for June was only 25% of the long-term average. In July, the temperature was at the level of the average values. At the same time, 307% of the monthly norm fell. On average, in August, the air temperature was 20.6 °C, which is 4.1 °C above the long-term average. In August, 72 mm of precipitation fell.

RESULTS AND DISCUSSION

On average, over the years of research, the maximum leaf area of clover was observed under the moldboard plowing system – 5.45 m²/m² (see Fig. 1). The use of surface tillage resulted in a decrease of the above-mentioned indicator by 1.0 m²/m². A similar pattern was observed regarding dry matter accumulation and photosynthetic potential. The minimum NPP was noted under moldboard plowing and amounted to 0.73 g/m² per day. The use of the surface-moldboard and surface tillage systems led to an increase in the studied indicator by 0.11 and 0.13 g/m² per day, respectively.

The application of fertilizers across different soil cultivation systems led to a significant increase in the leaf area of meadow clover, with the maximum values observed in the variant with straw and the full rate of mineral fertilizers – 5.93 m²/m². The combined use of organic and mineral fertilizers resulted in a statistically significant increase in dry matter accumulation, from 120.53 g/m² in the control to 181.71 g/m². The use of the studied fertilizers contributed to the growth of photosynthetic potential, with the highest values for the SNPK background – 2006.83 thousand m²/ha × days. The application of straw caused an increase in net photosynthetic productivity by 0.24 g/m2 per day.

The use of resource-saving soil treatment systems caused a decrease in leaf area, dry matter accumulation, and photosynthetic potential of timothy grass (see Fig. 2).

The lowest NPP on average across fertilizers and years of research was observed with the surface-moldboard system – 1.48 g/m² per day. The use of the surface treatment system caused an increase in the studied indicator by 0.13 g/m² per day. The application of the full rate of mineral fertilizers, both separately and together with straw, caused a significant increase in the leaf area of timothy grass. The application of all the studied fertilizers led to an increase in dry aboveground biomass and photosynthetic potential of the crop, with the highest values observed when straw and mineral fertilizers were used as a background. The highest net photosynthetic

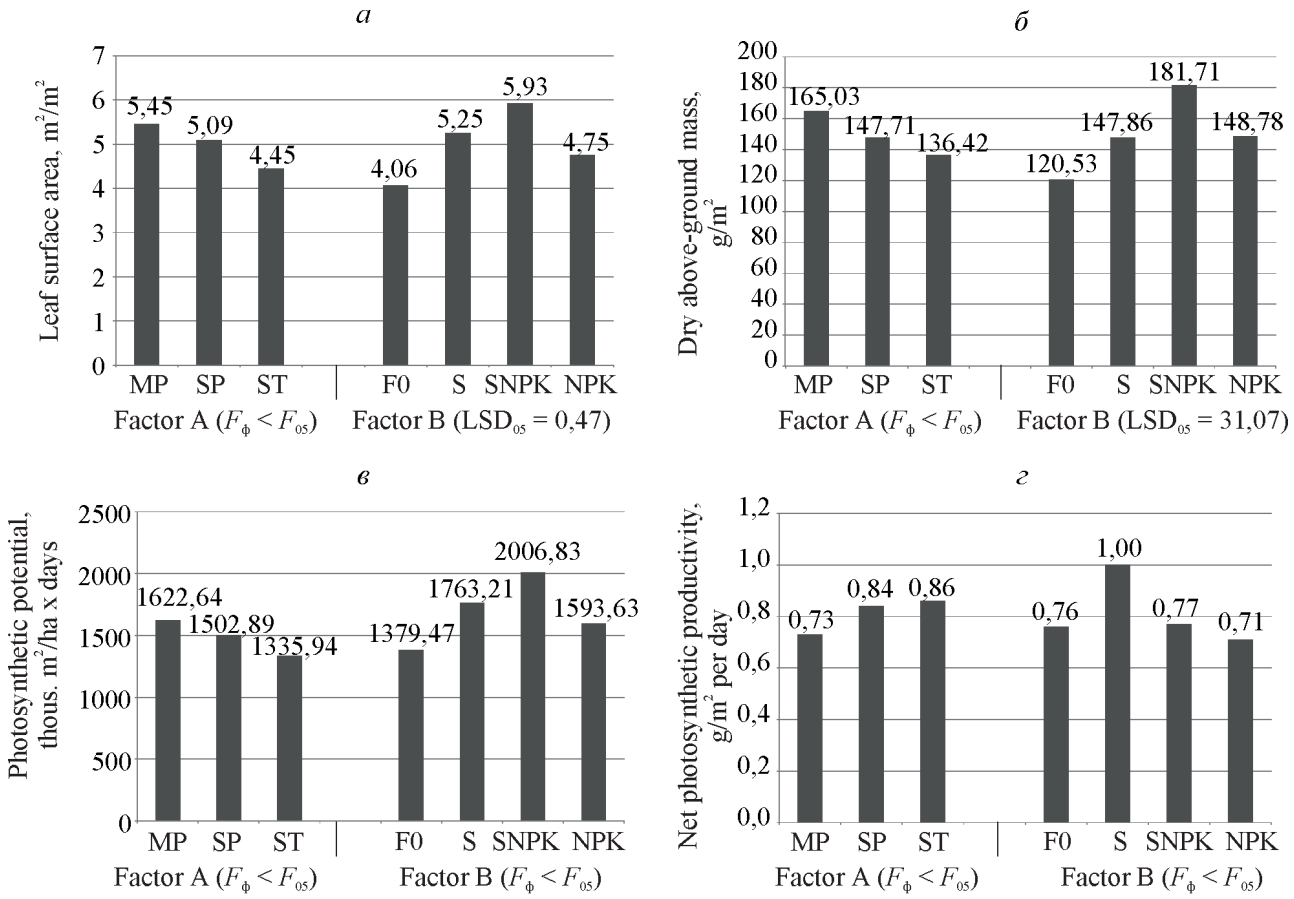


Рис. 1. Действие обработки почвы и удобрений на фотосинтетические показатели клевера лугового в среднем за 2023–2024 гг.:
а – площадь листовой поверхности; *б* – сухая надземная масса; *в* – фотосинтетический потенциал; *г* – чистая продуктивность фотосинтеза

Fig. 1. Effect of soil treatment and fertilizers on the photosynthetic performance of red clover, averaged over 2023–2024:
а – leaf surface area; *б* – dry aboveground mass; *в* – photosynthetic potential; *г* – net photosynthetic productivity

productivity of timothy grass was observed with the SNPK variant and amounted to 1.73 g/m² per day.

On average, over the years of research and across fertilizers, the use of a surface tillage system contributed to a significant reduction in the yield of perennial grasses by 19.45 c/ha (see Fig. 3). The use of fertilizers resulted in a statistically significant increase in this indicator, with the maximum values observed under the SNPK background – 212.02 c/ha.

CONCLUSION

On sod-podzolic gleyey loamy soil, the main recommended system is surface- moldboard soil treatment (SP), as well as the application of straw together with the full rate of mineral fertilizers (SNPK). These agro-practices contribute to an increase in photosynthetic indicators, as well as to obtaining high yields of perennial grasses.

СПИСОК ЛИТЕРАТУРЫ

1. *Wu S., Li R., Bu C., Zhu C., Miao* C., *Zhang Y., Cui J., Jiang J., Ding X.* Photoperiodic effect on growth, photosynthesis, mineral elements, and metabolome of tomato seedlings in a plant factory // Plants. 2024. Vol. 13 (22). P. 3119. DOI: 10.3390/plants13223119.
2. *Qu Y., Sakoda K., Fukayama H., Kondo E., Suzuki Y., Makino A., Terashima I., Yamori W.* Overexpression of both Rubisco and Rubisco activase rescues rice photosynthesis and biomass heat stress // Plant Cell Environment. 2021. Vol. 44 (7). P. 2308–2320. DOI: 10.1111/pce.14051.

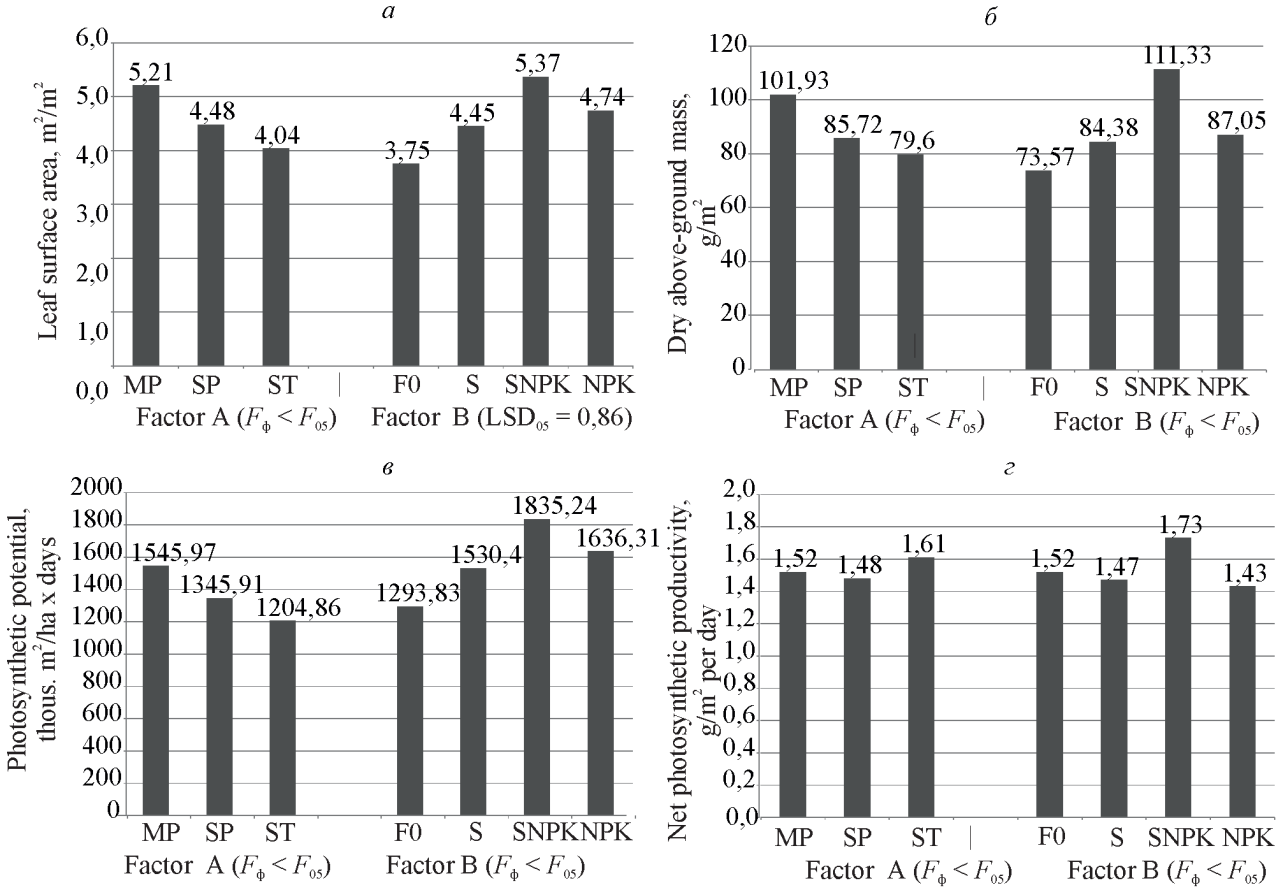


Рис. 2. Действие обработки почвы и удобрений на фотосинтетические показатели тимофеевки луговой в среднем за 2023–2024 гг.:
а – площадь листовой поверхности; *б* – сухая надземная масса; *в* – фотосинтетический потенциал; *г* – чистая продуктивность фотосинтеза

Fig. 2. The effect of soil treatment and fertilizers on the photosynthetic performance of timothy grass, averaged over 2023–2024:
а – leaf surface area; *б* – dry aboveground mass; *в* – photosynthetic potential; *г* – net photosynthetic productivity

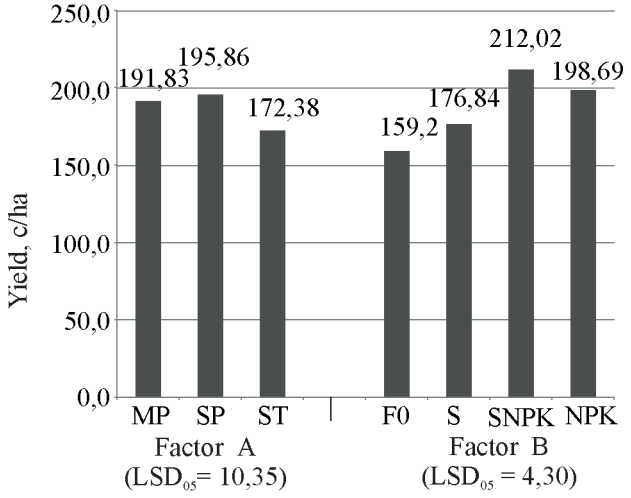


Рис. 3. Действие обработки почвы и удобрений на урожайность многолетних трав в среднем за 2023–2024 гг.

Fig. 3. The effect of tillage and fertilizers on the yield of perennial grasses on average for 2023–2024

3. *Stirbet A., Guo Y., Lazár D., Govindjee G.* From leaf to multiscale models of photosynthesis: applications and challenges for crop improvement // Photosynthesis Research. 2024. Vol. 161 (1–2). P. 21–49. DOI: 10.1007/s11120-024-01083-9.
4. *Zakharchenko E., Datsko O., Butenko S., Bakumenko O.* The influence of organic growing of maize hybrids on the formation of leaf surface area and chlorophyll concentration // Journal of Ecological Engineering. 2024. Vol. 25 (5). P. 156–164. DOI: 10.12911/22998993/186162.
5. *Liu X., Nadeem M., Rui Y.* Effects of nanofertilizers on the mechanism of photosynthetic efficiency in plants: A review // Phyton-International Journal of Experimental Botany. 2024. Vol. 93 (12). P. 3197–3216.
6. *Бильдиева Е.А., Ерошенко Ф.В., Гаджимура-*

дов Р.Г., Епифанова Р.Ф. Фотосинтетическая продуктивность озимой пшеницы, возделываемой по технологии No-Till // Аграрный научный журнал. 2021. № 3. С. 14–17.
7. *Бильдиева Е.А., Ерошенко Ф.В., Дридигер В.К.* Фотосинтез и азотное питание озимой пшеницы, возделываемой по технологии прямого посева // Достижения науки и техники АПК. 2022. Т. 36. № 5. С. 44–49.
8. *Воронкова Н.А., Балабанова Н.Ф., Волкова В.А., Цыганова Н.А.* Эффективность препарата НВ-101 для некорневой подкормки яровой пшеницы на лугово-чернозёмной почве Западной Сибири // Вестник Красноярского государственного аграрного университета. 2021. № 7. С. 11–17. DOI: 10.36718/1819-4036-2021-7-11-17.
9. *Анка М., Серегина И.И.* Роль препаратов Силипланта, Эпин-экстра и Циркона в формировании ассимиляционного аппарата проростков яровой пшеницы в зависимости от условий водообеспечения // Известия высших учебных заведений. Поволжский регион. Естественные науки. 2024. № 1. С. 72–80. DOI: 10.21685/2307-9150-2024-1-7.
10. *Воронкова Н.А., Волкова В.А., Цыганова Н.А., Балабанова Н.Ф.* Влияние макроудобрений и стимуляторов роста на содержание хлорофилла в листьях яровой пшеницы // Плодородие. 2022. № 1. С. 17–21. DOI: 10.25680/S19948603.2022.124.05.
11. *Бутковская Л.К., Бобровский А.В., Крылова О.К.* Влияние сроков посева, минеральных удобрений и средств защиты растений на фотосинтетическую деятельность (площадь листьев) и урожайность ярового ячменя сорта Емеля // Вестник Бурятской государственной сельскохозяйственной академии им. В.Р. Филиппова. 2022. № 3 (68). С. 6–12.
12. *Никулина А.С.* Возможности использования сапропеля для повышения продуктивности сельскохозяйственных культур // Известия Горского государственного аграрного университета. 2022. Т. 59-3. С. 7–14.
13. *Воронин А.Н., Труфанов А.М., Котяк П.А., Щукин С.В.* Влияние обработки почвы и удобрений на фауну дерново-подзолистой глееватой почвы и урожайность полевых культур // Сибирский вестник сельскохозяйственной науки. 2023. Т. 53. № 3. С. 5–14.

REFERENCES

1. Wu S., Li R., Bu C., Zhu C., Miao C., Zhang Y., Cui J., Jiang J., Ding X. Photoperiodic effect on growth, photosynthesis, mineral elements, and metabolome of tomato seedlings in a plant factory. *Plants,* 2024, vol. 13, p. 3119. DOI: 10.3390/plants13223119.
2. Qu Y., Sakoda K., Fukayama H., Kondo E., Suzuki Y., Makino A., Terashima I., Yamori W. Overexpression of both Rubisco and Rubisco activase rescue rice photosynthesis and biomass heat stress. *Plant Cell Environment,* 2021, vol. 44 (7), pp. 2308–2320. DOI: 10.1111/pce.14051.
3. Stirbet A., Guo Y., Lazár D., Govindjee G. From leaf to multiscale models of photosynthesis: applications and challenges for crop improvement. *Photosynthesis Research*, 2024, vol. 161 (1–2), pp. 21–49. DOI: 10.1007/s11120-024-01083-9.
4. Zakharchenko E., Datsko O., Butenko S., Bakumenko O. The influence of organic growing of maize hybrids on the formation of leaf surface area and chlorophyll concentration. *Journal of Ecological Engineering,* 2024, vol. 25 (5), pp. 156–164. DOI: 10.12911/22998993/186162.
5. Liu X., Nadeem M., Rui Y. Effects of nanofertilizers on the mechanism of photosynthetic efficiency in plants: A review. *Phyton-International Journal of Experimental Botany*, 2024, vol. 93 (12), pp. 3197–3216.
6. Bildieva E.A., Eroshenko F.V., Gadzhimuradov R.G., Epifanova R.F. Photosynthetic productivity of winter wheat cultivated using No-Till technology. *Agrarnyi nauchnyi zchurnal = The Agrarian Scientific Journal,* 2021, no. 3, pp. 14–17. (In Russian).
7. Bildieva E.A., Eroshenko F.V., Drigider V.K. Photosynthesis and nitrogen nutrition of winter wheat cultivated using direct sowing technology. *Dostizcheniya nauki i techniki APK = Achievements of Science and Technology of AIC*, 2022, vol. 36, no. 5, pp. 44–49. (In Russian).
8. Voronkova N.A., Balabanova N.F., Volkova V.A., Tsyganova N.A. Preparation HB-101 effectiveness for spring wheat non-root top dressing in Western Siberian meadow-chernozem soil. *Vestnik Krasnoyarskogo gosudarsstvennogo agrarnogo universiteta = Bulletin KrasSAU*, 2021, no. 7, pp. 11–17. (In Russian). DOI: 10.36718/1819-4036-2021-7-11-17.

9. Anka M., Seregina I.I. The role of Siliplant, Epin-extra and Zircon in the formation of the assimilation apparatus of spring wheat seedlings depending on water supply conditions. *Izvestiya vysshikh uchebnykh zavedeniy. Povolzhskiy region. Yestestvennye nauki = University proceedings. Volga region. Natural sciences*, 2024, no. 1, pp. 72–80. (In Russian). DOI: 10.21685/2307-9150-2024-1-7.
10. Voronkova N.A., Volkova V.A., Tsyganova N.A., Balabanova N.F. The content of chlorophyll in the leaves of spring soft wheat depending on the root nutrition with macro-fertilizers and growth stimulants. *Plodorodiye = Plodorodie*, 2022, no. 1, pp. 17–21. (In Russian). DOI: 10.25680/S19948603.2022.124.05.
11. Butkovskaya L.K., Bobrovsky A.V., Krylova O.K. Influence of the timing of sowing, mineral fertilizers and plant protection agents on photosynthetic activity (leaf area) and yield of spring barley of the Emelya variety. *Vestnik Buryatskoy gosudarstvennoy sel'skokhozyaystvennoy akademii im. V.R. Filippova = Vestnik of Buryat State Academy of Agriculture named after V. Philippov*, 2022, no. 3 (68), pp. 6–12. (In Russian).
12. Nikulina A.S. Opportunities of using sapropel to increase the productivity of agricultural crops. *Izvestiya Gorskogo gosudarsstvennogo agrarnogo universiteta = Proceedings of Gorsky State Agrarian University*, 2022, vol. 59-3, pp. 7–14. (In Russian).
13. Voronin A.N., Trufanov A.M., Kotyak P.A., Shchukin S.V. Influence of tillage and fertilizers on the fauna of sodpodzolic gleyic soil and the yield of field crops. *Sibirskii vestnik sel'skokhozyaystvennoi nauki = Siberian Herald of Agricultural Science,* 2023, vol. 53, no. 3, pp. 5–14. (In Russian).

ИНФОРМАЦИЯ ОБ АВТОРАХ

(✉)**Воронин Александр Николаевич,** доцент кафедры, кандидат сельскохозяйственных наук, доцент; SPIN-код 8605-2537; **адрес для переписки:** Россия, 150999, Ярославль, Тутаевское шоссе, 58; e-mail: voronin@yarcx.ru

Котяк Полина Алексеевна, доцент кафедры, кандидат сельскохозяйственных наук, доцент; SPIN-код 6062-0202

AUTHOR INFORMATION

(✉)**Alexander N. Voronin,** Assistant Professor, Candidate of Science in Agriculture, Associate Professor; SPIN-code 8605-2537; **address:** 58, Tutaevskoe highway, Yaroslavl, 150999, Russia; e-mail: voronin@yarcx.ru

Polina A. Kotyak, Assistant Professor, Candidate of Science in Agriculture, Associate Professor; SPIN-code 6062-0202

Дата поступления статьи / Received by the editors 01.04.2025
Дата принятия к публикации / Accepted for publication 09.06.2025
Дата публикации / Published 19.12.2025

https://doi.org/10.26898/0370-8799-2025-12-4
УДК 631.811.944
Тип статьи: оригинальная
Type of article: original

Апробация биопрепарата с наночастицами оксида железа на семенах льна различной скороспелости

(✉)**Любимова Н.А., Рабинович Г.Ю.**
Федеральный исследовательский центр «Почвенный институт им. В.В. Докучаева»
Москва, Россия
(✉)e-mail: n.nemygina@gmail.com

В рамках проведенного исследования наночастицы оксида железа Fe_3O_4, синтезированные с использованием экстракта зеленого чая и раствора железного купороса ($FeSO_4 \cdot 7H_2O$) в концентрации 0,1 моль/л, вводили в различных дозах в готовый жидкофазный биопрепарат (ЖФБ) на стадии его дозревания. Эффективность линейки биопрепаратов ЖФБ-Fe изучена в ходе лабораторного эксперимента на семенах льна-долгунца сортов Надежда и Дипломат различной скороспелости. Полученные результаты показали, что использование наночастиц Fe_3O_4 является эффективным приемом модернизации исходного биопрепарата. Во всех вариантах опыта при апробации биопрепаратов ЖФБ-Fe отмечено повышение энергии прорастания и всхожести семян на 10–20%, а также увеличение средней длины проростков на 4–5 см, их средней массы – на 5–26 мг. Для более полного понимания влияния биопрепаратов на растительный организм произведен расчет коэффициента корреляции (r) между микробиологическими и биохимическими параметрами полученных биопрепаратов и средними по варианту показателями энергии прорастания, всхожести и биометрических данных проростков. Выявлена умеренная обратная взаимосвязь между всхожестью семян льна сорта Надежда и численностью микроорганизмов, использующих органические формы азота (r = –0,64). Также выявлена умеренная прямая зависимость между активностью ферментов каталазы и дегидрогеназы и средней длиной проростка (r = 0,56 и 0,66 соответственно). Тогда как при исследовании семян сорта Дипломат средняя масса сырого проростка сильно коррелировала с численностью микроорганизмов, использующих минеральные формы азота (r = 0,85), и суммарным количеством микроорганизмов, использующих минеральные и органические формы азота (r = 0,91).

Ключевые слова: биопрепарат ЖФБ-Fe, лен, сорт Надежда, сорт Дипломат, энергия прорастания, всхожесть, средняя длина проростка, средняя масса проростка

Testing of a biopreparation with iron oxide nanoparticles on flax seeds of varying prematurity

(✉)**Lyubimova N.A., Rabinovich G.Yu.**
Federal Research Center "V.V. Dokuchaev Soil Science Institute"
Moscow, Russia
(✉)e-mail: n.nemygina@gmail.com

In the study, iron oxide Fe_3O_4 nanoparticles synthesized using green tea extract and a solution of ferrous sulfate ($FeSO_4 \cdot 7H_2O$) at a concentration of 0.1 mol/l were introduced in various doses into a finished liquid-phase biopreparation (LPB) at the maturation stage. The efficiency of the LPB-Fe line of biopreparations was studied in a laboratory experiment on flax seeds of the Nadezhda and Diplomat varieties of varying prematurity. The obtained results showed that the use of Fe_3O_4 nanoparticles is an effective method for upgrading the original biopreparation. In all experimental variants, when testing the LPB-Fe biopreparations, an increase in germination energy and seed viability by 10–20% was

noted, as well as an increase in the average length of seedlings by 4–5 cm and their average weight by 5–26 mg. For a more complete understanding of the effect of biopreparations on the plant organism, the correlation coefficients (*r*) between the microbiological and biochemical parameters of the obtained biopreparations and the average values for the variant of germination energy, viability and biometric data of flax seedlings were calculated. A moderate inverse relationship was found between the germination of flax seeds of the Nadezhda variety and the number of microorganisms using organic forms of nitrogen ($r = –0.64$). A moderate direct relationship was also found between the activity of catalase and dehydrogenase enzymes and the average length of one seedling ($r = 0.56$ and 0.66, respectively). Whereas when studying the seeds of the Diplomat variety, the average weight of one raw sprout strongly correlated with the number of microorganisms using mineral forms of nitrogen ($r = 0.85$) and the total number of microorganisms using mineral and organic forms of nitrogen ($r = 0.91$).

Keywords: biological product LPB-Fe, flax, variety Nadezhda, variety Diplomat, germination energy, viability, sprout average length, sprout average weight

Для цитирования: *Любимова Н.А., Рабинович Г.Ю.* Апробация биопрепарата с наночастицами оксида железа на семенах льна различной скороспелости // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 12. С. 36–46. https://doi.org/10.26898/0370-8799-2025-12-4

For citation: Lyubimova N.A., Rabinovich G.Yu. Testing of a biopreparation with iron oxide nanoparticles on flax seeds of varying prematurity. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 12, pp. 36–46. https://doi.org/10.26898/0370-8799-2025-12-4

Конфликт интересов
Авторы заявляют об отсутствии конфликта интересов.
Conflict of interest
The authors declare no conflict of interest.

Благодарность
Работа выполнена при поддержке Министерства науки и высшего образования Российской Федерации в рамках государственного задания ФГБНУ ФИЦ «Почвенный институт им. В.В. Докучаева» (тема FGUR-2025-0009).
Acknowledgements
The work was carried out with the support of the Ministry of Science and Higher Education of the Russian Federation within the framework of the state assignment of the FSBSI FRC "V.V. Dokuchaev Soil Science Institute" (topic FGUR-2025-0009).

INTRODUCTION

Flax (*Linum usitatissimum* L.) is one of the traditional crops that has long been cultivated in the territory of Russia. This crop has found its application in the food, textile, and chemical industries, as well as in medicine and the production of modern composite materials [1]. In 2022, fiber flax was grown in 22 regions of the Russian Federation, with the area under long-staple flax cultivation in the Tver region amounting to 2,000 hectares [2].

One of the ways to increase the yield of fiber flax, as well as the quality of the fiber obtained from it, is the use of modern fertilizers, such as bio-preparations and microelements in nano-form [3, 4]. Microelements are substances that are necessary for plants in small quantities, but their deficiency disrupts the physiological structure of plants [5]. For example, the formation of chlorophyll in plants depends on the iron they receive. A deficiency of this element reduces the intensity of photosynthesis, and consequently, the growth and development of plants, which ultimately leads to a decrease in yield. Iron deficiency manifests itself in the form of chlorosis (yellowing between the veins of the leaves). Iron is also involved in other important biochemical processes, such as respiration, symbiotic nitrogen fixation, electron transport, cytochrome biosynthesis, nutrient absorption, DNA and protein synthesis [6]. In this regard, iron can be classified as an element that determines the productivity level and quality of agricultural crops.

Among all iron-based nanomaterials, the most promising in plant cultivation as fertilizers are nano zero-valent iron Fe (0), as well as iron oxide nanoparticles Fe_2O_3 and Fe_3O_4 [7]. Thus,

foliar feeding of cucumber (*Cucumis sativus* L.) with Fe_3O_4 nanoparticles (200 mg/l) contributed to an increase in vine length, number, size, and mass of fruits both in open and protected ground. In addition, the weight of 1000 seeds, their germination energy, and germination rate increased compared to the control [8]. M. Li et al. [9] noted in their work that due to the use of Fe (0) and Fe_3O_4 nanoparticles at a concentration of 50–500 mg/l when growing rice in hydroponic solution with iron deficiency, root length and volume increased by 16–41% and 13–32%, respectively. The use of Fe_2O_3 nanoparticles at the same concentration, on the contrary, inhibited root growth by 25%.

The use of various biopreparations contributes to an increase in the number of beneficial microorganisms in the rhizosphere. When interacting with plants, they enhance the absorption of nitrogen and phosphorus, improve the efficiency of macro- and micronutrient utilization from fertilizers and soil, and stimulate plant growth and development. In addition, microbial preparations help suppress the growth of phytopathogenic organisms and increase plant stress resistance [10]. Despite the fact that the use of both iron nanoparticles and biopreparations in crop production is a promising direction, there is no data in the literature on the results of their combined application. For example, it is known that rhizobacteria facilitate the absorption of iron by thale cress (*Arabidopsis thaliana*) under conditions of its deficiency [11]. In addition, the combined use of rhizobacteria (strain leguminosarum CF1) and Fe_3O_4 nanoparticles for treating bean seeds contributed to an increase in root and shoot length, as well as leaf area, compared not only to the control but also to the variants where nanoparticles and bacteria were applied separately [12].

The purpose of the study is to investigate in laboratory conditions the effect of a liquid-phase biopreparation (LPB) enriched with iron oxide (Fe_3O_4) nanoparticles on the germination and biometric parameters of fiber flax seedlings of different maturity rates with initially low germination.

MATERIAL AND METHODS

The study used two varieties of flax – Nadezhda (medium-maturing) and Diplomat (late maturing). Both varieties are included in the State Register for the North-Western region[1]. The seeds were obtained from the FSBSI "Federal Research Center for Bast Fiber Crops" (Tver).

Fe_3O_4 nanoparticles were synthesized using green tea extract and a $FeSO_4 \cdot 7H_2O$ solution at a concentration of 0.1 mol/l. A detailed synthesis method is described in [13].

The used liquid-phase biopreparation is a development of the scientific team of the Biotechnology Department of the All-Russian Research Institute of Reclaimed Lands and represents a dark brown liquid obtained from a mixture of peat and livestock by-product (cattle manure) by the fermentation-extraction method [14]. A powder containing nanoparticles was added to the finished LPB to enhance its multifunctional properties at a dose of 25–500 mg/l. In both the original and nanoparticle-modified iron oxide LPB, the number of mesophilic microorganisms was determined by the standard microbiological method of serial dilutions on solid nutrient media: those using mineral forms of nitrogen were counted on starch-ammonium agar (SAA), and those using organic forms of nitrogen were counted on meat-peptone agar (MPA). In addition, in all LPB variants, the activity of catalase and dehydrogenase was determined by gasometric and photocolorimetric methods, respectively. All determinations were performed in triplicate analytical repetition.

Seed germination was carried out according to GOST 12038–842 for 7 days in glass Petri dishes at a temperature of 22 ± 1 °C in the dark. The seeds were placed in Petri dishes on filter paper moistened with water (control) or a solution of the studied biopreparations in a volume of 5 ml.

[1]FSBI 'State Commission for Selection Achievements': official site. URL: https://gossortrf.ru.

The concentration of the preparations was 0.1–1.4%. Each variant included four repetitions (35 seeds each). The evaluation of effectiveness was carried out by determining the germination energy on the 3rd day and seed germination, as well as measuring the length and mass of the seedling on the 7th day. Distilled water was used as a control. It should be noted that seeds with low germination were used during the experiment in order to most fully assess the effectiveness of the biopreparations.

For a more complete understanding of the effect of biopreparations on the plant organism, correlation coefficients (*r*) were calculated between the microbiological and biochemical parameters of the biopreparations and the average values of germination energy, seedling emergence, and biometric data of the sprouts.

The statistical processing of the results was carried out using Microsoft Office Excel 2007. The data in the tables are presented as the mean ± confidence interval.

RESULTS AND DISCUSSION

A range of biopreparations obtained by adding Fe_3O_4 nanoparticle powder to LPB was studied for the content of microflora that primarily utilizes organic (ammonifiers on MPA) and mineral forms of nitrogen (on SAA), as well as for the degree of oxidoreductase activity (see Table 1).

The analysis showed that the addition of Fe_3O_4 to LPB in the form of nanoparticle powder contributed to the acidification of the base biopreparation only when high doses of iron oxide (250 and 500 mg/l) were introduced, which is due to its strong oxidizing properties. It should be noted that this level of acidification is quite safe, as it remains within a pH range close to neutral.

Increasing the powder dose to 250 and 500 mg led to a sharp decrease in the number of microorganisms using mineral forms of nitrogen: by 2.2 and 48.0 times, respectively, compared to the initial LPB, in which the number of microorganisms using organic and mineral forms of nitrogen amounted to 20.2×10^{11} and 14.4×10^{11} CFU/ml, respectively. As for microorganisms that utilize organic nitrogen, their number decreased by 1.3–2.6 times upon the addition of Fe_3O_4 nanoparticles compared to LPB without additives, ranging from $8.0 \cdot 10^{11}$ to $15.6 \cdot 10^{11}$ CFU/ml depending on the powder dose. At the same time, when the powder was added in doses of 25 to 100 mg/l, the number of microorganisms utilizing mineral nitrogen increased by 2.7–3.5 times compared to LPB.

Табл. 1. Результаты микробиологического и биохимического анализов ЖФБ с наночастицами оксида железа

Table 1. Results of microbiological and biochemical analyses of LPB with iron oxide nanoparticles

Biopreparation	Powder dose, mg/l	pH	The number of microorganisms, × 10^{11} CFU/ml		Activity	
			using organic forms of nitrogen	using mineral forms of nitrogen	catalases, cm^3O_2/g/min	dehydrogenases, mg TFF/g/24 h
LPB	–	6,3	20,2	14,4	2,6 ± 0,03	1,7 ± 0,2
LPB -Fe-1	25	6,4	15,6	49,8	2,6 ± 0,4	2,1 ± 0,2
LPB -Fe-2	50	6,3	14,0	49,8	2,4 ± 0,3	2,0 ± 0,2
LPB -Fe-3	100	6,4	8,0	39,5	2,7 ± 0,3	2,5 ± 0,3
LPB -Fe-4	250	6,2	10,1	6,5	2,7 ± 0,3	1,7 ± 0,2
LPB -Fe-5	500	6,1	9,9	0,3	1,6 ± 0,5	1,3 ± 0,2

[2]GOST 12038–84. Seeds of agricultural crops. Methods for determining germination. Moscow: Standartinform, 2011.

As for catalase activity, the addition of Fe_3O_4 nanoparticles to LPB had practically no effect on it, except at the maximum concentration of the powder: in this case, catalase activity decreased significantly compared to LPB without additives. A similar trend was observed for dehydrogenase: when the powder with nanoparticles was introduced at a dose of 500 mg/l, its activity decreased by 1.3 times compared to LPB.

The obtained results indicate that Fe_3O_4 nanoparticles in large quantities possess oxidative and antimicrobial activity, as previously mentioned by other authors. For example, in [15] it is shown that Fe_3O_4 nanoparticles synthesized using *Melia azedarach* leaf extract and a solution of $FeCl_3 \cdot 6H_2O$ demonstrated clear antimicrobial activity against the pathogenic bacteria *Escherichia coli*, *Vibrio cholerae*, and *Salmonella enterica*.

The results of the laboratory experiment on flax seeds of the Nadezhda variety showed that when irrigated with the base LPB preparation, the germination energy increased by 10–16%, and germination – by 2–10% compared to the control variant (see Fig. 1).

When using the range of LPB-Fe biopreparations for irrigation, the germination energy and seed germination rate were higher than in the control in almost all variants. The use of LPB-Fe-1 with a minimal dose of powder containing nanoparticles and at a concentration of 0.1–0.8% increased the germination energy by 5–8% compared to the control. While with an increase in concentration to 1.4%, this parameter decreased to values equal to the control. Seed germination in the LPB -Fe-1 and LPB -Fe-2 variants increased by 1–7% and 6–10%, respectively. The maximum values of germination energy and germination were observed in the LPB-Fe-3 variant: they exceeded the control indicators by 15–20% and 13–16%, respectively. At the same time, in the variants with high doses of nanoparticles (250 and 500 mg/l), germination energy decreased again compared to the LPB-Fe-3 variant. However, it was higher than in the control by 7–12% and 11–14% in the LPB - Fe-4 and LPB - Fe-5 variants, respectively. Seed germination in these variants was higher than in the control by 6–9% and 5–11%. A moderate inverse relationship was found between seed germination and the abundance of microorganisms that use organic forms of nitrogen ($r = -0.64$).

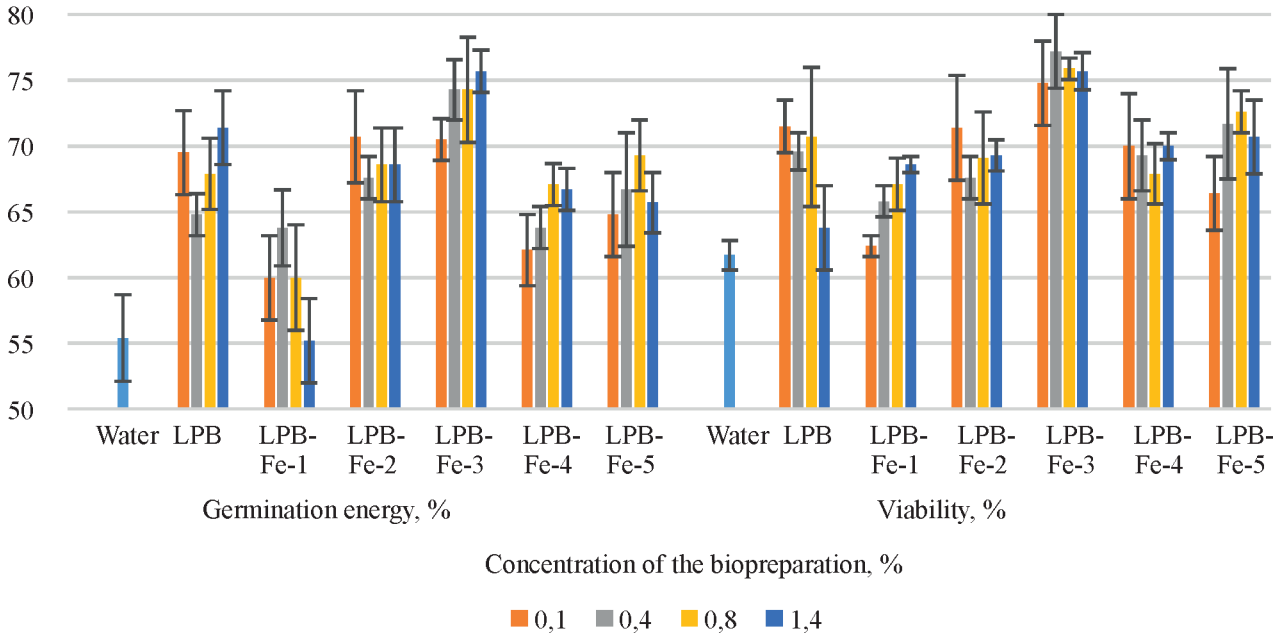


Рис. 1. Энергия прорастания и всхожесть семян льна сорта Надежда
Fig. 1. Germination energy and viability of flax seeds of the Nadezhda variety

The addition of Fe_3O_4 nanoparticles to the prepared LPB practically did not affect the average seedling length and average seedling mass, unlike the germination energy and germination rate (see Table 2). Thus, when watering with the original LPB, the average seedling length ranged from 13 to 16 cm, which is 1–3 cm longer than the control. In contrast, when using LPB-Fe with powder doses from 25 to 250 mg/l, the average seedling length in all variants was 15–17 cm, i.e., 3–5 cm longer relative to the control and only 1–2 cm longer compared to the variant without nanoparticles. In addition, in the variant with the maximum concentration of nanoparticles (powder dose of 500 mg/l), the average seedling length decreased, reaching 14–15 cm. It is likely that a further increase in the dose of nanoparticles would lead to even greater inhibition of plant growth due to toxic effects caused by high concentrations. At the same time, a moderate direct correlation is observed between catalase and dehydrogenase activity (see Table 1) and the average length of a single seedling (r = 0.56 and 0.66, respectively).

The average mass of the seedling practically did not depend on the quantity of nanoparticles and the concentration of the studied preparations (see Table 2). Thus, when using the original LPB for irrigation, the average mass of the seedling exceeded the control values by 2–7 mg, and this result is not statistically significant. Meanwhile, the most significant differences in average seedling mass were observed in the LPB-Fe-3 and LPB-Fe-4 variants, in which the average seedling mass was higher than the control by 10–15 and 14–18 mg, respectively.

Watering with LPB and LPB-Fe biopreparations with different concentrations of Fe_3O_4 nanoparticles mainly had a positive effect on the germination energy and seed germination of the late-maturing Diplomat variety (see Fig. 2). Thus, when using the original LPB, the germination energy increased by 6–13% compared to the control, as was the case with LPB-Fe at a powder dose of more than 50 mg/l. As for seed germination, it was almost the same in all the variants studied, with rare exceptions. The most noticeable effect on germination was exerted by the biopreparation LPB-Fe-3, which increased it by 4–9% compared to the control. In addition, a strong correlation was found between catalase and dehydrogenase activity in the bio-

Табл. 2. Результаты опыта по проращиванию семян льна сорта Надежда
Table 2. Results of the experiment on germination of flax seeds of the Nadezhda variety

Biopreparation	Concentration, %			
	0,1	0,4	0,8	1,4
Average sprout length, cm				
Control (water)	12,3 ± 1,2			
LPB	14,2 ± 2,1	15,9 ± 1,5	15,3 ± 2,2	13,2 ± 1,1
LPB -Fe-1	15,0 ± 0,8	16,1 ± 0,8	15,3 ± 0,8	15,4 ± 0,8
LPB -Fe-2	16,6 ± 0,6	17,0 ± 0,6	17,0 ± 0,7	15,7 ± 0,9
LPB -Fe-3	16,4 ± 0,8	17,1 ± 1,1	16,8 ± 1,4	16,0 ± 0,7
LPB -Fe-4	16,2 ± 0,8	17,4 ± 0,8	16,3 ± 0,9	15,3 ± 0,9
LPB -Fe-5	14,4 ± 0,7	14,3 ± 0,7	14,5 ± 0,8	15,2 ± 0,7
Average raw sprout mass, mg				
Control (water)	43,6 ± 3,8			
LPB	45,2 ± 3,2	49,8 ± 0,9	47,4 ± 2,3	50,6 ± 0,1
LPB -Fe-1	54,6 ± 3,8	51,9 ± 2,8	51,6 ± 3,8	54,2 ± 2,9
LPB -Fe-2	46,6 ± 2,5	51,0 ± 3,5	51,5 ± 1,2	45,8 ± 2,6
LPB -Fe-3	52,9 ± 0,9	58,3 ± 4,1	55,1 ± 4,3	52,1 ± 0,9
LPB -Fe-4	57,1 ± 2,4	57,7 ± 1,5	61,6 ± 1,7	60,6 ± 0,5
LPB -Fe-5	49,6 ± 3,3	46,3 ± 2,1	53,9 ± 1,7	49,4 ± 2,1

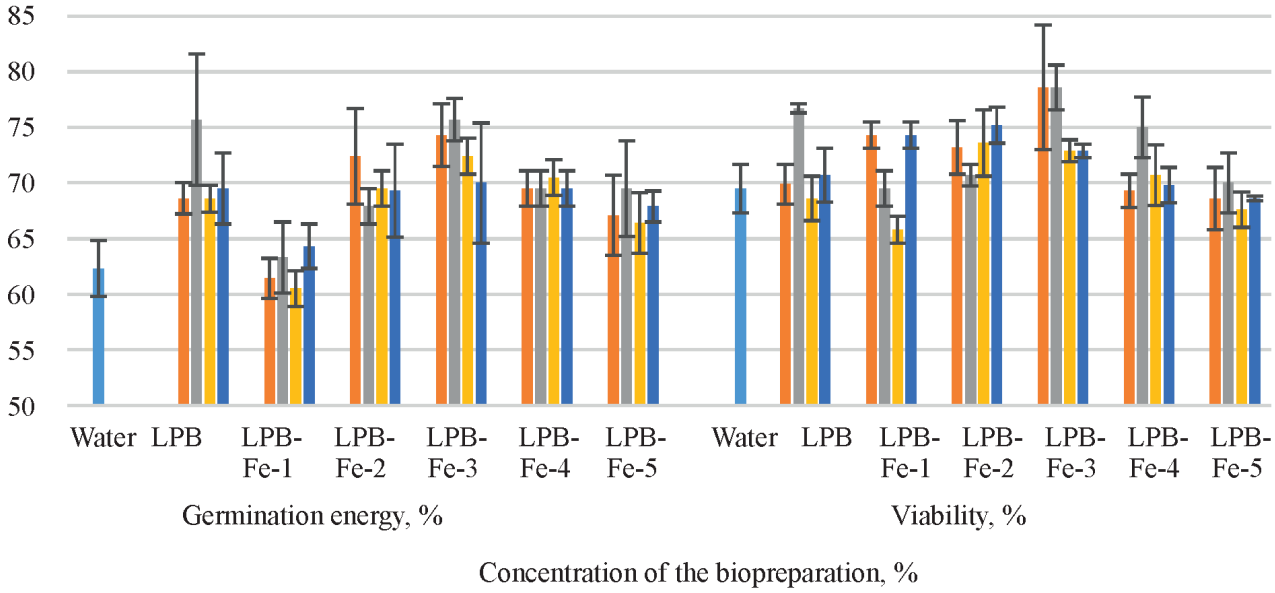


Рис. 2. Энергия прорастания и всхожесть семян льна сорта Дипломат
Fig. 2. Germination energy and viability of flax seeds of the Diplomat variety

preparations (see Table 1) and seed germination (r = 0.66 and 0.89, respectively).

The use of LPB and LPB-Fe biopreparations with different concentrations of nanoparticles affected the average length and average mass of the seedling (see Table 3). Thus, the average seedling length generally increased by 2–5 cm compared to the control. At the same time, the maximum values were obtained in the LPB-Fe-2 variant: exceeding the control figures by 4.0–5.5 cm. In addition, when germinating flax seeds of the Diplomat variety, unlike the Nadezhda variety, no negative effects of high concentrations of nanoparticles on the growth and development of plants were observed. The average mass of the fresh sprout was generally greater than in the control in all experimental variants. As with the average length, the maximum average mass was recorded in the LPB -Fe-2 variant: exceeding the control values by 10–26 mg. It should be emphasized that the average mass of the raw sprout was strongly correlated with the number of microorganisms using mineral forms of nitrogen (r = 0.85) and the total number of microorganisms using mineral and organic forms of nitrogen (r = 0,91).

It should be noted that in all the studied variants, the germination energy and seed germination of both varieties were quite low. On the one hand, this may be associated with their varietal characteristics, and on the other hand, the cause could be an incorrectly chosen watering volume (5 ml). It is reliably known that during a three-year field experiment, the germination of flax seeds of various varieties significantly decreased in the year characterized by relative moisture availability during the seed formation period (July – August) [16]. Nevertheless, in our experiment, the biopreparations with iron oxide nanoparticles used for irrigation positively influenced all the studied parameters.

The positive effect of iron oxide in nanoform has also been confirmed by other authors. For example, in [17] it is noted that foliar feeding of the medicinal plant *Pseudostellaria heterophylla* with a solution of Fe_3O_4 nanoparticles at a concentration of 20–50 mg/l stimulated an increase in the length and diameter of shoots and the dry mass of the root tuber, contributing to the growth of root tuber yield per unit area. At the same time, a further increase in concentration to 100 mg/l caused the opposite effect. The

Табл. 3. Результаты опыта по проращиванию семян льна сорта Дипломат
Table 3. Results of the experiment on germination of flax seeds of the Diplomat variety

Biopreparation	Concentration, %			
	0,1	0,4	0,8	1,4
Average sprout length, cm				
Control (water)	11,3 ± 0,4			
LPB	13,4 ± 1,3	14,3 ± 1,6	14,5 ± 1,2	14,1 ± 1,1
LPB -Fe-1	14,6 ± 1,3	14,2 ± 0,9	12,9 ± 1,0	13,0 ± 0,8
LPB -Fe-2	16,2 ± 0,6	16,1 ± 0,7	15,0 ± 0,8	16,5 ± 0,6
LPB -Fe-3	13,5 ± 0,7	13,3 ± 0,8	13,1 ± 0,7	14,0 ± 0,7
LPB -Fe-4	15,2 ± 1,0	14,9 ± 0,9	14,9 ± 1,0	16,2 ± 0,8
LPB Fe-5	16,1 ± 0,7	15,1 ± 0,6	14,0 ± 0,8	14,7 ± 0,6
Average raw sprout mass, mg				
Control (water)	48,1 ± 3,0			
LPB	53,2 ± 1,0	66,3 ± 3,3	47,7 ± 0,8	61,5 ± 2,7
LPB -Fe-1	59,2 ± 2,1	64,8 ± 3,6	60,0 ± 1,4	67,8 ± 4,0
LPB -Fe-2	74,6 ± 2,8	73,5 ± 6,8	58,3 ± 3,1	59,1 ± 2,2
LPB -Fe-3	51,8 ± 2,8	54,5 ± 2,1	54,1 ± 1,5	60,0 ± 2,1
LPB -Fe-4	55,3 ± 3,0	53,7 ± 2,9	48,7 ± 1,2	57,0 ± 4,7
LPB Fe-5	46,4 ± 2,1	53,2 ± 4,5	53,8 ± 5,1	48,0 ± 3,0

positive effect of nanoparticles on crop yield is attributed by the authors to the improvement of photosynthetic activity, as well as the stimulation of organic matter synthesis and its distribution within the plant body [17]. D.B. Dola et al. [18] found that foliar treatment of soybeans with Fe_3O_4 nanoparticles at a concentration of 200 ppm under dry conditions positively affects plant growth, which is reflected in an increase in their height, fresh leaf and stem mass, as well as total fresh and dry mass by 21, 31, 46, 33, and 48% respectively compared to the control.

CONCLUSION

The results of the laboratory experiment on flax seeds of the Nadezhda and Diplomat varieties showed that the bio-preparations LPB -Fe with different concentrations of Fe_3O_4 nanoparticles had a positive effect on all the parameters studied.

Thus, when germinating the seeds of the medium-maturing variety Nadezhda, the energy of germination and seed germination rate increased by 15–20% and 13–16%, respectively, compared to the control when irrigated with the biopreparation LPB-Fe-3 at a powder dose containing nanoparticles of 100 mg/l. In addition, in almost all cases, except for LPB-Fe-5 with a powder dose of 500 mg/l, the average seedling length ranged from 15 to 17 cm, i.e., it was 3–5 cm longer than in the control. A moderate inverse relationship was found between seed germination and the number of microorganisms using organic forms of nitrogen (r = –0.64), as well as a moderate direct relationship between catalase and dehydrogenase activity and the average length of the seedling (r = 0,56 and 0,66 respectively).

When germinating seeds of the late-maturing flax variety Diplomat, the greatest effect of the studied biopreparations on increasing the average length and average mass of the seedling was noted. Thus, the maximum increases relative to the control in seedling length and mass were observed in the LPB-Fe-2 variant (powder dose 50 mg/l) – 4.0–5.5 cm and 10.0–26.0 mg, respectively. It is important to note that the average mass of the raw sprout was strongly correlated with the number of microorganisms using mineral forms of nitrogen (r = 0.85) and the total

number of microorganisms using mineral and organic forms of nitrogen (r = 0,91).

СПИСОК ЛИТЕРАТУРЫ

1. *Базанов Т.А., Ущаповский И.В., Логинова Н.Н., Смирнова Е.В., Михайлова П.Д.* Метод ISSR-маркирования в исследовании генетического разнообразия сортов льна // Аграрная наука Евро-Северо-Востока. 2023. № 24 (5). С. 767–776. DOI: 10.30766/2072-9081.2023.24.5.767-776.
2. *Басова Н.В., Новиков Э.В.* Анализ производства лубяных культур в России за период импортозамещения // Технические культуры. Научный сельскохозяйственный журнал. 2023. № 2 (3). С. 54–63. DOI: 10.54016/SVITOK.2023.67.29.007.
3. *Круглова С.А., Золотова Р.П.* Эффективность применения биокомплекса «Фитогумат» при возделывании льна-долгунца в условиях Костромской области // Владимирский земледелец. 2020. № 4. С. 14–17. DOI: 10.24411/2225-2584-2020-10139.
4. *Конова А.М., Прудникова А.Г., Гаврилова А.Ю.* Управление продуктивностью льна-долгунца путем обработки семян микроэлементами и нанопрепаратом // Аграрный научный журнал. 2021. № 12. С. 27–31. DOI: 10.28983/asj.y2021i12pp27-31.
5. *Khatri A., Bhateria R.* Efficacy of nanofertilizers over chemical fertilizers in boosting agronomic production // Nature Environment and Pollution Technology. 2023. Vol. 22. N 2. P. 767–776. DOI: 10.46488/NEPT.2023.v22i02.019.
6. *Ahmed M.A., Shafei-Masouleh S.-S., Mohsin R.M., Salih Z.K.* Foliar application of iron oxide nanoparticles promotes growth, mineral contents, and medicinal qualities of *Solidago virgaurea* L. // Journal of Soil Science and Plant Nutrition. 2023. Vol. 23. P. 2610–2624. DOI: 10.1007/s42729-023-01218-2.
7. *Szuplewska A., Sikorski J., Matczuk M., Ruzik L.* Enhanced edible plant production using nano-manganese and nano-iron fertilizers: Current status, detection methods and risk assessment // Plant Physiology and Biochemistry. 2023. Vol. 199. P. 107745–107757. DOI: 10.1016/j.plaphy.2023.107745.
8. *Gupta N., Jain S.K., Tomar B.S., Anand A., Sagar V., Chaubey T., Singh A.K.* Impact of foliar application of ZnO and Fe_3O_4 nanoparticles on seed yield and physio-biochemical parameters of cucumber (*Cucumis sativus* L.) seed under open field and protected environment *vis a vis* during seed germination // Plants. 2022. Vol. 11. P. 3211–3231. DOI: 10.3390/plants11233211.
9. *Li M., Zhang P., Adeel M., Guo Zh.* Physiological impacts of zero valent iron, Fe_3O_4 and Fe_2O_3 nanoparticles in rice plants and their potential as Fe fertilizers // Environmental Pollution. 2021. Vol. 269. P. 116134–116145. DOI: 10.1016/j.envpol.2020.116134.
10. *Рассохина И.И.* Использование микроорганизмов как средство повышения продуктивности и устойчивости сельскохозяйственных культур // Агрозоотехника. 2021. Т. 4. № 3. С. 1–17. DOI: 10.15838/alt.2021.4.3.2.
11. *Kong W.-L., Wang Y.-H., Wu X.-Q.* Enhanced iron uptake in plants by volatile emissions of *Rahnella aquatilis* JZ-GX1 // Frontiers in Plant Science. 2021. Vol. 12. P. 704000–704012. DOI: 10.3389/fpls.2021.704000.
12. *De Souza-Torres A., Govea-Alcaide E., Gómez-Padilla E., Masunaga S.H.* Fe_3O_4 nanoparticles and *Rhizobium* inoculation enhance nodulation, nitrogen fixation and growth of common bean plants grown in soil // Rhizosphere. 2021. Vol. 17. P. 100275–100290. DOI: 10.1016/j.rhisph.2020.100275.
13. *Любимова Н.А., Рабинович Г.Ю.* Влияние наночастиц Fe_3O_4 на урожайность картофеля и развитие почвенной микрофлоры // Бюллетень Почвенного института им. В.В. Докучаева. 2024. № S1. С. 164–192. DOI: 10.19047/0136-1694-2024-SPYC-164-192.
14. *Fomicheva N.V., Rabinovich G.Yu., Kashkova A.A.* The effect of the biopreparation of LPB on the yield of vegetable crops // E3s web of conferences. 2023. Vol. 390. P. 01016.
15. *Abolarinwa T.O., Ajose D.J., Oluwarinde B.O.* Antimicrobial properties and cytotoxicity of iron oxide nanoparticles synthesized using *Melia azedarach* leaf extract against diarrhoeal pathogens // BioNanoScience. 2024. Vol. 14. P. 5003–5016. DOI: 10.1007/s12668-024-01393-1.
16. *Торопова Е.Ю., Купцевич Н.А., Порсев И.Н.* Факторы, определяющие качество семян льна в Курганской области // Вестник Алтайского государственного аграрного университета. 2014. № 12 (122). С. 15–19.
17. *Li J., Ma Y., Xie Y.* Stimulatory effect of Fe_3O_4 nanoparticles on the growth and yield of *Pseudostellaria heterophylla* via improved photosynthetic performance // HortScience. 2021.

Vol. 56 (7). P. 753–761. DOI: 10.21273/HORTSCI15658-20.
18. *Dola D.B., Mannan M.A., Sarker U.*, *Islam T., Ercisli S., Saleem M.H., Pop O.L., Marc R.A.* Nano-iron oxide accelerates growth, yield, and quality of *Glycine max* seed in water deficits // Frontiers in Plant Science. 2022. Vol. 13. P. 992535. DOI: 10.3389/fpls.2022.992535.

REFERENCES

1. Bazanov T.A., Uschapovsky I.V., Loginova N.N., Smirnova E.V., Mikhaylova P.D. Method of ISSR-marking in the study of genetic diversity of flax varieties. *Agrarnaya nauka Evro-Severo-Vostoka = Agricultural Science Euro-North-East*, 2023, no. 24 (5), pp. 767–776. (In Russian). DOI: 10.30766/2072-9081.2023.24.5.767-776.
2. Basova N.V., Novikov E.V. Analysis of the production of bast crops in Russia for the period of import substitution. *Tekhnicheskie kul'tury. Nauchnyj sel'skohozyajstvennyj zhurnal = Technical Crops. Scientific Agricultural Journal*, 2023, no. 2 (3), pp. 54–63. (In Russian). DOI: 10.54016/SVITOK.2023.67.29.007.
3. Kruglova S.A., Zolotova R.P. Efficiency of the biocomplex "Phytohumate" in cultivating linen flax in Kostroma region. *Vladimirskij zemledelec = Vladimir agricolist*, 2020, no. 4, pp. 14–17. (In Russian). DOI: 10.24411/2225-2584-2020-10139.
4. Konova A.M., Prudnikova A.G., Gavrilova A.Yu. Control the productivity of flax by treating seeds with microelements and nanopreparation. *Agrarnyj nauchnyj zhurnal = Agricultural Scientific journal*, 2021, no. 12, pp. 27–31. (In Russian). DOI: 10.28983/asj.y2021i12pp27-31.
5. Khatri A., Bhateria R. Efficacy of nanofertilizers over chemical fertilizers in boosting agronomic production. *Nature Environment and Pollution Technology*, 2023, vol. 22, no. 2, pp. 767–776. DOI: 10.46488/NEPT.2023.v22i02.019.
6. Ahmed M.A., Shafei-Masouleh S.-S., Mohsin R.M., Salih Z.K. Foliar application of iron oxide nanoparticles promotes growth, mineral contents, and medicinal qualities of Solidago virgaurea L. *Journal of Soil Science and Plant Nutrition*, 2023, vol. 23, pp. 2610–2624. DOI: 10.1007/s42729-023-01218-2.
7. Szuplewska A., Sikorski J., Matczuk M., Ruzik L. Enhanced edible plant production using nano-manganese and nano-iron fertilizers: Current status, detection methods and risk assessment. *Plant Physiology and Biochemistry*, 2023, vol. 199, pp. 107745–107757. DOI: 10.1016/j.plaphy.2023.107745.
8. Gupta N., Jain S.K., Tomar B.S., Anand A., Sagar V., Chaubey T., Singh A.K. Impact of foliar application of ZnO and Fe_3O_4 nanoparticles on seed yield and physio-biochemical parameters of cucumber (Cucumis sativus L.) seed under open field and protected environment vis a vis during seed germination. *Plants*, 2022, vol. 11, pp. 3211–3231. DOI: 10.3390/plants11233211.
9. Li M., Zhang P., Adeel M., Guo Zh. Physiological impacts of zero valent iron, Fe_3O_4 and Fe_2O_3 nanoparticles in rice plants and their potential as Fe fertilizers. *Environmental Pollution*, 2021, vol. 269, pp. 116134–116145. DOI: 10.1016/j.envpol.2020.116134.
10. Rassokhina I.I. The use of microorganisms as a means to increase productivity and sustainability of agricultural crops. *Agrozootekhnika = Agrozootekhnika*, 2021, vol. 4, no. 3. pp. 1–17. (In Russian). DOI: 10.15838/alt.2021.4.3.2.
11. Kong W.-L., Wang Y.-H., Wu X.-Q. Enhanced iron uptake in plants by volatile emissions of Rahnella aquatilis JZ-GX1. *Frontiers in Plant Science*, 2021, vol. 12, pp. 704000–704012. DOI: 10.3389/fpls.2021.704000.
12. De Souza-Torres A., Govea-Alcaide E., Gómez-Padilla E., Masunaga S.H. Fe_3O_4 nanoparticles and Rhizobium inoculation enhance nodulation, nitrogen fixation and growth of common bean plants grown in soil. *Rhizosphere*, 2021, vol. 17, pp. 100275–100290. DOI: 10.1016/j.rhisph.2020.100275.
13. Lyubimova N.A., Rabinovich G.Yu. Influence of Fe_3O_4 nanoparticles on potato yield and development of soil microflora. *Byulleten' Pochvennogo instituta im. V.V. Dokuchaeva = Dokuchaev Soil Bulletin*, 2024, no. S1, pp. 164–192. (In Russian). DOI: 10.19047/0136-1694-2024-SPYC-164-192.
14. Fomicheva N.V., Rabinovich G.Yu., Kashkova A.A. The effect of the biopreparation of LPB on the yield of vegetable crops. *E3s web of conferences*, 2023, vol. 390, P. 01016.
15. Abolarinwa T.O., Ajose D.J., Oluwarinde B.O. Antimicrobial properties and cytotoxicity of iron oxide nanoparticles synthesized using Melia azedarach leaf extract against diarrhoeal pathogens. *BioNanoScience*, 2024, vol. 14, pp. 5003–5016. DOI: 10.1007/s12668-024-01393-1.

16. Toropova E. Yu., Kuptsevich N.A., Porsev I.N. The factors determining linseed quality in the Kurgan region. *Vestnik Altajskogo gosudarstvennogo agrarnogo universiteta = Bulletin of Altai State Agricultural University*, 2014, no. 12 (122), pp. 15–19. (In Russian).
17. Li J., Ma Y., Xie Y. Stimulatory effect of Fe_3O_4 nanoparticles on the growth and yield of Pseudostellaria heterophylla via improved photosynthetic performance. *HortScience*, 2021, vol. 56 (7), pp. 753–761. DOI: 10.21273/HORTSCI15658-20.
18. Dola D.B., Mannan M.A., Sarker U., Islam T., Ercisli S., Saleem M.H., Pop O.L., Marc R.A. Nano-iron oxide accelerates growth, yield, and quality of Glycine max seed in water deficits. *Frontiers in Plant Science*, 2022, vol. 13, p. 992535. DOI: 10.3389/fpls.2022.992535.

ИНФОРМАЦИЯ ОБ АВТОРАХ

(✉)**Любимова Надежда Андреевна,** заведующая лабораторией, научный сотрудник, кандидат химических наук; SPIN-код 7515-3119, ORCID 0000-0002-5831-5000; **адрес для переписки:** Россия, 119017, Москва, Пыжевский пер., 7, стр. 2; e-mail: n.nemygina@gmail.com

Рабинович Галина Юрьевна, заведующая отделом, главный научный сотрудник, доктор биологических наук, профессор; SPIN-код 1437-3617, ORCID 0000-0002-5060-6241

AUTHOR INFORMATION

(✉)**Nadezhda A. Lyubimova,** Laboratory Head, Researcher, Candidate of Science in Chemistry; SPIN-code 7515-3119, ORCID 0000-0002-5831-5000; **address:** Build. 2, 7, Pyzhevsky Lane, Moscow, 119017, Russia; e-mail: n.nemygina@gmail.com

Galina Yu. Rabinovich, Department Head, Head Researcher, Doctor of Science in Biology, Professor; SPIN-code 1437-3617, ORCID 0000-0002-5060-6241

Дата поступления статьи / Received by the editors 20.04.2025
Дата принятия к публикации / Accepted for publication 01.07.2025
Дата публикации / Published 19.12.2025

https://doi.org/10.26898/0370-8799-2025-12-5
УДК 634.1.03
Тип статьи: оригинальная
Type of article: original

Сравнительная оценка клоновых подвоев яблони различного происхождения для использования в Иркутской области

Раченко А.М.[1, 2], (✉)Раченко М.А.[1], Мокшонова И.М.[1], Раченко Д.М.[2]
[1]*Сибирский институт физиологии и биохимии растений Сибирского отделения Российской академии наук*
Иркутск, Россия
[2]*Иркутский государственный аграрный университет им. А.А. Ежевского*
пос. Молодежный, Иркутская область, Россия
(✉)e-mail: bigmks73@rambler.ru

Использование клоновых подвоев яблони представляет потенциальную перспективу для садоводства в южной части Иркутской области. В данной работе отражены результаты многолетних исследований на территории Южного Предбайкалья. Все исследования проводились в 2018–2024 гг. на коллекционных участках Сибирского института физиологии и биохимии растений Сибирского отделения Российской академии наук, расположенных в Иркутске и Иркутском районе Иркутской области. Изучение подвоев в маточнике и сорто-подвойных комбинаций в саду проводили по Программе и методике сортоизучения плодовых, ягодных и орехоплодных культур. В результате оценки клоновых подвоев генотипы Арм-18 и К-2 при возделывании в условиях Иркутской области с 2018 по 2024 г. были оценены как слабозимостойкие, остальные генотипы – как зимостойкие. К высокозимостойким клоновым подвоям мы отнесли клон сибирской ягодной яблони, Урал, Урал 2, 4-12 (Волга 12) и Е-56. Для оценки сорто-подвойных комбинаций несколько генотипов клоновых подвоев были привиты сортами зимостойких яблонь-полукультурок. Все клоновые подвои, используемые для прививки, кроме контроля, клона сибирской ягодной яблони, были оценены как зимостойкие, клон сибирской ягодной яблони – как высокозимостойкий. Вступление в плодоношение у яблонь-полукультурок, привитых на клоновые подвои, наступало на год раньше, чем у привитых на сибирскую ягодную яблоню, при этом больших различий в продуктивности изученных деревьев отмечено не было. Многолетние исследования показали, что основная часть изученных клоновых подвоев перспективна для дальнейшего изучения.

Ключевые слова: яблоня, клоновые подвои, полевая зимостойкость, сорто-подвойные комбинации

Comparative evaluation of clonal apple rootstocks of various origin for use in the Irkutsk region

Rachenko A.M.[1, 2], (✉)Rachenko M.A.[1], Mokshonova I.M.[1], Rachenko D.M.[2]
[1]*Siberian Institute of Plant Physiology and Biochemistry, Siberian branch of the Russian Academy of Sciences*
Irkutsk, Russia
[2]*Irkutsk State Agrarian University named after A.A. Ezhevsky*
Molodezhny, Irkutsk region, Russia
(✉)e-mail: bigmks73@rambler.ru

The use of clonal apple rootstocks represents a potential prospect for horticulture in the southern part of the Irkutsk region. This paper presents the results of long-term research in the Southern Cis-Baikal region. All studies were conducted in 2018–2024 at the collection sites of the Institute of Physiology and Biochemistry of the Siberian Branch of the Russian Academy of Sciences, located in Irkutsk and the Irkutsk district of the Irkutsk region. The study of rootstocks in the nursery plantation and variety-rootstock combinations in the garden was carried out according to the Program and methodology for variety study of fruit, berry and nut crops. As a result of the evaluation of clonal rootstocks, the Arm-18 and K-2 genotypes were assessed as slightly winter-hardy when cultivated in the conditions of the Irkutsk region in the period from 2018–2024, the remaining genotypes were assessed as winter-hardy. We classified the Siberian berry apple clone, Ural, Ural 2, 4-12 (Volga 12) and E-56 as highly winter-hardy clonal rootstocks. To evaluate the variety-rootstock combinations, several gen-

otypes of clonal rootstocks were grafted with the varieties of winter-hardy semi-cultivated apple trees. All clonal rootstocks used for grafting, except for the control, the Siberian berry apple clone, were assessed as winter-hardy, the Siberian berry apple clone as highly winter-hardy. The semi-cultivated apple trees grafted onto clonal rootstocks began to bear fruit a year earlier than those grafted onto the Siberian berry apple tree, while no significant differences in the productivity of the trees studied were noted. Long-term studies have shown that most of the clonal rootstocks studied are promising for further study.

Key words: apple tree, clonal rootstocks, field winter hardiness, variety-rootstock combinations

Для цитирования: *Раченко А.М., Раченко М.А., Мокшонова И.М., Раченко Д.М.* Сравнительная оценка клоновых подвоев яблони различного происхождения для использования в Иркутской области // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 12. С. 47–55. https://doi.org/10.26898/0370-8799-2025-12-5

For citation: Rachenko A.M., Rachenko M.A., Mokshonova I.M., Rachenko D.M. Comparative evaluation of clonal apple rootstocks of various origin for use in the Irkutsk region. *Sibirski ivestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 12, pp. 47–55. https://doi.org/10.26898/0370-8799-2025-12-5

Конфликт интересов
Авторы заявляют об отсутствии конфликта интересов.
Conflict of interest
The authors declare no conflict of interest.

Благодарность
Работа выполнена на оборудовании центра коллективного пользования (ЦКП) «Биоаналитика» с использованием коллекций ЦКП «Биоресурсный центр» Сибирского института физиологии и биохимии растений Сибирского отделения Российской академии наук, Иркутск.
Исследование выполнено в рамках государственного задания Минобрнауки России для Сибирского института физиологии и биохимии растений Сибирского отделения Российской академии наук (рег. номер НИОКТР – 125021902487-9).
Acknowledgements
The work was carried out using the equipment of the "Bioanalytics" Shared Use Center (SUC) using the SUC collections of the "Bioresource Center" of the Siberian Institute of Plant Physiology and Biochemistry of the Siberian branch of the Russian Academy of Sciences, Irkutsk.
The research was carried out within the state assignment of Ministry of Science and Higher Education of the Russian Federation for the Siberian Institute of Plant Physiology and Biochemistry of the Siberian Branch of the Russian Academy of Sciences (R&D project registration No. – 125021902487-9).

INTRODUCTION

Irkutsk region is a risky agricultural zone, especially for the horticultural sector. Harsh climatic conditions of the Irkutsk region, with a short frost-free period, late return frosts, and critically low temperatures in the winter period, create a need for new adaptive crops and varieties capable of yielding high harvests to provide the local population with fresh fruits and berries. An important crop that can be considered for industrial purposes is the apple tree [1]. The most favorable areas for the development of horticulture are the southern regions of Irkutsk region.

At present, the assortment of apple trees in the region is mainly represented by hybrid apple varieties, which are grafted onto seedling rootstocks – Siberian crab apple (*Malus baccata*) seedlings. However, these seedlings are of varying quality, each possessing only its inherent heredity, and exerting its own specific influence on the grafted variety. In general, clonal rootstocks are characterized by genetic uniformity and therefore affect the grafted variety in the same way[1] [2]. The introduction of clonal rootstocks as a crop in the territory of Southern Pre-Baikal is possible only with the use of the genotypes with high adaptability and winter hardiness of the root system.

Research by modern breeders indicates a number of advantages of using dwarf clonal rootstocks for apple cultivation: high compatibility with promising apple varieties, high frost resistance of the root system (modern genotypes are able to withstand soil temperatures of –16…

[1]*Bochkarev E.A.* Preliminary assessment of new forms of clonal rootstocks of apple trees in the mother plantation // Selection and variety study of fruit and berry crops: collection of scientific papers, Kinel, 2025, pp. 97–103.

–18 °C). In addition, trees on clonal rootstocks are generally more resistant to diseases and pests [3–5].

It is believed that the introduction of clonal rootstocks will significantly reduce the time from obtaining the rootstock to harvest, change the habit of the fruit tree (dwarf trees are easier to care for), increase yield due to the greater number of plants per unit area, and reduce the time to fruiting due to scion-rootstock interactions [5, 6].

In general, thanks to their characteristics, the adaptive capabilities of clonal apple seedlings of different geographical origins represent a potential prospect for horticulture in the southern part of the Irkutsk region. Variety study, as one of the stages of breeding, involves a long-term study of new crops for the region and an analysis of factors affecting their successful development and growth.

In connection with the above, the purpose of this work was a comparative evaluation of apple clonal rootstocks of various origins for use in the Irkutsk region.

MATERIAL AND METHODS

The study used a collection of vegetatively propagated apple rootstocks of various geographical origins of breeding:

– Michurinsk State Agrarian University (Michurinsk);

– Armenian Scientific Research Institute of Viticulture, Winemaking and Fruit Growing;

– Estonian Scientific Research Institute of Agriculture and Land Reclamation;

– Federal Horticultural Center for Breeding, Agrotechnology and Nursery (Moscow) and Research Institute of Horticulture and Medicinal Plants (Samara);

– Crimean Experimental Breeding Station (Krymsk).

A clone of the Siberian crab apple tree was used as a control (*Malus baccata* (L.) Borkh.) (CSCAT).

All studies were conducted in 2018–2024 at the collection sites of the Siberian Institute of Plant Physiology and Biochemistry of the Siberian Branch of the Russian Academy of Sciences (SIPPB SB RAS), located in Irkutsk and the Irkutsk district of the Irkutsk region. The soil type at the sites is gray forest soil, and in terms of granulometric composition, it is loam of medium texture.

For collection study, a mother plantation was established in 2016 on a plot with artificial irrigation, located in the Irkutsk district. Between 4 and 10 mother bushes of each studied form were planted. The plant spacing was 100 × 50 cm. In the collection mother plantation, they studied the survival of rootstocks, the degree of winter damage to the bush head, the condition of the bush head, and the overall condition of the plant at the beginning of the growing season.

To determine the compatibility of rootstocks with the main half-cultured apple varieties grown in the region, the quality of seedlings, and the productivity of variety–rootstock combinations, a collection orchard was established on the plot in 2018 (with two-year-old seedlings). Well-studied half-cultured apple varieties were selected as scions: Katyusha, Prevoskhodnoe, Rayskoe, Lada. The criteria for selecting the grafted varieties were the commercial qualities of the fruits: taste, shelf life, and suitability for processing.

The study of rootstocks in the nursery and scion-rootstock combinations in the garden was carried out according to the Program and methodology for the varietal study of fruit, berry, and nut-bearing crops[2].

RESULTS AND DISCUSSION

Winter hardiness is a complex property of plants, which is related not only to the conditions

[2]Program and methodology for the study of varieties of fruit, berry, and nut crops / edited by Academician of RAAS E.N. Sedov, Doctor of Science in Agriculture T.P. Ogoltsova. Orel: Publishing House of the All-Russian Research Institute of Fruit Crop Selection, 1999, 608 p.

of the winter period, but also to the processes occurring in the plant throughout the year.

Particularly important in the comprehensive assessment of a fruit tree's winter hardiness is a characteristic such as field winter hardiness. One of the main causes of damage to fruit plants is the harsh climatic conditions in the region of study. A short frost-free period, insufficient positive temperatures, and prolonged precipitation, which contribute to lowering temperatures and the spread of diseases, lead to an incomplete progression of the growing season. The insufficient duration of the hardening process is caused by the sharp decrease in temperature at the beginning of October and has a negative impact on the final phase of leaf fall. Prolonged periods of extremely low temperatures in December to February (below –30 °C), as well as significant temperature fluctuations at the end of February and the beginning of March (from –25 to +5 °C), along with a high level of insolation reflected from the snow cover, exacerbate the negative effects of the cold. In addition, frequent temperature changes in April (from +22 to –10 °C) lead to the death of varieties that do not have sufficient winter hardiness[3].

Assessment of the winter hardiness of clonal rootstock plants in the nursery showed that throughout the entire observation period (2018–2024), all genotypes of the studied rootstocks exhibited high field winter hardiness of the root system and good regenerative capacity. Most of the studied rootstocks demonstrated average field winter hardiness of the aboveground part of the plant (the degree of damage did not exceed 2.5 points), only the clonal rootstocks Arm-18 and K-2 experienced irreversible damage to the crown of the bush each winter (3.0–3.5 points).

The harshest in all the research years turned out to be 2023 and 2024. The accumulated winter damage over several years led to many rootstocks being significantly affected, including E-56, which had shown high winter hardiness for many years (see Fig. 1). For most rootstocks, the condition of the trees was rated at 3 points. For the K-2 and Arm-18 rootstocks, the overall condition of the plants was rated at 2 points. The only rootstock that came through the winter without damage was CSCAT.

Over the years of observation, the best indicators of winter hardiness were shown by the rootstocks CSCAT, Ural, Ural 2, 4-12 (Volga 12), and E-56 – they can be classified as highly winter-hardy genotypes. The genotypes Arm-18 and K-2, when cultivated under the conditions of the Irkutsk region in 2018–2024, were assessed as weakly winter-hardy and were excluded from further studies. The remaining genotypes were assessed as winter-hardy.

In 2022, taking into account previous studies, a new mother plantation of clonal rootstocks was established. It included those forms of clonal rootstocks that showed high and medium winter hardiness. In addition, the collection was supplemented with new genotypes of clonal rootstocks, created by Doctor of Science in Agriculture E.Z. Savin and colleagues [7]. All rootstocks were planted in quantities of 10 specimens of each genotype in the mother plantation (see Table 1).

All studied genotypes took root well, survived the winter of 2022/23, and showed good growth during the growing season. Harsh conditions of the winter period 2023/24 did not significantly affect the condition of the plants in the new collection mother plantation; the overall condition of all plants was rated at 4–5 points. Observations of the rootstocks continue, and at present all genotypes are considered promising for further study in the conditions of the mother plantation and nursery.

In 2023, studies on the laboratory winter hardiness of clonal rootstocks were conduct-

[3]*Rachenko M., Rachenko A., Kiseleva E.* Winter hardiness of apple clonal rootstocks in Southern Cisbaikalia // E3S Web of Conferences: IX International Conference on Advanced Agritechnologies, Environmental Engineering and Sustainable Development, Namangan, Uzbekistan (Oct. 26, 2023), 2024, vol. 486, p. 02031. DOI: 10.1051/e3sconf/202448602031.

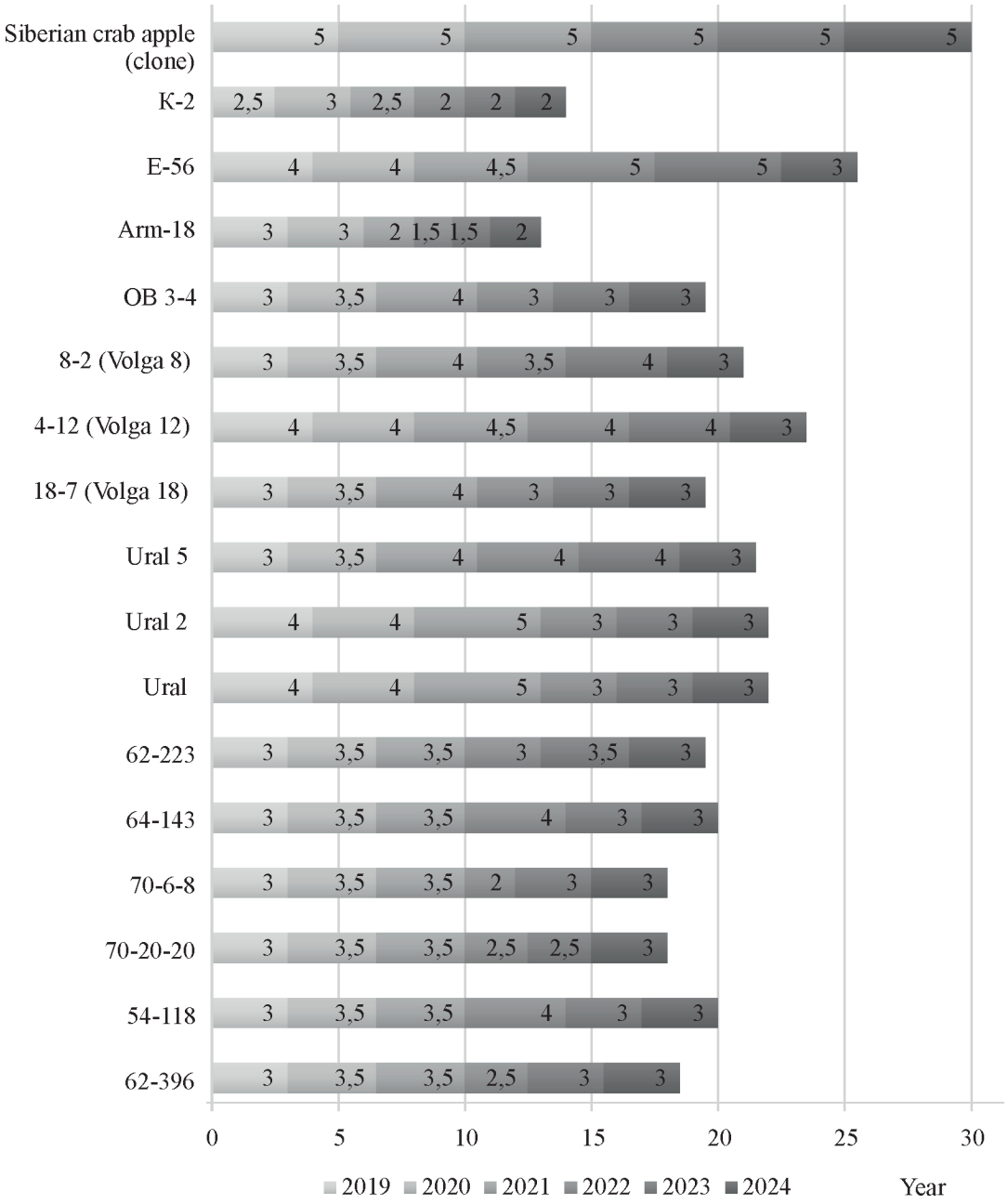


Рис. 1. Общее состояние растений клоновых подвоев к началу вегетационного периода, балл
Fig. 1. General condition of clonal rootstock plants at the beginning of the growing season, point

ed at SIPPB SB RAS according to 4 indicators of winter hardiness. Experiments on artificial freezing fully confirmed the data from field tests (see footnote 3).

It is known that the rootstock must be compatible with the scion and provide the grafted tree with the longest possible economic life [8]. Graft incompatibility is usually referred to as the inability of the rootstock and scion to join together and form a successful graft union. Scion incompatibility is a critical problem for the breeding of fruit tree rootstocks and the longevity of an orchard. This leads to the formation of unhealthy trees, breaking of the graft union, and premature death of grafted plants. When joining the rootstock and the scion, various factors are important, and signs of incompatibility may appear, such as poor bud formation, as well as anatomical and morphological anomalies during the scion union [9–11].

Табл. 1. Состав коллекционного маточника клоновых подвоев, заложенного в 2022 г., и общее состояние растений к началу вегетационного периода 2024 г.

Table 1. Composition of the collection nursery of clonal rootstocks laid in 2022, and the general condition of plants at the beginning of the growing season of 2024

Clonal rootstock	Seedling	Rating, score
OB 1-15	Unknown	5,0
OB 1-28	Elite dwarf form of unknown origin	5,0
OB 2-15	Ural 5	5,0
OB 2-2	K-2	4,5
OB 2-24	Elite dwarf form of unknown origin	5,0
OB 2-4	71-7-23	5,0
OB 2-6	Ural 5	5,0
OB 2-30	Elite dwarf form of unknown origin	5,0
OB 3-2	The same	5,0
OB 3-4	71-7-23	5,0
OB 3-7	62-396	5,0
OB 3-14	Ural 5	5,0
OB 7-5	Unknown	5,0
OB 7-8	»	5,0
4-5	65-972	5,0
8-8	57-366	5,0
19-10	57-490	5,0
151-1	65-151	5,0
CA-12-2	Ural 5	5,0
CA 12-3	E-56	5,0
CA 14-1	Ural 5	5,0
II Pole	Ural 5	5,0
Volga 3	65-972	5,0
Volga 8	57-233	5,0
Volga 12	13-14	5,0
Volga 18	Paradziki Budagovskogo	5,0
Ural 1	49-134	5,0
Ural 2	49-290	5,0
Ural 5	57-469	5,0
Ural 5-4	Elite dwarf form of unknown origin	5,0
62-396	No.13-14×ПБ9	4,0
54-118	(B9)×13-14	4,0
70-20-20	57-469×57-344	4,0
64-143	PB9×49290	4,0
62-223	Anoka×PB9	4,0
E-56	Unknown	5,0

The most significant influence of the rootstock on the scion variety is the control of tree size and the corresponding changes in morphology [12, 13].

All clonal rootstocks used for grafting, except for the control (CSCAT), are assessed as winter-hardy, CSCAT – as highly winter-hardy. Trees of the Katyusha variety in all variants are assessed as highly winter-hardy. The Rayskoe variety on clonal rootstocks 70-6-8, 62-396, and CSCAT is assessed as highly winter-hardy, on rootstocks 70-20-20 and 54-118 – as winter-hardy. The Prevoskhodnoe variety on the clonal rootstock CSCAT is assessed as highly winter-hardy, on clonal rootstocks 70-20-20 and 62-396 – as winter-hardy, and on clonal rootstocks 70-6-8 and 54-118 – as medium winter-hardy. The Lada variety in all variants is assessed as winter-hardy (see Table 2).

Табл. 2. Различия в перезимовке разных сортов яблони на клоновых подвоях в условиях Южного Предбайкалья, средняя степень повреждения, балл

Table 2. Differences in overwintering of different apple varieties on clonal rootstocks in the conditions of the Southern Cis-Baikal region, average damage level, point

Rootstock	Variety	Year			
		2018	2019	2020	2021
70-6-8 (semidwarf)	Katyusha	1,0	2,0	1,0	1,00
	Prevoskhodnoe	3,0	3,0	2,0	2,00
	Rayskoe	2,0	2,0	1,0	0,75
70-20-20 (medium-height)	Katyusha	1,7	2,0	1,2	0,50
	Prevoskhodnoe	2,0	3,0	2,3	2,00
	Rayskoe	2,0	3,0	2,5	2,00
62-396 (dwarf)	Katyusha	1,0	2,0	1,3	1,33
	Prevoskhodnoe	2,0	3,0	2,2	2,00
	Rayskoe	3,0	2,0	1,2	1,00
	Lada	2,0	3,0	1,7	2,00
54-118 (medium-height)	Katyusha	1,0	2,0	1,0	1,50
	Prevoskhodnoe	3,2	3,0	2,0	2,50
	Rayskoe	3,0	3,0	2,0	2,00
	Lada	3,5	2,0	1,2	1,25
Control (seedling of Siberian crab apple)	Katyusha	1,0	0	0	0
	Prevoskhodnoe	1,0	2,0	1,5	1,25
	Rayskoe	1,0	1,0	0,2	0,50
	Lada	1,0	3,0	2,0	2,25

Табл. 3. Максимальная продуктивность яблонь-полукультурок в зависимости от подвоя, 2024 г., кг/дерево

Table 3. Maximum productivity of semi-cultivated apple trees depending on the rootstock, 2024, kg/tree

Rootstock	Variety	Productivity
Siberian crab apple clone	Katyusha	15
	Prevoskhodnoe	–
	Lada	5
	Rayskoe	5
70-6-8	Katyusha	7
	Prevoskhodnoe	–
	Rayskoe	5
54-118	Katyusha	5
	Prevoskhodnoe	–
	Lada	3
	Rayskoe	3
62-396	Katyusha	10
	Prevoskhodnoe	–
	Lada	5
	Rayskoe	5
70-20-20	Katyusha	12
	Prevoskhodnoe	–
	Rayskoe	7

In the context of increasing climate fluctuations and a growing risk of weather-related stresses, special attention should be paid to identifying rootstock types with a high intrinsic adaptive potential that positively affects the resilience of grafted plants. Analyzing our observations, we can speak of the insufficient adaptive potential of the clone rootstock 54-118. The varieties grafted onto this rootstock most often had an average damage score of 2 or higher.

The onset of fruiting in semi-cultured apple trees grafted onto clonal rootstocks occurred a year earlier than in those grafted onto Siberian crab apple rootstocks, while no significant differences were observed in the productivity of the studied trees or in the influence of the rootstock on the fruiting periodicity (see Table 3).

CONCLUSION

Long-term research on the field winter hardiness of clonal rootstocks has shown that the majority of the studied genotypes are winter-hardy and promising for further study. The studies allowed us to identify the most valuable clonal rootstocks for gardening in the Southern Pre-Baikal region and their further use in breeding: E-56, Ural, Ural 2, 4-12 (Volga 12), and a clone of Siberian crab apple.

СПИСОК ЛИТЕРАТУРЫ

1. *Седов Е.Н., Янчук Т.В., Корнеева С.А.* Этапы совершенствования сортимента яблони в России // Вестник российской сельскохозяйственной науки. 2024. № 6. С. 31–36. DOI: 10.31857/S2500208224060082.
2. *Thakur G., Singh R.P.* Rootstock and its advantage in horticulture // Inclusive Fundamental of

Horticulture / eds. R.P. Singh, G. Sinha, G. Gonmei, S. Kumar. Delhi, 2025. P. 95–106.
3. *Мурсалимова Г.Р., Хардикова С.В.* Засухоустойчивость вегетативно размножаемых подвоев яблони в условиях Южного Урала // Вестник Оренбургского государственного университета. 2021. Т. 142. № 6. С. 63.
4. *Савин Е.З., Новиков В.А., Мушинский А.А., Березина Т.В., Саудабаева А.Ж.* Опыт выращивания отборных форм клоновых подвоев яблони в условиях Южного Урала // Аграрный научный журнал. 2024. № 10. С. 72–81. DOI: 10.28983/asj.y2024i10pp72-81.
5. *Трунов Ю.В., Соловьев А.В., Папихин Р.В., Дубровский М.Л., Шамшин И.Н.* Перспективные клоновые подвои яблони для интенсивных садов // Садоводство и виноградарство. 2020. № 2. С. 34–40. DOI: 10.31676/0235-2591-2020-2-34-40.
6. *Verma P., Sharma N.C., Sharma D.P., Kumar P., Chand K., Thakur H.* Dwarfism mechanism in Malus clonal rootstocks // Planta. 2024. Vol. 260. P. 133. DOI: 10.1007/s00425-024-04561-5.
7. *Савин Е.З., Березина Т.В., Василенко А.Ю.* Параметры и продуктивность яблони на клоновых подвоях в условиях Южного Урала // Известия Оренбургского государственного аграрного университета. 2023. № 4 (102). С. 106–112. DOI: 10.37670/2073-0853-2023-102-4-106-112.
8. *Бочкарев Е.А.* Перспективные сорто-подвойные комбинации яблони для интенсивного садоводства в Среднем Поволжье // Известия Самарской государственной сельскохозяйственной академии. 2024. Т. 9. № 1. С. 72–80. DOI: 10.55170/1997-3225-2024-9-1-72-80.
9. *Rasool A., Mansoor S., Bhat K.M., Hassan G.I., Baba T.R., Alyemeni M.N., Ahmad P.* Mechanisms underlying graft union formation and rootstock scion interaction in horticultural plants // Frontiers in Plant Science. 2020. Vol. 11. P. 590847. DOI: 10.3389/fpls.2020.590847.
10. *Solanki P.P., Rathva V.D.* Rootstock and its advantage in horticulture // Horticulture Symphony / eds. A. Krishnamoorthi, G.K. Choupdar, N. Divaker, P.P. Solanki, V. Kumar. Ambala, Cantt., 2025. P. 101–114.
11. *Robinson T.L., Nieto L.G., Ho Sh.T., Rickard B.J., Reig G., Lordan J., Fazio G., Hoying S.A., Fargione M.J., Sazo M.M.* Apple orchard economics: effects of cultivar, planting density and rootstock // Fruit Quarterly. 2024. Vol. 32 (2). P. 4–11.
12. *Jat M.L., Jat R.K., Shivran J.S.* Apple rootstock: capabilities and characteristics // Recent Innovative Approaches in Agricultural Science / eds. G.K. Yadav, S.H. Dadhich, M.C. Bhateshwar. Bhumi Publishing, 2022. Vol. 2. P. 154–163.
13. *Jian W., Li X., Xiao Zh., Yali H., Ke Zh., Dongxu F., Dong W.* A new function of MbIAA19 identified to modulate malus plants dwarfing growth // Plants. 2023. Vol. 12 (17). P. 3097. DOI: 10.3390/plants12173097.

REFERENCES

1. Sedov E.N., Yanchuk T.V., Korneeva S.A. Stages of improvement the apple tree assortment in Russia. *Vestnik rossiiskoi sel'skohozyaistvennoi nauki = Vestnik of the Russian Agricultural Science*, 2024, no. 6, pp. 31–36. (In Russian). DOI: 10.31857/S2500208224060082.
2. Thakur G., Singh R.P. Rootstock and its advantage in horticulture. *Inclusive Fundamental of Horticulture* / eds. R.P. Singh, G. Sinha, G. Gonmei, S. Kumar. Delhi, 2025, pp. 95–106.
3. Mursalimova G.R., Hardikova S.V. Drought resistance of clonal rootstocks apple in the Southern Ural. *Vestnik Orenburgskogo gosudarstvennogo universiteta = Vestnik of the Orenburg State University,* 2021, vol. 142, no. 6, p. 63. (In Russian).
4. Savin E.Z., Novikov V.A., Mushinskii A.A., Berezina T.V., Saudabaeva A.Zh. Experience in growing selected forms of clonal apple tree rootstocks in conditions of the Southern Urals. *Agrarnyj nauchnyj zhurnal = The Agrarian Scientific Journal,* 2024, no. 10, pp. 72–81. (In Russian). DOI: 10.28983/asj.y2024i10pp72-81.
5. Trunov Yu.V., Solov'ev A.V., Papihin R.V., Dubrovskii M.L., Shamshin I.N. Perspective apple clonal rootstocks for intensive orchards. *Sadovodstvo i vinogradarstvo = Horticulture and Viticulture*, 2020, no. 2, pp. 34–40. (In Russian). DOI: 10.31676/0235-2591-2020-2-34-40.
6. Verma P., Sharma N.C., Sharma D.P., Kumar P., Chand K., Thakur H. Dwarfism mechanism in Malus clonal rootstocks. *Planta,* 2024, vol. 260, p. 133. DOI: 10.1007/s00425-024-04561-5.
7. Savin E.Z., Berezina T.V., Vasilenko A.Yu. The parameters and productivity of apple trees on clonal rootstocks in the conditions of the Southern Urals. *Izvestiya Orenburgskogo gosudarstvennogo agrarnogo universiteta = Izvestia Orenburg State Agrarian University,* 2023,

no. 4 (102), pp. 106–112. (In Russian). DOI: 10.37670/2073-0853-2023-102-4-106-112.

8. Bochkarev E.A. Perspective stock-variety combinations of apple tree for intensive gardening in the Middle Volga region. *Izvestiya Samarskoi gosudarstvennoi sel'skohozyaistvennoi akademii = Bulletin Samara State Agricultural Academy,* 2024, vol. 9, no 1, pp. 72–80. (In Russian). DOI: 10.55170/1997-3225-2024-9-1-72-80.
9. Rasool A., Mansoor S., Bhat K.M., Hassan G.I., Baba T.R., Alyemeni M.N., Ahmad P. Mechanisms underlying graft union formation and rootstock scion interaction in horticultural plants. *Frontiers in Plant Science*, 2020, vol. 11, p. 590847. DOI: 10.3389/fpls.2020.590847.
10. Solanki P.P., Rathva V.D. Rootstock and its advantage in horticulture. *Horticulture Symphony* / eds. A. Krishnamoorthi, G.K. Choupdar, N. Divaker, P.P. Solanki, V. Kumar. Ambala, Cantt., 2025, pp. 101–114.
11. Robinson T.L., Nieto L.G., Ho Sh.T., Rickard B.J., Reig G., Lordan J., Fazio G., Hoying S.A., Fargione M.J., Sazo M.M. Apple orchard economics: effects of cultivar, planting density and rootstock. *Fruit Quarterly*, 2024, vol. 32 (2), pp. 4–11.
12. Jat M.L., Jat R.K., Shivran J.S. Apple rootstock: capabilities and characteristics. *Recent Innovative Approaches in Agricultural Science* / eds. G.K. Yadav, S.H. Dadhich, M.C. Bhateshwar. Bhumi Publishing, 2022, vol. 2, pp. 154–163.
13. Jian W., Li X., Xiao Zh., Yali H., Ke Zh., Dongxu F., Dong W. A new function of MbIAA19 identified to modulate malus plants dwarfing growth. *Plants,* 2023, vol. 12 (17), p. 3097. DOI: 10.3390/plants12173097.

ИНФОРМАЦИЯ ОБ АВТОРАХ

Раченко Анна Максимовна, инженер, аспирант; SPIN-код 6033-5300

(✉)**Раченко Максим Анатольевич,** заведующий лабораторией, главный научный сотрудник, доктор сельскохозяйственных наук; SPIN-код 1997-2163; **адрес для переписки:** Россия, 664033, Иркутск, ул. Лермонтова, 132; e-mail: bigmks73@rambler.ru

Мокшонова Ирина Матвеевна, ведущий технолог, кандидат сельскохозяйственных наук; ORCID 0000-0002-2518-9685

Раченко Дарья Максимовна, студент

AUTHOR INFORMATION

Anna M. Rachenko, Engineer, Post-graduate Student; SPIN-code 6033-5300

(✉)**Maxim A. Rachenko,** Laboratory Head, Head Researcher, Doctor of Sciences in Agriculture; SPIN-code 1997-2163; **address:** 132, Lermontov St., Irkutsk, 664033, Russia; e-mail: bigmks73@rambler.ru

Irina M. Mokshonova, Leading Technologist, Candidate of Sciences in Agriculture; ORCID 0000-0002-2518-9685

Darya M. Rachenko, Student

Дата поступления статьи / Received by the editors 22.08.2025
Дата принятия к публикации / Accepted for publication 13.10.2025
Дата публикации / Published 19.12.2025

https://doi.org/10.26898/0370-8799-2025-12-6
УДК 635.21:631.53
Тип статьи: оригинальная
Type of article: original

Семеноводство картофеля в Камчатском крае: оценка и отбор отечественных сортов

(✉)**Хасбиуллина О.И., Гайнатулина В.В., Хасбиуллин Р.А.**
Камчатский научно-исследовательский институт сельского хозяйства – филиал Федерального исследовательского центра «Всероссийский институт генетических ресурсов растений им. Н.И. Вавилова»
Камчатский край, с. Сосновка, Россия
(✉)e-mail: Khasbiullina@kamniish.ru

В статье представлены результаты оценки состояния отрасли картофелеводства и системы семеноводства в Камчатском крае. Анализ динамики 2020–2024 гг. показал, что суммарная площадь под картофелем в хозяйствах всех категорий за указанный период снизилась незначительно (на 0,9%; с 1,852 до 1,836 тыс. га), тогда как структура посевов изменилась достаточно сильно: в сельскохозяйственных предприятиях площади увеличились на 21,5%, в крестьянско-фермерских хозяйствах сократились на 16,8%, в личных подсобных хозяйствах остались на том же уровне. К 2024 г. валовой сбор картофеля снизился на 10,5% (с 39,679 до 35,519 тыс. т), средняя урожайность – на 15% (до 18,2 т/га). Наиболее заметное снижение отмечено у сельхозтоваропроизводителей, тогда как в личных подсобных хозяйствах показатели были близки к уровню 2020 г. Проведена агробиологическая и хозяйственная оценка современных отечественных сортов картофеля, представленных в банке здоровых сортов в культуре *in vitro*. Комплексная оценка по урожайности, стабильности и устойчивости к фитопатогенам и неблагоприятным факторам позволила выделить формы, адаптированные к условиям короткого и прохладного вегетационного периода. Среди раннеспелых сортов (Взрывной, Кармен, Купец и др.) урожайность составила 24,6–31,8 т/га, среди среднеранних (Фламинго, Евразия, Атлетик) – 28,2–35,7 т/га, что превышает показатели стандарта на 80% и более. По выходу семенной фракции рекомендованы к семеноводству сорта Взрывной, Кармен, Купец, Фламинго, Калинка, Евразия, Атлетик, Краса и Кумач. Полученные результаты дают возможность формировать устойчивую региональную базу семенного материала на основе отечественных сортов, обеспечивающих превышение стандарта по урожайности и стабильности, а также выходу семенной фракции при адаптированной технологии возделывания (уничтожение ботвы за 10–14 дней до уборки для повышения выхода семенной фракции и снижения риска латентных инфекций в условиях Камчатского края).

Ключевые слова: картофель, отечественные сорта, агроэкологическое испытание, продуктивность, товарность, качество, Камчатский край

Seed potato production in the Kamchatka Territory: evaluation and selection of domestic varieties

(✉)**Khasbiullina O.I., Gainatulina V.V., Khasbiullin R.A.**
Kamchatka Research Institute of Agriculture – Branch of the Federal Research Center "N.I. Vavilov All-Russian Institute of Plant Genetic Resources"
Sosnovka village, Kamchatka Territory, Russia
(✉)e-mail: Khasbiullina@kamniish.ru

The article presents the results of a study on the state of the potato industry and the seed production system in the Kamchatka Territory. An analysis of the 2020–2024 dynamics showed that the total potato area across all farm categories changed insignificantly (by 0.9 %; from 1.852 to 1.836 thousand ha), while the crop structure changed quite significantly: the area increased by 21.5 % in agricultural enterprises, while in peasant farms it decreased by 16.8 %, and in in private farms remained at the same level. By 2024, the gross potato harvest had decreased by 10.5 % (from 39.679 to 35.519 thousand tons), and the average yield declined to 18.2 t/ha (by 15 %). The most significant decrease was observed in agricultural enterprises, while private farms maintained the 2020 level. An agrobiological and economic evaluation of modern domestic potato varieties represented in the *in vitro* healthy varieties

bank was conducted. Comprehensive assessment of yield, stability, and resistance to phytopathogens and adverse environmental factors made it possible to identify the forms adapted to the short and cool growing season. Among early-maturing varieties (Vzryvnoi, Karmen, Kupets, etc.), yields ranged from 24.6 to 31.8 t/ha; among the middle-early ones (Flamingo, Evraziya, Atletik) – 28.2–35.7 t/ha, exceeding the standard by up to 80% and more. Based on the share of seed fraction, the varieties Vzryvnoi, Karmen, Kupets, Flamingo, Kalinka, Evraziya, Atletik, Krasa, and Kumach are recommended for seed production. The obtained results make it possible to form a sustainable regional seed base based on domestic varieties that exceed the standard for yield and stability, as well as the yield of the seed fraction with an adapted cultivation technology (destruction of tops 10–14 days before harvesting to increase the yield of the seed fraction and reduce the risk of latent infections in the conditions of the Kamchatka Territory).

Keywords: potato, domestic varieties, agroecological testing, productivity, marketability, quality, Kamchatka Territory

Для цитирования: *Хасбиуллина О.И., Гайнатулина В.В., Хасбиуллин Р.А.* Семеноводство картофеля в Камчатском крае: оценка и отбор отечественных сортов // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 12. С. 56–65. https://doi.org/10.26898/0370-8799-2025-12-6

For citation: Khasbiullina O.I., Gainatulina V.V., Khasbiullin R.A. Seed potato production in the Kamchatka Territory: evaluation and selection of domestic varieties. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 12, pp. 56–65. https://doi.org/10.26898/0370-8799-2025-12-6

Конфликт интересов
Авторы заявляют об отсутствии конфликта интересов.
Conflict of interest
The authors declare no conflict of interest.

Благодарность
Статья опубликована в соответствии с планом НИР Камчатского научно-исследовательского института сельского хозяйства – филиала ФГБНУ «Федеральный исследовательский центр Всероссийский институт генетических ресурсов растений им. Н.И. Вавилова» в рамках государственного задания № FGEM-2025-0010.
Acknowledgements
The article was published in accordance with the research plan of the Kamchatka Research Institute of Agriculture – Branch of the Federal Research Center "N.I. Vavilov All-Russian Institute of Plant Genetic Resources" within the framework of the state assignment No. FGEM-2025-0010.

INTRODUCTION

Potatoes are a key food crop of the Kamchatka Territory, shaping the resilience of the regional food system. The extreme soil and climatic conditions in the territory (short growing season (80–90 days), moderately low temperatures, moisture deficit in the first half of summer and waterlogging in the second half, increased phytosanitary pressure) determine the decisive role of seed quality and correct varietal selection[1] [1–4]. Solving food security issues and maintaining the quality of life of the population directly depend on stable potato production and the availability of a self-sustaining seed production system [5–7].

Over the years of work at the Kamchatka NIISKh – a branch of VIR, substantial practical experience in potato seed production has been accumulated. Until 1985, the health improvement of seed material was carried out through clonal selection; since 1985, the technology has been switched to a virus-free basis, which has allowed for a significant improvement in the initial seed quality. In 2007, the production of healthy mini-tubers on the KD-10 hydroponic system was started. The transition to primary seed production schemes based on biotechnological methods (*in vitro* meristem culture, microclonal propagation) simplified the control of the phytosanitary status of the starting material and re-

[1] *Ryakhovskaya N.I., Gainatulina V.V., Vlasenko G.P.* Agrobiological substantiation of seed potato cultivation in the conditions of the Kamchatka Territory. Petropavlovsk-Kamchatsky: Kamchatpress. 2016. 240 p.

duced the risk of reinfection during mini-tuber production. At the same time, the method used proved to be costly and low-yielding, which limited its widespread adoption[2] [8].

Currently, potato seed production at the Kamchatka Research Institute of Agriculture is conducted according to a five-year scheme for growing elite varieties. Disease-free microplants are obtained from the healthy varieties bank of the Russian Potato Research Centre, and microclonal propagation to the required volumes is carried out in the biotechnology laboratory of the Federal Scientific Center of Agricultural Biotechnology of the Far East named after A.K. Chaiki. For obtaining mini-tubers, plants are planted in summer greenhouses *in vitro*. Next, the mini-tubers, the first field generation, and the super-super elite are grown in seed-breeding nurseries with strict adherence to crop rotations, protective measures, and technological regulations in accordance with the current standard[3] [2, 9, 10].

From 2001 to 2021, comparative agroecological trials of the best domestic and foreign varieties were conducted, based on the results of which, using a set of economically valuable traits, the following varieties were recommended for cultivation under the conditions of the Kamchatka Territory: Fresco, Latona, Sante, Raia, Red Scarlett, Secura, Rosara, Udacha, Vulkan, Geyser. For more than 20 years, imported varieties were widely cultivated in the region. In 2019, two varieties of Kamchatka breeding – Vulkan and Geyser – were sanitized and introduced into *in vitro* culture at the Russian Potato Research Centre, which made it possible to include them in the production scheme of original seed breeding.

In the current conditions, the regulatory and target guidelines are set by the Decree of the President of the Russian Federation No. 20 dated 21.01.2020 (Doctrine of Food Security of the Russian Federation; share of domestic varieties ≥ 75%) and the Decree of the President of the Russian Federation No. 350 dated 21.07.2016, in implementation of which the Federal Scientific and Technical Program for the Development of Agriculture for 2017–2030 was approved[4-6] [11, 12].

To achieve the target indicators of this Program in 2024, the Kamchatka NIISKh – a branch of VIR, has begun the selection and testing of modern domestic varieties to expand their range and subsequent implementation in production. Taken together, this defines the current priorities of regional varietal policy and seed production: accelerated comprehensive (multi-criteria) evaluation and selection of adapted domestic varieties that ensure early formation of marketable products, stable yields, and resistance to key diseases; development of specialized links of primary seed production with modern laboratory, greenhouse, and storage facilities; formation of a regionally adapted assortment for agricultural producers (AP), peasant farms (PF), and personal subsidiary plots (PSP); planned variety rotation and variety renewal; methodological support for producers, demonstration plantings, and short-term training (primarily for PSP and PF) [2, 13].

In this regard, the objectives of this work were to analyze the problems of the current state of

[2]*Kim I.V., Gainatulina V.V., Voznyuk V.P., Volkov D.I., Anikina O.V., Khasbiullina O.I.* Directions and main research results in potato breeding and seed production in the Far East // State and prospects of breeding and seed production of major agricultural crops: collection of scientific articles based on materials from the scientific-practical conference, Ussuriysk, July 18–19, 2020, pp. 119–125.

[3]GOST 33996–2016. Seed Potatoes. Technical Specifications and Methods for Quality Assessment. Moscow: Standartinform, 2017.

[4]Decree of the President of the Russian Federation of January 21, 2020 No. 20 'On approval of the food security doctrine of the Russian Federation' // Official website of the Administration of the President of Russia. URL: http://www.kremlin.ru/acts/bank/45106.

[5]Decree of the President of the Russian Federation dated 21.07.2016 No. 350 (as amended on 28.09.2023) "On measures for the implementation of state scientific and technical policy in the interests of agricultural development" // Official website of the Administration of the President of Russia. URL: http://www.kremlin.ru/acts/bank/41139.

[6]Resolution of the Government of the Russian Federation dated 25.08.2017 No. 996 'On approval of the Federal Scientific and Technical Program for the Development of Agriculture for 2017–2030' // State System of Legal Information: official Internet portal of legal information. URL: http://publication.pravo.gov.ru/document/0001201708300023.

the seed production complex of potato growing in the Kamchatka Territory, as well as to conduct a comprehensive assessment and selection of the promising domestic potato varieties to organize effective seed production.

Research objectives:

1) analysis of the state of the industry and the seed fund (2020–2024);

2) ecological and economic testing of the varieties under conditions of a short growing season;

3) multicriteria assessment based on productivity, early yield accumulation, disease resistance, technological qualities, and storability;

4) development of practical recommendations on the structure of the assortment for AP / PF / PSP and the phased organization of primary seed production on a virus-free basis.

MATERIAL AND METHODS

The study was conducted at the Kamchatka Research Institute of Agriculture. Field experiments were laid out at the experimental plot of the Laboratory of Biotechnology of Field Crops and Potato Breeding in 2025. The work was carried out using a set of appropriate methods[7-13]. Laboratory studies were carried out at the laboratory of the Kamchatka Research Institute of Agriculture using the following instruments: analytical balances, flame photometer, selective electrode, ionomer, photo-electrocalorimeter, and the capillary electrophoresis system 'Kapel-105M'.

Potato varieties of domestic breeding from different maturity groups were selected as the objects of study, taking into account the availability of the source material in the healthy variety bank of the Russian Potato Research Centre and the OOO "Doka-Gene Technologies." The standards adopted were the released varieties of Kamchatka breeding, differing in maturity: Zhemchuzhina Kamchatki – early, Vulkan – middle-early, Kamchatka – medium-maturing. The technology of potato cultivation is zonal, mechanized.

RESULTS AND DISCUSSION

Analysis of the structure of potato production by farm categories in the Kamchatka Territory shows that small-scale production predominates in the region. According to the Territorial Body of the Federal State Statistics Service for the Kamchatka Territory, in 2020–2024 the total area under potatoes in the farms of all categories was 1,836–2,038 thous. ha[14]. At the same time, the maximum occurred in 2022 (2,038 thous. ha), after which a moderate reduction was observed: 2023 – 1,967 thous. ha, 2024 – 1,836 thous. ha. By 2024, the volume of the sown areas decreased slightly (by 0.9% compared to 2020; from 1,852 to 1,836 thous. ha), however, the production structure changed quite significantly: in AP, the areas increased by 21.5%, in PF, on the contrary, decreased by 16.8%, in PSP remained at the 2020 level (see Table 1).

The presented data indicate significant structural changes: an increase in the areas in AP, a decrease in PF, stabilization in PSP.

The total gross potato harvest in the Kamchatka Territory in 2024 amounted to 35,519 thous. tons, which is 10.5% lower than the 2020 level (39,679 thous. tons). The dynamics are wave-

[7]*Dospekhov B.A.* Methodology of field experiment (with the basics of statistical processing of research results). Moscow: Kolos, 1985. 416 p.

[8]Methodology of state variety testing of agricultural crops. Moscow, 2019.

[9]*Milekhin A.V.* Methodological recommendations for potato cultivation. Samara, 2005, 21 p.

[10]Research methods for protecting potatoes from diseases, pests, weeds and immunity / compiled by A.S. Volovik et al., Moscow, 1995, 107 p.

[11]Methodology for conducting field surveys and post-harvest quality control of seed potatoes / compiled by B.V. Anisimov, A.I. Uskov, E.A. Simakov et al., Moscow, 2005, 112 p.

[12]Methods of physiological and biochemical studies of potatoes. Moscow, 1989, 142 p.

[13]Methodology for conducting agrotechnical experiments, records, observations and analyses on potatoes / compiled by S.V. Zhevora, L.S. Fedotova, V.I. Starovoytov et al., Moscow, 2019, 120 p.

[14]Agriculture, hunting and forestry // Territorial body of the Federal State Statistics Service for the Kamchatka Territory: official website. URL: https://41.rosstat.gov.ru/agriculture.

Табл. 1. Площади под картофелем в Камчатском крае, тыс. га
Table 1. Area under potatoes in the Kamchatka Territory, thous. ha

Indicator	2020	2021	2022	2023	2024	2024 in % to 2020
Farms of all categories	1,852	1,909	2,038	1,967	1,836	99,1
AP	0,321	0,356	0,383	0,379	0,390	121,5
PF	0,507	0,560	0,498	0,471	0,422	83,2
PSP	1,024	0,993	1,157	1,117	1,024	100,0

like, with a peak in 2022 (41,089 thous. tons), after which two consecutive declines are recorded: by 6.3% (2023/2022) and 7.7% (2024/2023) (see Table 2).

The ratio of the contribution of different categories of households to the total gross harvest has also changed. In 2020, the share of PSP was 57%, PF – 24%, AP – 19%. By 2024, the share of PSP had grown to 62.5%, PF decreased to 19%, and AP remained approximately at the same level (around 18.5%). Consequently, under conditions of a decrease in the total gross yield, it was PSP that most significantly "sustained" production, while the main reduction in indicators occurred due to PF. The decrease in gross yield in 2024 compared to 2020 was formed by two factors: a reduction in yield (see Table 3) and a decrease in sowing areas in PF (see Table 1). The increase in areas in AP did not affect the growth of gross yield due to the decrease in yield on farms.

The average yield across farms of all categories decreased over 5 years by 3.2 t/ha (from 21.4 to 18.2 t/ha, or by 15%). This indicator was relatively stable in 2021–2023 (around 19.5–19.6 t/ha) and decreased most noticeably in 2024 (by 7.1% compared to 2023). At the same time, the yield for PSP in 2024 was 21.7 t/ha and significantly exceeded the indicators for AP and PF (see Table 3).

The assessment shows that PSP provided the most stable yields in 2020–2024, whereas AP

Табл. 2. Валовой сбор картофеля в Камчатском крае, тыс. т
Table 2. Gross potato harvest in the Kamchatka Territory, thous. tons

Indicator	2020	2021	2022	2023	2024	2024 in % to 2020
Farms of all categories	39,679	39,167	41,089	38,496	35,519	89,5
AP	7,434	5,972	7,394	6,645	6,560	88,2
PF	9,609	10,476	8,841	9,145	6,763	70,4
PSP	22,628	22,719	24,854	22,706	22,196	98,1

Табл. 3. Урожайность картофеля в Камчатском крае, т/га
Table 3. Potato yield in the Kamchatka Territory, t/ha

Indicator	2020	2021	2022	2023	2024	2024 in % to 2020
Farms of all categories	21,4	19,5	19,5	19,6	18,2	85,0
AP	23,1	16,8	19,3	17,5	16,8	72,7
PF	18,9	18,7	17,7	19,4	16,0	84,6
PSP	22,0	22,9	21,5	20,3	21,7	98,6

were characterized by increased variability of the indicator. Combined with the data in Tables 1 and 2, this explains why, with the expansion of AP areas, the gross harvest in this category of farms did not increase: the area growth effect was offset by a decline in yield. The key constraint on final production in 2024 was the decrease in yield, primarily in AP and PF. The stability of PSP in terms of yield largely supported the overall production level.

The indicated trends, in addition to changes in weather conditions over the years, reflect a shortage of high-quality improved seed material, insufficient speed of variety rotation and renewal, as well as inconsistency in the organization of primary seed production [2, 6].

In the register of breeding achievements for 2024, there were a total of 567 potato varieties. Of these, 81 varieties were approved for use in the Far Eastern region, including 62 varieties of domestic breeding and 19 of foreign breeding. In recent years, thanks to the introduction of various subprograms for potato breeding and seed production, there has been an increase in the number of new domestic varieties in Russia. This has become possible as a result of increased funding for scientific research and support for breeding centers, which allows for the faster development of varieties that are more resistant to local conditions, diseases, and pests, as well as adapted to the modern needs of the processing industry and consumers. The increase in the number of domestic varieties helps reduce dependence on imported seed material and allows for ensuring the country's food security by offering varieties that are more suitable for the Russian climate and soil [2, 8].

In this regard, work has begun at the Kamchatka Research Institute of Agriculture on the ecological testing of domestic varieties to expand the existing assortment and subsequently introduce them into production under the conditions of the Kamchatka Territory. Out of 40 domestic varieties, differing in ripening times, 18 were identified in 2025 as promising in terms of economically valuable traits, resistant to phytopathogens and extreme conditions of the peninsula (see Table 4).

According to phenological observations, the appearance of mass seedlings in the studied varieties was recorded from the 26th to the 30th day. The earliest seedlings were observed in early-maturing varieties: Zhemchuzhina Kamchatki, Vzryvnoi, Oskar, Kupets, Carmen, Gulliver, Triumph, Arktika, Evraziya. Mid-ripening varieties emerged on average 4 days later. The budding and flowering phases occurred on the 46th–51st and 58th–60th days, respectively. Field germination for all varieties was high – 99.2–100.0%. For the standards, this indicator was as follows: Zhemchuzhina Kamchatki – 99.0%, Vulkan – 99.2%, Kamchatka – 99.4%.

The yield of early varieties ranged from 24.6 to 31.8 t/ha. The varieties Vzryvnoi, Gulliver, Carmen, Triumph, and Oscar turned out to be the most productive: their indicators exceeded the standard by 4.5–9.5 t/ha, or 20.2–46.2%. The share of commercial tubers was 52–68%, seed fraction – 40–48%. The number of tubers per hill was 11–13 pcs./bush. In the group of middle-early varieties, the yield ranged from 23.1 to 35.7 t/ha, which is higher than the standard by 4.0–16.6 t/ha, or 20.9–86.9%. The share of commercial and seed fractions amounted to 50–60% and 30–49%, respectively, with the number of tubers being 8–15 per bush. In the group of mid-ripening varieties, the following varieties were characterized by high yield: Sarmat – 32.8 t/ha, Prime – 30.2 t/ha, Ariel – 27.3 t/ha, Krasa – 21.6 t/ha. At the same time, the increase relative to the standard was 7.0–18.2 t/ha, or 47.9–124.6%. The share of the commercial fraction was 51–67%, the seed fraction 27–47%, with the number of tubers being 11–14 per bush.

For the pace of harvest accumulation to obtain early production, the Gulliver and Oscar varieties are recommended: by September 1, their biological yield amounted to 31.0 and 33.9 t/ha respectively, which is higher than the standard by 8.4 and 18.5%. The share of marketable tubers is 74% and 70%, the average weight of a marketable tuber is 102 and 131 g respectively.

According to the results of the biochemical analysis, the starch content in the tubers of the studied varieties ranged from 8.0 to 13.4% (min-

Табл. 4. Урожайность и биохимические показатели качества клубней перспективных сортов картофеля (2025 г.)
Table 4. Productivity and biochemical quality indicators of the promising potato variety tubers (2025)

Variety	Yield, t/ha	Marketability, %		Content			
		commercial fraction	seed fraction	starch, %	dry matter, %	ascorbic acid, mg %	nitrates, mg/kg
Early varieties							
Zhemchuzhina Kamchatki (standard)	22,3	63	31	9,7	14,75	10,7	73,42
Vzryvnoi	27,5	52	48	10,7	15,75	8,7	33,56
Gulliver	27,3	74	24	9,7	14,75	9,1	31,32
Carmen	26,8	54	40	10,5	15,50	6,5	55,70
Triumph	27,1	49	44	9,4	14,30	10,4	65,44
Oskar	31,8	68	30	11,5	16,50	7,2	42,25
Kupets	24,6	55	40	12,9	18,00	11,2	42,25
LSD_{05}	2,8						
Middle-early varieties							
Vulkan (standard)	19,1	50	42	12,0	17,10	10,0	10,37
Flamingo	29,3	56	42	10,5	15,50	7,3	55,70
Konkurent	35,7	60	38	10,7	15,75	12,7	26,66
Kalinka	23,1	50	49	13,4	18,50	10,9	41,29
Arktika	30,9	67	30	8,9	14,00	4,0	62,49
Evraziya	28,2	53	41	11,5	16,50	8,5	47,40
Real	26,6	60	35	10,0	18,54	7,5	26,66
Atletik	30,8	51	46	11,9	17,00	4,5	9,68
LSD_{05}	3,5						
Medium-maturing varieties							
Kamchatka (standard)	14,6	57	40	13,7	18,75	6,9	101,3
Kumach	12,7	51	43	11,0	16,00	7,0	21,67
Ariel	27,3	63	27	10,5	15,50	8,8	47,40
Krasa	21,6	51	47	13,3	18,30	12,3	27,91
Sarmat	32,8	67	30	13,4	18,87	6,3	47,40
Prime	30,2	64	34	8,0	14,31	7,0	27,91
LSD_{05}	2,6						

imum – Prime, maximum – Kamchatka), and dry matter (DM) – from 14.0 to 18.9%.

In the early group, increased starch and dry matter content was noted in the varieties Carmen, Vzryvnoi, Oscar, and Kupets (starch – 10.5–12.9%, DM – 15.5–18.0%). The maximum values in the group were recorded in the variety Kupets (starch – 12.9%, DM – 18.0%).

Among the middle-early varieties, the standout ones were Flamingo, Konkurent, Evraziya, Atletik, and Kalinka (starch – 10.5–13.4%, dry matter – 15.5–18.5%). In terms of dry matter content, the absolute maximum was noted in the Kalinka variety (18.5%).

In the group of mid-ripening varieties, the starch content of the Ariel, Kumach, Krasa,

and Sarmat varieties was 10.5–13.4%, and the dry matter content was 15.5–18.9%. The highest values were shown by the Sarmat variety (starch – 13.4%, dry matter – 18.9%) and the Krasa (starch – 13.3%, dry matter – 18.3%).

In terms of ascorbic acid content, the early ripening group was distinguished by the Kupets variety (11.2 mg%, or +10.7 mg% compared to the standard); among the middle-early varieties – the Konkurent and Kalinka varieties (12.7 and 10.9 mg%, respectively, or +2.7 and 0.9 mg% compared to the standard); among the mid-ripening varieties – the Krasa and Ariel varieties (12.3 and 8.8 mg%, respectively, or +5.4 and 1.9 mg% compared to the standard).

The maximum allowable concentration of nitrates in potato tubers is 240 mg/kg. In the tubers of the early varieties, the value of this indicator ranged from 31.32 to 65.44 mg/kg, i.e., it was 3.7–7.7 times lower than the MAC and 7.98–42.10 mg/kg below the standard. Varieties of the mid-early group accumulated 9.68–62.49 mg/kg of nitrates, which is 3.8–24.8 times lower than the MAC. The minimum was recorded in the Atletik (9.7 mg/kg) and Vulkan (10.4 mg/ kg) varieties. The nitrate content in the tubers of mid-ripening varieties was the lowest – 21.67–47.40 mg/kg, which is 192.6–218.3 mg/kg below the MAC, and 53.90–79.63 mg/kg below the standard.

CONCLUSIONS

1. *Early-maturing group*. The varieties Vzryvnoi, Gulliver, Carmen, Oscar, and Kupets demonstrated a yield of 24.6–31.8 t/ha, which is higher than the standard (Zhemchuzhina Kamchatki) by 2.3–9.5 t/ha, or 10.3–46.2%. The share of marketable fraction was 52–74%, seed fraction – 24–48%, number of tubers – 11–13 per bush. The Gulliver and Oscar varieties are recommended to obtain early yields: by the beginning of September, their biological yield reached 31.0 and 33.9 t/ha, which exceeds the standard by 8.4 and 18.5%. The share of marketable tubers is 74 and 70%, and the average mass of a marketable tuber is 102 and 131 g, respectively.

2. *Middle-early group.* The yield of varieties here ranged from 23.1 to 35.7 t/ha, which exceeds the standard (Vulkan) by 4.0–16.6 t/ha, or 20.9–86.9%. The share of commercial and seed fractions is 50–60% and 30–49%, respectively, with the number of tubers being 8–15 pcs per bush.

3. *Medium-maturing group.* High yields in this group were shown by the varieties Sarmat, Prime, Ariel, and Krasa – 21.6–32.8 t/ha, which is higher than the standard (Kamchatka) by 7.0–18.2 t/ha, or 47.9–124.6%. The share of marketable fraction is 51–67%, seed fraction – 27–47%, number of tubers – 11–14 per bush.

4. *Seed-growing potential.* For the formation of the seed fund, it is advisable to use all the released high-yield varieties, providing for earlier destruction of the tops (desiccation/cutting 10–14 days before harvest) to increase the output of the seed fraction and reduce phytosanitary risks. According to the data on the dynamics of seed yield accumulation, the following varieties are preliminarily recommended: among the early-maturing – Vzryvnoi (48% seed fraction), Triumph (44), Carmen (40), Kupets (40%); among the middle-early – Kalinka (49%), Atletik (46), Flamingo (42), Evraziya (41%); among the medium-maturing – Krasa (47%), Kumach (43%).

5. *Biochemical indicators of quality.* In the conditions of the northern region, the following varieties stood out for their high starch content (10.5–13.4%) and dry matter: among the early-maturing varieties – Carmen, Vzryvnoi, Oscar, Kupets (DM – 15.5–18.0%); among the middle-early varieties – Flamingo, Konkurent, Evraziya, Atletik, Kalinka (DM – 15.5–18.5%); among the medium-maturing varieties – Ariel, Kumach, Krasa, Sarmat (DM – 15.5–18.9%).

Varieties with high dry matter and starch content (Kupets, Kalinka, Real, Sarmat, Krasa) are promising for processing (puree, fries, chips). Varieties with moderate starch content and high marketability (Arctika, Oscar, Gulliver) are for the 'table' direction and early sale. Such a distribution by technological directions, complemented by low nitrate background and acceptable levels of vitamin C, allows for forming a set of varieties for the Kamchatka region with a focus on domestic seed production and the release of products with predictable quality parameters.

6. Thus, the obtained results confirm that a number of domestic varieties possess high productivity, technological suitability, and adaptability to the conditions of the Kamchatka Territory. The compiled list of 18 promising varieties provides the basis for subsequent agro-ecological trials and the launch of original seed production aimed at increasing the region's self-sufficiency with seed material of domestic breeding.

СПИСОК ЛИТЕРАТУРЫ

1. Селекция и семеноводство картофеля: монография / под. ред. С.В. Жеворы, Е.А. Симакова, Б.В. Анисимова. Чебоксары, 2020. 189 с.
2. *Ким И.В., Клыков А.Г.* Биоресурсный потенциал картофеля на Дальнем Востоке: монография. Владивосток: Дальнаука, 2023. 336 с.
3. *Власенко Г.П.* Оценка ранних и среднеранних сортов картофеля в условиях Камчатского края // Дальневосточный аграрный вестник. 2020. № 4 (56). С. 12–16. DOI: 10.24411/1999-6837-2020-14042.
4. *Киселев Е.П.* Аномалии дальневосточного климата и необходимость совершенствования агротехнологий возделывания сельскохозяйственных культур // Дальневосточный аграрный вестник. 2020. № 4 (56). С. 22–31. DOI: 10.22450/1999-6837-2020-4-22-31.
5. *Рафальская О.М., Рафальский С.В., Мельникова Т.В., Рафальская Н.Б.* Изучение перспективных сортообразцов картофеля в условиях Приамурья // Агронаука. 2023. Т. 1. № 1. С. 120–124.
6. *Жевора С.В., Симаков Е.А., Анисимов Б.В.* Селекция и семеноводство картофеля: научное обеспечение и бизнес-проекты // Картофель и овощи. 2023. № 4. С. 6–10. DOI: 10.25630/PAV.2023.22.92.003.
7. *Карaваева Е.С.* Результаты испытания сортов картофеля в условиях Европейского Севера // Овощи России. 2023. № 6. С. 123–128. DOI: 10.18619/2072-9146_2023-6_123-128.
8. *Симаков Е.А., Анисимов Б.В., Жевора С.В., Митюшкин А.В., Журавлев А.А., Митюшкин А.В., Гайзатулин А.С.* Актуальные направления развития селекции и семеноводства картофеля в России // Картофель и овощи. 2020. № 12. С. 22–26. DOI: 10.25630/PAV.2020.49.70.005.
9. *Симаков Е.А., Анисимов Б.В., Митюшкин А.В., Журавлев А.А., Зебрин С.Н., Овечкин С.В., Семёнов В.А., Гайзатулин А.С.* Развитие селекции и семеноводства картофеля в условиях современного рынка. Чебоксары, 2022. 16 с.
10. *Зебрин С.Н., Грачева И.А., Анисимов Б.В.* Мониторинг сортообразцов оригинального семенного картофеля методом грунтового контроля // Картофель и овощи. 2021. № 2. С. 24–27. DOI: 10.25630/PAV.2021.27.78.005.
11. *Карпухин М.Ю., Мишуров Н.П., Моторин О.А., Подъяблонский П.А.* Анализ рисков и разработка механизмов их снижения при реализации ФНТП развития сельского хозяйства России // Аграрный вестник Урала. 2022. № 5 (220). С. 73–81. DOI: 10.32417/1997-4868-2022-220-05-73-81.
12. *Кузьмин В.Н., Мишуров Н.П., Моторин О.А., Подъяблонский П.А.* Подходы к классификации рисков научно-технического развития сельского хозяйства в контексте ФНТП // Управление рисками в АПК. 2021. № 4 (42). С. 9–18. DOI: 10.53988/24136573-2021-04-01.
13. *Симаков Е.А., Анисимов Б.В., Жевора С.В., Митюшкин А.В., Журавлев А.А., Гайзатулин А.С.* Актуальные направления селекции на улучшение питательной ценности клубней картофеля // Картофель и овощи. 2020. № 2. С. 35–40. DOI: 10.25630/PAV.2020.18.2.008.

REFERENCES

1. *Potato breeding and seed production* / ed. by S.V. Zhevory, E.A. Simakov, B.V. Anisimov. Cheboksary, 2020, 189 p. (In Russian).
2. Kim I.V., Klykov A.G. *Bioresource potential of potatoes in the Far East*. Vladivostok: Dalnauka, 2023, 336 p. (In Russian).
3. Vlasenko G.P. Assessment of early and mid-early varieties of potato on the Kamchatka Territory. *Dalnevostochniy agrarniy vestnik = Far East Agrarian Herald*, 2020, no. 4 (56), pp. 12–16. (In Russian). DOI: 10.24411/1999-6837-2020-14042.
4. Kiselev E.P. Anomalies of the Far Eastern climate and the need to improve agricultural technologies for crop cultivation. *Dalnevostochniy agrarniy vestnik = Far East Agrarian Herald*, 2020, no. 4 (56), pp. 22–31. (In Russian). DOI: 10.22450/1999-6837-2020-4-22-31.
5. Rafalskaya O.M., Rafalsky S.V., Melnikova T.V., Rafalskaya N.B. The study of promising potato varieties in the Amur region. *Agronauka = Agroscience*, 2023, vol. 1, no. 1, pp. 120–124. (In Russian).

6. Zhevora S.V., Simakov E.A., Anisimov B.V. Potato breeding and seed production: scientific support and business projects. *Kartofel' i ovoshchi = Potatoes and vegetables*, 2023, no. 4, pp. 6–10. (In Russian). DOI: 10.25630/PAV.2023.22.92.003.
7. Karavaeva E.S. Results of testing potato varieties in the European North. *Ovoshchi Rossii = Vegetable Crops of Russia*, 2023, no. 6, pp. 123–128. (In Russian). DOI: 10.18619/2072-9146_2023-6_123-128.
8. Simakov E.A., Anisimov B.V., Zhevora S.V., Mityushkin A.V., Zhuravlev A.A., Mityushkin A.V., Gaizatulin A.S. Current trends in the development of potato breeding and seed production in Russia. *Kartofel' i ovoshchi = Potatoes and vegetables*, 2020, no. 12, pp. 22–26. (In Russian). DOI: 10.25630/PAV.2020.49.70.005.
9. Simakov E.A., Anisimov B.V., Mityushkin A.V., Zhuravlev A.A., Zebrin S.N., Ovechkin S.V., Semenov V.A., Gaizatulin A.S. *Development of potato breeding and seed production in the conditions of the modern market*. Cheboksary, 2022, 16 p. (In Russian).
10. Zebrin S.N., Gracheva I.A., Anisimov B.V. Monitoring of variety samples of original seed potatoes by the method of field trial of samples. *Kartofel' i ovoshchi = Potatoes and vegetables*, 2021, no. 2, pp. 24–27. (In Russian). DOI: 10.25630/PAV.2021.27.78.005.
11. Karpukhin M.Yu., Mishurov N.P., Motorin O.A., Podiablonsky P.A. Analysis of risks and improvement of mechanisms for their reduction in the implementation of the Federal Scientific and Technical Program for the Development of Agriculture in Russia. *Agrarniy vestnik Urala = Agrarian Bulletin of the Urals*, 2022, no. 5 (220), pp. 73–81. (In Russian). DOI: 10.32417/1997-4868-2022-220-05-73-81.
12. Kuzmin V.N., Mishurov N.P., Motorin O.A., Podyablonsky P.A. Approaches to risk classification of scientific and technical development of agriculture in the context of FSTP. *Upravlenie riskami v APK = Agricultural Risk Management*, 2021, no. 4 (42), pp. 9–18. (In Russian). DOI: 10.53988/24136573-2021-04-01.
13. Simakov E.A., Anisimov B.V., Zhevora S.V., Mityushkin A.V., Zhuravlev A.A., Gaizatulin A.S. Current trends in the development of potato breeding and seed production in Russia. *Kartofel' i ovoshchi = Potatoes and vegetables*, 2020, no. 2, pp. 35–40. (In Russian). DOI: 10.25630/PAV.2020.18.2.008.

ИНФОРМАЦИЯ ОБ АВТОРАХ

(✉)**Хасбиуллина Ольга Ивановна,** директор, ведущий научный сотрудник, кандидат сельскохозяйственных наук; SPIN-код 2013-9669, ORCID 0000-0001-7368-0244; **адрес для переписки:** Россия, 684033, Камчатский край, с. Сосновка, ул. Центральная, 4; e-mail: Khasbiullina@kamniish.ru

Гайнатулина Вера Васильевна, ведущий научный сотрудник, кандидат сельскохозяйственных наук; SPIN-код 2640-7165, ORCID 0000-0002-6164-3195

Хасбиуллин Роман Ахтямович, научный сотрудник; ORCID 0000-0001-5633-7276

AUTHOR INFORMATION

(✉)**Olga I. Khasbiullina,** Director, Lead Researcher, Candidate of Science in Agriculture; SPIN-code 2013-9669, ORCID 0000-0001-7368-0244; **address:** 4, Tsentralnaya St., Sosnovka village, Kamchatka Territory, 684033, Russia; e-mail: Khasbiullina@kamniish.ru

Vera V. Gainatulina, Lead Researcher, Candidate of Science in Agriculture; SPIN-code 2640-7165, ORCID 0000-0002-6164-3195

Roman A. Khasbiullin, Researcher; ORCID 0000-0001-5633-7276

Дата поступления статьи / Received by the editors 13.10.2025
Дата принятия к публикации / Accepted for publication 03.11.2025
Дата публикации / Published 19.12.2025

https://doi.org/10.26898/0370-8799-2025-12-7
УДК 632.51:632.954:633.853.52 (571.63)
Тип статьи: оригинальная
Type of article: original

Щетинники зеленый и сизый в агроценозах Приморского края и поиск эффективных почвенных гербицидов для борьбы с ними в посевах сои

(✉)**Басай З.В., Мороховец В.Н., Мороховец Т.В., Вострикова С.С., Маркова Е.С.**
Дальневосточный научно-исследовательский институт защиты растений – филиал Федерального научного центра агробиотехнологий Дальнего Востока им. А.К. Чайки
Приморский край, Ханкайский район, с. Камень-Рыболов, Россия
(✉)e-mail: dalniizr@mail.ru

В период с 2015 по 2024 г. были изучены распространенность и обилие щетинника зеленого *Setaria viridis* (L.) Beauv. и щетинника малорослого (сизого) *Setaria pumila* (Poir.) Schult. в агроценозах Приморского края. Оба вида на протяжении 10 лет стабильно присутствовали в качестве сорных растений в посевах сои, кукурузы и ранних зерновых культур, достигая в отдельные годы высоких уровней встречаемости (60–91%) и обилия (9,8–17,9 шт./м^2). Для контролирования этих видов в посевах сои, наиболее важной для юга Дальнего Востока культуры, осуществлен поиск гербицидов, обладающих почвенной активностью и способных эффективно ее защитить на ранних стадиях роста и развития. С этой целью в условиях вегетационного домика в 2021–2022 гг. была изучена чувствительность двух видов щетинника к семи препаратам, разрешенным для защиты сои от сорных растений: Пледж, СП (действующее вещество (д.в.) – флумиоксазин, 500 г/кг), Зенкор Ультра, КС (д.в. – метрибузин, 600 г/л), Комманд, КЭ (д.в. – кломазон, 480 г/л), Гезагард, КС (д.в. – прометрин, 500 г/л), Гардо Голд, КС (д.в. – С-метолахлор + тербутилазин, 312,5 + 187,5 г/л), Дуал Голд, КЭ (д.в. – С-метолахлор, 960 г/л) и Пропонит, КЭ (д.в. – пропизохлор, 720 г/л). Гербициды в максимально допустимых нормах расхода наносили на поверхность почвы в сосудах через сутки после посева сорняков. По снижению сырой надземной биомассы обоих видов щетинника максимальную эффективность (96–100%) продемонстрировали препараты Пропонит в норме расхода 3,0 л/га, Дуал Голд – 1,6, Гардо Голд – 4,5 и Гезагард – 3,5 л/га.

Ключевые слова: щетинник зеленый, щетинник малорослый (сизый), встречаемость, обилие, соя, почвенный гербицид, эффективность, чувствительность

Green bristle-grass and yellow foxtail in the agrocenoses of the Primorsky Territory and the search for effective soil herbicides to control them in soybean crops

(✉)**Basai Z.V., Morokhovets V.N., Morokhovets T.V., Vostrikova S.S., Markova E.S.**
The Far Eastern Research Institute of Plant Protection – Branch of Federal Scientific Center of Agricultural Biotechnology of the Far East named after A.K.Chaiki
Kamen-Rybolov, Khankaysky district, Primorsky Territory, Russia
(✉)e-mail: dalniizr@mail.ru

In the period from 2015 to 2024, the occurrence and abundance of green bristle-grass *Setaria viridis* (L.) Beauv. and yellow foxtail *Setaria pumila* (Poir.) Schult. were studied in the agrocenoses of the Primorsky Territory. Both species have been consistently present as weeds in soybean, corn, and early grain crops for 10 years, reaching high levels of occurrence (60–91%) and abundance (9.8–17.9 pcs/m^2) in some years. To control these species in soybean crops, the most important crop for the south of the Far East, a search has been carried out for the herbicides with soil activity and capable of effectively protecting it at early stages of growth and development. For this purpose, in the condi-

tions of a vegetation house in 2021–2022, the sensitivity of two types of bristle was studied to seven preparations approved for the protection of soybeans from weeds: Pledge, WP (active ingredient (a.i.) flumioxazine, 500 g/kg), Zenkor Ultra, SC (a.i. metribuzin, 600 g/l), Kommand, EC (a.i. klomazon, 480 g/l), Gezagard, SC (a.i. promethrin, 500 g/l), Gardo Gold, SC (a.i. C-metolachlor + terbutylazine, 312.5 + 187.5 g/l), Dual Gold, EC (a.i. C-metolachlor, 960 g/l), and Proponite, EC (a.i. propizochlor, 720 g/l). Herbicides in the maximum allowable rates were applied to the soil surface in vessels a day after sowing the weeds. In terms of reducing the crude aboveground biomass of both species of bristle grass, the maximum efficiency (96-100%) was demonstrated by Proponite at a rate of 3.0 l/ha, Dual Gold 1.6 l/ha, Gardo Gold 4.5 l/ha, and Gezagard 3.5 /ha.

Keywords: green bristle-grass, yellow foxtail, occurrence, abundance, soybean, soil herbicide, effectiveness, sensitivity

Для цитирования: *Басай З.В., Мороховец В.Н., Мороховец Т.В., Вострикова С.С., Маркова Е.С.* Щетинники зеленый и сизый в агроценозах Приморского края и поиск эффективных почвенных гербицидов для борьбы с ними в посевах сои // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 12. С. 66–74. https://doi.org/10.26898/0370-8799-2025-12-7

For citation: Basai Z.V., Morokhovets V.N., Morokhovets T.V., Vostrikova S.S., Markova E.S. Green bristle-grass and yellow foxtail in the agrocenoses of the Primorsky Territory and the search for effective soil herbicides to control them in soybean crops. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 12, pp. 66–74. https://doi.org/10.26898/0370-8799-2025-12-7

Конфликт интересов
Авторы заявляют об отсутствии конфликта интересов.
Conflict of interest
The authors declare no conflict of interest.

INTRODUCTION

Under the monsoon climate of the southern Far East, weed species of the family Poaceae Barnhart or grasses (Gramineae Juss.), usually possessing high tolerance to waterlogging and low temperatures, successfully compete not only with cultivated plants but also with broadleaf weeds, which are more thermophilic and often suffer from excess soil moisture. According to our data, the density of weed grasses can reach 415–608 pcs./m² (67–82% of the total number of weeds) in soybean crops during years with excessive rainfall in the spring-summer period, and their raw aboveground biomass can reach 1697–1828 g/m² (53–59% of the total weed biomass).

Green bristle grass *Setaria viridis* (L.) Beauv. and yellow foxtail *Setaria pumila* (Poir.) Schult have been consistently present among the weedy cereal species in the agrocenoses of the Primorsky Territory over the past decade. These are late spring annuals, widely spread across the globe. Both species have high ecological plasticity – they are drought-resistant but also grow well on waterlogged soils. As weeds, they are mainly found in row-crop and cereal crops, and have adapted to waterlogged rice paddies. In dense grass stands, they heavily deplete the soil[1–3] [1].

In the Russian Federation, green bristle grass and yellow foxtail contaminate agricultural crops in the Pskov, Novgorod, Leningrad, Astrakhan, Kemerovo, and Orenburg regions, in the Volga region, in the Krasnoyarsk Territory, Yakutia, and in other regions[4] [2–7].

In the south of the Far East, these species were previously found in 50–70% of surveyed soybean, grain and corn crops [1].

Soybeans (*Glycine max* (L.) Merr.) remain the

[1]Vascular Plants of the Soviet Far East: in 8 vols. Leningrad: Nauka, 1985, vol. 1, 398 p.

[2]Flora of the Russian Far East: Additions and Changes to the Publication 'Vascular Plants of the Soviet Far East. Vladivostok: Dalnauka, 2006, vol. 1–8 (1985–1996), 456 p.

[3]*Kostylyov P.I., Artokhin K.S.* Weed plants, diseases and pests of rice agrocenoses in the south of Russia: scientific and reference textbook. Moscow: Pechatny Gorod, 2010, 368 p.

[4]*Beketova O.A.* The analysis of species diversity of weeds in the Sukhobuzimsky District of Krasnoyarsk Region // Bulletin of the Krasnoyarsk State Agrarian University, 2016, N 1, pp. 108–114.

main, strategic crop for the Far Eastern region, the sown area of which in Russia from 2012 to 2021 increased more than twofold and reached 3.07 million hectares. By 2031, gross soybean harvests in the Russian Federation are projected to increase to 411 million tons, which will significantly exceed the total production volume of other oilseed crops (188 million tons) [8, 9].

One of the key factors hindering yield increases for agricultural crops in general, and soybeans in particular, is weed infestation. Due to competition with weeds for light, water, nutrients, and space, yield losses of the main crop can reach 45–95%. Therefore, weed control has been and remains one of the most important components of soybean cultivation technologies [10, 11]. From the germination stage until the formation of the main above-ground mass, soybeans compete weakly with weeds. The use of soil-applied herbicides significantly reduces weed infestations during this period and creates optimal conditions for crop growth and development. Soil-applied herbicides are applied before sowing or immediately after (pre-emergence) and ensure that agrocenoses are free primarily of annual grasses and susceptible biennial dicotyledonous weeds. For soil-applied herbicides to work reliably, careful field preparation, uniform seed placement, and adequate soil moisture in the topsoil are essential. Under these optimal conditions and with low infestation of crops, primarily susceptible weeds, a single soil application of herbicides may be sufficient to keep crops clean throughout the growing season. In less favorable situations, with the abundant presence of resistant weeds, including perennial weeds, in the field, the use of soil preparations provides acceptable conditions for the early growth and development of the crop and serves as the basis for the subsequent successful use of foliar herbicides [12–14].

The aims and objectives of the study are to determine the dynamics of the prevalence and abundance of green bristle-grass and yellow foxtail in the Primorsky Territory based on the analysis of long-term data from herbological studies of soybean and other crop agrocenoses; to conduct a study of herbicides with soil activity used for weed control in soybean crops, and to identify the products that are most effective in controlling foxtail species.

MATERIAL AND METHODS

Surveys of agricultural crops in the Primorsky Territory on weed infestation were carried out from 2015 to 2024 according to the methodology set out in the guide “Forecasting and Mapping of Weeds”[5]. The species membership of the found weeds was determined according to the publication "Vascular Plants of the Soviet Far East" and "Flora of the Russian Far East: Additions and Changes to the Publication 'Vascular Plants of the Soviet Far East'" (see footnotes 1 and 2). The occurrence of each weed species was calculated according to E.N. Mysnik[6]; the average weed density taking into account the areas of the surveyed fields – according to the formula proposed by T.V. Morokhovets and co-authors [1]. The study of the biological activity of herbicides was conducted in 2021 and 2022 at the vegetation house site of the Far Eastern Research Institute of Plant Protection in accordance with the "Methodical Guide to the Study of Herbicides Used in Crop Production"[7].

The objects of research are harmful and widespread weeds in the Primorsky Territory in soybean and other crop fields – green bristle-grass and yellow foxtail; as well as herbicides with soil activity, among those permitted for use in soybean crops[8]. The sensitivity of two species of bristle grass to the following drugs, applied at the maximum permissible rates, was studied:

[5]*Isaev V.V.* Weed forecasting and mapping. Moscow: Agropromizdat, 1990, 192 p.

[6]*Mysnik E.N.* To the question of the integrated assessment of the occurrence and abundance of weeds // Plant Protection News, 2012, N 2, pp. 66–67.

[7]*Spiridonov Yu.Ya., Larina G.E., Shestakov V.G.* Methodical guide to the study of herbicides used in crop production. Moscow: Pechatny Gorod, 2009, 252 p.

[8]List of pesticides and agrochemicals permitted for use on the territory of the Russian Federation. Moscow, 2021, 848 p. (Appendix to the journal "Plant Protection and Quarantine", 2021, No. 4).

Pledge, WP (active ingredient (a.i.) flumioxazine, 500 g/kg), 0,12 kg/ha; Zenkor Ultra, SC (a.i. metribuzin, 600 g/l) 1,0 l/ ha; Kommand, EC (a.i. klomazon, 480 g/l) 1,0 l/ ha; Gezagard, SC (a.i. promethrin, 500 g/l), 3,5 l/ ha; Gardo Gold, SC (a.i. C-metolachlor + terbutylazine, 312.5 + 187.5 g/l), 4,5 l/ha; Dual Gold, EC (a.i. C-metolachlor, 960 g/l), 1,6 l/ha and Proponite, EC (a.i. propizochlor, 720 g/l) 3,0 l/ha.

As a substrate for growing bristle grasses, the typical meadow-brown podzol soil of the Primorsky Territory was used. The soil, sieved through a 5 mm mesh, was placed in plastic growth vessels in amounts of 0.5 kg, the surface was compacted, the bristle grass seeds with pre-determined germination rates were evenly spread in quantities sufficient to form 10–12 strong seedlings in the control (without herbicides), covered with a 1 cm layer of soil, and watered. A day after sowing the weeds, solutions of the tested herbicides were applied to the soil surface using an OP-5 laboratory sprayer designed by the All-Russian Scientific Research Institute of Phytopathology (see footnote 7). Soil moisture in the containers was maintained at 60–70% of field capacity by daily watering. The plants were not removed until the experiments were completed. Each experiment was repeated 10 times.

During the research, regular visual observations were carried out on the control and experimental bristle grass plants, recording all possible signs of their suppression and damage (growth and development delays, changes in leaf coloration, presence of local damage in the form of spots, and other deviations from the control). After 25–29 days following the application of herbicides, the weed plants were cut and weighed to determine the raw aboveground biomass. The degree of toxicity of herbicidal preparations for two species of bristle-grass was judged by the reduction of the aboveground biomass of experimental plants compared to the control, using the following gradation of herbicidal activity levels: a reduction of experimental plant biomass by 91–100% – very good effect, 76–90% – good, 51–75% – satisfactory, and 0–50% – no effect/weak effect [15].

RESULTS AND DISCUSSION

The average occurrence of green bristle-grass in the surveyed crops in the Primorsky Territory from 2015 to 2024 was 31.3%, with a maximum for early cereal crops – 48.3% – and a minimum – 20.2% – for corn fields (see the table).

The average over 10 years density of green bristle-grass infestation in soybean, corn, and early cereal crops was low and ranged from 1.2 to 1.6 plants/m². The maximum density of green bristle-grass (9.8 plants/m²) was recorded in 2022 in corn crops. In soybean and cereal crops, the highest number of plants of this species was found in 2015 – 6.0 and 5.8 plants/m², respectively.

The yellow foxtail occurrence in these years in all the surveyed areas was higher than the occurrence of green bristle-grass, and approximately equal in soybean, corn, and early cereal crops – on average 57.0–66.2% (see table).

In 2022, yellow foxtail was detected in 90.0–90.9% of the surveyed fields of early cereal crops and corn. The maximum occurrence of this weed species in soybean fields—76.3%—was recorded in 2019. The density of yellow foxtail on all surveyed areas was also higher than that of green bristle-grass, averaging 2.7 plants/m² over 10 years. This species was most abundant in early cereal crops, averaging 5.8 plants/m². In 2022, the highest recorded infestation of yellow foxtail in the years of research was in soybean fields—3.4 plants/m², early cereal crops—8.9, and corn—9.2 plants/m².

In 2021 and 2022, under greenhouse conditions, seedlings of green bristle-grass and yellow foxtail appeared 4–5 days after sowing in the control (without herbicides) and in the variants with the use of herbicides Kommand 1.0 l/ ha, Zenkor Ultra 1.0 l/ha, and Pledge 0.12 kg/ha. Three days later, visually noticeable symptoms of herbicide toxicity were observed on plants of both species. Under the influence of Kommand, weeds lagged in height compared to the control and acquired a light, almost white coloration (a characteristic reaction to the action of clomazone). In the variant using Zenkor Ultra, a weakening of the intensity of the green coloration of

Встречаемость и обилие щетинника зеленого и малорослого (сизого) в посевах сельскохозяйственных культур в Приморском крае

he occurrence and abundance of green bristle-grass in crops in the Primorsky Territoty in

Culture	Year										Average over 10 years
	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	
Occurrence of green bristle grass, %											
In the crops of all cultures, including:	16,0	27,9	19,4	43,6	38,0	26,1	51,7	42,2	27,2	21,0	31,3
soybean	16,7	21,6	20,8	44,4	40,7	31,0	50,7	38,7	27,4	28,6	32,1
corn	–	10,0	12,5	20,0	25,0	–	54,5	45,4	17,6	17,2	20,2
early grain crops *	28,0	50,0	40,0	58,3	37,5	55,6	60,0	60,0	33,3	60,0	48,3
Abundance, pcs/m²											
In the crops of all cultures, including:	4,5	0,4	0,4	0,7	0,4	0,5	1,7	2,0	1,3	0,1	1,2
soybean	6,0	0,4	0,5	0,7	0,4	0,5	1,9	0,6	1,9	0,1	1,3
corn	–	0,3	0,3	0,1	0,5	–	0,7	9,8	0,2	0,1	1,2
early grain crops *	5,8	0,8	0,2	1,2	0,2	3,9	0,8	1,3	1,0	0,8	1,6
Occurrence of yellow foxtail, %											
In the crops of all cultures, including:	48,8	62,3	40,3	43,6	73,4	51,1	61,8	72,3	62,0	66,1	58,2
soybean	43,3	54,0	45,8	40,7	76,3	53,4	61,6	66,1	56,9	71,4	57,0
corn	50,0	70,0	25,0	40,0	75,0	28,6	63,6	90,9	70,6	82,8	59,6
early grain crops*	71,0	75,0	30,0	50,0	50,0	88,9	60,0	90,0	66,7	80,0	66,2
Abundance, pcs/m²											
In the crops of all cultures, including:	4,0	2,8	1,8	1,3	2,6	3,0	2,7	4,9	3,1	0,5	2,7
soybean	2,2	2,6	1,1	1,6	3,1	2,4	3,0	3,4	2,6	0,4	2,2
corn	1,6	2,9	0,2	0,5	1,5	1,1	1,7	9,2	5,5	0,5	2,5
early grain crops*	14,9	4,0	6,3	0,9	1,2	17,9	1,1	8,9	1,8	1,6	5,9

* Wheat, barley, oats.

the leaves was observed. Subsequently, there was some increase in the phytotoxicity of Kommand and a weakening of the effect of Zenkor Ultra on green bristle-grass and yellow foxtail. No noticeable negative impact of Pledge on the growth, development, and leaf coloration of the experimental plants of both foxtail species was found.

Bristle grass seedlings in the variants with the use of herbicides Proponite, 3,0 l/ ha, Dual Gold 1,6 l/ha, Gardo Gold 4,5 l/ha and Gezagard 3,5 l/ha appeared later, 8–9 days after the sowing. During the next 5 days, the plants in these variants became chlorotic and began to noticeably lag behind the control weeds in growth; local necroses in the form of spots appeared on the leaves, and drying of the distal edges of the leaf blades was observed. By the end of the experiments, in the variants with the use of Proponite, all plants died; as a result of the herbicidal action of Dual Gold, Gardo Gold, and Gezagard, up to 70–85% of green bristle-grass and yellow foxtail plants died.

After 25–29 days following herbicide application, the control and surviving experimental

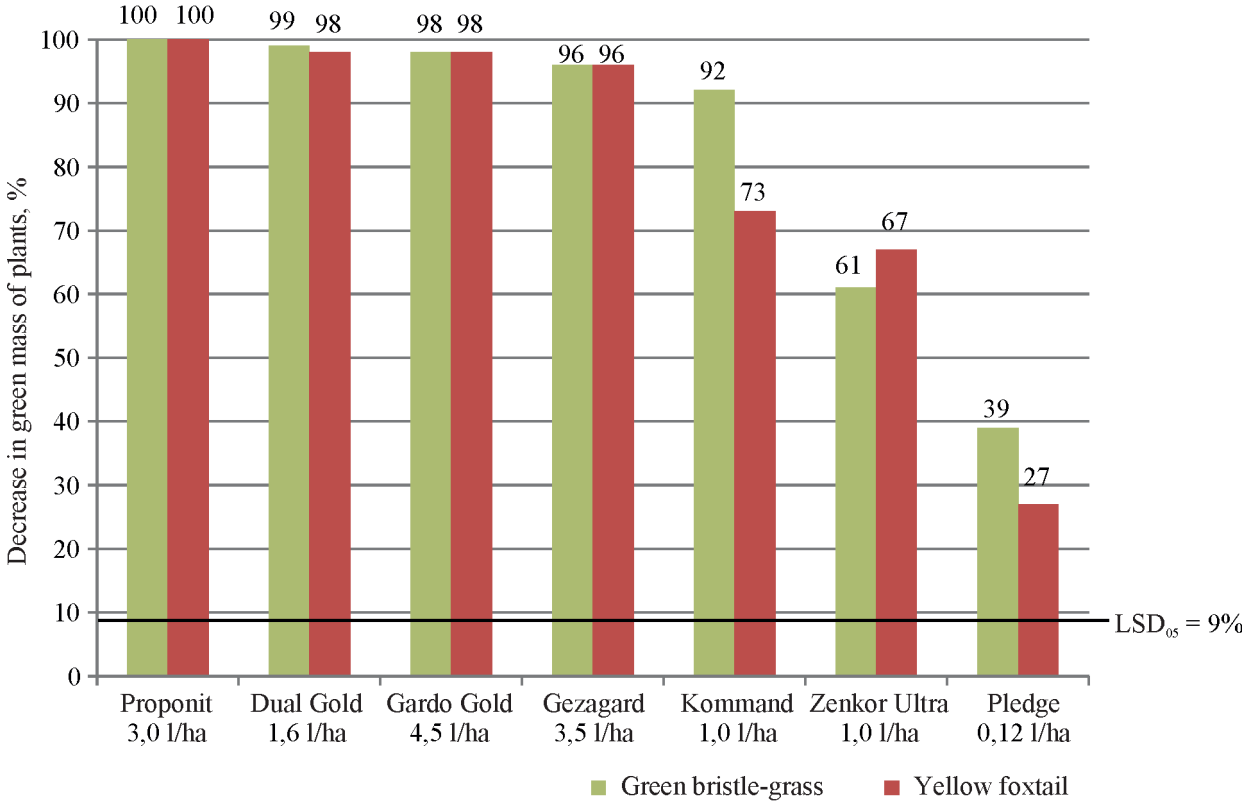
plants were cut and the aboveground part was weighed. In the control, green bristle-grass and yellow foxtail plants had reached the 5-leaf development stage by the time of cutting and formed a fresh aboveground mass averaging 16.3 and 15.0 g per vessel, respectively.

The absolute result – the death of 100% of green bristle-grass and yellow foxtail plants – was achieved using the herbicide Proponite at an application rate of 3.0 l/ha (see the figure).

Very good herbicidal action (reduction in plant mass on average in two experiments by 96–99%) was provided by the products Dual Gold 1.6 l/ha; Gardo Gold 4.5 l/ha and Gezagard 3.5 l/ha. Kommand at a rate of 1.0 l/ha demonstrated very good effectiveness only against green bristle-grass (mass reduction by 92%); on the yellow foxtail plants this herbicide acted satisfactorily, suppressing their mass on average by 73%. Control of two types of bristle-grass with Zenkor Ultra at the normal rate of 1.0 l/ha was no more than satisfactory – a reduction in green mass by 61–67%. Pledge 0.12 kg/ha did not have a significant effect on the accumulation of plant biomass of the tested species.

CONCLUSION

Based on the results of herbological studies of soybean, corn, and early cereal crops conducted in 2015–2024, the occurrence and abundance of green bristle-grass and yellow foxtail plants were determined. In the years most favorable for the growth and development of cereal weeds, their occurrence in the crops of certain cultures reached 60–91%, with a standing density of 9.8–17.9 pcs./m². Thus, both species are steadily present in the agrocenoses of the Primorsky Territory and, as weeds, can be economically significant. To control them in soybean crops, a



Биологическая эффективность почвенных гербицидов в отношении щетинника зеленого и сизого (среднее за 2021 и 2022 гг.) ($НСР_{05}$ – наименьшая существенная разность при уровне значимости 5%)

Biological effectiveness of soil herbicides against green bristle-grass and yellow foxtail (average for 2021 and 2022) (LSD_{05} – least significant difference at a significance level of 5%)

strategic crop for the south of the Far East, soil herbicides that have shown maximum effectiveness (96–100% reduction in raw aboveground weed biomass) in the experiments conducted under greenhouse conditions are recommended: Proponite at a rate of 3.0 l/ha; Dual Gold – 1.6 l/ha; Gardo Gold – 4.5 l/ha; and Gezagard – 3.5 l/ha.

СПИСОК ЛИТЕРАТУРЫ

1. *Мороховец Т.В., Мороховец В.Н., Вострикова С.С., Басай З.В., Штерболова Т.В.* Оценка обилия сорных растений в посевах сельскохозяйственных культур Приморского края // Успехи современной науки. 2017. № 11. С. 233–244.
2. *Лунева Н.Н., Федорова Ю.А.* Фитосанитарное районирование сорных растений на макроуровне на примере Северо-Западного региона России // Вестник защиты растений. 2019. № 2 (100). С. 15–23. DOI: 10.31993/2308-6459-2019-2(100)-15-23.
3. *Лактионов А.П., Афанасьев В.Е., Капитонова О.А.* Конспект флоры Астраханского государственного природного биосферного заповедника // Фиторазнообразие Восточной Европы. 2020. Т. 16. № 4. С. 398–419. DOI: 10.24411/2072-8816-2020-10083.
4. *Михайлова С.И., Эбель Т.В., Шереметова С.А., Эбель А.Л.* Сорные растения в агроценозах и зернопродукции Кемеровской области // Вестник Красноярского государственного аграрного университета. 2022. № 6. С. 58–64. DOI: 10.36718/1819-4036-2022-6-58-64.
5. *Иванова Е.А., Васильева Т.Н., Рябинина З.Н.* Сорные растения с лекарственными свойствами в окрестностях города Оренбурга // Вестник Красноярского государственного аграрного университета. 2023. № 11. С. 55–63. DOI: 10.36718/1819-4036-2023-11-55-63.
6. *Морозов В.И., Тойгильдин А.Л., Подсевалов М.И.* Флористический состав и динамика численности сорных растений агрофитоценозов в севооборотах лесостепной зоны Поволжья // Вестник Ульяновской государственной сельскохозяйственной академии. 2018. № 4. С. 102–109. DOI: 10.18286/1816-4501-2018-4-102-109.
7. *Данилова Н.С., Борисова С.З., Захарова В.И.* Динамика видового разнообразия и обилия сорных растений сельскохозяйственных полей г. Якутска // Вестник Красноярского государственного аграрного университета. 2022. № 8. С. 3–11. DOI: 10.36718/1819-4036-2022-8-3-11.
8. *Синеговский М.О.* Роль правовой защиты новых сортов сои в современных условиях // Вестник Российской сельскохозяйственной науки. 2022. № 3. С. 9–12. DOI: 10.30850/vrsn/2022/3/9-12.
9. *Литвиненко О.В., Корнева Н.Ю., Кодирова Г.А., Кубанкова Г.В.* Результаты сравнительного изучения сортов сои по показателям биохимического состава зерна // Агронаука. 2023. Т. 1. № 4. С. 62–70. DOI: 10.24412/2949-2211-1-4-62-70.
10. *Choudhary C.S., Behera B., Raza M.B., Mrunalini K., Bhoi T.K., Lal M.K., Nongmaithem D., Pradhan S., Song B., Das T.K.* Mechanisms of alleopathic interactions for sustainable weed management // Rhizosphere. 2023. Vol. 25 (3). P. 100667. DOI: 10.1016/j.rhisph.2023.100667.
11. *Лобачев Ю.В., Красильников В.Т.* Влияние новых баковых смесей и композиций гербицидов на хозяйственно-полезные показатели сои // Аграрный научный журнал. 2020. № 2. С. 16–23. DOI: 10.28983/asj.y2020i2pp16-23.
12. *Крылова Т.С., Дубровин А.Н., Дорожкина Л.А.* Эффективность почвенных гербицидов и их смесей в посевах сои в условиях Амурской области // Земледелие. 2020. № 4. С. 33–36. DOI: 10.24411/0044-3913-2020-10409.
13. *Маханькова Т.А., Голубев А.С.* Новые гербициды для защиты посевов сои // Защита и карантин растений. 2024. № 9. С. 15–16. DOI: 10.47528/1026-8634_2024_9_15.
14. *Епифанцев В.В., Панасюк А.Н., Осипов Я.А., Вайтехович Ю.А., Андриенко С.В.* Влияние гербицидов на видовой состав сорняков и продуктивность сои // Земледелие. 2020. № 1. С. 22–26. DOI: 10.24411/0044-3913-2020-10106.
15. *Мороховец Т.В., Мороховец В.Н., Маркова Е.С., Басай З.В., Вострикова С.С., Скорик Н.С.* Фазовая чувствительность некоторых видов широколистных сорных растений к гербициду Флекс // Сибирский вестник сельскохозяйственной науки. 2022. Т. 52. № 5. С. 32–41. DOI: 10.26898/0370-8799-2022-5-4.

REFERENCES

1. Morokhovets T.V., Morokhovets V.N., Vostrikova S.S., Basai Z.V., Shterbolova T.V. Assessment of the abundance of weeds in field crops in Primorsky krai. *Uspekhi sovremennoi nauki = Modern Science Success*, 2017, no. 11, pp. 233–244. (In Russian).
2. Luneva N.N., Fedorova Yu.A. Phytosanitary zoning of weeds at the macro level: a case study of the north-western region of Russia. *Vestnik zashchity rastenii = Plant Protection News,* 2019, no. 2 (100), pp. 15–23. (In Russian). DOI: 10.31993/2308-6459-2019-2(100)-15-23.
3. Laktionov A.P., Afanas'ev V.E., Kapitonova O.A. Checklist of the flora of Astrakhan Nature Biosphere Reserve. *Fitoraznoobrazie Vostochnoi Evropy = Phytodiversity of Eastern Europe,* 2020, vol. 16, no. 4, pp. 398–419. (In Russian). DOI: 10.24411/2072-8816-2020-10083.
4. Mikhailova S.I., Ebel' T.V., Sheremetova S.A., Ebel' A.L. Weeds in agrocenoses and grain products of the Kemerovo region. *Vestnik Krasnoyarskogo gosudarsstvennogo agrarnogo universiteta = Bulletin KrasSAU*, 2022, no. 6, pp. 58–64. (In Russian). DOI: 10.36718/1819-4036-2022-6-58-64.
5. Ivanova E.A., Vasil'eva T.N., Ryabinina Z.N. Weeds with medicinal properties in the vicinity of the city of Orenburg. *Vestnik Krasnoyarskogo gosudarsstvennogo agrarnogo universiteta = Bulletin KrasSAU*, 2023, no. 11, pp. 55–63. (In Russian). DOI: 10.36718/1819-4036-2023-11-55-63.
6. Morozov V.I., Toigil'din A.L., Podsevalov M.I. Floristic composition and weed number dynamics of agrophytocenosis in crop rotation of the forest-steppe zone of the Volga region. *Vestnik Ul'yanovskoi gosudarstvennoi sel'skokhozyaistvennoi akademii = Vestnik of Ulyanovsk State Agricultural Academy*, 2018, no. 4, pp. 102–109. (In Russian). DOI: 10.18286/1816-4501-2018-4-102-109.
7. Danilova N.S., Borisova S.Z., Zakharova V.I. Dynamics of species diversity and weeds abundance in the Yakutsk city agricultural fields. *Vestnik Krasnoyarskogo gosudarsstvennogo agrarnogo universiteta = Bulletin KrasSAU*, 2022, no. 8, pp. 3–11. (In Russian). DOI: 10.36718/1819-4036-2022-8-3-11.
8. Sinegovskii M.O. The role of legal protection of new soybean varieties in current conditions. *Vestnik Rossiiskoi sel'skokhozyaistvennoi nauki = Vestnik of the Russian agricultural science,* 2022, no. 3, pp. 9–12. (In Russian). DOI: 10.30850/vrsn/2022/3/9-12.
9. Litvinenko O.V., Korneva N.Yu., Kodirova G.A., Kubankova G.V. Results of a comparative study of soybean varieties according to the biochemical composition of grain. *Agronauka = Agroscience,* 2023, vol. 1, no. 4, pp. 62–70. (In Russian). DOI: 10.24412/2949-2211-1-4-62-70.
10. Choudhary C.S., Behera B., Raza M.B., Mrunalini K., Bhoi T.K., Lal M.K., Nongmaithem D., Pradhan S., Song B., Das T.K. Mechanisms of alleopathic interactions for sustainable weed management. *Rhizosphere*, 2023, vol. 25 (3), p. 100667. DOI: 10.1016/j.rhisph.2023.100667.
11. Lobachev Yu.V., Krasil'nikov V.T. The effect of new tank mixtures and herbicide compositions on economically useful indicators of soy. *Agrarnyi nauchnyi zhurnal = The Agrarian Scientific Journal,* 2020, no. 2, pp. 16–23. (In Russian). DOI: 10.28983/asj.y2020i2pp16-23.
12. Krylova T.S., Dubrovin A.N., Dorozhkina L.A. Efficiency of soil herbicides and their mixtures in soybean crops in the Amur region. *Zemledelie = Zemledelie,* 2020, no. 4, pp. 33–36. (In Russian). DOI: 10.24411/0044-3913-2020-10409.
13. Makhan'kova T.A., Golubev A.S. Novel herbicides for protection of soybean crops. *Zashchita i karantin rastenii = Plant Protection and Quarantine,* 2024, no. 9, pp. 15–16. (In Russian). DOI: 10.47528/1026-8634_2024_9_15.
14. Epifantsev V.V., Panasyuk A.N., Osipov Ya.A., Vaitekhovich Yu.A., Andrienko S.V. Influence of herbicides on the weeds species composition and productivity of soybean crops. *Zemledelie = Zemledelie,* 2020, no. 1, pp. 22–26. (In Russian). DOI: 10.24411/0044-3913-2020-10106.
15. Morokhovets T.V., Morokhovets V.N., Markova E.S., Basai Z.V., Vostrikova S.S., Skorik N.S. Phase sensitivity of some broad-leaved weed species to the herbicide Flex. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2022, vol. 52, no. 5, pp. 32–41. (In Russian). DOI: 10.26898/0370-8799-2022-5-4.

СВЕДЕНИЯ ОБ АВТОРАХ

(✉)**Басай Зоя Викторовна,** старший научный сотрудник, кандидат сельскохозяйственных наук; SPIN-код 1191-5029; **адрес для переписки:** Россия, 692682, Приморский край, Ханкайский район, с. Камень-Рыболов, ул. Мира, 42-а; e-mail: dalniizr@mail.ru

Мороховец Вадим Николаевич, директор, кандидат биологических наук; SPIN-код 5253-7379

Мороховец Тамара Викторовна, ведущий научный сотрудник, кандидат сельскохозяйственных наук; SPIN-код 2289-3518

Вострикова Светлана Сергеевна, научный сотрудник; SPIN-код 2318-1707

Маркова Елена Сергеевна, младший научный сотрудник; SPIN-код 4922-8763

AUTHOR INFORMATION

(✉)**Zoya V. Busai,** Senior Researcher, Candidate of Science in Agriculture; SPIN-code 1191-5029; **address:** 42-a, Mira St., Kamen-Rybolov, Khankaysky District, Primorsky Territory, 692682, Russia; e-mail: dalniizr@mail.ru

Vadim N. Morokhovets, Director, Candidate of Science in Biology; SPIN-code 5253-7379

Tamara V. Morokhovets, Lead Researcher, Candidate of Science in Agriculture; SPIN-code 2289-3518

Svetlana S. Vostrikova, Researcher; SPIN-code 2318-1707

Elena S. Markova, Junior Researcher; SPIN-code 4922-8763

Дата поступления статьи / Received by the editors 10.07.2025
Дата принятия к публикации / Accepted for publication 15.08.2025
Дата публикации / Published 19.12.2025

https://doi.org/10.26898/0370-8799-2025-12-8
УДК 636.018:577.21
Тип статьи: оригинальная
Type of article: original

Полиморфизм генов *CSN3, BLG, TNF-α-824, Pit-1, SCD1* и их влияние на молочную продуктивность коров черно-пестрой породы

Авадани Д.А.[1,2], (✉)Гончаренко Г.М.[1], Хорошилова Т.С.[1], Гришина Н.Б.[1], Халина О.Л.[1]
[1]*Сибирский федеральный научный центр агробиотехнологий Российской академии наук*
Новосибирская область, р.п. Краснообск, Россия,
[2]*Новосибирский государственный аграрный университет*
Новосибирск, Россия
(✉)e-mail: gal.goncharenko@mail.ru

Изучен полиморфизм генов *CSN3, BLG, TNF-α-824, SCD1, Pit-1* и связи их генотипов с молочной продуктивностью коров черно-пестрой породы. Молекулярно-генетические исследования проведены на коровах данной породы (*n* = 100). Выявлена частота генотипов и аллелей у коров черно-пестрой породы, обусловленная предшествующей селекционно-племенной работой. Сравнительная оценка полиморфизма изучаемых генов с другими российскими молочными породами показала хорошее совпадение результатов. Установлено, что коровы с генотипом $CSN3^{AA}$ имели более высокий (на 707,3 кг) удой в сравнении с гетерозиготным генотипом $CSN3^{AB}$, содержание массовой доли жира было выше у коров с генотипом $CSN3^{BB}$ на 0,76% в сравнении с генотипом $CSN3^{AB}$ и на 0,69% – с $CSN3^{AA}$. Соответственно более высокое (на 66,1 кг) содержание молочного жира имели коровы с генотипом $CSN3^{BB}$, чем животные с генотипом $CSN3^{AB}$. Коровы с генотипом BLG^{BB} имели удой на 944,4 кг больше, содержание молочного жира выше на 46,2 кг по сравнению с животными генотипа BLG^{AA}. Более высокая молочная продуктивность отмечена у гетерозиготных животных $TNF\text{-}α\text{-}824^{GA}$, превосходящая гомозиготные генотипы по удою на 688,7–753,8 кг, содержанию молочного белка на 20,7–27,2 кг, содержанию молочного жира на 20,6 кг. Коровы с генотипом $SCD1^{CC}$ превосходили по удою на 511,3 и 792,1 кг животных с альтернативными генотипами. По содержанию молочного жира белка приоритетное положение занимали коровы с генотипом $SCD1^{CC}$. У коров с разными генотипами $Pit\text{-}1^{AA}$ небольшое преимущество отмечено по содержанию белка. Выявленные ассоциативные связи генотипов *CSN3*, *BLG*, *TNF-α-824*, *SCD1*, *Pit-1* с удоем и качеством молока возможно использовать в селекции путем отбора и подбора родительских пар с желательными генотипами.

Ключевые слова: черно-пестрая порода, молочная продуктивность, генотип, частота, полиморфизм, ассоциативная связь, лактация

Polymorphism of the *CSN3*, *BLG*, *TNF-α-824*, *Pit-1*, *SCD1* genes and their influence on milk productivity of cows of the Black-and-White breed

Avadani D.A.[1,2], (✉)Goncharenko G.M.[1], Khoroshilova T.S.[1], Grishina N.B.[1], Khalina O.L.[1]
[1]*Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences*
Krasnoobsk, Novosibirsk Region, Russia
[2]*Novosibirsk State Agrarian University*
Novosibirsk, Russia
(✉)e-mail: gal.goncharenko@mail.ru

The polymorphism of the genes *CSN3*, *BLG*, *TNF-α-824*, *SCD1*, *Pit-1* and the relationship of their genotypes with milk productivity of Black-and-White cows were studied. Molecular genetic studies were conducted on the Black-and-White cows (*n* = 100). The genotype and allele frequency in the

Black-and-White cows which is a consequence of the previous selection and breeding work was identified. A comparative assessment of the polymorphism of the studied genes with other Russian dairy breeds showed good agreement of the results. It was found that cows with the $CSN3^{AA}$ genotype had a higher milk yield (by 707,3 kg) compared to the heterozygous genotype $CSN3^{AB}$; the fat mass fraction content was higher in cows with the $CSN3^{BB}$ genotype by 0,76% compared to the $CSN3^{AB}$ genotype and by 0,69% with $CSN3^{AA}$. Accordingly, cows with the $CSN3^{BB}$ genotype had a higher milk fat content (by 66,1 kg) than animals with the $CSN3^{AB}$ genotype. Cows with the BLG^{BB} genotype had a milk yield of 944.4 kg more and a milk fat content of 46.2 kg higher compared to animals with the BLG^{AA} genotype. Higher milk productivity was noted in heterozygous animals $TNF\text{-}\alpha\text{-}824^{GA}$, exceeding homozygous genotypes in milk yield by 688.7-753.8 kg, milk protein content by 20,7-27,2 kg, milk fat content by 20,6 kg. Cows with the $SCD1^{CC}$ genotype exceeded animals with alternative genotypes in milk yield by 511,3 and 792,1 kg. In terms of milk fat and protein content, cows with the $SCD1^{CC}$ genotype have a priority position. Cows with different $Pit\text{-}1^{AA}$ genotypes had a slight advantage in protein content. The identified associative links of the *CSN3*, *BLG*, *TNF-α-824*, *SCD1*, *Pit-1* genotypes with milk yield and milk quality can be used in selection by selecting and matching parental pairs with desirable genotypes.

Keywords: Black-and-White breed, milk productivity, genotype, frequency, polymorphism, associative linkage, lactation

Для цитирования: *Авадани Д.А., Гончаренко Г.М., Хорошилова Т.С., Гришина Н.Б., Халина О.Л.* Полиморфизм генов *CSN3, BLG, TNF-α-824, Pit-1, SCD1* и их влияние на молочную продуктивность коров черно-пестрой породы // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55 № 12 . С. 75–85. https://doi.org/10.26898/0370-8799-2025-12-8

For citation: *Avadani D.A., Goncharenko G.M., Khoroshilova T.S., Grishina N.B., Khalina O.L.* Polymorphism of the *CSN3*, *BLG*, *TNF-α-824*, *Pit-1*, *SCD1* genes and their influence on milk productivity of cows of the Black-and-White breed. *Sibirskii vestnik sel'skokhozyaistvennoi nauki* = Siberian Herald of Agricultural Science, 2025, vol. 55, no. 12, pp. 75–85. https://doi.org/10.26898/0370-8799-2025-12-8

Конфликт интересов
Авторы заявляют об отсутствии конфликта интересов.
Conflict of interest
The authors declare no conflict of interest.

Благодарность
Работа выполнена в рамках выполнения темы FNUU-2024-0009.
Acknowledgments
The work was carried out within the framework of the topic FNUU-2024-0009.

INTRODUCTION

The search for new and the use of the tested genetic markers that influence the development of phenotypic traits complement traditional breeding methods by providing a more accurate assessment of the genetic potential of animal productivity. In dairy cattle breeding, genes associated with milk yield, milk quality, as well as animal resistance, are of great interest, such as *CSN3, BLG, TNF-α-824, SCD1, Pit-1.*

Among the most studied is the *CSN3* gene, the $CSN3^{BB}$ genotype of which, as shown by numerous studies, is associated with increased protein content and cheesemaking properties [1–3]. The milk whey protein *BLG* is valuable in dairy cattle breeding due to its influence on cow milk yield, and the fat and protein content of cow's milk [4]. The *TNF-α* (*824 A/G*) gene arouses a certain interest, especially when evaluating the reproductive capacity of cows and their milk productivity [5–6]. *Pit-1* gene participates in the transcription of several genes *GHRH*, *TSH*, *PRL*, performing important functions in the body in the processes of growth, development, milk synthesis, and reproductive ability. In dairy breeds, the frequency of genotypes of this gene does not have significant differences [7].

At present, due to the special demand for product quality, especially their fatty acid composition, the *SCD1* gene is gaining greater significance, as it has been shown to be associated

with lipogenesis, lipid oxidation, and thermogenesis[1] [8].

The predictive assessment of cow productivity using genetic markers (SNP) will be more successful when establishing the links between genotypes and the main breeding-relevant traits, confirmed across several breeds or repeated within a single herd.

The purpose of the study is to examine the associative connections of genotypes *CSN3, BLG, TNF-α* (*824 A/G*)*, Pit-1, SCD1* genes with the milk yield and quality composition of milk of the Black-and-White breed cows.

MATERIAL AND METHODS

Molecular genetic studies of black-and-white breed cows (n = 100) were conducted in the biotechnology laboratory of the Siberian Research and Design and Technological Institute of Animal Husbandry of the Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences (SibRDTIAH SFSCA RAS). Genomic DNA was extracted from blood using the clinical material extraction kit "Ampli Prime DNA-Sorb-V" according to the manufacturer's instructions, OOO "NextBio" (Moscow). The quality and concentration of the extracted DNA were assessed on a 1% agarose gel using horizontal electrophoresis with the E-Box-CX5. TS-20.M gel documentation system under ultraviolet light by ethidium bromide fluorescence.

Polymorphism of the *CSN3* and *BLG* genes was determined using the PCR-RFLP method described in the methodological manual[2]. Detection of the *TNF-α-824 A/G* gene polymorphism was conducted according to the methodology[3]. Genotypes of the *SCD1* gene were identified according to the protocol[4]. *Pit-1* gene genotypes were identified according to the methodology [9].

Amplification was carried out in a C1000 thermocycler «BioRad». The obtained gene amplification products were treated with the restriction endonucleases Hind III, EcoICRI, Nae III, RsaI (SibENZYM, Novosibirsk) according to the manufacturer's instructions. Visualization and genotype identification were determined by electrophoresis in a 3% agarose gel under UV light.

Statistical processing of the obtained data was carried out using the computer programs Microsoft Excel and generally accepted biometric processing methods in animal science.

RESULTS AND DISCUSSION

Genotypic structure of the Black-and-White breed by genes *CSN3, BLG, TNF-α-824, Pit-1, SCD1* is shown in Fig. 1.

The Black-and-White breed cows are characterized by almost the same frequency of genotypes $CSN3^{AA}$ and $CSN3^{AB}$ (44 and 46%). The share of the homozygous genotype $CSN3^{BB}$ is only 10%. Such a frequency of genotypes quite corresponds to the Russian Black-and-White breed of cattle. So, in the studied [10] lines of the Black-and-White breed Vis Back Ideal, Reflection Sovering, and Montwick Chieftain, the genotype $CSN3^{BB}$ is identified from 4,0 to 9,4%. Frequency of the genotype $CSN3^{AA}$ – 37–45%, and a heterozygous genotype was identified in 51–57% of the animals.

A more even ratio of genotypes is noted in the *BLG* gene. The BLG^{BB} genotype was identified in 20.0%, while the other two account for 37.0% and 43.0%, respectively. A similar ratio of genotypes for this gene (0.331; 0.489; and 0.181) was found in the Holstein breed herd by the authors [11].

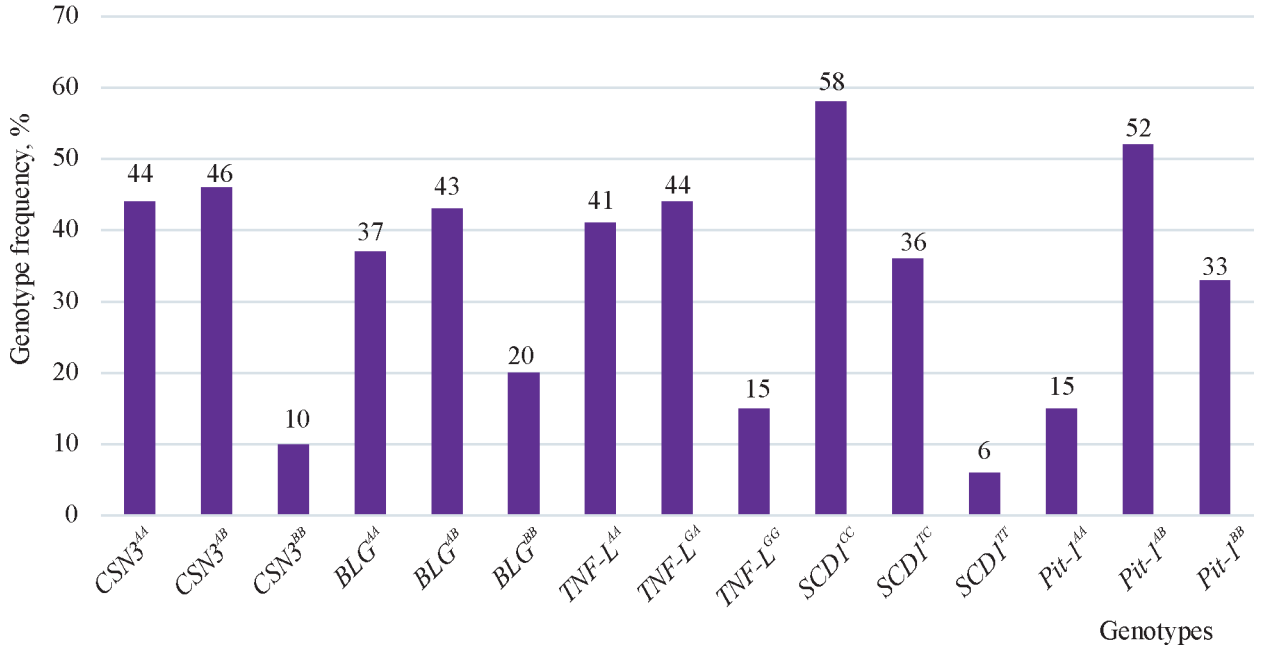
The *TNF-L* gene is represented by three genotypes in the studied herd of cows – *TNF-*

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

[2] *Kalashnikova L.A., Khabibrakhmanova Y.A., Pavlova I.Yu., Ganchenkova T.B., Dudin M.I., Pridanova I.E.* Recommendations for genomic assessment of cattle. Lesnye Polyany, 2015, 33 p.

[3] *Lyukhanov M.P., Korotkevich O.S., Sebezhko O.I., Yudin N.S.* Single nucleotide polymorphism in the cattle population of Red Steppe breed // Modern Problems of Science and Education, 2014, N 1, p. 326.

[4] *Pozovnikova M.V., Serdyuk G.N., Tulinova O.V., Terletsky V.P., Dementyeva N.V., Mitrofanova O.V.* Association of polymorphic types of Stearoyl-CoA Desaturase gene (SCD1) with economically valuable traits in Russian population of Ayrshire cows // Agricultural biology, 2017, vol. 52, N 6, pp. 1139–1147. DOI: 10.15389/agrobiology.2017.6.1139rus.



Puc. 1. Частота генотипов *CSN3, BLG, TNF-α-824, Pit-1, SCD1* генов у коров черно-пестрой породы
Fig. 1. Genotype frequency of the *CSN3*, *BLG*, *TNF-α-824*, *Pit-1*, *SCD1* genes in cows of the Black-and-White breed

L^{AA}, *TNF-*L^{GA}, *TNF-*L^{GG} – with the frequency of 41,0; 44,0 and 15,0% respectively. For Black-and-White cows, a distinctive feature is the low frequency of the genotype $SCD1^{TT}$ – 6,0%. The same frequency of this genotype (5.7%) was found in the Holstein cows in Tatarstan. At the same time, the heterozygous genotype accounts for 70.4% [12]. At the same time, in beef cattle breeds, for example, Hereford, the ratio of genotypes of this gene is different: $SCD1^{CC}$ – 22,0%, $SCD1^{TC}$ – 44,0, $SCD1^{TT}$ – 34,0%. In the Kazakh White-headed breed, this ratio is represented as 45,6 : 36,8 : 17,6 [13].

In the *Pit-1* gene in the Black-and-White cows three genotypes are identified – *Pit-*1^{AA}, *Pit-*1^{AB}, *Pit-*1^{BB} – with the frequency of 15,0; 52,0 and 33,0% respectively. A comparative assessment with the literature data showed some of its differences from other breeds of dairy cattle. Thus, in the Holstein breed, according to [9], the frequency of the genotypes is: AA – 11,7%, AB – 40,5, BB – 47,7%. In the dairy breeds of Kazakhstan, this gene has the following frequency: Red Steppe – 0,092; 0,433 and 0,475, Simmental – 0,222; 0,476 and 0,302 [7].

Allele frequency of genes *CSN3, BLG, TNF-α-824, SCD1, Pit-1* of the Black-and-White cows is shown in Fig.2.

The most common alleles in the Black-and-White breed include $CSN3^{A}$, BLG^{B}, *TNF-*L^{G}, *SCD1*^{C}, *Pit-*1^{B} with the frequency higher than 0,5. Among the alternative alleles, the *Pit-*1^{A} – 0,24 allele is the least frequently encountered.

Based on the analysis of genotype and allele frequencies, it can be assumed that those involved in the selection process are the ones associated with productivity or qualitative indicators of milk and, accordingly, have a higher frequency of occurrence.

Studies of the most significant and well-tested gene in dairy cattle, *CSN3*, have shown that in the second lactation, Holstein cows with the *CSN3*^{AA} genotype had a higher milk yield (by 707.3 kg) compared to the heterozygous $CSN3^{AB}$ genotype ($p \leq 0,05$) (see Table 1). Cows with the *CSN3*^{AA} genotype also had higher milk fat content (by 34.7 kg) compared to the $CSN3^{AB}$ genotype ($p \leq 0,05$). No significant differences were found in the considered indicators for the first and third lactations, although the milk yield of cows in the

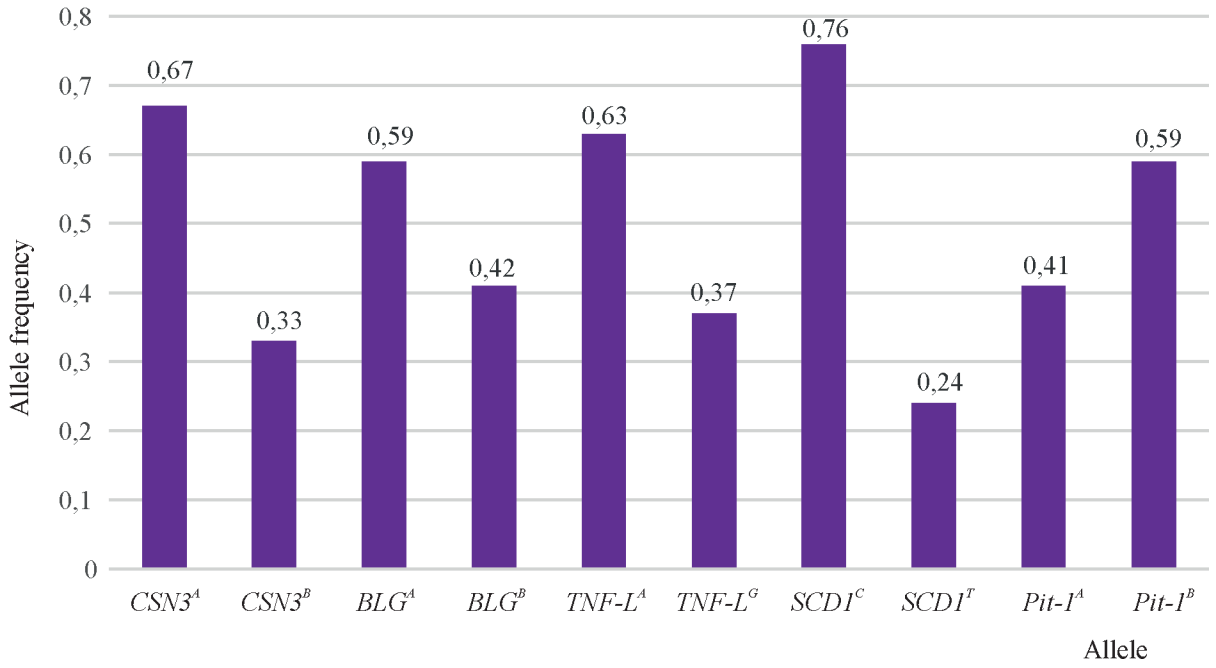


Рис. 2. Частота аллелей *CSN3, BLG, TNF-α-824, SCD1, Pit-1* генов коров черно-пестрой породы

Fig. 2. Allele frequency of the *CSN3*, *BLG*, *TNF-α-824*, *SCD1*, *Pit-1* genes in cows of the Black-and-White breed

Табл. 1. Молочная продуктивность коров с генотипами гена *CSN3*

Table 1. Milk productivity of cows with the *CSN3* gene genotypes

Genotype	*n*	Milk yield, kg	Fat, %	Protein, %	Fat, kg	Protein, kg
First lactation						
$CSN3^{AA}$	44	6741,5 ± 165,3	4,08 ± 0,05	3,20 ± 0,02	275,1 ± 7,9	217,4 ± 6,0
$CSN3^{AB}$	43	6640,6 ± 161,3	4,06 ± 0,05	3,20 ± 0,02	268,9 ± 6,7	214,6 ± 6,0
$CSN3^{BB}$	4	6137,5 ± 415,3	4,02 ± 0,15	3,18 ± 0,05	248,8 ± 24,8	195,4 ± 15,5
Second lactation						
$CSN3^{AA}$	28	8159,4 ± 210,7	4,09 ± 0,07	3,20 ± 0,02	333,5 ± 9,8	261,6 ± 7,7
$CSN3^{AB}$	25	7452,1 ± 288,5	4,02 ± 0,06	3,20 ± 0,02	298,8 ± 12,2	244,4 ± 9,6
Third lactation and older						
$CSN3^{AA}$	30	7708,9 ± 279,0	4,23 ± 0,07	3,16 ± 0,02	325,1 ± 11,8	244,8 ± 10,0
$CSN3^{AB}$	24	7285,3 ± 223,7	4,04 ± 0,09	3,16 ± 0,02	305,3 ± 14,6	236,4 ± 9,7

third lactation with the $CSN3^{AA}$ genotype reaches 7708.9 kg, whereas with the heterozygous genotype it is 7285.3 kg.

The data we obtained on the priority of the $CSN3^{AA}$ genotype for milk yield coincide with the results of the studies of the Simmental breed cows, where animals with this genotype also had a higher milk yield (by 398.6 kg) compared to the $CSN3^{BB}$ genotype [3]. Slightly different results were obtained in the Black-and-White cows [14]. Animals with the $CSN3^{BB}$ genotype had higher milk protein content (by 0.09–0.17%) compared to alternative genotypes. Researchers came to similar conclusions when studying the relationship between *CSN3* gene genotypes and the milk productivity of Holstein cows [15].

When analyzing the associative relationships of the genotypes of the *BLG* gene with milk productivity, it was found that cows with the BLG^{BB} genotype in the second lactation had higher milk yield (by 944.4 kg) and milk fat content (by 46.2 kg) compared to the animals with the BLG^{AA} genotype ($p \leq 0,05$) (see Table 2). For other recorded traits in the first and third lactations, no significant differences were found among the cows with different genotypes. At the same time,

it should be noted that the literature data are contradictory. Higher milk yield (by 694 kg) was observed in the cows with the BLG^{AA} genotype compared to heterozygotes, while the fat and protein content in milk was higher by 55.7 and 26.8 kg, respectively, in the animals with the BLG^{BB} genotype[5]. However, in the studies [16] on the evaluation of female ancestors of stud bulls, the complex genotype, consisting of the genotypes BLG^{AB} and BLG^{AA}, was identified as the priority for milk yield and milk fat content. In the cows of the Red Belarusian breed, the best complex genotype was $DGAT1^{KK}$ GH^{LL} PRL^{AA} BLG^{AB}, which included the genotype BLG^{AB} [17].

When analyzing the milk productivity of cows with different *TNF-α-824* genotypes it is shown that the milk yield in the first lactation of the cows with the genotype $TNF\text{-}α\text{-}824^{GA}$ reaches 7073,7 kg, that is 688,7–753,8 kg higher than in the animals with alternative homozygous genotypes $TNF\text{-}α\text{-}824^{AA}$ and $TNF\text{-}α\text{-}824^{GG}$ ($p \leq 0{,}01$) (see Table 3). In addition, these cows also showed an increased (by 20.6 kg) milk fat content compared to cows with the genotype $TNF\text{-}α\text{-}824^{AA}$ ($p \leq 0{,}05$). Heterozygous cows for this gene also showed a higher (by 20.7–27.2 kg) milk protein content compared to animals with alternative homozygous genotypes

Табл. 2. Продуктивность коров с учетом генотипов по гену *BLG*
Table 2. Productivity of cows taking into account genotypes for the *BLG* gene

Genotype	*n*	Milk yield, kg	Fat, %	Protein, %	Fat, kg	Protein, kg
First lactation						
BLG^{AA}	34	6710,7 ± 161,0	4,05 ± 0,07	3,19 ± 0,02	271,4 ± 7,5	217,1 ± 5,7
BLG^{AB}	40	6716,5 ± 174,3	4,06 ± 0,04	3,21 ± 0,02	272,7 ± 7,5	217,2 ± 6,6
BLG^{BB}	17	6464,5 ± 302,1	4,10 ± 0,07	3,19 ± 0,03	266,2 ± 14,6	206,7 ± 10,3
Second lactation						
BLG^{AA}	22	7408,0 ± 374,3	4,01 ± 0,06	3,18 ± 0,02	296,0 ± 14,6	242,5 ± 13,2
BLG^{AB}	19	7902,0 ± 161,7	4,15 ± 0,09	3,23 ± 0,02	328,2 ± 10,6	255,4 ± 6,5
BLG^{BB}	14	8352,4 ± 219,5	4,10 ± 0,11	3,19 ± 0,02	342,2 ± 11,7	266,5 ± 7,2
Third lactation and older						
BLG^{AA}	23	7231,6 ± 214,9	4,03 ± 0,07	3,15 ± 0,02	295,5 ± 9,3	231,6 ± 6,9
BLG^{AB}	20	7453,2 ± 249,4	4,21 ± 0,09	3,17 ± 0,02	312,4 ± 10,0	236,2 ± 8,4
BLG^{BB}	12	8079,2 ± 594,5	4,30 ± 0,14	3,18 ± 0,04	346,9 ± 26,3	258,5 ± 21,2

Табл. 3. Продуктивность коров за 305 дней лактации с учетом генотипов по гену *TNF-α-824*
Table 3. Productivity of cows for 305 days of lactation taking into account genotypes for the *TNF-α-824* gene

Genotype	*n*	Milk yield, kg	Fat, %	Protein, %	Fat, kg	Protein, kg
First lactation						
$TNF\text{-}α\text{-}824^{AA}$	34	6385,0 ± 160,16	4,12 ± 0,06	3,20 ± 0,02	263,0 ± 7,2	207,7 ± 6,1
$TNF\text{-}α\text{-}824^{GA}$	39	7073,7 ± 146,60	4,01 ± 0,06	3,21 ± 0,02	283,6 ± 7,2	228,4 ± 5,5
$TNF\text{-}α\text{-}824^{GG}$	18	6319,9 ± 314,13	4,08 ± 0,06	3,18 ± 0,02	258,8 ± 14,4	201,2 ± 10,7
Second lactation						
$TNF\text{-}α\text{-}824^{AA}$	22	7483,1 ± 233,48	4,12 ± 0,06	3,21 ± 0,02	309,0 ± 11,1	242,9 ± 8,1
$TNF\text{-}α\text{-}824^{GA}$	25	8000,9 ± 304,9	4,08 ± 0,08	3,19 ± 0,02	325,1 ± 13,0	260,0 ± 10,2
$TNF\text{-}α\text{-}824^{GG}$	8	8174,4 ± 298,36	3,98 ± 0,11	3,20 ± 0,04	327,0 ± 18,9	261,7 ± 10,9
Third lactation and older						
$TNF\text{-}α\text{-}824^{AA}$	22	7505,1 ± 369,6	4,30 ± 0,10	3,18 ± 0,02	327,5 ± 16,6	243,4 ± 12,8
$TNF\text{-}α\text{-}824^{GA}$	29	7464,5 ± 206,59	4,04 ± 0,06	3,16 ± 0,02	301,3 ± 8,8	236,3 ± 7,2
$TNF\text{-}α\text{-}824^{GG}$	4	7689,2 ± 348,53	4,22 ± 0,11	3,10 ± 0,03	324,3 ± 13,1	238,7 ± 13,5

[5]*Rachkova E.N.* The heritability of milk productivity depending on polymorphism gene beta-lactoglobulin // Academic Notes of Kazan State Academy of Veterinary Medicine named after N.E. Bauman, 2016, vol. 226, N 2, pp. 209–213.

($p \leq 0{,}05$). No significant differences were found in the second and third lactations. Other data on the priority of gene genotypes were obtained in the studies [5], which showed that higher milk yield was observed in cows with the genotype *TNF-α-824*^{AA}, however, these animals have the highest rate of infertility.

Among cows with different *SCD1* genotypes, the *SCD1*^{CC} genotype can be distinguished as the priority genotype for milk yield in the first lactation, with animals having a yield of 6927.4 kg, which is 511.3 and 792.1 kg higher than cows with *SCD1*^{CT} and *SCD1*^{TT} genotypes, respectively. ($p \leq 0{,}05$) (see Table 4). Significant differences in milk fat and protein content were found in these same cows. Thus, in terms of milk fat content, the superiority reaches 26.7 kg over the *SCD1*^{CT} genotype and 35.6 kg over the *SCD1*^{TT} genotype ($p \leq 0{,}05$). In terms of protein content, the difference is 21.7 and 30.5 kg, respectively ($p \leq 0.05$). The data (see footnote 4) support our findings on the desirability of the *SCD1*^{CC} and *SCD1*^{CT} genotypes in Ayrshire cows, which have been found to have higher breeding value in terms of milk yield, milk fat, and milk protein. In the Holstein breed of the Republic of Tatarstan, a higher milk yield (by 711.34 kg) was also recorded in animals with the *SCD1*^{CC} genotype compared to the heterozygous *SCD1*^{CT} genotype. However, in terms of the fat content in milk and the yield of milk fat, the desirable genotype was the homozygous genotype *SCD1*^{TT} [12].

No advantages in terms of milk production traits were found in the cows with different *Pit-1* genotypes, except for the protein mass fraction in the second lactation, where a higher content was noted in cows with the genotype *Pit-1*^{AA} – 3,27%, что выше на 0,09%, чем у коров с генотипом *Pit-1*^{BB} ($p \leq 0{,}05$) (see Table 5).

No link between the *Pit-1* gene and milk yield has been established in the studies [9], however, the best indicators for fat content, milk fat yield, and protein were found in the cows with *Pit-1*^{AB} and *Pit-1*^{BB} genotypes. In Holstein cows with different *Pit-1* gene genotypes, no significant differences were found among the recorded indicators[6].

The identified priority genotypes with higher milk yield and quality composition will be the subject of further research with an expanded sample and the determination of a comprehensive genotype for this herd or in a comparative assessment with other breeds and herds.

Табл. 4. Продуктивность коров за 305 дней лактации с учетом генотипов по гену *SCD1*
Table 4. Productivity of cows for 305 days of lactation taking into account genotypes for the *SCD1* gene

Genotype	*n*	Milk yield, kg	Fat, %	Protein, %	Fat, kg	Protein, kg
First lactation						
SCD1^{CC}	48	6927,4 ± 158,8	4,11 ± 0,04	3,22 ± 0,02	284,2 ± 6,9	225,4 ± 6,0
SCD1^{CT}	37	6416,1 ± 162,2	4,01 ± 0,06	3,18 ± 0,02	257,5 ± 7,6	204,7 ± 5,4
SCD1^{TT}	6	6135,3 ± 314,2	4,06 ± 0,18	3,16 ± 0,03	248,6 ± 14,2	194,9 ± 13,1
Second lactation						
SCD1^{CC}	32	8061,8 ± 201,9	4,09 ± 0,06	3,21 ± 0,02	330,0 ± 9,5	262,6 ± 6,6
SCD1^{CT}	20	7567,1 ± 313,7	4,07 ± 0,09	3,19 ± 0,02	307,5 ± 13,9	244,3 ± 10,6
SCD1^{TT}	3	6909,0 ± 1065,5	4,04 ± 0,14	3,14 ± 0,04	276,4 ± 35,2	217,7 ± 36,1
Third lactation and older						
SCD1^{CC}	35	7340,8 ± 176,5	4,19 ± 0,06	3,16 ± 0,02	306,7 ± 7,7	232,6 ± 6,1
SCD1^{CT}	19	7723,9 ± 415,8	4,11 ± 0,12	3,16 ± 0,03	323,9 ± 19,4	250,0 ± 14,5

[6] *Pozovnikova M.V., Serdyuk G.N.* The relationship of gene polymorphism of Pit-1 with the productive characteristics of Holsteinized Black-Motley cattle // Genetics and Breeding of Animals, 2017, N 4, pp. 37–41.

Табл. 5. Продуктивность коров за 305 дней лактации с учетом генотипов по гену *Pit-1*

Table 5. Productivity of cows for 305 days of lactation taking into account genotypes for the *Pit1* gene

Genotype	*n*	Milk yield, kg	Fat, %	Protein, %	Fat, kg	Protein, kg
First lactation						
Pit-1^{AA}	11	6912,2 ± 3320,0	4,07 ± 0,11	3,22 ± 0,04	281,7 ± 14,9	223,2 ± 13,2
Pit-1^{AB}	43	6768,4 ± 173,8	4,05 ± 0,05	3,21 ± 0,02	274,7 ± 8,1	219,6 ± 6,3
Pit-1^{BB}	37	6476,9 ± 159,6	4,08 ± 0,06	3,18 ± 0,02	263,6 ± 6,9	207,3 ± 5,5
Second lactation						
Pit-1^{AA}	7	7944,6 ± 579,0	4,08 ± 0,07	3,27 ± 0,03	325,0 ± 26,2	275,3 ± 13,5
Pit-1^{AB}	29	7729,5 ± 226,3	4,05 ± 0,07	3,20 ± 0,02	314,0 ± 11,4	247,8 ± 7,9
Pit1^{BB}	19	7909,5 ± 315,8	4,12 ± 0,08	3,18 ± 0,02	324,2 ± 11,6	255,5 ± 10,6
Third lactation and older						
Pit-1^{AA}	11	7505,5 ± 278,5	4,30 ± 0,11	3,17 ± 0,03	321,6 ± 12,6	237,6 ± 8,6
Pit-1^{AB}	26	7426,7 ± 229,8	4,12 ± 0,07	3,16 ± 0,02	304,8 ± 9,3	235,2 ± 7,9
Pit-1^{BB}	18	7593,6 ± 428,7	4,13 ± 0,12	3,16 ± 0,03	320,5 ± 20,3	246,4 ± 15,3

CONCLUSION

The studies conducted showed that Black-and-White cows have good polymorphism of the *CSN3*, *BLG*, *TNF-α-824*, *SCD1*, *Pit-1* genes, which is a result of the selection process, breeding, and selection aimed at increasing milk productivity, fat, and protein content in cow's milk. It has been shown that in terms of genotype and allele frequencies, the Black-and-White breed is characterized by a fairly similar profile to other dairy breeds.

Given the functional role of SNPs in the manifestation of the phenotype, their relationship with productive traits is of interest. The identified associations of certain genotypes with milk yield, fat, and protein content can be used in further selection to increase its efficiency.

СПИСОК ЛИТЕРАТУРЫ

1. *Авадани Д.А., Шукюрова А.М., Кванская Т.А., Хорошилова Т.С., Гончаренко Г.М.* Популяционно-генетическая характеристика симментальской породы разного экогенеза по генам CSN3, BLG, PRL и TNF-α // Вестник КрасГАУ. 2023. № 12 (201). С. 190–198. DOI: 10.36718/1819-4036-2023-12-190-198.
2. *Глотова Г.Н., Позолотина В.А.* Действие аллельных вариантов гена CSN3 молока на его состав и физико-химические показатели при переработке творога // Вестник Рязанского государственного агротехнологического университета им. П.А. Костычева. 2021. Т. 13. № 2. С. 14–20. DOI: 10.36508/RSATU.2021.50.2.002.
3. *Панин В.А.* Оценка генотипа по генам CSN3 и LGB, влияющим на синтез молочного белка и жира в молоке симментальских коров // Известия Оренбургского государственного аграрного университета. 2020. № 1 (81). С. 197–201.
4. *Гильманов Х.Х., Тюлькин С.В., Ржанова И.В., Вафин Р.Р.* Характеристика быков-производителей с комплексными генотипами генов BLG и INOS по молочной продуктивности женских предков // Ученые записки Казанской академии ветеринарной медицины им. Н.Э. Баумана. 2020. Т. 241. № 1. С. 71–75. DOI: 10.31588/2413-4201-1883-241-1-71-76.
5. *Сафина Н.Ю., Фаттахова З.Ф. Гайнутдинова Э.Р., Шакиров Ш.К.* Экономические потери молока и выручка вследствие яловости коров с разными генотипами гена TNF-A // Ученые записки Казанской академии ветеринарной медицины им. Н.Э. Баумана. 2022. Т. 252. № 4. С. 216–221. DOI: 10.31588/2413_4201_1883_4_252_216.
6. *Калашникова Л.А., Багаль И.Е., Калашников В.Е.* Полиморфизм гена фактора некроза опухоли (TNF) у крупного рогатого скота холмогорской породы // Вестник Ошского государственного университета. Сельское хозяйство: агрономия, ветерина-

рия и зоотехния. 2023. № 4. С. 63–67. DOI: 10.52754/16948696_2023_4_9.

7. *Джаксыбаева Г.Г., Кочнев Н.Н., Кайниденов Н.Н.* Полиморфные варианты гена PIT-1 крупного рогатого скота симментальской и красной степной пород Республики Казахстан // Вестник НГАУ. 2023. № 3 (68). С. 167–175. DOI: 10.31677/2072-6724-2023-68-3-167-175.
8. *Liu R., Fang X., Lu X., Liu Y., Li Y., Bai X., Ding X., Yang R.* Polymorphisms of the SCD1 Gene and Its Association Analysis with Carcass, Meat Quality, Adipogenic Traits, Fatty Acid Composition, and Milk Production Traits in Cattle // Animals. 2024. Vol. 14 (12). P. 1759. DOI: 10.3390/ani14121759.
9. *Гайнутдинова Э.Р., Сафина Н.Ю., Зиннатова Ф.Ф., Шакиров Ш.К.* Связь полиморфизма гена PIT-1 (POU1F1) с признаками молочной продуктивности и воспроизводительной способности голштинского крупного рогатого скота // Достижения науки и техники АПК. 2019. Т. 33. № 11. С. 69–73. DOI: 10.24411/0235-2451-2019-11115.
10. *Ершов Р.О., Карамаева А.С., Карамаев С.В.* Продуктивные качества коров самарского типа черно-пестрой породы разных линий в зависимости от полиморфизма гена каппа-казеина // Известия Оренбургского государственного аграрного университета. 2023. № 2 (100). С. 276–281.
11. *Афанасьева А.И., Сарычев В.А.* Характеристика генетического профиля крупного рогатого скота черно-пестрой породы на основе ДНК-диагностики по генам каппа-казеина (CSN3), бета-лактоглобулина (BLG) альфа-лактальбумина (LALBA) и лептина (LEP) // Вестник Алтайского государственного аграрного университета. 2022. № 5 (211). С. 48–52. DOI: 10.53083/1996-4277-2022-211-5-48-52.
12. *Зиннатов Ф.Ф., Якупов Т.Р., Зиннатова Ф.Ф., Ахметов Т.М., Овсянников А.П., Чевтаева Н.Д.* Взаимосвязь генов LEP, TG5 и SCD1 с жирномолочностью коров // Ученые записки Казанской академии ветеринарной медицины им. Н.Э. Баумана. 2022. Т. 250. № 2. С. 85–92. DOI: 10.31588/2413_4201_1883_2_250_85.
13. *Герасимов Н.П., Елемесов Б.К., Сангаков А.К., Бельков Г.И., Дунин И.М.* Генотипическая и фенотипическая характеристика бычков герефордской и казахской белоголовой пород // Животноводство и кормопроизводство. 2025. Т. 250. № 2. С. 74–86. DOI: 10.33284/2658-3135-108-2-74.
14. *Шайдуллин Р.Р., Шарафутдинов Г.С., Москвичёва А.Б.* Белковомолочность в течение лактации у первотелок с разными генотипами CSN3 и DGAT1 // Достижения науки и техники АПК. 2019. Т. 33. № 5. С. 55–58. DOI: 10.24411/0235-2451-2019-10513.
15. *Лоретц О.Г., Чеченихина О.С., Ражина Е.В., Смирнова Е.С.* Каппа-казеин как один из факторов, влияющих на продуктивные качества коров // Молочнохозяйственный вестник. 2023. № 3 (51). С. 123–136. DOI: 10.52231/2225-4269_2023_3_123.
16. *Загидуллин Л.Р., Гилемханов И.Ю., Зарипов Р.У., Ахметов Т.М., Ламара М., Тюлькин С.В.* Оценка быков-производителей с разными генотипами генов соматотропинового каскада по молочной продуктивности и качеству молока ближайших женских предков // Ученые записки Казанской академии ветеринарной медицины им. Н.Э. Баумана. 2020. Т. 244. № 4. С. 86–91. DOI: 10.31588/2413-4201-1883-244-4-86-92.
17. *Михалюк А.Н., Танана Л.А.* Ассоциация комплекса полиморфных вариантов генов DGAT1, GH, PRL и BLG с показателями молочной продуктивности коров красной белорусской породной группы // Молекулярная и прикладная генетика. 2022. Т. 33. С. 109–118. DOI: 10.47612/1999-9127-2022-33-109-118.

REFERENCES

1. Avadani D.A., Shukyurova A.M., Kvanskaya T.A., KhoroshilovA T.S., Goncharenko G.M. Population-genetic characteristics of the Simmental breed of different ecogenesis by the CSN3, BLG, PRL AND TNF-α genes. *Vestnik KrasGAU = Bulletin of KrasSAU*, 2023, no. 12 (201), pp. 190–198. (In Russian). DOI: 10.36718/1819-4036-2023-12-190-198.
2. Glotova G.N., Pozolotina V.A. The effect of allelic variants of the CSN3 gene of milk on its composition and physico-chemical parameters in the production of cottage cheese. *Vestnik Ryazanskogo gosudarstvennogo agrotekhnologicheskogo universiteta im. P.A. Kostycheva = Herald of Ryazan State Agrotechnological University named after P. A. Kostychev*, 2021,

vol. 13, no. 2, pp. 14–20. (In Russian). DOI: 10.36508/RSATU.2021.50.2.002.

3. Panin V.A. The genotype assessment by the CSN3 and LGB GENES, affecting the synthesis of milk protein and fat in the milk of Simmental cows. *Izvestiya Orenburgskogo gosudarstvennogo agrarnogo universiteta = Izvestia Orenburg State Agrarian University,* 2020, no. 1 (81), pp. 197–201. (In Russian).
4. Gilmanov Kh.Kh., Tyulkin S.V., Rzhanova I.V., Vafin R.R. Characteristics of bull-producers with complex genotypes genes of BLG and INOS by milk productivity of female ancestors. *Uchenye zapiski Kazanskoi akademii veterinarnoi meditsiny im. N.E. Baumana = Scientific Notes of the Kazan Academy of Veterinary Medicine named after N.E. Bauman*, 2020, vol. 241, no. 1, pp. 71–75. (In Russian). DOI: 10.31588/2413-4201-1883-241-1-71-76.
5. Safina N.Yu., Fattakhova Z.F., Gaynutdinova E.R., Shakirov Sh.K. Economic milk losses and revenues due to barrenness cows with different genotypes of TNF-α gene. *Uchenye zapiski Kazanskoi akademii veterinarnoi meditsiny im. N.E. Baumana = Scientific notes of the Kazan Academy of Veterinary Medicine named after N.E. Bauman,* 2022, vol. 252, no. 4, pp. 216–221. (In Russian). DOI: 10.31588/2413_4201_1883_4_252_216.
6. Kalashnikova L.A., Bagal I.E., Kalashnikov V.E. Polymorphism of the tumor necrosis factor (TNF) gene in cattle of the Kholmogory breed. *Vestnik Oshskogo gosudarstvennogo universiteta. Sel'skoe khozyaistvo: agronomiya, veterinariya i zootekhniya = Journal of Osh State University. Agriculture: Agronomy, Veterinary and Zootechnics*, 2023, no. 4, pp. 63–67. (In Russian). DOI: 10.52754/16948696_2023_4_9.
7. Jaxybayeva G.G., Kochnev N.N., Kaynidenov N.N. Polymorphic variants of the PIT-1 gene in simmental and red steppe cattle of the Republic of Kazakhstan. *Vestnik NGAU = Bulletin of NSAU,* 2023, no. 3 (68), pp. 167–175. (In Russian). DOI: 10.31677/2072-6724-2023-68-3-167-175.
8. Liu R., Fang X., Lu X., Liu Y., Li Y., Bai X., Ding X., Yang R. Polymorphisms of the SCD1 Gene and Its Association Analysis with Carcass, Meat Quality, Adipogenic Traits, Fatty Acid Composition, and Milk Production Traits in Cattle. *Animals,* 2024, vol. 14 (12), p. 1759. DOI: 10.3390/ani14121759.
9. Gainutdinova E.R., Safina N.Yu., Zinnatova F.F., Shakirov Sh.K. Relationship between PIT-1 (POU1F1) gene polymorphism with milk productivity and reproductive capacity of Holstein cattle. *Dostizheniya nauki i tekhniki APK = Achievements of Science and Technology of AIC*, 2019, vol. 33, no. 11, pp. 69–73. (In Russian). DOI: 10.24411/0235-2451-2019-11115.
10. Ershov R.O., Karamaeva A.S., Karamaev S.V. Reproductive qualities of Samara-type cows of Black-and-White breed of different lines depending on polymorphism of the kappa-casein gene. *Izvestiya Orenburgskogo gosudarstvennogo agrarnogo universiteta = Izvestia Orenburg State Agrarian University,* 2023, no. 2 (100), pp. 276–281. (In Russian).
11. Afanasieva A.I., Sarychev V.A. Characteristics of black pied cattle genetic profile based on DNA diagnostics by kappa-casein (CSN3), beta-lactoglobulin (BLG), alpha-lactoalbumin (LALBA) and leptin (LEP) genes. *Vestnik Altaiskogo gosudarstvennogo agrarnogo universiteta = Bulletin of Altai State Agricultural University,* 2022, no. 5 (211), pp. 48–52. (In Russian). DOI: 10.53083/1996-4277-2022-211-5-48-52.
12. Zinnatov F.F., Yakupov T.R., Zinnatova F.F., Akhmetov T.M., Ovsyannikov A.P., Chevtaeva N.D. Relationship of LEP, TG5, and SCD1 genes with milk fat in cows. *Uchenye zapiski Kazanskoi akademii veterinarnoi meditsiny im. N.E. Baumana = Scientific notes of the Kazan Academy of Veterinary Medicine named after N.E. Bauman*, 2022, vol. 250, no. 2, pp. 85–92. (In Russian). DOI: 10.31588/2413_4201_1883_2_250_85.
13. Gerasimov N.P., Elemesov B.K., Sangakov A.K., Bel'kov G.I., Dunin I.M. Genetic and phenotypic characteristics of Hereford and Kazakh white-headed bulls. *Zhivotnovodstvo i kormoproizvodstvo = Animal Husbandry and Fodder Production,* 2025, vol. 250, no. 2, pp. 74–86. (In Russian). DOI: 10.33284/2658-3135-108-2-74.
14. Shaydullin R.R., Sharafutdinov G.S., Moskvicheva A.B. Protein content in the milk of first calf heifers of different *CSN3 AND DGAT1* genotypes during lactation. *Dostizheniya nauki i tekhniki APK = Achievements of Science and Technology of AIC,* 2019, vol. 33, no. 5, pp. 55–58. (In Russian). DOI: 10.24411/0235-2451-2019-10513.
15. Loretts O.G., Chechenikhina O.S., Razhina E.V.,

Smirnova E.S. Kappa-casein as one of the factors affecting productive qualities of cows. *Molochnokhozyaistvennyi vestnik = Dairy Farming Journal,* 2023, no. 3 (51), pp. 123–136. (In Russian). DOI: 10.52231/2225-4269_2023_3_123.

16. Zagidullin L.R., Gilemkhanov I.Yu., Zaripov R.U., Akhmetov T.M., Lamara M., Tyul'kiin S.V. Evaluation of breeding bulls with different genotypes of somatotropin cascade genes for milk productivity and milk quality of the closest female ancestors. *Uchenye zapiski Kazanskoi akademii veterinarnoi meditsiny im. N.E. Baumana = Scientific notes of the Kazan Academy of Veterinary Medicine named after N.E. Bauman*, 2020, vol. 244, no. 4, pp. 86–91. (In Russian). DOI: 10.31588/2413-4201-1883-244-4-86-92.
17. Mikhaliuk A.N., Tanana L.A. Association between the complex of polymorphic variants of DGAT1, GH, PRL and BLG genes and milk yield indicators of the cows of the Belarusian Red breed group. *Molekulyarnaya i prikladnaya genetika = Molecular and Applied Genetics*, 2022, vol. 33, pp. 109–118. (In Russian). DOI: 10.47612/1999-9127-2022-33-109-118.

ИНФОРМАЦИЯ ОБ АВТОРАХ

Авадани Диана Александровна, младший научный сотрудник; SPIN-код 1051-7053

(✉)**Гончаренко Галина Моисеевна,** главный научный сотрудник, доктор биологических наук; SPIN-код 7129-7759; **адрес для переписки:** Россия, 630501, Новосибирская область, р.п. Краснообск, ул. Центральная, 2Б; e-mail: gal.goncharenko@mail.ru

Хорошилова Татьяна Сергеевна, старший научный сотрудник, кандидат биологических наук; SPIN-код 6629-8399

Гришина Наталья Борисовна, старший научный сотрудник, кандидат биологических наук; SPIN-код 4803-4208

Халина Ольга Леонидовна, научный сотрудник; SPIN-код 2829-6687

AUTHOR INFORMATION

Diana A. Avadani, Junior Researcher; SPIN-code 1051-7053

(✉)**Galina M. Goncharenko,** Head Researcher, Doctor of Science in Biology; SPIN-code 7129-7759; **address:** 2B, Tsentralnaya St., Krasnoobsk, Novosibirsk Region, 630501, Russia; e-mail: gal.goncharenko@mail.ru

Tatiana S. Khoroshilova, Senior Researcher, Candidate of Science in Biology; SPIN-code 6629-8399

Natalia B. Grishina, Senior Researcher, Candidate of Science in Biology; SPIN-code 4803-4208

Olga L. Khalina, Researcher; SPIN-code 2829-6687

Дата поступления статьи / Received by the editors 07.10.2025
Дата принятия к публикации / Accepted for publication 11.11.2025
Дата публикации / Published 19.12.2025

https://doi.org/10.26898/0370-8799-2025-12-9
УДК 619:577.2:636.2:001.608.1
Тип статьи: обзорная
Type of article: review

Молекулярно-генетический мониторинг наследственных аномалий у крупного рогатого скота: гипотрихоз, идиопатическая эпилепсия и дилютор-фенотип (обзор)

Безбородова Н.А., Соколова О.В., Мартынов Н.А., Зверев А.В., (✉)Романов Е.В., Юсупова Ч.Р.
Уральский федеральный аграрный научно-исследовательский центр Уральского отделения Российской академии наук
Екатеринбург, Россия
(✉)e-mail: romanov.egor.2303@gmail.com

Статья посвящена актуальной проблеме снижения репродуктивной функции у крупного рогатого скота герефордской и казахской белоголовой пород, что оказывает значительное влияние на экономические показатели животноводства. Основное внимание уделено трем ключевым генетическим нарушениям: гипотрихоз (HY), идиопатическая эпилепсия (IE) и дилютор-фенотип (DL), которые существенно снижают продуктивность и воспроизводительные способности животных. Подробно рассматриваются молекулярно-генетические механизмы каждого из нарушений. Для гипотрихоза выявлены ключевые гены, ответственные за развитие шерстного покрова (*MC1R*, *PMEL*, *KRT71*). В случае идиопатической эпилепсии основное внимание уделено мутациям в гене *DYRK1B*, влияющим на неврологические функции. Дилютор-фенотип, проявляющийся в ослаблении пигментации, преимущественно связан с мутацией в гене *PMEL* (p.Leu18del). Установлено, что гипотрихоз, обусловленный мутациями в генах *KRT71* и *LYN*, имеет низкую распространенность в российской популяции абердин-ангусов (0,02%), но высокую – среди уругвайских герефордов (41,2%). Данные о распространенности идиопатической эпилепсии у герефордов и представителей казахской белоголовой породы отсутствуют. Дилютор-фенотип, ассоциированный преимущественно с мутациями в гене *PMEL*, выявлен у герефордов. Установлено, что данное генетическое нарушение оказывает плейотропное влияние, улучшая качество мяса, но повышая чувствительность животных к солнечной радиации. Современные методы геномного анализа (ПЦР, секвенирование, GWAS) позволяют эффективно выявлять носителей генетических аномалий. Перспективным направлением является использование геномного редактирования (CRISPR-Cas9) для создания адаптированных к различным климатическим условиям линий скота без потери продуктивности. Создание систем генетического мониторинга и селекции на основе ДНК-тестирования необходимо для минимизации экономических потерь и повышения эффективности племенной работы. Особое внимание уделяется необходимости контроля импортируемого племенного материала и разработке стратегий управления генетическими рисками.

Ключевые слова: крупный рогатый скот, генетические дефекты, гипотрихоз, идиопатическая эпилепсия, дилютор-фенотип, герефордская порода, казахская белоголовая порода, ген *DYRK1B*, ген *PMEL*, ген *KRT71*, молекулярная диагностика, ПЦР-генотипирование, секвенирование, селекционный контроль

Molecular genetic monitoring of hereditary abnormalities in cattle: hypotrichosis, idiopathic epilepsy and dilutor phenotype (review)

Bezborodova N.A., Sokolova O.V., Martynov N.A., Zverev A.V., (✉)Romanov E.V., Yusupova Ch.R.
Ural Federal Agrarian Research Center of the Ural Branch of the Russian Academy of Sciences
Yekaterinburg, Russia
(✉)e-mail: romanov.egor.2303@gmail.com

The article describes the urgent problem of reducing reproductive function in cattle of the Hereford and Kazakh white-headed breeds, which has a significant impact on the economic performance of animal husbandry. The main attention is paid to three key genetic disorders: hypotrichosis (HY), idiopathic epilepsy (IE) and dilutor phenotype (DL), which significantly reduce productivity and re-

productive abilities of animals. The materials discuss in detail the molecular and genetic mechanisms of each of the disorders. Key genes (*MC1R*, *PMEL*, *KRT71*) responsible for the development of the coat have been identified for hypotrichosis. In the case of idiopathic epilepsy, the focus is on mutations in the *DYRK1B* gene that affect neurological functions. The dilutor phenotype, which manifests itself in a decrease in pigmentation, is mainly associated with the *PMEL* mutation (p.Leu18del). It has been established that hypotrichosis associated with mutations in the *KRT71* and *LYN* genes has a low prevalence in Russian Aberdeen-Angus populations (0.02%), but a high prevalence in Uruguayan Herefords (41.2%). There is no data on the prevalence of IE in Herefords and Kazakh white-headed breeds. Dilutor-phenotype, associated mainly with mutations in the *PMEL* gene, was identified in Hereford cattle. It has been established that this genetic disorder has a pleiotropic effect, improving the quality of meat, but increasing the sensitivity of animals to solar radiation. Modern methods of genomic analysis (PCR, sequencing, GWAS) allow for the effective detection of carriers of abnormalities. A promising approach is the use of genomic editing (CRISPR-Cas9) to create climate-adapted cattle lines without compromising productivity. The development of genetic monitoring and selection systems based on DNA testing is necessary to minimize economic losses and increase the efficiency of breeding work. Special attention is paid to the need to control imported breeding material and develop strategies for managing genetic risks.

Keywords: cattle, genetic defects, idiopathic epilepsy, hypotrichosis, dilutor phenotype, Hereford breed, Kazakh white-headed breed, *DYRK1B* gene, *PMEL* gene, *KRT71* gene, molecular diagnostics, PCR genotyping, sequencing, breeding control

Для цитирования: *Безбородова Н.А., Соколова О.В., Мартынов Н.А., Зверев А.В., Романов Е.В., Юсупова Ч.Р.* Молекулярно-генетический мониторинг наследственных аномалий у крупного рогатого скота: гипотрихоз, идиопатическая эпилепсия и дилютор-фенотип (обзор) // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 12. С. 86–93. https://doi.org/10.26898/0370-8799-2025-12-9

For citation: Bezborodova N.A., Sokolova O.V., Martynov N.A., Zverev A.V., Romanov E.V., Yusupova Ch.R. Molecular genetic monitoring of hereditary abnormalities in cattle: hypotrichosis, idiopathic epilepsy and dilutor phenotype (review). *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 12, pp. 86–93. https://doi.org/10.26898/0370-8799-2025-12-9

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 № 0532-2025-0003 «Разработка высокоточных методов идентификации генетических детерминант устойчивости к заболеваниям для использования в селекции крупного рогатого скота».
Acknowledgements
The work was carried out as part of the state assignment of the Ministry of Science and Higher Education of the Russian Federation No. 0532-2025-0003 "Development of high-precision methods for identifying genetic determinants of disease resistance for use in cattle breeding".

INTRODUCTION

The decline in reproductive performance of farm animals has an adverse effect on the economic efficiency of the industry. In recent decades, there has been a steady deterioration in the natural reproductive capacity of cattle, both dairy and beef. This trend is due to the following key factors: intensive selection for productive traits that have negative genetic correlations with fertility indicators; accumulation of inbreeding depression in populations; spread of hereditary reproductive anomalies[1] [1].

Currently, there is a shift in priorities in breeding practice: increasing attention is being paid to the balance between productive and reproductive traits. The development of modern

[1]*Dunin I.M., Butusov D.V., Shichkin G.I.* The state of beef cattle breeding in the Russian Federation // Yearbook on breeding work in beef cattle farms of the Russian Federation (2019), Moscow, 2020, pp. 3–16.

technologies, such as high-density genotyping, whole-genome analysis, and molecular genetic screening, makes it possible to carry out comprehensive selection that takes into account not only economically useful traits but also genetic markers of fertility, including recessive alleles associated with reproductive function disorders[2] [2].

Recessive lethal alleles are one of the causes of reduced reproductive efficiency in cattle of various breeds, since these genetic disorders lead to embryonic death if the embryo is homozygous. They can also cause reduced survival of embryos and live-born animals when their effect is not fully expressed (incomplete penetrance), which may manifest as a lower conception rate, longer calving intervals, or reduced survival of born calves[3] [3].

The frequency of recessive lethal alleles in a population is generally quite low. However, in the absence of control, the number of homozygous cases among embryos increases, causing significant economic damage. The reasons for the increase in the frequency of recessive alleles in a cattle population can be genetic drift, linkage with favorable alleles, and heterozygote advantage[4] [4]. A recessive lethal allele indicates a heterozygote advantage if it has a positive pleiotropic effect on productive traits, thereby providing an advantage to heterozygous carriers rather than homozygous embryos. This would lead to the selection of heterozygous carriers as parents of the next generation, the spread of the recessive lethal allele throughout the population, and consequently, a significant impact on reproduction[5-7] [3]. This phenomenon is called 'genetic hitchhiking,' when lethal alleles are maintained in a population due to the selective advantage of heterozygous carriers. The described problem requires the development of special genetic management strategies in animal breeding [3, 5].

MAIN BODY

The following is an overview of the available scientific literature on the results of the studies of hypotrichosis, idiopathic epilepsy, and dilutor, which are the most significant genetic disorders identified in Hereford and Kazakh White-headed breeds of cattle, as well as in crossbred animals.

Hypotrichosis, HY, is a hereditary disease characterized by abnormal development of the hair coat of animals (sparse, brittle, or absent hair). In cattle, it is associated with mutations in several genes affecting pigmentation (*MC1R*, *PMEL*) and hair shaft structure (*KRT71*). Hypotrichosis is inherited in an autosomal recessive manner [5].

Melanocortin 1 receptor (alpha-melanocyte-stimulating hormone receptor) (*MC1R*) was the first gene studied in relation to coat color in cattle. Since this gene has only one exon, its complete coding sequence can be obtained from a continuous fragment of genomic DNA. A premature stop codon (p.Tyr155*) leads to the production of only pheomelanin in the organism of homozygous cattle[8]. Earlier, scientists suggested that cattle with at least one ED

[2]*Zimina A.A., Romanenkova O.S.* Genetic anomalies of Holsteinized Simmentals // Genetics, Breeding, Biotechnology: Integration of Science and Practice in Animal Husbandry: Proceedings of the International Scientific and Practical Conference, Pushkin, 2021, pp. 58–59.

[3]*Cole J.B., Van Raden P.M., O'Connell J.R., Van Tassell C.P., Sonstegard T.S., Schnabel R.D., Taylor J.F., Wiggans G.R.* Discovery of mutations for recessive lethal genetic defects in cattle using a haplotype-based approach // Journal of Animal Science, 2016, vol. 94, N 1, pp. 21–31.

[4]*Adams H.A., Sonstegard T.S., Van Raden P.M., Null D.J., Van Tassell C.P., Larkin D.M., Lewin H.A.* Identification of a nonsense mutation in APAF1 that causes calf death and neonatal loss in cattle // BMC Genomics, 2016, vol. 17, N 542, p. 12.

[5]*Mc Clure M.C., Bickhart D., Null D., Van Raden P., Xu L., Wiggans G., Liu G., Schroeder S., Glasscock J., Armstrong J., Cole J.B., Van Tassell C.P., Sonstegard T.S.* Bovine exome sequence analysis and targeted SNP genotyping of recessive fertility defects BH1, HH2, and HH3 reveal a putative causative mutation in SMC2 for HH3 // Proceedings of the National Academy of Sciences, 2014, vol. 111, N 19, pp. 7103–7108.

[6]*Brenneman R.A., Sanders J.O., Davis S.K., Burns B.M.* MC1R and coat defects in cattle // Journal of Animal Science, 2016, vol. 94, N 5, pp. 789–800.

[7]*Konovalova E.N., Selionova M.I., Romanenkova O.S., Evstafieva L.V.* Genetic assessment of the Russian population of beef cattle breeds // Genetic resources of animal husbandry and crop production: state and prospects in the field of agriculture: collection of scientific papers of the International Scientific-Practical Conference (Makhachkala, November 3–4, 2022), Makhachkala: ALEF, 2022, pp. 17–25.

[8]*Hauser M., Wolf-Hofstetter S., Acklin-Menzi F., Studer E., Rediger D., Seefried F., Drögemüller C.* Grey, curly and short-haired Swiss Holstein cattle show genetic traces of the Simmental breed // SAT, 2020, vol. 162 (9), pp. 551–559.

(p.99Pro) allele could have only eumelanin hair pigmentation. However, the interaction of this gene with *DEFB103* allows Holstein individuals with the ED/ genotype to have red hair color and a phenotype indistinguishable from the phenotype of individuals with the e/e genotype[9]. Cattle carrying the e+ allele or the wild-type allele are capable of producing either eumelanin or pheomelanin. Other variants in *MC1R* have also been reported, none of which are associated with phenotypic changes in coat color[10].

The presence of a mutation in the *PMEL* gene (p.Leu18del) is associated with the diluter phenotype and is not a direct cause of hypotrichosis. However, in some cases, these traits may appear together due to the peculiarities of melanogenesis and hair follicle development (especially in homozygous individuals) (see footnote 6) [6–8].

A mutation in the *LYN* gene (locus on the 23rd chromosome), which is involved in the development of hair follicles[11], is the cause of hypotrichosis. This gene encodes a specific hair follicle protein K71, which participates in the formation of structurally important keratin intermediate filaments in the inner root sheath of the hair follicle [7]. Affected calves are born with partial or complete absence of hair, especially on the head, neck, and torso. Heterozygous individuals are carriers but are phenotypically healthy [9].

Modern methods for diagnosing hypotrichosis: PCR, sequencing, genotyping, mutation analysis. Within the framework of studies described in the scientific literature aimed at the study of hypotrichosis, DNA extraction was carried out from blood and sperm samples of animals [9].

In the study by E.N. Konovalova et al., conducted in 2017–2022, it was shown that among 1,948 heads of Russian beef cattle (nine populations of the Aberdeen Angus breed), the frequency of hypotrichosis was 0.02%. This indicates a low level of prevalence of this anomaly in the studied herds, but confirms its presence in the Russian population. The work emphasizes the importance of genetic monitoring for controlling hereditary diseases (see footnote 11).

J. Viera [10], in the course of a genetic study of the Hereford cattle population in Uruguay, identified a nonsense mutation c.658C>T in the *KRT71* gene, which is the cause of the autosomal recessive form of hypotrichosis. Analysis of 34 animals revealed seven homozygous individuals with clinical manifestations and 14 heterozygous carriers, indicating a high prevalence of the allele in the studied population (41.2%). During the study, pedigree analysis, sequencing, and PCR-based genotyping were performed. The obtained data emphasize the need for genetic monitoring during international exchange of breeding material.

Idiopathic epilepsy, IE, is a group of genetically determined neurological disorders with non-epileptic paroxysms, characterized by spontaneous recurrent seizures and associated with a mutation in the DYRK1B gene. Epilepsy can be divided into idiopathic (genetic) and structural [11].

The affected *DYRK1B* gene encodes the dual-specificity tyrosine-phosphorylation-regulated kinase 1B protein, which has both serine/threonine and tyrosine kinase activity and plays a crucial role in the repair of double-stranded rDNA breaks and in maintaining its copy number [12]. DNA damage and repair is a continuous process necessary for maintaining genomic integrity. Double-strand break repair is important for post-mitotic, non-dividing, long-lived cells of the central nervous system. A reduction in these mechanisms leads to disruption of neural networks due to the loss of neuronal populations. Thus, they impair vital motor functions [11, 12].

[9]*Dreger D.L., Schmutz S.M.* The variant red coat colour phenotype of Holstein cattle maps to BTA27 // Animal Genet., 2010, vol. 41 (1), pp. 109–112.

[10]*Schmutz S.M., Dreger D.L.* Interaction of MC1R and PMEL alleles on solid coat colors in Highland cattle // Animal Genet., 2013, vol. 44 (1), pp. 9–13.

[11]*Konovalova E.N., Romanenkova O.S., Zimina A.A., Sermyagin A.A.* Strategies for Genetic Improvement of Beef Cattle Breeds // Animal Genomics and Biotechnology: Proceedings of the International Scientific and Practical Conference within the implementation of the program "Priority – 2030" (Makhachkala, December 23, 2021). Makhachkala, 2021, pp. 69–75.

Methods used in the study of epilepsy: sequencing and genotyping. DNA extraction for these studies is carried out by standard methods from blood samples with EDTA (see footnote 11) [5].

At present, there is no information in the international scientific literature on the confirmed cases of idiopathic epilepsy associated with a mutation in the *DYRK1B* gene in representatives of the Hereford breed of cattle.

Dilutor, DL, is the dilution of pigmentation of the hair and skin in cattle, which can be caused by various genetic mutations**.** Identified genes associated with the dilutor are the following: *PMEL* (*SILV*) – the main gene marker, *MITF* – regulatory gene, *TYRP1* – melanogenesis structural gene, *ASIP* – pigmentation gene inhibitor. The following mutations and molecular changes may be observed in the listed genes: *PMEL* – TGG deletion (p.Leu18del), *MITF* – regulatory polymorphisms, *TYRP1* – missense mutations, *ASIP* – promoter variations. *PMEL* carries a disruption in the formation of melanosomes, *MITF* – reduction of expression of melanogenic genes, *TYRP1* causes defects in eumelanin synthesis, *ASIP* – melanin suppression. The mutation is common among the representatives of the Hereford (by the gene *PMEL* – 10–18%, international populations) and Kazakh White-headed breed (by the gene *MITF* – 1–8%, regional lines). DL phenotype in the Hereford and Kazakh White-headed breeds requires monitoring due to risks to animal health. The optimal strategy is genetic testing and careful mate selection [13–16].

In the study by S. Kimura et al. [14], the analysis of data from 522 heads of Japanese Brown cattle of the Kumamoto subbreed revealed the presence of the p.Leu18del deletion in the *PMEL* gene in 277 animals (53.1%), of which 81 individuals (15.5%) were homozygous (del/del), and 196 individuals (37.5%) were heterozygous (del/wt). The overall frequency of the recessive allele in the population was 34.2%. Along with pigmentation changes, the mutation under consideration significantly improves key meat quality indicators: marbling, color, firmness, and texture. The results obtained demonstrate the pleiotropic effect of the mutation and confirm the promising potential of using this allele in breeding programs to simultaneously improve the exterior and productive qualities of cattle.

A 1776 study of Reggiana cattle revealed the genetic basis of the breed's key traits. The intensity of red coat color is controlled by the *PMEL* (lightening) and *EDN3* (darkening) genes. The face color is determined by the *MC1R* gene, and the brindledness by the *KIT* gene. Growth is associated with the *NCAPG–LCORL* region on BTA6. Nipple defects are related to *TBX3*/*TBX5*, *MCC* and *LGR5* genes. This scientific work demonstrates the value of genomic methods for the selection and conservation of local breeds, and the possibility of targeted improvement of economically important traits based on the DNA. [15].

J. Wang et al. [16], based on the results of a genome-wide association study (GWAS), identified a significant effect of the *PMEL* gene on phenotypic traits in Simmental-Holstein cattle. The following patterns were established: black-and-white coloration corresponds to the homozygous genotype for the *PMEL* mutation, gray-and-white coloration is associated with the heterozygous state, and heterozygous individuals demonstrate a significantly higher birth weight (42.58 ± 3.09 kg) compared to homozygous individuals, with the maximum weight observed in gray-and-white calves (49.40 ± 7.11 kg). The obtained results indicate a pleiotropic effect of the *PMEL* gene, affecting both pigmentation and animal growth. The study data are significant for the development of breeding programs aimed at improving the productive qualities of livestock.

In one study, scientists successfully applied CRISPR-Cas9 technology to introduce the p.Leu18del mutation into the *PMEL* gene in Holstein breed embryos. As a result, calves with a consistently lightened coat color were obtained, inheriting the modified trait. Key results: preservation of productive qualities and reproductive function, demonstration of trait inheritance in the next generation. This work opens up prospects for creating breeds with increased resistance to heat stress without loss of produc-

tivity. The method used can be adapted for other types of farm animals [17].

CONCLUSION

Further research in the field of the development of diagnostic systems will allow more effective identification of the carriers of genetic defects and their exclusion from breeding. A comprehensive approach to genetic monitoring will help minimize economic losses and increase the efficiency of breeding work in domestic animal husbandry. Special attention should also be paid to the creation of a system of genetic audit of breeding livestock and the development of a regulatory framework governing genetic control in animal husbandry [9, 18, 19].

СПИСОК ЛИТЕРАТУРЫ

1. *Bytov M.V., Zubareva V.D., Volskaya S.V.* Assessing the Genetic Diversity of Five Cattle Breeds Using SNP Markers Associated with Health // Russian Journal of Genetics. 2024. Vol. 60. N 6. P. 747–753. DOI: 10.1134/s1022795424700182.
2. *Jenko J., Mc Clure M.C., Matthews D.* Analysis of a large dataset reveals haplotypes carrying putatively recessive lethal and semi-lethal alleles with pleiotropic effects on economically important traits in beef cattle // Genetics Selection Evolution. 2019. Vol. 51. P. 9.
3. *Van Raden P.M., Tooker M.E., O'Connell J.R., Cole J.B., Bickhart D.M.* Selecting sequence variants to improve genomic predictions for dairy cattle // Genetics Selection Evolution. 2019. Vol. 51. P. 12.
4. *Бытов М.В., Соколова О.В., Безбородова Н.А.* Методы генотипирования крупного рогатого скота для post-GWAS аннотирования SNPs // Аграрный вестник Урала. 2023. Т. 23. № 6. С. 67–75. DOI: 10.32417/1997-4868-2023-235-06-67-75.
5. *Федоренко В.Ф., Мишуров Н.П., Кузьмина Т.Н., Тихомиров А.И.* Анализ состояния и перспективы улучшения генетического потенциала крупного рогатого скота специализированных мясных пород отечественной селекции: монография. М., 2019. 80 с.
6. *Drögemüller C., Philipp U., Haase B., Günzel-Apel A.-R., Leeb T.* KRT71-related hypotrichosis in Dexter cattle // PLoS Genetics. 2018. Vol. 14 (3). P. e1007287. DOI: 10.1371/journal.pgen.1007287.
7. *Jacinto J.G.P., Markey A.D., Veiga I.M.B., Paris J.M., Welle M., Beever J.E., Drögemüller C.* A KRT71 Loss-of-Function Variant Results in Inner Root Sheath Dysplasia and Recessive Congenital Hypotrichosis of Hereford Cattle // Genes (Basel). 2021. N 12 (7). P. 1038. DOI: 10.3390/genes12071038.
8. *Romero-Benavente A., Briano-Rodriguez C., Dutra Quintela F.* Hypotrichosis congenita (KRT71 mutation) in Hereford cattle in Uruguay // Pesquisa Veterinária Brasileira. 2023. Vol. 43. DOI: 10.1590/1678-5150-pvb-7327.
9. *Столповский Ю.А., Кузнецов С.Б., Солоднева Е.В., Шумов И.Д.* Новая система генотипирования крупного рогатого скота на основе технологии ДНК-микрочипов // Генетика. 2022. Т. 58. № 8. С. 857–871. DOI: 10.31857/S0016675822080094.
10. *Viera J.* Identification of KRT71 mutation in Hereford cattle with hypotrichosis in Uruguay // Genes. 2021. Vol. 12 (7). P. 1038.
11. *Kinsey N., Belanger J.M., Mandigers P.J.J.* Idiopathic Epilepsy Risk Allele Trends in Belgian Tervuren: A Longitudinal Genetic Analysis // Genes. 2024. Vol. 15 (1). P. 114. DOI: 10.3390/genes15010114.
12. *Charalambous M., Fischer A., Potschka H., Walker M.C., Raedt R., Vonck K., Boon P., Lohi H., Löscher W., Worrell G., Leeb T., Mc Evoy A., Striano P., Kluger G., Galanopoulou A.S., Volk H.A., Bhatti S.F.M.* Translational veterinary epilepsy: A win-win situation for human and veterinary neurology // Veterinary Journal. 2023. N 293. P. 105956. DOI: 10.1016/j.tvjl.2023.105956.
13. *Jacinto J.G.P., Bolcato M., Häfliger I.M., Oevermann A., Gentile A., Drögemüller C.* DYRK1B haploinsufficiency in a Holstein cattle with epilepsy // Animal Genetics. 2023. Vol. 54. P. 623–627. DOI: 10.1111/age.13348.
14. *Kimura S., Hatakeyama T., Koutaka T., Kubo K., Morita S., Eguchi K., Saitoh K., Yamauchi K., Imai S., Kashimura A., Inenaga T., Matsumoto H.* PMEL p.Leu18del dilutes coat color of Kumamoto sub-breed of Japanese Brown cattle // BMC Genomics. 2022. N 23. P. 694. DOI: 10.1186/s12864-022-08916-8.
15. *Bovo S., Schiavo G., Kazemi H., Moscatelli G., Ribani A., Ballan M., Bonacini M., Prandi M., Dall'Olio S., Fontanesi L.* Exploiting within-breed variability in the autochthonous Reggiana breed identified several candidate genes affecting pigmentation-related traits, stature and udder defects in cattle // Animal Genetics. 2021. Vol. 52. P. 579–597. DOI: 10.1111/age.13109.
16. *Wang J., Fan T., Du Z., Xu L., Chen Y., Zhang L., Gao H., Li J., Ma Y., Gao X.* Genome-wide association analysis identifies the PMEL gene affec-

ting coat color and birth weight in Simmental × Holstein // Animals (Basel). 2023. N 13. P. 3821. DOI: 10.3390/ani13243821.
17. *Wei J., Brophy B., Cole S.A., Leath S., Oback B., Boch J., Wells D.N., Laible G.* Production of light-coloured, low heat-absorbing Holstein Friesian cattle by precise embryo-mediated genome editing // Reproduction, Fertility and Development. 2023. N 36. P. 112–123. DOI: 10.1071/RD23163.
18. *Laible G., Cole S.A., Brophy B., Wei J., Leath S., Jivanji S., Littlejohn M.D., Wells D.N.* Holstein Friesian dairy cattle edited for diluted coat color as a potential adaptation to climate change // BMC Genomics. 2021. N 22. P. 856. DOI: 10.1186/s12864-021-08175-z.
19. *Knaust J., Weikard R., Albrecht E., Brunner R.M., Günther J., Kühn C.* Indication of premelanosome protein (PMEL) expression outside of pigmented bovine skin suggests functions beyond eumelanogenesis // Genes (Basel). 2020. Vol. 11. P. 788. DOI: 10.3390/genes11070788.

REFERENCES

1. Bytov M.V., Zubareva V.D., Volskaya S.V. Assessing the Genetic Diversity of Five Cattle Breeds Using SNP Markers Associated with Health. *Russian Journal of Genetics*, 2024, vol. 60, no. 6, pp. 747–753. DOI: 10.1134/s1022795424700182.
2. Jenko J., Mc Clure M.C., Matthews D. Analysis of a large dataset reveals haplotypes carrying putatively recessive lethal and semi-lethal alleles with pleiotropic effects on economically important traits in beef cattle. *Genetics Selection Evolution*, 2019, vol. 51, p. 9.
3. Van Raden P.M., Tooker M.E., O'Connell J.R., Cole J.B., Bickhart D.M. Selecting sequence variants to improve genomic predictions for dairy cattle. *Genetics Selection Evolution*, 2019, vol. 51, p. 12.
4. Bytov M.V., Sokolova O.V., Bezborodova N.A. Cattle genotyping methods for post-GWAS annotation of SNPs. *Agrarniy vestnik Urala = Agrarian Bulletin of the Urals*, 2023, vol. 23, no. 6, pp. 67–75. (In Russian). DOI: 10.32417/1997-4868-2023-235-06-67-75.
5. Fedorenko V.F., Mishurov N.P., Kuzmina T.N., Tikhomirov A.I. *Analysis of the state and prospects of improving the genetic potential of cattle of specialized meat breeds of domestic breeding*. Moscow, 2019, 80 p. (In Russian).
6. Drögemüller C., Philipp U., Haase B., Günzel-Apel A.-R., Leeb T. KRT71-related hypotrichosis in Dexter cattle. *PLoS Genetics*, 2018, vol. 14 (3), p. e1007287. DOI: 10.1371/journal.pgen.1007287.
7. Jacinto J.G.P., Markey A.D., Veiga I.M.B., Paris J.M., Welle M., Beever J.E., Drögemüller C. A KRT71 Loss-of-Function Variant Results in Inner Root Sheath Dysplasia and Recessive Congenital Hypotrichosis of Hereford Cattle. *Genes* (*Basel*), 2021, no. 12 (7), p. 1038. DOI: 10.3390/genes12071038.
8. Romero-Benavente A., Briano-Rodriguez C., Dutra Quintela F. Hypotrichosis congenita (KRT71 mutation) in Hereford cattle in Uruguay. *Pesquisa Veterinária Brasileira*, 2023, vol. 43. DOI: 10.1590/1678-5150-pvb-7327.
9. Stolpovsky Yu.A., Kuznetsov S.B., Solodneva E.V., Shumov I.D. New cattle genotyping system based on DNA microarray technology. *Genetika = Genetics*, 2022, vol. 58, no. 8. pp. 857–871. (In Russian). DOI: 10.31857/S0016675822080094.
10. Viera J. Identification of KRT71 mutation in Hereford cattle with hypotrichosis in Uruguay. *Genes*, 2021, vol. 12 (7), p. 1038.
11. Kinsey N., Belanger J.M., Mandigers P.J.J. Idiopathic Epilepsy Risk Allele Trends in Belgian Tervuren: A Longitudinal Genetic Analysis. *Genes*, 2024, vol. 15 (1), p. 114. DOI: 10.3390/genes15010114.
12. Charalambous M., Fischer A., Potschka H., Walker M.C., Raedt R., Vonck K., Boon P., Lohi H., Löscher W., Worrell G., Leeb T., Mc Evoy A., Striano P., Kluger G., Galanopoulou A.S., Volk H.A., Bhatti S.F.M. Translational veterinary epilepsy: A win-win situation for human and veterinary neurology. *Veterinary Journal*, 2023, no. 293, p. 105956. DOI: 10.1016/j.tvjl.2023.105956.
13. Jacinto J.G.P., Bolcato M., Häfliger I.M., Oevermann A., Gentile A., Drögemüller C. DYRK1B haploinsufficiency in a Holstein cattle with epilepsy. *Animal Genetics*, 2023, vol. 54, pp. 623–627. DOI: 10.1111/age.13348.
14. Kimura S., Hatakeyama T., Koutaka T., Kubo K., Morita S., Eguchi K., Saitoh K., Yamauchi K., Imai S., Kashimura A., Inenaga T., Matsumoto H. PMEL p.Leu18del dilutes coat color of Kumamoto sub-breed of Japanese Brown cattle. *BMC Genomics*, 2022, no. 23, p. 694. DOI: 10.1186/s12864-022-08916-8.

15. Bovo S., Schiavo G., Kazemi H., Moscatelli G., Ribani A., Ballan M., Bonacini M., Prandi M., Dall'Olio S., Fontanesi L. Exploiting within-breed variability in the autochthonous Reggiana breed identified several candidate genes affecting pigmentation-related traits, stature and udder defects in cattle. *Animal Genetics*, 2021, vol. 52, pp. 579–597. DOI: 10.1111/age.13109.
16. Wang J., Fan T., Du Z., Xu L., Chen Y., Zhang L., Gao H., Li J., Ma Y., Gao X. Genome-wide association analysis identifies the PMEL gene affecting coat color and birth weight in Simmental × Holstein. *Animals* (*Basel*), 2023, no. 13, p. 3821. DOI: 10.3390/ani13243821.
17. Wei J., Brophy B., Cole S.A., Leath S., Oback B., Boch J., Wells D.N., Laible G. Production of light-coloured, low heat-absorbing Holstein Friesian cattle by precise embryo-mediated genome editing. *Reproduction, Fertility and Development*, 2023, no. 36, pp. 112–123. DOI: 10.1071/RD23163.
18. Laible G., Cole S.A., Brophy B., Wei J., Leath S., Jivanji S., Littlejohn M.D., Wells D.N. Holstein Friesian dairy cattle edited for diluted coat color as a potential adaptation to climate change. *BMC Genomics*, 2021, no. 22, p. 856. DOI: 10.1186/s12864-021-08175-z.
19. Knaust J., Weikard R., Albrecht E., Brunner R.M., Günther J., Kühn C. Indication of premelanosome protein (PMEL) expression outside of pigmented bovine skin suggests functions beyond eumelanogenesis. *Genes* (*Basel*), 2020, vol. 11, p. 788. DOI: 10.3390/genes11070788.

ИНФОРМАЦИЯ ОБ АВТОРАХ

Безбородова Наталья Александровна, старший научный сотрудник, кандидат ветеринарных наук; SPIN-код 7012-0999, ORCID 0000-0003-2793-5001

Соколова Ольга Васильевна, ведущий научный сотрудник, доктор ветеринарных наук; SPIN-код 7437-2300, ORCID 0000-0002-1169-4090

Мартынов Николай Александрович, лаборант; SPIN-код 7332-1403, ORCID 0000-0001-9251-0056

Зверев Анатолий Валерьевич, лаборант-исследователь; SPIN-код 6187-6175, ORCID 0009-0009-9408-8106

(✉) **Романов Егор Владимирович,** младший научный сотрудник; SPIN-код 4108-5689, ORCID 0009-0006-4980-0481; **адрес для переписки:** Россия, 620142, Екатеринбург, ул. Белинского, 112А; e-mail: romanov.egor.2303@gmail.com

Юсупова Чулпан Рифовна, ведущий научный сотрудник, доктор биологических наук; SPIN-код 3428-7317, ORCID 0000-0003-2970-6528

AUTHOR INFORMATION

Natalia A. Bezborodova, Senior Researcher, Candidate of Science in Veterinary Medicine; SPIN-code 7012-0999, ORCID 0000-0003-2793-5001

Olga V. Sokolova, Lead Researcher, Doctor of Science in Veterinary Medicine; SPIN-code 7437-2300, ORCID 0000-0002-1169-4090

Nikolay A. Martynov, Laboratory Assistant; SPIN-code 7332-1403, ORCID 0000-0001-9251-0056

Anatoly V. Zverev, Research Assistant; SPIN-code 6187-6175, ORCID 0009-0009-9408-8106

(✉) **Egor V. Romanov,** Junior Researcher; SPIN-code 4108-5689, ORCID 0009-0006-4980-0481; **address:** 112A, Belinskogo St., Yekaterinburg, 620142, Russia; e-mail: romanov.egor.2303@gmail.com

Chulpan R. Yusupova, Lead Researcher, Doctor of Science in Biology; SPIN-code 3428-7317, ORCID 0000-0003-2970-6528

Дата поступления статьи / Received by the editors 29.07.2025
Дата принятия к публикации / Accepted for publication 30.09.2025
Дата публикации / Published 19.12.2025

https://doi.org/10.26898/0370-8799-2025-12-10
УДК 636.234.1:612.017
Тип статьи: оригинальная
Type of article: original

Иммунный статус голштинизированных коров с разным уровнем молочной продуктивности

(✉)**Новикова Н.Н., Власенко В.С.**
Омский аграрный научный центр
Омск, Россия
(✉)e-mail: novikova@anc55.ru

Целью данной работы являлось определение иммунного статуса коров красной степной породы с разным уровнем молочной продуктивности и различной кровностью по улучшающим породам. Исследование проводили в хозяйстве Омской области. Для определения иммунного статуса дойных коров разделили на три группы по показателям пожизненного удоя, уровню продуктивности, кровности по улучшающим породам, срокам стельности и состоянию здоровья. Первую группу составили животные с низким уровнем продуктивности (20 000–25 000 кг; $n = 7$), вторую – со средним (25 000–30 000 кг; $n = 10$), третью – с высоким (30 000 кг и более; $n = 7$). Статистическую обработку данных проводили с применением однофакторного дисперсионного анализа (ANOVA), а также специальной программы по оценке эффективности иммунных реакций методом нормированных отклонений, которая позволила оперативно провести диагностику нарушений иммунологической реактивности различных иммунокомпетентных клеток и их функционального состояния. Достоверность различий определяли по критерию Стьюдента при вероятности ошибки $p < 0,05$. В результате проведенных исследований установили, что при повышении кровности по голштинской породе (51% и выше) происходит снижение резистентности организма животных до выраженного иммунодефицита без клинических проявлений. Оказалось, что выявленные отклонения у всех особей связаны с нарушением иммунной функции нейтрофилов. Отмечено снижение абсолютной концентрации нейтрофилов и лимфоцитов в группе низкопродуктивных животных относительно группы со средней продуктивностью на 16,5 и 16,0% соответственно, при сопоставлении с коровами с высоким удоем – на 20,5 и 21,5%. Также в этой группе была снижена концентрация Т-лимфоцитов на 39%, В-лимфоцитов – на 54%, цитотоксических Т-лимфоцитов – на 52%. Голштинизированные коровы с содержанием англерской крови на уровне 50% и более имели сильный иммунитет при высоком прижизненном удое.

Ключевые слова: крупный рогатый скот, породы, кровность, иммунный статус, молочная продуктивность

Immune status of Holsteinized cows with different levels of milk productivity

(✉)**Novikova N.N., Vlasenko V.S.**
Omsk Agricultural Research Center
Omsk, Russia
(✉)e-mail: novikova@anc55.ru

The aim of this work was to determine the immune status of Red Steppe cows with different levels of milk productivity and blood relationship across the upgrading breeds. The studies were conducted on a farm in the Omsk region. To determine the immune status of dairy cows, they were divided into three groups based on lifetime milk yield, productivity level, blood relationship across the upgrading breeds, pregnancy period, and health status. The first group consisted of the animals with low productivity (20,000–25,000 kg; $n = 7$), the second – with medium productivity (25,000–30,000 kg; $n = 10$), and the third – with high productivity (30,000 kg or more; $n = 7$). Statistical data processing was performed using one-way analysis of variance (ANOVA), as well as a special program for assessing the effectiveness of immune responses using the normalized deviations method, which allowed for prompt diagnostics of impaired immunological reactivity of various immunocompetent cells and assessment of their functional state. The reliability of differences was determined using the Student's t-test with an error probability of $p < 0.05$. As a result of the conducted research, it was established

that with an increase in Holstein blood (51% and higher), the resistance of the animal's body decreases to a pronounced immunodeficiency without clinical manifestations. It turned out that the deviations identified in all individuals were associated with a disruption of the immune function of neutrophils. A decrease in the absolute concentration of neutrophils and lymphocytes was found in the group of low-yielding animals, compared with the group with average productivity by 16.5 and 16.0%, respectively, and when compared with the cows with high milk yield – by 20.5 and 21.5%. Also in this group, the concentration of T-lymphocytes was reduced by 39%, B-lymphocytes by 54% and cytotoxic T-lymphocytes by 52%. Holsteinized cows with Angler blood content of 50% or more had strong immunity with high lifetime milk yield.

Keywords: cattle, breeds, blood relationship, immune status, milk production

Для цитирования: *Новикова Н.Н., Власенко В.С.* Иммунный статус голштинизированных коров с разным уровнем молочной продуктивности // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 12. С. 94–102. https://doi.org/10.26898/0370-8799-2025-12-10

For citation: Novikova N.N., Vlasenko V.S. Immune status of Holsteinized cows with different levels of milk productivity. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 12, pp. 94–102. https://doi.org/10.26898/0370-8799-2025-12-10

Конфликт интересов
Авторы заявляют об отсутствии конфликта интересов.
Conflict of interest
The authors declare no conflict of interest.

INTRODUCTION

Currently, the priority goals of breeding work in dairy livestock farming are identified as the detection and consolidation of outstanding indicators for the most significant traits, such as reproduction, productivity, longevity, and health.

As a result of the breeding work carried out since the 1930s with the Red Steppe cattle breed, the quantitative and qualitative characteristics of milk have significantly improved: for example, its volume increased from 3,000 to 5,700 kg, and the fat content – from 3.75 to 4.01%, depending on the type [1, 2]. The introduction of semen from domestic and imported improvement bulls has increased productivity by 2.4%. At the same time, the efficiency of using Russian bulls was higher in the herds of the Red Steppe cows with a milk yield of 7000 kg, while imported bulls were more efficient in the herds with a milk yield of 8000 kg and above, without inheriting the trait of productive longevity [3, 4].

Significant success in increasing productive indicators due to Holsteinization of livestock has led to the suppression of its immune system, a decrease in resistance to diseases and a reduction in the period of economic use to 1.5–2.0 lactations [5]. Studies on the immune status assessment have shown that among the cows of indigenous breeds, immunosuppressive conditions and autoimmune diseases are observed much less frequently than in the Holsteins [6]. With increasing gestation period, indicators of immunodeficiency increase, which is associated with the synthesis of immunoglobulin G in the mammary gland and the development of the fetal immune system [7].

It has been established that the highest average values of lysozyme and bactericidal activity are recorded in cows aged 3–4 years [8]. At a later age (5–8 years), there is a decrease in the body's natural resistance and the local immunity of the udder [9], which leads to the development of mastitis, which, in turn, negatively affects the balance of immune cells [10]. Selection based on the genes *CD14*, *CXCR1*, responsible for resistance to mastitis, can improve the situation regarding this disease [11, 12]. Identifying beneficial immune traits that correlate with health and viability indicators (CD4+/CD8+ lymphocytes and subclinical mastitis, CD8+ lymphocytes and fertility) will allow patterns for the genetic selection of animals to be discovered [13].

The study of the correlation characteristics of cellular immunity can serve as a foundation for the development of breeding strategies in animal husbandry, based on the use of genetic markers

and immunoprophylaxis methods, which will allow improving health and increasing the productivity of animals [14].

The purpose of the study is to determine the immune status of Red Steppe cows with different levels of milk productivity and varying degrees of ancestry from improving breeds.

The research objectives are:

1) distribution of the Red Steppe breed cows into groups taking into account their productivity and bloodline with improving breeds;

2) determination of the baseline state of the indicators of nonspecific resistance of cows depending on the level of milk productivity;

3) study of the nature and frequency of immunological disorders in cows with varying bloodlines across improved breeds and with different productivity levels.

MATERIAL AND METHODS

The study was conducted at APC "Rassokhinsky" of the Novovarshavsky district of the Omsk region on the herd of the Red Steppe dairy cows under tie-up housing and identical feeding. The zootechnical and breeding record data are based on the information from the IAS" SELEKS – Dairy Cattle".

At first, the livestock presented in the farm was divided into general groups taking into account productivity indicators and bloodlines according to the first and second improving breeds.

Next, to determine the immune status, three groups of dairy cows were formed according to their lifetime milk yield, level of productivity, pedigree in improving breeds, gestation periods, and health status (without clinical [subclinical] signs of mastitis). The first group included animals with a low level of productivity (20,000–25,000 kg of milk; $n = 7$), the second group – with an average level (25,000–30,000 kg; $n = 10$), and the third – with a high level (30,000 kg and above; $n = 7$).

Blood was taken from the tail vein into the tubes for hematological studies. The quantitative composition of immunocompetent cells (T-, B-lymphocytes, cytotoxic T-lymphocytes) and the functional state of neutrophils were determined in accordance with the methodological recommendations for assessing immune status[1]. The activity of intracellular components of neutrophils (myeloperoxidase, cationic proteins) was assessed using the Graham–Knoll method with the use of benzidine[2] and the method of M.G. Shubich using bromophenol blue[3]. When analyzing the smears, the percentage of positively reacting cells was counted and, according to the standard methods, the average cytochemical coefficient was calculated. Statistical processing of the data was carried out in Microsoft Excel using one-way analysis of variance (ANOVA), as well as a specialized program for evaluating the effectiveness of immune responses by the method of normalized deviations. The significance of differences was determined using the Student's t-test. Differences were considered significant at an error probability of $p < 0.05$.

RESULTS AND DISCUSSION

To classify the animals into general groups, the entire herd analysis was carried out based on the productivity indicators and the proportion of improved breed bloodlines (see Table 1). The results showed that with an increase in the bloodline proportion by 3.2% for the first breed (Holstein Red-and-White), milk productivity increased by 10,000 kg of lifetime yield. The indicators in this group are statistically significant ($p \leq 0.05$ according to ANOVA). In the groups for the second improved breed (Angler and Danish Red), no statistically significant differences were found.

Many authors in their studies show that Holsteinization of the herd leads to a decrease in the immune responses of dairy cows [5–10], there-

[1]*Vlasenko V.S., Bazhin M.A., Dudoladova T.S., Novikov A.N., Mironenko V.A.* Assessment of the immune status in cattle with leukemia: methodological recommendations. Omsk, 2010, 31 p.

[2]*Hrycek A.* Functional characterization of peripheral blood neutrophils in patients with primary hypothyroidism // Folia Biologica, 1993, vol. 39, N 6, pp. 304–310.

[3]*Shubich M.G.* Detection of cationic protein in the cytoplasm of leukocytes using bromophenol blue // Cytology, 1974, vol. 16, N 10, pp. 1321–1322.

Табл. 1. Соотношение уровня продуктивности и кровности по улучшающим породам ($M \pm m$)
Table 1. The ratio of productivity level and blood relationship across the upgrading breeds ($M \pm m$)

Productivity level	The first improving breed		The second improving breed			
	Holstein Red-and-White		Angler		Danish Red	
	heads	%	heads	%	heads	%
General groups						
Low	611	65,1 ± 0,70*	102	51,8 ± 1,5	21	46,1 ± 2,9
Medium	377	64,2 ± 1,05*	103	35,1 ± 1,8	14	48,2 ± 3,1
High	389	68,3 ± 0,90*	95	33,1 ± 1,9	12	46,4 ± 3,5
Groups for determining immune status						
Low	7	46,7 ± 2,8	4	43,7 ± 6,2	1	25,0 ± 0,0
Medium	10	54,5 ± 8,8	8	47,5 ± 6,2	–	–
High	7	44,0 ± 5,7	5	55,6 ± 4,8	–	–

*$p \leq 0,05$.

fore the groups were formed depending on the increase in productivity with a decrease in Holstein blood and an increase in Angler blood.

Groups for assessing immune status were also formed based on the productivity indicators (see Table 1). Analysis of production indicators shows that, with an increase in the proportion of Angler breed, cows with high productivity have a lifetime milk fat content increase of 0.02% compared to low-producing animals without a decrease in lifetime protein content. It should be noted that cows in this group are 0.3 lactations younger, yet their lactation stability coefficient is 90.38%, which is an indicator of balanced milk yield compared to other groups (see Table 2).

Analysis of the parameters of nonspecific resistance shows that low milk productivity is accompanied by an unreliable decrease in the number of white blood cells compared to the identical indicators in the animals with medium and high levels of productivity (see Table 3). In particular, there is a decrease in the absolute concentration of neutrophils and lymphocytes, although their number is 16.5% and 16.0% lower, respectively, compared to individuals with medium productivity, and 20.5% and 21.5% lower when compared to cows with high milk yield.

The reduction in the number of lymphoid cells in low-yield cows occurs due to T and B lymphocytes, as well as cytotoxic lymphocytes, and shows the most significant difference compared to the group of high-yield cows. Thus, the concentration of T lymphocytes was reduced by 39% ($p < 0,05$), B-lymphocytes – by 54% ($p < 0.05$), cytotoxic T-lymphocytes – by 52% ($p < 0,05$). It should be noted that, compared to cattle with an average milk yield, there was also a decrease in the content of immunocompetent cells, especially concerning B-lymphocytes, the

Табл. 2. Средние производственные показатели в группах для определения иммунного статуса ($M \pm m$)
Table 2. Average production indicators in groups to determine the immune status ($M \pm m$)

Indicator	Productivity level		
	low ($n = 7$)	medium ($n = 10$)	high ($n = 7$)
Total lactations	4,40 ± 0,200	4,9 ± 0,300	4,10 ± 0,200
Lifetime milk yield, kg	21460,20 ± 1155,800	27794,80 ± 1759,200	30540,20 ± 1363,500
Lifetime fat content, %	3,88 ± 0,002	3,89 ± 0,008	3,90 ± 0,010
Lifetime protein content, %	3,46 ± 0,005	3,47 ± 0,004	3,47 ± 0,002
Lactation stability coefficient, %	80,57 ± 3,010	85,36 ± 3,190	90,38 ± 1,690
Milk yield for 305 days, kg	5088,70 ± 143,700	6085,10 ± 119,900	7402,50 ± 516,100

Табл. 3. Средние значения показателей неспецифической резистентности у коров с разным уровнем продуктивности ($M \pm m$)

Table 3. Average values of non-specific resistance indicators in cows with different productivity levels ($M \pm m$)

Indicator	Productivity level		
	low	medium	high
Leukocytes, × 10^9/l	6,94 ± 0,23	8,17 ± 0,79	8,63 ± 1,12
Neutrophils, × 10^9/l	3,35 ± 0,15	4,02 ± 0,44	4,22 ± 0,70
Lymphocytes, × 10^9/l	3,24 ± 0,25	3,86 ± 0,46	4,14 ± 0,51
T- lymphocytes, × 10^9/l	0,74 ± 0,07	0,87 ± 0,14	1,22 ± 0,16*
B- lymphocytes, × 10^9/l	0,58 ± 0,08	0,92 ± 0,14*	1,26 ± 0,24*
Cytotoxic T lymphocytes, × 10^9/l	0,56 ± 0,09	0,79 ± 0,12	1,16 ± 0,25*
Lysosomal cationic proteins, c.u.	1,05 ± 0,11	1,05 ± 0,04	0,99 ± 0,10
Myeloperoxidase, c.u.	1,11 ± 0,15	1,28 ± 0,13	0,98 ± 0,08
NBT stimulation coefficient, c.u.	1,02 ± 0,03	1,01 ± 0,06	1,06 ± 0,04

*$p \leq 0,05$.

number of which was 37% lower ($p < 0,05$) (see Table 3).

Although there were no significant changes between the average group indicators of the functional state of aerobic (myeloperoxidase enzymatic activity, tetrazolium activity) and anaerobic (cationic proteins) bactericidal systems of neutrophils in all studied groups, nevertheless, there was some tendency for them to decrease in high-yielding cows.

At the next stage, in order to determine the severity of immunodeficiency both on average for the group and for each individual, a statistical analysis was conducted using a special computer program.

For this purpose, a calculation of the deviation from the reference values was carried out, using indicators of nonspecific resistance of cows with average milk yield as the reference. The calculations were performed according to the following formula:

$$t = \frac{M_2 - M_1}{S_{d_1}},$$

where t – deviation from the reference group; $M1$ and $M2$ – the mean of the reference and experimental groups, respectively; $Sd1$ – standard deviation of the reference group.

A critically significant level of deviation, indicating a pronounced immunodeficiency of a specific component of the immune system, was considered to be when the studied parameter fell beyond –1.0 sigma from the average level.

According to the data presented in Table 4, cows with low milk yield showed a deficiency of immunocompetent cells, which reaches its maximum values in populations of B lymphocytes (t = -0.78) and cytotoxic T lymphocytes (t = –0,56).

At the same time, in cattle with high productivity, these indicators, relative to the reference group, on the contrary, were increased to 0.76 and 0.90, respectively. Nevertheless, a deficiency of certain parameters of the functional state of neutrophils was noted: myeloperoxidase activity (t = –0,71) and cationic proteins (t = –0,44).

Despite the absence of critically significant deviations in the group average indicators ($t >$ –1.0), they were detected when analyzing individual values of nonspecific resistance parameters (see Table 5).

Analyzing the data for the low productivity group, it can be noted that only animal No. 5 of the third lactation with 50% Angler breed ancestry showed no critically significant deviations in

Табл. 4. Отклонения параметров неспецифической резистентности от эталонной группы у коров с низким и высоким уровнями продуктивности

Table 4. Deviations of non-specific resistance parameters in cows with high and low productivity levels from the reference group

Parameter	Productivity level	
	low	high
Leukocytes	–0,49	+0,18
Neutrophils	–0,48	+0,15
Lymphocytes	–0,43	+0,19
T- lymphocytes	–0,31	+0,56
B- lymphocytes	–0,78	+0,76
Cytotoxic T lymphocytes	–0,56	+0,90
Lysosomal cationic proteins	+0,01	–0,44
Myeloperoxidase	–0,39	–0,71
NBT stimulation coefficient	+0,03	+0,27

all the studied parameters, indicating high organism resistance. Animals No. 6 and 7 of the fourth lactation with 25% ancestry from the secondary improving breeds (Angler and Danish Red) exhibited immunodeficiency in at least two indicators of nonspecific resistance.

Among the highly productive livestock, deviations were not registered in the animals No. 1 and 6 of the fifth lactation with 50% and 52% purity of the Angler breed, as well as in the third lactation with 50% purity of the Angler breed. In highly productive cows No. 5 and 7 of the fourth lactation with 51% and 66% purity of the Holstein breed, without adding the purity of the Red breeds, immunodeficiency was observed in more than one parameter of nonspecific resistance. It should be noted that the identified abnormalities in all individuals were associated with impaired neutrophil immune function. Our data are con-

Табл. 5. Индивидуальные отклонения параметров неспецифической резистентности от эталонной группы у коров с низкой и высокой продуктивностью

Table 5. Individual deviations of non-specific resistance parameters from the reference group in cows with low productivity

Parameter	Animal number in the group						
	1	2	3	4	5	6	7
Low productivity level							
Leukocytes	–0,47	–0,27	–0,55	–0,47	–0,15	–0,87	–0,67
Neutrophils	–0,47	–0,68	–0,06	–0,78	–0,25	–0,30	–0,83
Lymphocytes	–0,39	+0,03	–0,93	–0,15	+0,13	–1,05	–0,65
T- lymphocytes	–0,28	+0,06	–0,33	–0,08	+0,22	–1,00	–0,74
B- lymphocytes	–0,39	–0,14	–0,39	–0,93	–0,80	–1,49	–1,36
Cytotoxic T lymphocytes	–0,70	+0,17	–0,29	–0,27	–0,27	–1,01	–1,52
Lysosomal cationic proteins	–2,68	+0,60	–1,84	–0,54	–0,85	+4,27	+1,14
Myeloperoxidase	–0,54	–1,35	–0,40	–1,07	–0,54	+1,57	–0,38
NBT stimulation coefficient	–0,07	+0,55	–0,07	–0,07	+0,50	–0,58	–0,07
High productivity level							
Leukocytes	+0,33	+2,73	–0,67	–0,15	–0,75	+0,05	–0,27
Neutrophils	–0,69	+3,15	–0,27	–0,31	–0,49	–0,32	–0,04
Lymphocytes	+1,12	+1,47	–0,96	+0,24	–0,84	+0,60	–0,28
T- lymphocytes	+1,79	+1,58	–0,88	+0,98	–0,74	+0,71	+0,45
B- lymphocytes	+1,99	+2,64	–0,86	+1,43	–0,95	+1,20	–0,14
Cytotoxic T lymphocytes	+1,48	+3,81	–0,91	+0,45	–1,17	+1,19	+1,76
Lysosomal cationic proteins	+2,82	+0,45	–1,23	–1,31	–3,75	+0,91	–1,00
Myeloperoxidase	–0,59	–0,40	–0,66	–0,12	–1,66	–0,57	–1,00
NBT stimulation coefficient	–0,58	+0,50	+0,65	+0,50	–0,07	+0,96	–0,07

sistent with the findings of other authors, who also observed a decrease in leukocyte functional activity with increased animal productivity [15].

CONCLUSIONS

1. An increase in the bloodline of the Red Steppe breed by 3.2% due to the Holstein Red-and-White breed contributed to an increase in milk productivity by 10,000 kg of lifetime yield.

2. With an increase in the degree of inbreeding in the Holstein breed by 51% and above, there was a decrease in the animals' resistance leading to pronounced immunodeficiency without clinical manifestations.

3. Holsteinized cows with Angler blood content at the level of 50% or more showed strong immunity with high lifetime milk yield.

4. The detected abnormalities in all the individuals are associated with impaired neutrophil immune function.

5. A decrease in the absolute concentration of neutrophils and lymphocytes was observed in the low-productivity animal group compared to the medium-productivity group by 16.5% and 16.0%, respectively, and when compared with high-milk-yield cows – by 20,5 and 21,5%.

6. It was determined that low-productive animals had a 39% decrease in the concentration of T-lymphocytes ($p < 0.05$), a 54% decrease in B-lymphocytes ($p < 0.05$), and a 52% decrease in cytotoxic T-lymphocytes ($p < 0,05$).

7. Thus, in the process of selection, it is necessary to take into account the indicators of immune status and carry out selection based on them, as well as to use a second improving breed, responsible not only for productivity but also for the health of the animals. This approach can help in the development of immune preventive measures aimed at preventing systemic imbalance in the animals' bodies and increasing their productivity.

СПИСОК ЛИТЕРАТУРЫ

1. *Петрова М.Ю.* Красный степной скот Западной Сибири: прошлое и настоящее: монография. Омск, 2023. 140 с.
2. *Перминова О.В.* Эффективность использования быков российской и импортной селекции на маточном поголовье красной степной и черно-пестрой пород в хозяйствах Омской области // Сибирский вестник сельскохозяйственной науки. 2024. Т. 54. № 1. С. 98–106. DOI: 10.26898/0370-8799-2024-1-11.
3. *Гукежев В.М., Хуранов А.М.* Племенная ценность коров – методы учета и оценки // Сибирский вестник сельскохозяйственной науки. 2022. Т. 52. № 4. С. 83–89. DOI: 10.26898/0370-8799-2022-4-9.
4. *Перминова О.В.* Взаимосвязь американской оценки быков и фактической молочной продуктивности коров красной степной породы в условиях Омской области // Пермский аграрный вестник. 2023. № 1. С. 139–146. DOI: 10.47737/2307-2873_2023_41_139.
5. *Сердюк Г.Н., Батраков А.Я., Племяшов К.В.* Способы улучшения воспроизводительных и адаптационных качеств голштинизированного крупного рогатого скота // Ветеринария. 2022. № 6. С. 42–45. DOI: 10.30896/0042-4846.2022.25.6.42-45.
6. *Порываева А.П., Исаева А.Г., Красноперов А.С., Кривоногова А.С., Буркат Н.В., Романова А.С.* Адаптивные возможности крупного рогатого скота разных пород // Ветеринария Кубани. 2025. № 1. С. 11–15. DOI: 10.33861/2071-8020-2025-1-11-15.
7. *Карпенко Л.Ю., Погодаева А.А., Бахта А.А.* Динамика показателей неспецифической защиты организма голштинизированных черно-пестрых пород коров в зависимости от месяца стельности // Международный вестник ветеринарии. 2020. № 2. С. 178–182. DOI: 10.17238/issn2072-2419.2020.2.178.
8. *Довыденкова М.В.* Изучение динамики иммунитета у коров черно-пестрой породы в зависимости от возраста // Молочное и мясное скотоводство. 2020. № 7. С. 49–51. DOI: 10.33943/MMS.2020.33.88.011.
9. *Дементьева Е.С., Магер С.Н.* Показатели общего гомеостаза у коров в разные периоды лактаций // Сибирский вестник сельскохозяйственной науки. 2021. Т. 51. № 2. С. 56–64. DOI: 10.26898/0370-8799-2021-2-7.
10. *Довыденкова М.В.* Изучение резистентности коров при заболевании маститом в зависимости от возраста лактации // Аграрная наука. 2021. № 11 С. 27–31. DOI: 10.32634/0869-8155-2021-354-11-12-27-31.
11. *Yanthi N.D., Anggraeni A., Said S., Saputra S., Muladno M., Herlina N., Nasrulloh M.F., Tiffa-*

rent R. Differential expression of *TLR* and *CXCR* genes in mammary HC11 cells challenged with *Bacillus cereus* and *Bacillus subtilis*: Implications for mastitis resistance // Veterinary World. 2025. Vol. 18 (4). P. 1014–1024. DOI: 10.14202/vetworld.2025.1014-1024.

12. *Zhiguo L., Tianwen W., Guangming X., Hui W., Bingyuan W., Kui L.* Enhancing Animal Disease Resistance, Production Efficiency, and Welfare through Precise Genome Editing // International Journal of Molecular Sciences. 2022. Vol. 23. N 13. P. 7331. DOI: 10.3390/ijms23137331.
13. *Makau M.C., Powell J., Prendergast J., Latre de Late P., Morrison L.J., Kitala Ph., Connelley T., Toye Ph.* Corrigendum to Inverted CD4+/CD8+ T cell ratio in Boran (*Bos indicus*) cattle // Veterinary Immunology and Immunopathology. 2021. Vol. 235. P. 110219. DOI: 10.1016/j.vetimm.2020.110126.
14. *Кузьмина И.Ю.* Метод повышения резистентности молодняка крупного рогатого скота // Сибирский вестник сельскохозяйственной науки. 2023. Т. 53. № 1. С. 62–70. DOI: 10.26898/0370-8799-2023-1-8.
15. *Еремина М.А., Иолчиев Б.С.* Влияние быков зарубежной и отечественной селекции на показатели молочной продуктивности и естественной резистентности дочерей // Достижения науки и техники АПК. 2022. Т. 36. № 4. С. 107–111. DOI: 10.53859/02352451_2022_36_4_107.

REFERENCES

1. Petrova M.Yu. *Red steppe cattle of Western Siberia: past and present*. Omsk, 2023, 140 p. (In Russian).
2. Perminova O.V. Efficiency of the use of bulls of the Russian and imported selection of the breeding stock of the Red Steppe and Black-and-White breeds at the farms of the Omsk region. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2024, vol. 54, no. 1, pp. 98–106. (In Russian). DOI: 10.26898/0370-8799-2024-1-11.
3. Gukezhev V.M., Khuranov A.M. Breeding value of cows – methods of recording and evaluation. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2022, vol. 52, no. 4, pp. 83–89. (In Russian). DOI: 10.26898/0370-8799-2022-4-9.
4. Perminova O.V. The relationship between the American assessment of bulls and the actual milk productivity of cows of the Red Steppe breed in the conditions of the Omsk oblast. *Permskiy agrarniy vestnik = Perm Agrarian Journal*, 2023, no. 1, pp. 139–146. (In Russian). DOI: 10.47737/2307-2873_2023_41_139.
5. Serdyuk G.N., Batrakov A.Ya., Plemyashov K.V. Methods for improving the reproductive and adaptive qualities of Holsteinized cattle. *Veterinariya = Veterinary Medicine*, 2022, no. 6, pp. 42–45. (In Russian). DOI: 10.30896/0042-4846.2022.25.6.42-45.
6. Poryvaeva A.P., Isaeva A.G., Krasnoperov A.S., Krivonogova A.S., Burkat N.V., Romanova A.S. Adaptive capabilities of cattle of different breeds. *Veterinariya Kubani = Veterinaria Kubani*, 2025, no. 1, pp. 11–15. (In Russian). DOI: 10.33861/2071-8020-2025-1-11-15.
7. Karpenko L.Yu., Pogodaeva A.A., Bakhta A.A. Dynamics of indicators of non-specific protection of holstein black-and-white breeds of cows depending on the month of pregnancy. *Mezhdunarodniy vestnik veterinarii = International Journal of Veterinary Medicine*, 2020, no. 2, pp. 178–182. (In Russian). DOI: 10.17238/issn2072-2419.2020.2.178.
8. Dovydenkova M.V. Study of the dynamics of immunity in Black-and-White cows depending on age. *Molochnoe i myasnoe skotovodstvo = Dairy and beef cattle farming*, 2020, no. 7, pp. 49–51. (In Russian). DOI: 10.33943/MMS.2020.33.88.011.
9. Dementyeva E.S., Mager S.N. Indicators of total homeostasis in cows in different periods of lactations. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2021, vol. 51, no. 2, pp. 56–64. (In Russian). DOI: 10.26898/0370-8799-2021-2-7.
10. Dovydenkova M.V. Study of the resistance of cows with mastitis depending on the age of lactation. *Agrarnaya nauka = Agrarian science*, 2021, no. 11, pp. 27–31. (In Russian). DOI: 10.32634/0869-8155-2021-354-11-12-27-31.
11. Yanthi N.D., Anggraeni A., Said S., Saputra S., Muladno M., Herlina N., Nasrulloh M.F., Tiffarent R. Differential expression of TLR and CXCR genes in mammary HC11 cells challenged with Bacillus cereus and Bacillus subtilis: Implications for mastitis resistance. *Veterinary World*, 2025, vol. 18 (4), pp. 1014–1024. DOI: 10.14202/vetworld.2025.1014-1024.
12. Zhiguo L., Tianwen W., Guangming X., Hui W., Bingyuan W., Kui L. Enhancing Animal Disease

Resistance, Production Efficiency, and Welfare through Precise Genome Editing. *International Journal of Molecular Sciences*, 2022, vol. 23, no. 13, p. 7331. DOI: 10.3390/ijms23137331.

13. Makau M.C., Powell J., Prendergast J., Latre de Late P., Morrison L.J., Kitala Ph., Connelley T., Toye Ph. Corrigendum to Inverted CD4+/CD8+ T cell ratio in Boran (Bos indicus) cattle. *Veterinary Immunology and Immunopathology*, 2021, vol. 235, p. 110219. DOI: 10.1016/j.vetimm.2020.110126.
14. Kuzmina I.Yu. The method of increasing the resistance of young cattle. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2023, vol. 53, no. 1, pp. 62–70. (In Russian). DOI: 10.26898/0370-8799-2023-1-8.
15. Eremina M.A., Iolchiev B.S. Influence of foreign and domestic breeding bulls on indicators of lactation performance and natural resistance of daughters. *Dostizheniya nauki i tekhniki APK = Achievements of Science and Technology of AIC*, 2022, vol. 36, no. 4, pp. 107–111. (In Russian). DOI: 10.53859/02352451_2022_36_4_107.

ИНФОРМАЦИЯ ОБ АВТОРАХ

(✉)**Новикова Наталья Николаевна,** ведущий научный сотрудник, кандидат ветеринарных наук; SPIN-код 5421-7928; **адрес для переписки:** Россия, 644001, Омск, ул. Лермонтова, 93; e-mail: novikova@anc55.ru

Власенко Василий Сергеевич, главный научный сотрудник, доктор биологических наук, профессор; SPIN-код 8354-6130

AUTHOR INFORMATION

(✉)**Natalia N. Novikova,** Lead Researcher, Candidate of Science in Veterinary Medicine; SPIN-code 5421-7928; **address:** 93, Lermontova St., Omsk, 644001, Russia; e-mail: novikova@anc55.ru

Vasily S. Vlasenko, Head Researcher, Doctor of Science in Biology, Professor; SPIN-code 8354-6130

Дата поступления статьи / Received by the editors 07.08.2025
Дата принятия к публикации / Accepted for publication 13.10.2025
Дата публикации / Published 19.12.2025

https://doi.org/10.26898/0370-8799-2025-12-11
УДК 619.615.015.4:616.3:636.4
Тип статьи: оригинальная
Type of article: original

Эффективность нового средства природного происхождения при лечении желудочно-кишечных болезней телят, сопровождающихся диареей

(✉)**Савельева Л.Н., Бондарчук М.Л., Некрасова О.С., Базарон Б.З., Дашинимаев Б.Ц.**
Научно-исследовательский институт ветеринарии Восточной Сибири – филиал Сибирского федерального научного центра агробиотехнологий Российской академии наук
Чита, Россия
(✉)e-mail: luba.saveleva@mail.ru

В статье представлены результаты оценки эффективности нового средства на основе природного сырья для лечения молодняка крупного рогатого скота от желудочно-кишечных болезней, сопровождающихся диареей. Объектом исследования послужили две группы новорожденных телят с признаками диареи. Животные опытной группы получали разработанное нами средство (состав: корневище бадана, лист фенхеля, цветы календулы, семена амаранта, пробиотик, NaCl), контрольной – фитосбор желудочный № 1 (состав: корневище бадана, семена тмина, трава тысячелистника и солянки холмовой, лист смородины и подорожника). Терапию каждого теленка осуществляли по следующей схеме: двукратно (утром и вечером) внутрь в форме отвара в дозировке 2 мл/кг живой массы. В результате эксперимента на 3-и сутки терапии у представителей опытной группы эффективность лечения составила 90%, в контроле на 7-е сутки – 80%. При этом показатели общего анализа крови в опытной группе соответствовали норме на 10-е сутки лечения. В контроле уровень лейкоцитов и гематокрита превышал референсные значения на 40,4 и 15,7% соответственно ($p < 0,001$). В биохимическом статусе опытной группы молодняка наблюдали положительную динамику в сторону нормализации значений. В контроле показатели водно-солевого обмена (Na, K) были ниже нормы на 41,2 и 20,7% соответственно, уровень кальция был ниже на 63,1% ($p < 0,001$), показатели фосфора и железа соответствовали нижнему порогу нормы. Стоимость курсового лечения опытным средством составила 123 р., контрольным – 260 р. на одного теленка. Среднесуточный прирост живой массы в опытной группе на 69,5% превосходил данные контроля ($p < 0,001$). С целью предотвращения экономического ущерба, связанного с падежом телят и недополучением привеса, изученный фитопробиотический комплекс рекомендуется применять при первых признаках диареи в качестве безопасного вяжущего, противовоспалительного и обволакивающего средства.

Ключевые слова: телята, диарея, фитосредства, гематология, биохимия, терапевтическая эффективность

Efficacy of a new natural remedy in the treatment of calves with gastrointestinal diseases accompanied by diarrhea

(✉)**Savelyeva L.N., Bondarchuk M.L., Nekrasova O.S., Bazaron B.Z., Dashinimaev B.Ts.**
Research Institute of Veterinary Science of Eastern Siberia – Branch of the Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences
Chita, Russia
(✉)e-mail: luba.saveleva@mail.ru

The article presents the results of an evaluation of the effectiveness of a new product based on natural raw materials for the treatment of young cattle from gastrointestinal diseases accompanied by diarrhea. The object of the study was two groups of newborn calves with signs of diarrhea. The experimental group animals received the product we developed (composition: rhizome of bergenia, fennel leaf, calendula flowers, amaranth seeds, probiotic, NaCl), the control group received the gastric herbal collection No. 1 (composition: rhizome of bergenia, caraway seeds, yarrow and saltwort herb, currant and plantain leaves). The therapy for each calf was carried out according to the following scheme: twice (morning and evening) orally in the form of a decoction at a dosage of 2 ml/kg of live weight. As a result of the experiment, on the 3rd day of therapy, the treatment effectiveness in the experimental group was 90%, in the control group on the 7th day – 80%. Moreover, the general blood test results

in the experimental group were within the normal range on the 10th day of treatment. In the control, the level of leukocytes and hematocrit exceeded the reference values by 40.4 and 15.7%, respectively ($p < 0.001$). Positive dynamics towards normalization of values were observed in the biochemical status of the experimental group of young animals. In the control group, the water-salt metabolism indicators (Na, K) were below the norm by 41.2 and 20.7%, respectively, the calcium level was lower by 63.1% ($p < 0.001$), the phosphorus and iron indicators corresponded to the lower limit of the norm. The cost of a treatment course with the experimental agent was 123 rubles, and with the control agent – 260 rubles per calf. The average daily gain in live weight in the experimental group was 69.5% higher than the control data ($p < 0.001$). In order to prevent economic losses associated with calf mortality and the loss of weight gain, the studied phyto probiotic complex is recommended for use at the first signs of diarrhea as a safe astringent, anti-inflammatory and enveloping agent.

Keywords: calves, diarrhea, herbal remedies, hematology, biochemistry, therapeutic efficacy

Для цитирования: *Савельева Л.Н., Бондарчук М.Л., Некрасова О.С., Базарон Б.З., Дашинимаев Б.Ц.* Эффективность нового средства природного происхождения при лечении желудочно-кишечных болезней телят, сопровождающихся диареей // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 12. С. 103–110. https://doi.org/10.26898/0370-8799-2025-12-11

For citation: Savelyeva L.N., Bondarchuk M.L., Nekrasova O.S., Bazaron B.Z., Dashinimaev B.Ts. Efficacy of a new natural remedy in the treatment of calves with gastrointestinal diseases accompanied by diarrhea. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 12, pp. 103–110. https://doi.org/10.26898/0370-8799-2025-12-11

Конфликт интересов
Авторы заявляют об отсутствии конфликта интересов.
Conflict of interest
The authors declare no conflict of interest.

INTRODUCTION

The development of beef cattle breeding is of great importance for ensuring food security in the Trans-Baikal Territory and the entire country. According to the scientifically based dietary standards presented by the specialists from the Federal Research Center for Nutrition, Biotechnology, and Food Safety, a person's need for meat products is 86 kg per year. At the same time, beef in a person's diet should account for 40–45% of the total meat consumption[1].

Despite the existing achievements in studying the problems of preserving young cattle, the incidence of gastrointestinal diseases among calves is 10–70%. Since the neonatal period is a "transitional link" from intrauterine life to extrauterine life, at this stage calves exhibit adaptive reactions aimed at adjusting the body to new living conditions, including acute gastrointestinal disorders (diarrhea) and, as a result, dehydration and disruption of the water-salt balance.

According to data from several authors who study digestive diseases in young animals, during diarrhea, water and electrolytes (sodium, chloride, potassium, bicarbonate) are lost from the body along with liquid stool. Chronic diarrhea often causes vitamin deficiency and mineral deficiency, which can lead to the development of anemia, as well as dysfunction of the entire body. At the same time, about 40% of cases end in death, thereby causing significant economic damage [1–3].

Currently, pet owners use chemotherapeutic drugs for therapeutic purposes, which, although effective, have side effects. A number of specialists and our research have confirmed that medicinal and prophylactic agents of plant origin have low toxicity and a wide range of pharmacological effects [4–11]. Because of this, herbal remedies are increasingly recommended by scientists and practicing veterinarians.

The purpose of the study is to evaluate the effectiveness of the developed remedy based on

[1]*Plyaskina V.A.* Meat cattle breeding – the most important element of the region's cultural heritage // Trans-Baikal Village: yesterday, today, tomorrow: materials of the XVIII regional scientific-practical student conference, dedicated to the 45th anniversary of the Trans-Baikal Agricultural Institute (Branch of the Irkutsk State Agrarian University named after A.A. Ezhevsky) and the 90th Anniversary of Doctor of Science in Agriculture, Prof. I.I. Vinogradov. Chita, 2024, 182 p.

natural raw materials for treating calves from gastrointestinal diseases accompanied by diarrhea.

MATERIAL AND METHODS

During the experiment at the "S.D. Batuev" farm, two groups of newborn calves were formed based on the principle of analogues (10 heads in each group). Signs of diarrhea were noted in all animals in the groups.

The experimental group was treated with a remedy developed by us, which includes fennel leaf (*Folia Foeniculum*), rhizome of bergenia (*Rhizoma Bergeniae*), amaranth seeds (*Semen Amaranthi*), calendula flowers (*Flores Calendulae*), probiotic (*Bacillus subtilis*, DSM 32424 strain, at least 1×10^6 CFU/g of live microbial cells) and NaCl.

The control was served by young animals, for the treatment of which they used gastric herbal collection No. 1 from the company "Biolit" (Russia). The collection includes caraway fruits (*Fructus Carvi*), rhizome of bergenia (*Rhizoma Bergeniae*), yarrow herb (*Herba Achilleae*) and saltwort herb (*Herba Salicorniae*), currant leaves (*Folia Ribis*) and plantain leaves (*Folia Plantaginis*).

Both remedies were given in the form of decoctions orally to each of the animals in the morning and evening at a dosage of 2 ml/kg of body weight.

It has been proven that the herbs included in the studied remedies contain a large number of minerals (iron, silicon, boron, copper, etc.), flavonoids, glycosides, ascorbic acid, carotene, B vitamins, protect the mucous membrane of the gastrointestinal tract from irritation, have anti-inflammatory and healing effects, relieve spasms and pain, eliminate digestive disorders, improve intestinal microbiota, and have a synergistic, antibacterial, antitoxic, and astringent effect [1, 2, 4–6, 10, 11].

The probiotic promotes the strengthening of the body's defense functions, contributes to the normalization of the intestinal biocenosis, absorption and metabolism of iron, calcium, proteins, carbohydrates, restoration of the intestinal mucosa, normalization of digestive processes, which is especially important during the adaptation period of newborn calves.

According to the results of in vitro, preclinical, and clinical studies obtained by us, the developed agent is not toxic to the bodies of animals, has a pronounced astringent and anti-inflammatory effect, and an antibacterial effect with respect to *Escherichia coli* and *Enterococcus faecalis* [6].

The assessment of the therapeutic efficacy of the investigated agents was carried out according to a previously developed scheme, used during the clinical trials of the agent [6]. This scheme included daily recording of various physiological indicators: body temperature, pulse and respiratory rates, condition of visible mucous membranes, level of body dehydration, stool consistency (presence of diarrhea), and behavioral activity until the recovery period.

For the general and biochemical blood analysis on the 10th day of the experiment, blood samples were collected in the morning into tubes with and without a preservative. To determine the main clinical parameters of whole blood, a hematology analyzer PCE 90 Vet (USA) and special consumable reagents (Clinical Diagnostic Solutions, Russia; TU 9398-001-85747522-2009) were used; for the study of blood serum for the main biochemical parameters, a biochemical analyzer URIT 800 Vet (China) and DiaVetTest reagents (Russia) were used[2].

Laboratory research was conducted at the scientific laboratory of the Research Institute of Veterinary Science of Eastern Siberia.

The economic efficiency of the use of drugs was calculated according to the methodology of I.N. Nikitin[3].

[2]Methodological recommendations for the use of "DiaVetTest" reagent kits for biochemical studies of animal blood serum (plasma) on automatic and semi-automatic analyzers. Moscow, 2018.

[3]*Nikitin I.N.* Organization of veterinary affairs: Textbook. St. Petersburg: Lan, 2022, 288 p.

RESULTS AND DISCUSSION

During the clinical examination of calves in the control and experimental groups before the start of therapy, diarrhea, an increase in body temperature up to 41.5 ± 0.13 °C ($p < 0.05$), depressed condition, decreased appetite and skin turgor, dry coat, and paleness of the conjunctiva were recorded.

It should be noted that in this experiment, no infectious etiology was identified in newborn calves, and the effects of the studied drugs were assessed as symptomatic, pathogenetic, and general strengthening therapy.

As a result of therapy with the studied herbal remedies, in the subjects of the experimental group the disease proceeded in a milder form, and clinical indicators normalized. Thus, on the 3rd day of treatment, stool became formed, the skin more elastic, mucous membranes pink and shiny, activity and exploratory behavior were observed. Body temperature, pulse rate, and respiratory rate were within the physiological norm: 38.5 ± 0.33 °C; 136.4 ± 1.73 beats/min; 23.2 ± 1.13 breaths/min, respectively.

During the same period, 70% of the animals in the control group still had elevated body temperature, shortness of breath, rapid, weak, and irregular pulse, and loose feces. During treatment, the average physiological constants in the control group were slightly above normal: body temperature – 41.0 ± 0.23 °C; pulse – 166.0 ± 2.31 beats/min; respiratory rate – 35.0 ± 1.22 breaths/min ($p < 0.001$). The normalization of these indicators was recorded on the 7th day.

In the process of raising young animals, one of the most important factors is weight gain.

The indicators of average daily gain for the experimental period are presented in Table 1.

Analysis of the dynamics of the average weight of calves showed that the animals of the experimental group in terms of average daily weight gain significantly ($p < 0.001$) exceeded the representatives of the control group by 69.5% during the period from the 2nd to the 12th day.

Based on the obtained results, the economic efficiency of the therapy course in the studied groups was calculated (see the figure).

The data in the chart show the low cost of treatment with both drugs. At the same time, treatment with the test drug turned out to be 137.56 rubles cheaper, which is an important factor for pet owners in a market economy.

A significant role in the pharmacological correction of digestive diseases accompanied by diarrhea is played by blood tests [9].

Table 2 presents a comparative analysis of the main blood indicators of calves in both groups.

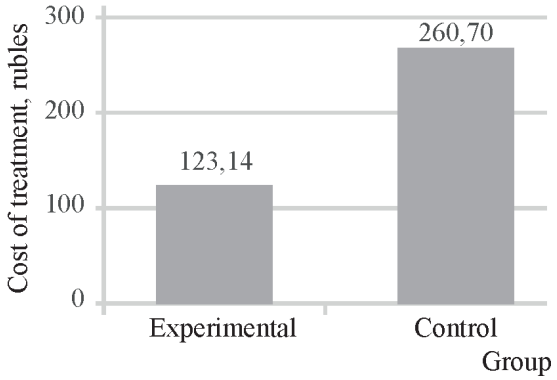
The results of the comparative analysis showed significant differences between the studied groups. Thus, the number of leukocytes in the control group was 23.13% ($p < 0.001$) above the upper limit of the normal range[4], which may

Табл. 1. Весовые показатели телят в исследуемых группах ($M \pm m$, $n = 20$)

Table 1. Weight indicators of calves in the study groups ($M \pm m$, $n = 20$)

Indicator	Group	
	experimental	control
Body weight, kg:		
at the beginning of the experiment	29,4 ± 0,44	29,4 ± 0,44
after 10 days of therapy	33,3 ± 1,03	31,7 ± 1,14
Average daily weight gain, g	390 ± 4,33	230 ± 3,62*

*$p < 0,001$.



Сравнительный анализ стоимости курса лечения исследуемыми лекарственными средствами

Comparative analysis of the cost of a course of treatment with the drugs under study

[4]*Bazhibina E.B., Korobov A.V., Sereda S.V., Saprykin V.P.* Methodological foundations for the assessment of clinical and morphological blood parameters in domestic animals: textbook. Moscow, 2007, 128 p.

be due to the body's adaptive-response reaction and the presence of inflammatory processes.

The use of the new remedy normalized hemoglobin levels, whereas in the control group its level was 10% below the lower limit of the norm.

In the experimental group, the proportion of erythrocytes in the total blood volume (hematocrit) was within the normal range (45.3%). In the control group, this indicator was significantly ($p < 0.001$) higher than the reference values by 19%, which is characteristic of physiological processes in young animals against the background of dehydration of the body during gastrointestinal diseases accompanied by diarrhea [3, 6, 11].

The obtained results on the main biochemical elements of blood are consistent with the data of the previous studies. It was previously established that after therapy with the drug, the baseline levels of sodium and potassium in the serum of animals in the control group were below the physiological norm by 41.2% and 20.7%, respectively, whereas in the experimental group they corresponded to the physiological norms [6].

After phytocomplex therapy, hypocalcemia was observed in the young animals of the control group: calcium content decreased by 63.1% ($p < 0.001$). The level of inorganic phosphorus corresponded to the lower limit of the physiological norm[5], and the iron content in the control had deviations from the lower limit of the norm by 25%, which in the future may affect enzyme production and lead to anemia [7–15].

In the calves of the experimental group, the treatment effectiveness on the 3rd day was 90%, while in the control group on the 7th day it was 80%. The complete blood count indicators in the experimental group corresponded to the norm on the 10th day. In the control group during the same period, the levels of leukocytes and hematocrit exceeded the reference values by 40.4% and 15.7%, respectively ($p < 0,001$). In the biochemical status of the animals in the experimental group, a positive dynamic with a tendency toward normalization of the values was observed. In the control group, the indicators of water-salt metabolism (Na, K) were below the norm by 41.2% and 20.7%, respectively; the calcium level was lower by 63.1% ($p < 0.01$); the phosphorus and iron indicators corresponded to the lower limit of the norm.

The cost of a course treatment with the experimental remedy was 123 rubles per calf, and with the control – 260 rubles. The average daily weight gain in the calves of the experimental group exceeded the control data by 69.5%.

Табл. 2. Сравнительная характеристика основных показателей крови ($M \pm m$, $n = 20$)
Table 2. Comparative characteristics of the main blood parameters ($M \pm m$, $n = 20$)

Indicator	Norm	Group	
		experimental	control
Leukocytes (WBC), 10^9/l	8–16	10,8 ± 0,71	18,3 ± 1,3**
Erythrocytes (RBC), 10^{12}/l	6,0–7,5	7,2 ± 0,89	6,2 ± 0,64*
Hemoglobin (HGB), g/l	90–110	98,0 ± 2,42	81,0 ± 2,51
Hematocrit (HCT), %	36–50	45,3 ± 4,20	64,3 ± 5,62**
Sodium, mmol/l	135–148	141,6 ± 6,11	95,6 ± 4,21*
Potassium, mmol/l	3,5–4,5	4,0 ± 0,14	2,9 ± 0,22*
Calcium, mmol/l	2,5–3,3	3,1 ± 0,54	1,9 ± 0,14**
Phosphorus, mmol/l	1,4–1,9	1,7 ± 0,80	1,4 ± 0,32
Iron, mmol/l	1,0–3,4	2,8 ± 0,36	0,8 ± 0,11**

*$p < 0,01$.
**$p < 0,001$.

[5]*Medvedeva M.A.* Clinical Veterinary Laboratory Diagnostics: Reference for Veterinarians. Moscow, 2008, 416 p.

CONCLUSION

The conducted study allowed us to expand and deepen the previously obtained results. Thus, for the first time, the most pronounced therapeutic effect of the remedy we developed (90%) was proven compared to gastric collection No. 1. The therapeutic effect amounted to 80%.

The cost of the course treatment in the experienced group turned out to be 137 rubles lower than in the control group, while the average daily gain, on the contrary, was 160 g higher, which is economically beneficial.

The total blood count indicators in the experimental group of calves on the 10th day of therapy were within the normal range. In the control group, the levels of leukocytes and hematocrit exceeded the reference values by 40.4% and 15.7%, respectively ($p < 0,01$).

In the biochemical status of the experimental group of young animals, a more positive trend toward normalization of the values was also observed. In the control group, the content of Na and K was below normal by 41.2% and 20.7%, respectively, and Ca by 63.1% ($p < 0,01$).

Thus, in order to prevent economic damage associated with the insufficient weight gain of calves with digestive organ diseases accompanied by diarrhea, we recommend using the developed phytobiotic complex at the first signs of the disease as a safe astringent, anti-inflammatory, and enveloping agent.

СПИСОК ЛИТЕРАТУРЫ

1. *Лашкова Т.Б., Петрова Г.В., Жукова М.Ю., Митюков А.С.* Влияние фульвокислоты на усвоение питательных веществ рациона и продуктивность молодняка КРС // Вестник Красноярского государственного аграрного университета. 2024. № 6. С. 109–114. DOI: 10.36718/1819-4036-2024-6-109-114.
2. *Великанов В.И., Кляпнев А.В., Харитонов Л.В., Терентьев С.С.* Физиологическое состояние, становление неспецифической резистентности и иммунологического статуса телят раннего постнатального периода онтогенеза после применения Тимогена, Полиоксидония, Ронколейкина и Синэстрола 2% коровам-матерям перед отелом: монография. Нижний Новгород, 2020. 224 с.
3. *Афанасьева А.И., Сарычев В.А., Смеян Д.А.* Морфологический статус крови и показатели роста телят раннего постнатального периода при использовании фитоадаптогенов // Вестник Алтайского государственного аграрного университета. 2022. № 8 (214). С. 51–58.
4. *Zhang Y., Nie Y., Zhou X.* Enhancement of pullulanase production from recombinant *Bacillus subtilis* by optimization of feeding strategy and fermentation conditions // AMB Express. 2020. Vol. 10. P. 1–9.
5. *Наумов Н.М., Свазлян Г.А.* Влияние *Bacillus subtilis* и его метаболитов на обмен веществ у поросят в период доращивания // Достижения науки и техники АПК. 2021. Т. 35. № 6. С. 63–67. DOI: 10.24411/0235-2451-2021-10611.
6. *Савельева Л.Н., Бондарчук М.Л.* Антибактериальная эффективность растительного сырья в условиях *in vitro* // Сибирский вестник сельскохозяйственной науки. 2024. Т. 54. № 11. С. 126–131. DOI: 10.26898/0370-8799-2024-11-13.
7. *Terre M., Prat N., Sabrià D.* Supplementing a Bacillus-based direct-fed microbial improves feed efficiency in lactating dairy cows // Translational Animal Science. 2024. Vol. 8. P. 110. DOI: 10.1093/tas/txae110.
8. *Молянова Г.В., Ноготков М.П.* Воздействие препарата на основе *Bacillus subtilis* на росто-весовые параметры телят голштино-фризской породы // Известия Самарской государственной сельскохозяйственной академии. 2021. Т. 6. № 1. С. 46–51. DOI: 10.12737/42658.
9. *Краскова Е.В.* Изменение гемопоэза новорожденных телят при диспепсиях // Вестник Алтайского государственного аграрного университета. 2022. № 5 (211). С. 53–56.
10. *Жарикова Е.А., Бойко Т.В.* Оценка терапевтической эффективности биологически активной композиции микробного происхождения «Симбион-Д» при диспепсии у телят // Вестник Омского государственного аграрного университета. 2022. № 2 (46). С. 85–92. DOI: 10.48136/2222-0364_2022_2_85.
11. *Xu R.J., Zhang S.H., Wang F.U.* Postnatal adaptation of the gastrointestinal tract in neonatal pigs: a possible role of milk-borne growth factors // Livestock Production Science. 2000. N 66. P. 95–107.
12. *Никитина М.М., Севастьянова В.М.* Исполь-

зование престартерных комбикормов «Каргилл» и «Дельта фидс» в рационах телят // Вестник Красноярского государственного аграрного университета. 2021. № 6. С. 109–113. DOI: 10.36718/1819-4036-2021-6-109-113.

13. *Павлов А.Г., Неустроев М.П.* Антагонистическая активность штаммов бактерий *Bacillus subtilis* 2СП В-14405 и *Bacillus subtilis* 5СП В-14406 // Ветеринария и кормление. 2024. № 5. С. 72–75. DOI: 10.30917/ATT-VK-1814-9588-2024-5-17.
14. *Лазарев С.А., Арзуманян В.Г., Михайлова Н.А.* Влияние состава питательной среды на прирост биомассы и синтез противомикробных метаболитов пробиотических штаммов *Bacillus subtilis* // Бактериология. 2021. Т. 6. № 2. С. 38–42. DOI: 10.20953/2500-1027-2021-2-38-42.
15. *Эленшлегер А.А., Утц С.А.* Эффективность применения пробиотика «Ветом 1.2» для повышения уровня иммуноглобулинов в молозиве коров и в крови у коров и телят // Вестник Алтайского государственного аграрного университета. 2020. № 11 (193). С. 79–84.

REFERENCES

1. Lashkova T.B., Petrova G.V., Zhukova M.Yu., Mityukov A.S. Fulvic acid effect on nutrients absorption in young cattle diet and productivity. *Vestnik Krasnoyrskogo gosudarstvennogo agrarnogo universiteta = Bulletin of KrasSAU*, 2024, no. 6, pp. 109–114. (In Russian). DOI: 10.36718/1819-4036-2024-6-109-114.
2. Velikanov V.I., Klyapnev A.V., Kharitonov L.V., Terentyev S.S. *Physiological state, formation of nonspecific resistance and immunological status of calves of the early postnatal period of ontogenesis after administration of Thymogen, Polyoxidonium, Roncoleukin and Synestrol 2% to mother cows before calving*. Nizhny Novgorod, 2020, 224 p. (In Russian).
3. Afanasyeva A.I., Sarychev V.A., Smeyan D.A. Blood morphological status and growth rates of calves in the early postnatal period when using phytoadaptogens. *Vestnik Altaiskogo gosudarstvennogo agrarnogo universiteta = Bulletin of Altai State Agricultural University*, 2022, no. 8 (214), pp. 51–58. (In Russian).
4. Zhang Y., Nie Y., Zhou X. Enhancement of pullulanase production from recombinant Bacillus subtilis by optimization of feeding strategy and fermentation conditions. *AMB Express*, 2020, vol. 10, pp. 1–9.
5. Naumov N.M., Svazlyan G.A. Effect of Bacillus subtilis and its metabolites on the metabolism of piglets during the rearing period. *Dostizheniya nauki i tekhniki APK = Achievements of Science and Technology of AIC*, 2021, vol. 35, no. 6, pp. 63–67. (In Russian). DOI: 10.24411/0235-2451-2021-10611.
6. Savelyeva L.N., Bondarchuk M.L. Antibacterial efficacy of plant raw materials under in vitro conditions. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2024, vol. 54, no. 11, pp. 126–131. (In Russian). DOI: 10.26898/0370-8799-2024-11-13.
7. Terre M., Prat N., Sabrià D. Supplementing a Bacillus-based direct-fed microbial improves feed efficiency in lactating dairy cows. *Translational Animal Science*, 2024, vol. 8, p. 110. DOI: 10.1093/tas/txae110.
8. Molyanova G.V., Nogotkov M.P. Effect of Bacillus subtilis preparations on height and weight of Holstein-Frisian calves. *Izvestiya Samarskoi GSKhA = Bulletin Samara State Agricultural Academy*, 2021, vol. 6, no. 1, pp. 46–51. (In Russian). DOI: 10.12737/42658.
9. Kraskova E.V. Hematopoietic changes in newborn calves with dyspepsia. *Vestnik Altaiskogo gosudarstvennogo agrarnogo universiteta = Bulletin of Altai State Agricultural University*, 2022, no. 5 (211), pp. 53–56. (In Russian).
10. Zharikova E.A., Boyko T.V. Evaluation of the therapeutic efficacy of the biologically active composition of microbial origin "Symbion-D" in dyspepsia in calves. *Vestnik Omskogo gosudarstvennogo agrarnogo universiteta = Vestnik of Omsk SAU*, 2022, no. 2 (46), pp. 85–92. (In Russian). DOI: 10.48136/2222-0364_2022_2_85.
11. Xu R.J., Zhang S.H., Wang F.U. Postnatal adaptation of the gastrointestinal tract in neonatal pigs: a possible role of milk-borne growth factors. *Livestock Production Science*, 2000, no. 66, pp. 95–107.
12. Nikitina M.M., Sevastyanova V.M. Use of pre-starter combined feeds "Cargill" and "Delta feeds" in the diets of calves. *Vestnik Krasnoyrskogo gosudarstvennogo agrarnogo universiteta = Bulletin of KrasSAU*, 2021, no. 6, pp. 109–113. (In Russian). DOI: 10.36718/1819-4036-2021-6-109-113.
13. Pavlov A.G., Neustroev M.P. Antagonistic activity of Bacillus subtilis 2SP B-14405 and Bacillus subtilis 5SP B-14406 bacterial strains.

Veterinariya i kormlenie = Veterinaria i kormlenie, 2024, no. 5, pp. 72–75. (In Russian). DOI: 10.30917/ATT-VK-1814-9588-2024-5-17.

14. Lazarev S.A., Arzumanyan V.G., Mikhailova N.A. Influence of nutrient medium composition on biomass growth and antimicrobial metabolites synthesis of Bacillus subtilis probiotic strains. *Bakteriologiya = Bacteriology*, 2021, vol. 6, no. 2, pp. 38–42. (In Russian). DOI: 10.20953/2500-1027-2021-2-38-42.
15. Elenshleger A.A., Utts S.A. The effectiveness of using the probiotic product Vetom 1.2 to increase the level of immunoglobulins in cow colostrum and in the blood of cows and calves. *Vestnik Altaiskogo gosudarstvennogo agrarnogo universiteta = Bulletin of Altai State Agricultural University*, 2020, no. 11 (193), pp. 79–84. (In Russian).

ИНФОРМАЦИЯ ОБ АВТОРАХ

(✉)**Савельева Любовь Николаевна,** ведущий научный сотрудник, кандидат биологических наук; SPIN-код 9797-0914; **адрес для переписки:** Россия, 672010, Чита, ул. Кирова, 49; e-mail: luba.saveleva@mail.ru

Бондарчук Мария Львовна, младший научный сотрудник; SPIN-код 9774-7000

Некрасова Ольга Сергеевна, младший научный сотрудник; SPIN-код 9101-0145

Базарон Бадма Зилимович, старший научный сотрудник, кандидат сельскохозяйственных наук; SPIN-код 5878-4474

Дашинимаев Баир Цирендоржиевич, старший научный сотрудник, кандидат ветеринарных наук; SPIN-код 6843-4171, ORCID 0000-0002-7833-3206

AUTHOR INFORMATION

(✉)**Lyubov N. Savelyeva,** Lead Researcher, Candidate of Science in Biology; SPIN-code 9797-0914; **address:** 49, Kirova St., Chita, 672010, Russia; e-mail: luba.saveleva@mail.ru

Maria L. Bondarchuk, Junior Researcher; SPIN-code 9774-7000

Olga S. Nekrasova, Junior Researcher; SPIN-code 9101-0145

Badma Z. Bazaron, Senior Researcher, Candidate of Science in Agriculture; SPIN-code 5878-4474

Bair Ts. Dashinimaev, Senior Researcher, Candidate of Science in Veterinary Medicine; SPIN-code 6843-4171, ORCID 0000-0002-7833-3206

Дата поступления статьи / Received by the editors 08.09.2025
Дата принятия к публикации / Accepted for publication 29.11.2025
Дата публикации / Published 19.12.2025

https://doi.org/10.26898/0370-8799-2025-12-12
УДК 639.3.043.13
Тип статьи: оригинальная
Type of article: original

Влияние использования в кормах про- и пребиотиков на физиологические показатели личинок тиляпии

Пономарева Е.Н.[1], (✉)Ширина Ю.М.[1], Григорьев В.А.[1], Сорокина М.Н[1], Файзулина Д.Р.[2], Ковалева А.В.[2], Мазанко М.С.[3]
[1]*Федеральный исследовательский центр Южный научный центр Российской академии наук*
Ростов-на-Дону, Россия
[2]*Астраханский государственный технический университет*
Астрахань, Россия
[3]*Донской государственный технический университет*
Ростов-на-Дону, Россия
(✉)e-mail: uliabakaneva@yandex.ru

Исследовано влияние использования в кормах про- и пребиотиков на некоторые физиологические (рыбоводно-биологические и гематологические) показатели личинок тиляпии. Объектом исследования являлись личинки нильской тиляпии (*Oreochromis niloticus*), перешедшие на активное питание. Рыбу разделили на 4 группы: контрольная – корм без добавления пробиотического препарата и 3 опытные: 1-я – корм с добавлением пребиотика инулина; 2-я – корм с добавлением пробиотического препарата + инулин; 3-я – корм с добавлением пробиотического препарата. Эксперимент проводился в лаборатории аквакультуры и водных биоресурсов Южного научного центра Российской академии наук. Экспериментальные партии кормов, в том числе корма с добавлением пробиотического препарата, содержащего штаммы бактерий *Bacillus velezensis* и обладающего ферментативной активностью, а также пребиотика инулина были изготовлены в Донском государственном техническом университете. В течение первых 6 недель эксперимента прирост массы был выше в 3-й группе. На этом этапе можно говорить о раннем воздействии на микрофлору личинок и о перспективности применения пробиотического препарата для повышения выживаемости и темпа роста на начальных этапах выращивания. Затем прирост массы в 3-й группе незначительно снизился: это может свидетельствовать о том, что пробиотики могут модулировать микрофлору кишечника и со временем вызывать негативные эффекты, однако эти данные не были подтверждены гематологическими показателями, которые во всех группах были в пределах референсных значений, характерных для данного вида. Достаточно высокие уровни гемоглобина, количества эритроцитов и тромбоцитов, лейкоцитарный индекс интоксикации по В.К. Островскому свидетельствовали о положительном влиянии инулина и пробиотического препарата на состояние здоровья тиляпии. Таким образом, применение пребиотика инулина и пробиотического препарата, содержащего штаммы бактерий *Bacillus velezensis*, оказало положительный эффект на здоровье и иммунитет молоди тиляпии.

Ключевые слова: пробиотический препарат, пребиотик инулин, личинки, тиляпия, рыбоводно-биологические и физиологические показатели

The effect of using pro- and prebiotics in feed on the physiological parameters of tilapia larvae

Ponomareva E.N.[1], (✉)Shirina Yu.M.[1], Grigoriev V.A.[1], Sorokina M.N.[1], Faizulina D.R.[2], Kovaleva A.V.[2], Mazanko M.S.[3]
[1]*Federal Research Centre the Southern Scientific Centre of the Russian Academy of Sciences*
Rostov-on-Don, Russia
[2]*Astrakhan State Technical University*
Astrakhan, Russia
[3]*Don State Technical University*
Rostov-on-Don, Russia
(✉)e-mail: uliabakaneva@yandex.ru

The effect of the use of pro- and prebiotics in feed on some physiological (fish-biological and hematological) parameters of tilapia larvae has been studied. The object of the study was the larvae of the Nile tilapia (Oreochromis niloticus), which switched to active nutrition. The fish were divided into 4 groups: control – feed without the addition of a probiotic drug; experiment 1 – feed with the addition

of the prebiotic inulin; experiment 2 – feed with the addition of a probiotic drug + inulin; experiment 3 – feed with the addition of a probiotic drug. The experiment was conducted at the Laboratory of Aquaculture and Aquatic Bioresources of the Southern Scientific Centre of the Russian Academy of Sciences. Experimental batches of feed, including feed with the addition of a probiotic drug containing strains of Bacillus velezensis bacteria and possessing enzymatic activity, as well as the inulin prebiotic, were manufactured at the Don State Technical University. During the first 6 weeks of the experiment, weight gain was higher in the experiment 3. At this stage, we can talk about early effects on the microflora of larvae and the prospects of using a probiotic drug to increase survival and growth rate at the initial stages of cultivation. Then the weight gain in the experiment 3 decreased slightly, which may indicate that probiotics can modulate the intestinal microflora and cause negative effects over time, but these data have not been confirmed by hematological parameters, which in all groups were within the limits of the reference values typical for this species. Sufficiently high levels of hemoglobin, the number of red blood cells and platelets, and the leukocyte intoxication index according to V.K. Ostrovsky testified to the positive effect of inulin and a probiotic drug on tilapia's health. Thus, the use of the prebiotic inulin and a probiotic drug containing bacterial strains of Bacillus velezensis had a positive effect on the health and immunity of juvenile tilapia.

Keywords: probiotic preparation, prebiotic inulin, larvae, tilapia, fish farming biological and physiological indicators

Для цитирования: *Пономарева Е.Н., Ширина Ю.М., Григорьев В.А., Сорокина М.Н., Файзулина Д.Р., Ковалева А.В., Мазанко М.С.* Влияние использования в кормах про- и пребиотиков на физиологические показатели личинок тиляпии // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 12. С. 111–119. https://doi.org/10.26898/0370-8799-2025-12-12

For citation: *Ponomareva E.N., Shirina Yu.M., Grigoriev V.A., Sorokina M.N., Faizulina D.R., Kovaleva A.V., Mazanko M.S.* The effect of using pro- and prebiotics in feed on the physiological parameters of tilapia larvae. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 12, pp. 111–119. https://doi.org/10.26898/0370-8799-2025-12-12

Конфликт интересов
Авторы заявляют об отсутствии конфликта интересов.
Conflict of interest
The authors declare no conflict of interest.

Благодарность
Публикация подготовлена в рамках реализации гранта РНФ «Стратегия молекулярной аквакультуры в разработке новых синбиотических препаратов для улучшения здоровья и качества рыбы» (соглашение № 23-76-30006 от 13.04.2023).
Acknowledgements
This publication was prepared within the framework of the Russian Science Foundation grant “Molecular aquaculture strategy for the development of new synbiotic preparations to improve fish health and quality” (agreement No. 23-76-30006 dated April 13, 2023).

INTRODUCTION

Over the past decades, aquaculture as an industry has begun to develop more rapidly, which has led to a deterioration of the environment and a decrease in the productivity of some species. The need to increase disease resistance, growth of aquatic organisms, and feeding efficiency has led to the use of pro- and prebiotics in aquaculture [1].

Probiotics are live microorganisms that, when used correctly, have a positive effect on the health of the body [2]. They increase the digestibility of nutrients in farmed fish, which leads to accelerated growth and improved feed conversion. Prebiotics are indigestible food ingredients that have a beneficial effect on the host's health by selectively stimulating the growth and/or activity of beneficial bacteria and combating undesirable bacteria in the gastrointestinal tract [3]. The use of pro- and prebiotics in tilapia farming is considered a viable, safe, and environmentally friendly alternative that increases growth rates, improves feed utilization, strengthens immunity, enhances disease resistance, and survival of fish under conditions of pathogens and environmental stress [4].

Although probiotics represent a promising alternative for the use of chemicals (for disinfection, feed additives, disease treatment in fish, and water purification) and antibiotics in aquaculture and help protect against diseases, it is necessary to consider the benefits that probiot-

ics bring to the hosts when used in aquaculture. Various factors, such as the source, dose, and duration of administration of pro- and prebiotics, can affect their immunomodulatory activity [5]. Understanding the mechanisms of action, as well as the appropriate methods of application, may be the key to the use of pro- and prebiotics in aquatic systems [6].

The purpose of the work is to assess the impact of using pro- and prebiotics in feed on certain physiological indicators of tilapia larvae.

MATERIAL AND METHODS

The experiment was conducted in the laboratory of aquaculture and aquatic biological resources of the Southern Scientific Center of the Russian Academy of Sciences. Experimental batches of feed, including feed with the addition of a probiotic preparation containing strains of *Bacillus velezensis* bacteria, which have enzymatic activity, as well as the prebiotic inulin, were produced at the Don State Technical University. The control and experimental batches of feed included the following components: wheat, chicken meat and bone meal, pork meat meal, fish meal, blood meal, feed yeast, corn gluten, flaxseed cake, dehulled soybean cake, premix, rapeseed oil, fish oil, experimental probiotic preparation, prebiotic inulin. The protein/fat ratio in the feed was 45/12. The probiotic preparation and inulin were added to the feed mixture in dry form at a rate of 50 g/kg of feed. The pellet diameter depended on the larva's size (from fine dust to 1–2 mm).

The object of the study was the larvae of Nile tilapia (*Oreochromis niloticus*) that had switched to active feeding. The transported larvae were placed in laboratory conditions in aquariums with a water temperature of 25 ± 0.42 °C and were not fed for 4 hours to allow them to adapt to the change in the environment.

After adaptation, the larvae were randomly distributed into 4 aquariums with a volume of 50 liters, 58 individuals in each. Fish of the control group received feed without the addition of a probiotic preparation; the 1st experimental group – feed with the addition of the prebiotic inulin; the 2nd experimental group – feed with the addition of the probiotic preparation + inulin; the 3rd experimental group – feed with the addition of the probiotic preparation.

Fish feeding was carried out manually during the daytime at intervals of every 2 hours until visible satiety, at a rate of 12% of the total fish biomass in each aquarium. The duration of the experiment was 60 days. Lighting was maintained on a 12:12 h light/dark cycle under artificial illumination. контрольные взвешивания производили с помощью электронных весов OHAUS PA-2102 (accuracy class according to GOST OIML R 76-1–2011[1] – high), the linear dimensions of the studied fish were determined using a millimeter tape. Water quality was assessed daily. Water temperature and dissolved oxygen were measured using an OxyGuard Handy Polaris oximeter (accuracy ± 0.2 °C), pH – using a portable Hanna pH meter. At the end of the experiment, based on biometric measurements, the main growth indicators were determined: absolute and average daily weight gain, mass accumulation coefficient, average daily and specific growth rate[2, 3]. For hematological analyses in juvenile tilapia, blood was collected by cutting off the tail stem. In fresh blood samples, the amount of hemoglobin, erythrocytes, and the calculated indicator of the mean hemoglobin content in erythrocytes (MCH) were determined. Prepared blood smears were air-dried and stained with the eosin-methylene blue fixative dye according to May-Grünwald. Using an Olympus BX53 microscope (Japan), the ratio of erythroid series cells, the types and number

[1]GOST OIML R 76-1–2011. State system for ensuring the uniformity of measurements. Non-automatic weighing instruments. Moscow: Standartinform, 2013, 132 p.

[2]*Lugert V.* A review on fish growth calculation: multiple functions in fish production and their specific application // Reviews in Aquaculture, 2016, vol. 8, N 1, pp. 30–42.

[3]*Castell J.D., Tiews K.* Report of the EIFAC, IUNS and ICES Working Group on the standardization of the methodology in fish nutrition research. Hamburg (Federal Republic of Germany, March 21-23, 1979). EIFAC tech. pap., 36, 1979, pp. 1–24.

of pathomorphological changes in erythrocytes, the number of platelets, and the leukocyte formula were determined. Calculated indicators (the coefficient of basophilic normoblasts/polychromatic normoblasts (BN/PN), Krebs index, Bredeck coefficient, leukocyte intoxication index (LII) according to V.K. Ostrovsky, leukocyte abundance index) were determined according to standard methods and formulas [7, 8].

Statistical data analysis was conducted using the descriptive statistics method. Data are presented as mean ± standard error ($M \pm m$). For normally distributed data, differences were considered significant according to Student's parametric criterion ($p < 0.05$); for abnormally distributed data, differences between the samples were assessed according to the non-parametric Mann–Whitney criterion ($p < 0,05$).

RESULTS AND DISCUSSION

The water temperature during the experiment in the aquariums was 25–27 ºC, the dissolved oxygen content in the water was 5.66–6.6 mg/l, and the pH was 4.9–7.1. During the first 6 weeks of the experiment, the weight gain was higher in the 3rd experimental group, where the feed was supplemented with a probiotic preparation (see Table 1, Fig. 1). The absolute gain during this period in the 3rd group was 1.5 g, which is higher compared to the control, 1st, and 2nd experimental groups by 0.7, 0.4, and 0.6 g respectively (see Fig. 1). The average daily gain indicators did not differ and were 0.034, 0.039, 0.316, and 0.0322 g. At this stage, it is possible to speak of early effects on the larvae's microflora and the prospects of using a probiotic preparation to increase survival and growth rate in the initial stages of cultivation. Then the weight gain in the 3rd experimental group decreased slightly: this may indicate that probiotics can modulate the gut microflora and over time cause negative effects, however, these data were not confirmed by hematological indicators.

At the end of the experiment, the best results were observed in the first group, where the feed was supplemented with the prebiotic inulin. The absolute gain in this group was 2.3 g, which is higher compared to the control and the second and third experimental groups by 2.0, 0.5, and 0.4 g, respectively. As can be seen, the differenc-

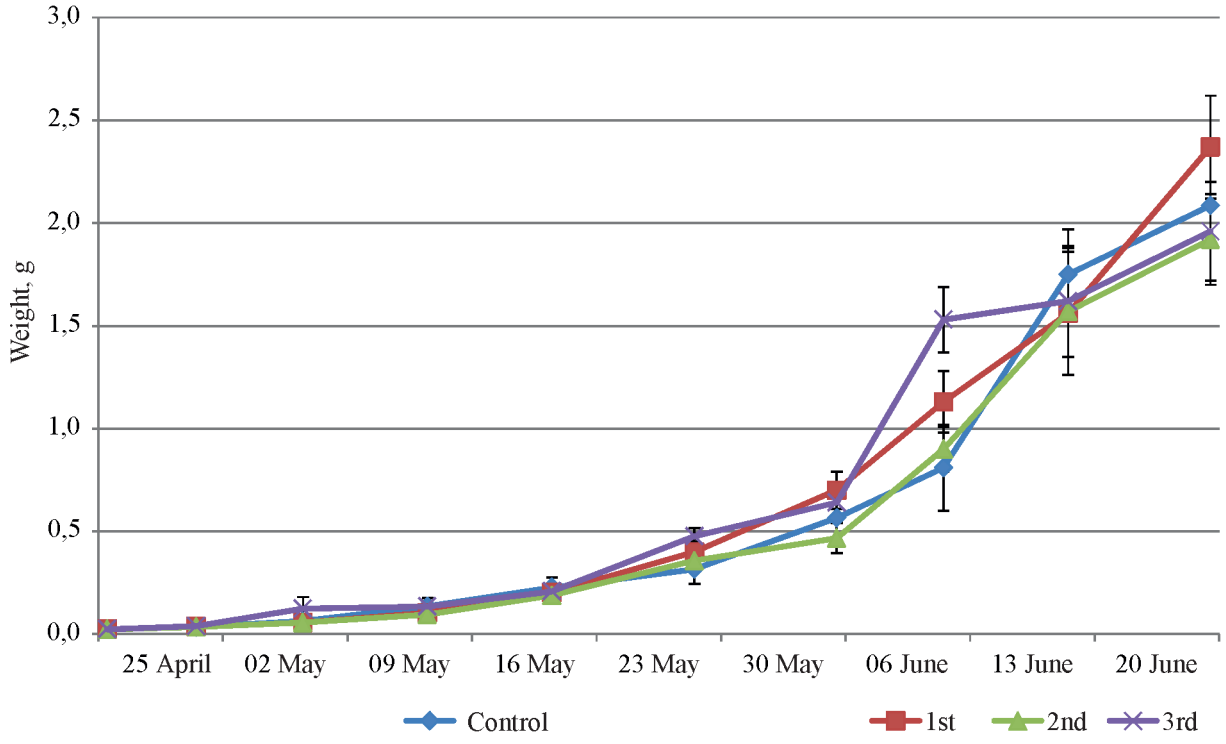


Рис. 1. Прирост массы личинок тиляпии на контрольном и опытных кормах
Fig. 1. Weight gain of tilapia larvae on control and experimental feeds

Табл. 1. Рыбоводно-биологические показатели личинок тиляпии, выращенной на кормах с введением пре- и пробиотиков

Table 1. Fish farming and biological indicators of tilapia larvae grown on the feed with the introduction of pre- and probiotics

Indicator	Group			
	Control	1st	2nd	3rd
Initial mass, g	0,024 ± 0,0088			
Final mass, g	2,086 ± 0,22	2,37 ± 0,25	1,92 ± 0,22	1,96 ± 0,24
Absolute initial length, mm	1,23 ± 0,023			
Absolute final length, mm	4,97 ± 0,16	4,99 ± 0,21	4,46 ± 0,16	4,71 ± 0,22
Absolute gain, g	2,062	2,346	1,896	1,936
Daily average gain, g	0,034	0,039	0,0316	0,0322
Daily average growth rate, %	7,89	8,12	7,73	7,77
Specific growth rate, %	3,23	3,32	3,17	3,19
Mass accumulation coefficient, units	0,049	0,052	0,047	0,048
Survival rate, %	81	66	78	66
Duration of the experiment, days.	60			

es in weight turned out to be insignificant and cannot directly indicate insufficient effectiveness of the probiotic preparation, which is further confirmed by hematological indicators.

Hematological indicators of Nile tilapia juveniles in control and experimental groups are presented in Table 2. Significant differences between hematological indicators were found in individuals of the 1st and 2nd groups. The hemoglobin level differed between individuals of different groups, although not significantly. The highest indicator was characteristic of the 1st group of fish, and the lowest – of the 2nd group, although in all groups the values did not exceed the reference range typical for tilapia juveniles (65.8–159.8 g/l) [9].

The fish from the 1st and 3rd experimental groups are closest to the optimal values [10]. The average number of red blood cells in the blood of tilapia in all groups was within the reference range for this species – 0.7–2.8 million/µl [9]. However, the highest level was recorded in the fish from the 3rd group, and the lowest in the control group. The average hemoglobin content in the erythrocytes of Nile tilapia was normal only in the fish that received experimental feeds – 5.0–80.4 pg (according to A.S.H. Hamid et al.[4]), while in the control group this indicator was significantly higher than the reference limits (see Table 2), which is apparently associated with a compensatory reaction to a low level of erythrocytes in the blood.

In microscopic examination of blood smears from juvenile tilapia, basophilic, polychromatophilic, and oxyphilic normoblasts were detected, erythroblasts were not observed (see Fig. 2). The highest erythropoiesis activity was observed in Group 1: here, the proportion of young erythrocyte forms and the BN/PN coefficient were also the highest (see Table 2). The lowest number of abnormal erythrocytes was recorded in fish from the 1st and 2nd experimental groups, the highest – in the control group, although, overall, it was low in all fish. The following erythrocyte abnormalities were identified: changes in shape (mainly dacryocytes) and size, micronuclei in erythrocytes, nuclear invagination, cytoplasmic vacuolization, erythrocytes with scalloped edges, hypochromia of erythrocytes, hemolyzed cells and nuclear shadows, agglutination, amitosis (see Fig. 2).

As studies have shown, platelets are involved in the process of hemostasis and play a protec-

[4]*Hamid A.S.H., Ahmed M.F.A., Mohammed A.M.I., Ali M.S.I.* Physical and chemical caracteristics of blood of two fish species (*Oreochromis niloticus* and *Clarias lazera*) // World's Veterinary Journal, 2013, vol. 3 (1), pp. 17–20.

Табл. 2. Гематологические показатели молоди тиляпии
Table 2. Hematological parameters of juvenile tilapia

Indicator	Group			
	Control	1st	2nd	3rd
Hemoglobin, g/l	73,5 ± 0,35	96,5 ± 6,72	52,0 ± 3,54	80,0 ± 1,41
Number of erythrocytes, mln/µl	1,06 ± 0,62	1,53 ± 0,34	1,58 ± 0,16	2,18 ± 0,20
MCH, pg	165,54 ± 112,33	68,99 ± 16,94	33,05 ± 0,84	37,03 ± 2,23
Immature erythrocytes, %	5,60 ± 1,09	7,63 ± 0,33[1–2]	5,80 ± 0,24[1–2]	6,05 ± 1,09
Adult erythrocytes, %	94,40 ± 1,09	92,38 ± 0,33[1–2]	94,20 ± 0,24[1–2]	93,95 ± 1,09
BN/PN coefficient	2,80 ± 0,75	2,86 ± 0,43[1–2]	2,35 ± 0,30[1–2]	2,40 ± 0,10
Abnormal erythrocytes, %	8,45 ± 1,09	7,45 ± 1,11	7,00 ± 1,26	8,28 ± 1,18
Platelets, pcs./1000 er.	59,00 ± 7,14	50,00 ± 19,58	28,25 ± 2,10	40,00 ± 7,07
Leucocytary formula				
Myelo- and metamyelocytes, %	5,75 ± 1,31	6,00 ± 2,12	4,00 ± 1,08	3,00 ± 0,58
Lymphocytes, %	89,00 ± 1,78	88,25 ± 3,61	88,75 ± 2,93	93,50 ± 1,44
Band eosinophils, %	0,75 ± 0,25	0,25 ± 0,25	1,50 ± 1,19	0,00
Segmented eosinophils, %	0,75 ± 0,25	0,25 ± 0,25	0,50 ± 0,29	0,00
Basophils, %	0,00	0,00	0,00	0,50 ± 0,29
Band neutrophils, %	2,00 ± 0,41	3,25 ± 2,29	3,00 ± 0,71	1,75 ± 0,48
Segmented neutrophils, %	1,75 ± 0,48	2,00 ± 1,08	2,25 ± 0,25	1,25 ± 0,25
Leukocyte indices				
Krebs index, c. u.	0,04 ± 0,01	0,06 ± 0,03	0,06 ± 0,01	0,03 ± 0,01
Bredeck coefficient, c. u.	52,67 ± 14,25	48,43 ± 23,73	34,54 ± 7,13	66,96 ± 17,05
LII, c. u.	0,11 ± 0,02	0,13 ± 0,05	0,10 ± 0,02	0,06 ± 0,01
Leukocyte abundance index, un. /p.f.	2,23 ± 0,45	2,49 ± 0,39	4,78 ± 1,65	1,95 ± 0,21

Note. MCH – mean corpuscular haemoglobin; BN/PN – basophilic normoblasts / polychromatophilic normoblasts; LII – leukocytal intoxication index; er. – erythrocytes; un. /p.f. – units per field.

* Statistically significant differences between fish groups ([1] – experiment 1, [2] – experiment 2) ($p < 0,05$).

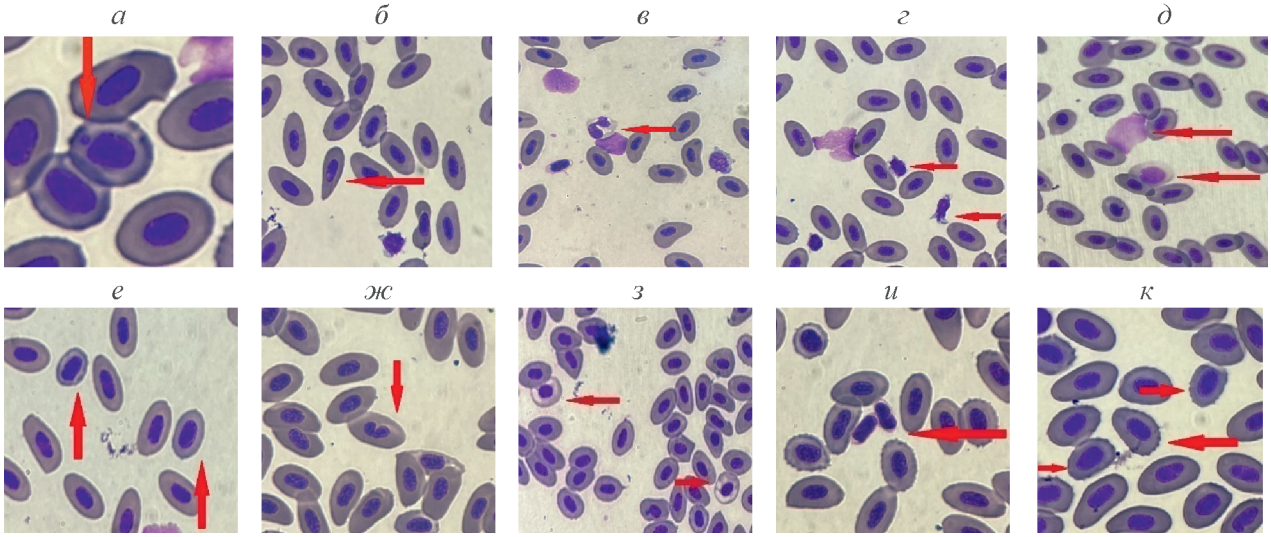


Рис. 2. Клетки крови тиляпии:
а – эритроцит (нормобласт) с микроядром; *б* – аномальная форма эритроцита; *в* – нейтрофил; *г* – лимфоциты; *д* – ядерная тень и лизис эритроцита; *е* – нормобласты; *ж* – инвагинация ядра эритроцита; *з* – гипохромазия эритроцитов; *и* – тромбоциты; *к* – фестончатый край у эритроцитов

Fig. 2. Tilapia blood cells:
а – red blood cell (normoblast) with a micronucleus; *б* – abnormal shape of a red blood cell; *в* – neutrophil; *г* – lymphocytes; *д* – nuclear shadow and lysis of a red blood cell; *е* – normoblasts; *ж* – invagination of the red blood cell nucleus; *з* – hypochromasia of red blood cells; *и* – platelets; *к* – fringed edge of red blood cells

tive role in the bodies of fish[5]. Among the experimental groups, the highest level was noted in the fish from the 1st group, which contributed to an increase in immunity due to an increase in the absolute number of platelets.

Microscopic analysis of blood smears from Nile tilapia juveniles revealed the presence of lymphocytes (small and large), eosinophilic, neutrophilic, and basophilic granulocytes, monocytes were not detected (see Table 2, Fig. 2).

The ratio of leukocytes in all groups of fish was characteristic of the juveniles of this species [11]. In the fish of the 3rd group, an increase in the number of lymphocytes and a decrease in the relative content of neutrophils were observed (see Table 2). This turned out to be very typical for Nile tilapia when using probiotics in feeding, which indicates the activation of the specific branch of immune defense, primarily provided by T- and B-lymphocytes.

A lower level of neutrophils and the absence of eosinophils in the blood of tilapia receiving only the probiotic, unlike the control and other groups, indicates an enhancement of the nonspecific branch of cellular immunity, which does not require its activation [12].

The Krebs index, which indirectly characterizes the activity of phagocytic reactions and specific immune factors, as well as their involvement in maintaining the overall reactivity of the organism, was highest in the 1st and 2nd groups, indicating the activation of a protective response. The Bredeck coefficient was highest in fish of the 3rd group. Its increase indicates a rise in the level of nonspecific resistance, while a decrease is a sign of the opposite process. [13]. However, in the 3rd group, the lowest survival of larvae was observed during the experimental period, which probably did not depend on feeding characteristics, and the activation of nonspecific resistance and the formation of cellular immunity are associated with the mobilization of the body's defense forces. Meanwhile, the LII was highest in the fish that were given the prebiotic inulin in their feed. A decrease in this index may indicate suppression of leukopoiesis centers, an immunosuppressive condition. This can also be evidenced by a reduction in the leukocyte abundance index. It was almost the same in all fish, except for the fish in the 2nd group, in which it was higher.

CONCLUSION

The assessment of fish-farming biological and physiological indicators of tilapia juveniles fed diets supplemented with pro- and prebiotics allows us to conclude about their favorable condition. The growth of larvae in all groups was uniform, differences between the groups in weight were insignificant (data not significant), and hematological parameters were within the reference values characteristic of this species. Relatively high levels of hemoglobin, red blood cells, and platelets, as well as the LII, indicated the positive effect of pro- and prebiotics on the health status of tilapia. Thus, the use of a probiotic preparation containing strains of *Bacillus velezensis* bacteria, as well as the prebiotic inulin, had a positive effect on the health and immunity of tilapia juveniles.

СПИСОК ЛИТЕРАТУРЫ

1. *Kochetkova N.I., Nikiforov-Nikishina D.L., Klimuka A.A., Smorodinskayaa S.V., Nikiforov-Nikishina A.L., Marsovab M.V., Vatlinb A.A., Klimov V.A.* Modern approaches to investigating the effectiveness of probiotics in aquaculture // Biology Bulletin Reviews. 2024. Vol. 14. Suppl. 3. P. 376–404.
2. *Todorov S.D., Lima J.M.S., Bucheli J.E.V., Popov I.V., Tiwari S.K., Chikindas M.L.* Probiotics for aquaculture: hope, truth, and reality // Probiotics and Antimicrobial Proteins. 2024. Vol. 16. P. 2007–2020.
3. *Mugwanya M., Dawood M.A.O., Kimera F., Sewilam H.* Updating the role of probiotics, prebiotics, and synbiotics for tilapia aquaculture as leading candidates for food sustainability: a review // Probiotics and Antimicrobial Proteins. 2022. Vol. 14. P. 130–157.
4. *Kuebutornye F.K.A., Abarike E.D., Sakyi M.E., Lu Y., Wang Z.* Modulation of nutrient utilization, growth, and immunity of Nile tilapia (Oreochro-

[5]*Tavares-Dias M., Oliveira S.* A review of the blood coagulation system of fish // Brazilian Journal of Biological Sciences. 2009. Vol. 7. P. 205–224.

mis niloticus) // Aquaculture International. 2020. Vol. 28. P. 277–291.
5. *Torres-Maravilla E., Parra M., Maisey K., Vargas R.A., Cabezas-Cruz A., Gonzalez A., Tello M., Bermúdez-Humarán L.G.* Importance of probiotics in fish aquaculture: towards the identification and design of novel probiotics // Microorganisms. 2024. Vol. 12. P. 1–32.
6. *Rathod A.C., Khedkar C.D., Sarode A.R., Kalyankar S.D., Deosarkar S.S., Lule V.K., Patil P.S.* Commercially available probiotic products for wellbeing of mankind, livestock and fishery: a review // Asian Journal of Dairy and Food Research. 2025. Vol. 44 (1). P. 1–7. DOI: 10.18805/ajdfr.DR-1803.
7. *Егорова В.И., Волкова И.В*. Динамика интегральных гематологических индексов рыб при хронической интоксикации // Рыбное хозяйство. 2024. № 1. С. 81–88.
8. *Пронина Г.И., Саная О.В.* Сравнительная физиолого-иммунологическая характеристика рыб семейства цихловые и карповые // Известия Тимирязевской сельскохозяйственной академии. 2020. № 6. С. 26–33.
9. *Tabassum T., Mahamud S.U., Acharjee T.K., Hassan R., Snigdha T., Islam T., Akter F., Azad R., Al Mahamud A., Ahmed G., Rahman T.* Probiotic supplementations improve growth, water quality, hematology, gut microbiota and intestinal morphology of Nile tilapia // Aquaculture Reports. 2021. Vol. 21. P. 100972.
10. *Zafar Md.A., Roni M., Rana M., Akter N.* Growth, digestive enzyme activities, proximate composition and hemato-biochemcial responses of juvenile Nile tilapia (Oreochromis niloticus) reared at various stocking densities in a recirculatory aquaculture system // Journal of Applied Aquaculture. 2022. Vol. 35. P. 1–23.
11. *Rezende R.A.E., Soares M.P., Sampaio F.G., Cardoso I., Dallago B.S.L., Rantin F.T., Teixeira M.C*. Phytobiotics blend as a dietary supplement for Nile tilapia health improvement // Fish & Shellfish Immunology. 2021. Vol. 114. P. 293–300.
12. *Пронина Г.И., Саная О.В., Дернаков В.В., Черкалин А.И., Уварова Е.Ю., Хрупкин В.М.* Применение пробиотика "Субтилис-С" при разведении нильской тиляпии (*Oreochromis niloticus*) // Рыбоводство и рыбное хозяйство. 2022. Т. 16. № 3 (194). С. 201–211.
13. *Леонов В.В., Павлова О.Н., Гуленко О.Н., Кузнецова О.Г., Варфоломеева Л.Г.* Интегральные гематологические индексы как способ оценки реактивных изменений крови на нагрузку антиоксидантами // Вестник новых медицинских технологий. Электронное издание. 2022. № 4. С. 133–140.

REFERENCES

1. Kochetkova N.I., Nikiforov-Nikishina D.L., Klimuka A.A., Smorodinskayaa S.V., Nikiforov-Nikishina A.L., Marsovab M.V., Vatlinb A.A., Klimov V.A. Modern approaches to investigating the effectiveness of probiotics in aquaculture. *Biology Bulletin Reviews*, 2024, vol. 14, suppl. 3. pp. 376–404.
2. Todorov S.D., Lima J.M.S., Bucheli J.E.V., Popov I.V., Tiwari S.K., Chikindas M.L. Probiotics for aquaculture: hope, truth, and reality. *Probiotics and Antimicrobial Proteins*, 2024, vol. 16, pp. 2007–2020.
3. Mugwanya M., Dawood M.A.O., Kimera F., Sewilam H. Updating the role of probiotics, prebiotics, and synbiotics for tilapia aquaculture as leading candidates for food sustainability: a review. *Probiotics and Antimicrobial Proteins,* 2022, vol. 14, pp. 130–157.
4. Kuebutornye F.K.A., Abarike E.D., Sakyi M.E., Lu Y., Wang Z. Modulation of nutrient utilization, growth, and immunity of Nile tilapia (Oreochromis niloticus). *Aquaculture International*, 2020, vol. 28, pp. 277–291.
5. Torres-Maravilla E., Parra M., Maisey K., Vargas R.A., Cabezas-Cruz A., Gonzalez A., Tello M., Bermúdez-Humarán L.G. Importance of probiotics in fish aquaculture: towards the identification and design of novel probiotics. *Microorganisms,* 2024, vol. 12, pp. 1–32.
6. Rathod A.C., Khedkar C.D., Sarode A.R., Kalyankar S.D., Deosarkar S.S., Lule V.K., Patil P.S. Commercially available probiotic products for wellbeing of mankind, livestock and fishery: a review. *Asian Journal of Dairy and Food Research*, 2025, vol. 44 (1), pp. 1–7. DOI: 10.18805/ajdfr.DR-1803.
7. Egorova V.I., Volkova I.V. Dynamics of integral hematological indices of fish in chronic intoxication. *Rybnoye Khozyaistvo = Fisheries,* 2024, no. 1, pp. 81–88. (In Russian).
8. Pronina G.I., Sanaya O.V. Comparative physiological and immunological characteristics of fish species of cichlidae and cyprinidae families. *Izvestiya Timiryazevskoi Sel'skokhozyaistvennoi Akademii = Izvestiya of Timiryazev Agricultural*

Academy, 2020, no. 6, pp. 26–33. (In Russian)
9. Tabassum T., Mahamud S.U., Acharjee T., Hassan R., Snigdha T., Islam T., Akter F., Azad R., Al Mahamud A., Ahmed G., Rahman T. Probiotic supplementations improve growth, water quality, hematology, gut microbiota and intestinal morphology of Nile tilapia. *Aquaculture Reports,* 2021, vol. 21, pp. 100972.
10. Zafar Md. A., Roni M., Rana M., Akter N. Growth, digestive enzyme activities, proximate composition and hemato-biochemcial responses of juvenile Nile tilapia (Oreochromis niloticus) reared at various stocking densities in a recirculatory aquaculture system. *Journal of Applied Aquaculture*, 2022, vol. 35, pp. 1–23.
11. Rezende R.A.E., Soares M.P., Sampaio F.G., Cardoso I., Dallago B.S.L., Rantin F.T., Teixeira M.C. Phytobiotics blend as a dietary supplement for Nile tilapia health improvement. *Fish & Shellfish Immunology,* 2021, vol. 114, pp. 293–300.
12. Pronina G.I., Sanaya O.V., Dernakov V.V., Cherkalin A.I., Uvarova E.Yu., Khrupkin V.M. The use of the probiotic Subtilis-C in the breeding of the Nile tilapia (Oreochromis niloticus). *Rybovodstvo i Rybnoye Khozyaistvo = Fish Breeding and Fisheries,* 2022, vol. 16, no. 3 (194), pp. 201–211. (In Russian).
13. Leonov V.V., Pavlova O.N., Gulenko O.N., Kuznetsova O.G., Varfolomeeva L.G. Integral hematological indices as a way for assessing reactive blood changes under to load with antioxidants. *Vestnik Novykh Meditsinskikh Tekhnologii. Elektronnoye izdanie = Journal of New Medical Technologies. eEdition,* 2022, no. 4, pp. 133–140. (In Russian).

СВЕДЕНИЯ ОБ АВТОРАХ

Пономарева Елена Николаевна, главный научный сотрудник, доктор биологических наук, профессор; SPIN-код 4917-1435

(✉)**Ширина Юлия Михайловна,** научный сотрудник, кандидат сельскохозяйственных наук, доцент; SPIN-код 9216-0545; **адрес для переписки:** Россия, 344006, Ростов-на-Дону, пр. Чехова, 41; e-mail: uliabakaneva@yandex.ru

Григорьев Вадим Алексеевич, ведущий научный сотрудник, кандидат биологических наук; SPIN-код 7185-4077

Сорокина Марина Николаевна, ведущий научный сотрудник, кандидат биологических наук, доцент; SPIN-код 1850-7215

Файзулина Дина Рубиновна, старший преподаватель; SPIN-код 2734-3805

Ковалева Анжелика Вячеславовна, старший научный сотрудник, кандидат биологических наук; SPIN-код 1943-4189

Мазанко Мария Сергеевна, ведущий научный сотрудник, кандидат биологических наук; SPIN-код 2849-1879

AUTHOR INFORMATION

Elena N. Ponomareva, Head Researcher, Doctor of Science in Biology, Professor; SPIN-code 4917-1435

(✉)**Yulia M. Shirina,** Researcher, Candidate of Science in Agriculture, Associate Professor; SPIN-код 9216-0545; **address:** 41, Chekhov ave., Rostov-on-Don, 344006, Russia; e-mail: uliabakaneva@yandex.ru

Vadim A. Grigoriev, Lead Researcher, Candidate of Science in Biology; SPIN-code 7185-4077

Marina N. Sorokina, Lead Researcher, Candidate of Science in Biology, Associate Professor; SPIN-code 1850-7215

Dina R. Faizulina, Senior Lecturer; SPIN-code 2734-3805

Anjelika V. Kovaleva, Senior Researcher, Candidate of Science in Biology; SPIN-code 1943-4189

Maria S. Mazanko, Lead Researcher, Candidate of Science in Biology; SPIN-code 2849-1879

Дата поступления статьи / Received by the editors 04.08.2025
Дата принятия к публикации / Accepted for publication 02.10.2025
Дата публикации / Published 19.12.2025

https://doi.org/10.26898/0370-8799-2025-12-13
УДК 631.461:631
Тип статьи: обзорная
Type of article: review

Полвека изучения плодородия черноземов Сибири (к 45-летию со дня образования лаборатории плодородия почв СибНИИ кормов СФНЦА РАН)

(✉)**Данилова А.А., Ткаченко Г.И., Колбин С.А.**
Сибирский федеральный научный центр агробиотехнологий Российской академии наук
Новосибирская область, р.п. Краснообск, Россия
(✉)e-mail: Danilovaaa@sfsca.ru

Представлен краткий обзор результатов исследований плодородия почв Сибири. Проведен количественный анализ продукционного процесса зерновых в годы с различными погодными условиями; экспериментально обосновано отсутствие необходимости в специальном регулировании содержания гумуса в почве. Вскрыта роль мобильной фракции органического вещества почвы в стабилизации запасов гумуса. Установлена возможность миграции азота за пределы корнеобитаемого слоя при среднегодовом балансе азота, близком к бездефицитному. Предложена методика расчета сравнительной эффективности биологического и технического азота в конкретных агротехнологических условиях. Обоснована необходимость расчета доз фосфорных удобрений под зерновые на основе величины отчуждения элемента с урожаем зерна. Показано, что для условий лесостепи Приобья доза $P_{40–60}$, рекомендованная для почв Российской Федерации, является избыточной и не окупается урожаем зерна. Оценен вклад комплекса средств химизации в приросте урожайности яровой пшеницы: вклад гербицидов составляет около 10%, фунгицидов – 20, минеральных удобрений – 70% при окупаемости 1 кг д.в. 12,4 кг зерна. Предложена типизация лет по погодным условиям для расчета экономической целесообразности применения удобрений в разные по условиям увлажнения годы. Создана программа Agroten для принятия решений по применению средств интенсификации в технологиях выращивания культур. Сформулированы почвенно-микробиологические основы минимизации основной обработки почв в Приобье. Защищены патентами Российской Федерации новые способы оценки устойчивости микробиома почв к воздействию агрогенных стресс-факторов. Предложена шкала для оценки вероятности накопления в почве остаточного количества пестицидов. Экспериментально обосновано положение, что солома является возобновляемым ресурсом агроценоза, обеспечивающим его экотоксикологическое благополучие. Завершен первый этап метагеномного анализа микробиома чернозема выщелоченного Приобья.

Ключевые слова: чернозем выщелоченный, гумус, азот, фосфор, удобрения, пестициды, микробиом почвы

Half a century of studying Siberian chernozem fertility (on the 45th anniversary of the foundation of the Soil Fertility Laboratory of the Siberian Research Institute of Fodder Crops SFSCA RAS)

(✉)**Danilova A.A., Tkachenko G.I., Kolbin S.A.**
Siberian Federal Research Centre of Agro-BioTechnologies of the Russian Academy of Sciences
Krasnoobsk, Novosibirsk region, Russia
(✉)e-mail: Danilovaaa@sfsca.ru

A brief overview of the results of the studies of soil fertility in Siberia is presented. Quantitative analysis of grain production processes in the years with varying weather conditions was conducted; experimental evidence was provided to demonstrate the absence of the need for special regulation of

humus content in the soil; the role of the mobile fraction of soil organic matter in stabilizing humus reserves was revealed. The possibility of nitrogen migration beyond the root zone was established with an average annual nitrogen balance close to the deficit-free one. The method for calculating the comparative efficiency of biological and technical nitrogen under specific agro-technological conditions was proposed. The necessity of calculating the doses of phosphorus fertilizers for grain crops based on the amount of element alienation with the grain yield was substantiated. It was shown that for the forest-steppe conditions of the Ob region, the dose of $P_{40–60}$ recommended for the soils of the Russian Federation is excessive and does not pay off in terms of grain yield. The contribution of a complex of chemicals to the increase in the yield of spring wheat was estimated: the contribution of herbicides is about 10%, fungicides – 20%, mineral fertilizers – 70% with a payback of 1 kg of active ingredient of 12.4 kg of grain. Classification of the years based on the weather conditions was proposed for calculating the economic feasibility of using fertilizers in the years with different moisture conditions. The Agroten program was created for decision-making on the use of intensification tools in crop cultivation technologies. Soil microbiological principles for minimizing primary tillage in the Ob region were formulated. New methods for assessing the resilience of soil microbiomes to agrogenic stress factors were patented by the Russian Federation. A scale for assessing the probability of accumulation of pesticide residues in soil was proposed. The idea that straw is a renewable resource for agrocenoses, ensuring their ecotoxicological well-being, was experimentally substantiated. The first stage of a metagenomic analysis of the microbiome of leached chernozem in the Ob region was completed.

Keywords: leached chernozem, humus, nitrogen, phosphorus, fertilizers, pesticides, soil microbiome

Для цитирования: *Данилова А.А., Ткаченко Г.И., Колбин С.А.* Полвека изучения плодородия черноземов Сибири (к 45-летию со дня образования лаборатории плодородия почв СибНИИ кормов СФНЦА РАН) // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 12. С. 120–128. https://doi.org/10.26898/0370-8799-2025-12-13

For citation: Danilova A.A., Tkachenko G.I., Kolbin S.A. Half a century of studying Siberian chernozem fertility (on the 45th anniversary of the foundation of the Soil Fertility Laboratory of the Siberian Research Institute of Fodder Crops SFSCA RAS). *Sibirskii vestnik sel'skhozyastvennoi nayki = Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 12, pp. 120–128. https://doi.org/10.26898/0370-8799-2025-12-13

Конфликт интересов
Авторы заявляют об отсутствии конфликта интересов.
Conflict of interest
The authors declare no conflict of interest.

Благодарность
Благодарим Ассоциацию специалистов в области молекулярной, клеточной и синтетической биологии (АМКСБ) (https://amcsb.ru) за помощь и сотрудничество в проведении метагеномного анализа почв.
Acknowledgements
We thank the Association of Specialists in Molecular, Cellular and Synthetic Biology (AMCSB) (https://amcsb.ru) for their assistance and collaboration in conducting the metagenomic analysis of soils.

The beginning of the study of pressing issues of fertilizer application in Siberia was laid by the head of the Siberian branch of VASKhNIL, I.I. Sinyagin. The expansion and deepening of soil-agrochemical research continued in 1980 with the arrival of V.I. Kiryushin as the head of the Siberian Research Institute of Agriculture and Chemization (SibNIIKhim) of the Siberian Branch of VASKhNIL. Under his leadership, a laboratory for the cycling of substances in agrocenoses was established as part of SibNIIKhim. Since 2006, it has been called the Soil Fertility Laboratory. In 2022, it was transferred to the Siberian Research Institute of Fodder Crops of the SFSCA RAS. The heads of the laboratory were Academician V.I. Kiryushin (1980–1987), Doctor of Science in Biology I.N. Sharkov (1987–2022), Doctor of Science in Biology A.A. Danilova (since 2022 to the present).

Main results of the study of the fertility of the chernozems of the Priobye (the Ob River region)

The main task of the laboratory is to develop the fundamental principles of intensifying the cultivation of agricultural crops in Siberia. The solution to the problem is based on a deep under-

standing of the characteristics of the production process in the agrocenosis.

For the first time in Siberia, a quantitative analysis of the process was carried out in the years with different weather conditions. As a result, it was established that:

– its dynamics is determined by the hydrothermal conditions of the season;

– mineral fertilizers increase the intensity of the process, but practically do not affect its dynamics.;

– on average, the stocks and growth of all fractions of the phytomass without fertilizers are lower, and the amplitude of their interannual fluctuations is wider than in the variants with fertilizers;

– the primary production of biologically similar grain agrocenoses in different regions of the temperate zone has little if any differences;

– the human-controlled components of the phytomass balance differ significantly – removal with the harvest and input into the soil[1].

The laboratory staff made a significant contribution to solving the humus problem in the country's agriculture. At the end of the 20th–21st centuries, there was a discussion in domestic agricultural science on the issues of regulating humus content in the soil, which is of great importance in determining priorities in soil fertility management. A program was adopted in the country to increase the humus content in the soil through the application of organic fertilizers, primarily peat. The process of draining swamps for raw material extraction began (as is known, later they had to be re-flooded). Under these conditions, extensive laboratory research was carried out, based on the results of which the main patterns of change in the relative loss of humus in a geographical aspect in the chernozems of Trans-Urals, Siberia, and Kazakhstan under long-term agricultural use were established. The position was substantiated that the reduction of humus content during the plowing of virgin land and the subsequent stabilization of the indicator is an inevitable process associated with a decrease in the input of plant residues[2].

In the laboratory, it was experimentally established that there is no need for special regulation of humus content in the soil, since the equilibrium level of humus can be maintained through the plant residues of cereal crops in crop rotations. At the same time, it was found that when cultivating wheat on old arable chernozem using intensive technology, the amount of resulting plant residues is sufficient to ensure high yield and the effectiveness of nitrogen fertilizer through an increase in grain. Increasing the input of plant residues into the soil (through the cultivation of cover crops or other crops in crop rotations) should be justified from the standpoint of economic feasibility, unless it is related to preventing soil degradation as a result of wind or water erosion. The role of the easily mineralizable fraction of soil organic matter in stabilizing humus reserves has been revealed. The extent of organic matter mineralization in the main zonal soils of Siberia has been determined. Methods for obtaining totally C14-labeled plant residues for studying soil organic matter transformation processes have been developed[3].

A special section of research is related to the nitrogen regime of agricultural soils. As is known, this element is the second factor, after weather conditions, limiting crop yields. With the participation of the institute's staff, the balance and transformation of nitrogen fertilizers in the soils of southern Western Siberia were studied. The dynamics of the element in the fertilizer–soil–plant system was studied using labeled N15 fertilizers. The feasibility of the localized

[1]*Shatokhina N.G.* Biological productivity and nutrient consumption in high-yielding agrocenoses of spring wheat // Siberian Herald of Agricultural Science, 1989, N5, pp. 47–54.

[2]*Kiryushin V.I., Ganzhara N.F., Kaurichev I.S., Orlov A.A., Titlyanova A.A., Fokin A.D.* The concept of optimizing the regime of soil organic matter in agro-landscapes. Moscow: Publishing House of MSKhA, 1993, 93 p.

[3]*Sharkov I.N., Danilova A.A., Prozorov A.S., Samokhvalova L.M., Bushmeleva T.I., Shepelev A.G.* Reproduction of humus as a component of the soil fertility management system: methodological manual. Novosibirsk: RAS, 2010, 36 p. DOI: 10.31251/pos.v5i2.175.

method of fertilizer application and the use of prolonged-release fertilizer forms was justified[4]. The relevance of these conclusions is partly related to the environmental problems arising from the use of nitrogen fertilizers, in particular with the migration of nitrates beyond the root zone of the soil.

Based on the results of route-expedition surveys of soils from long-term stationary experiments in the Krasnoyarsk Territory, Novosibirsk, Omsk, Kemerovo, Kurgan, and Chelyabinsk regions, it was established that with long-term use of chernozems in crop rotations with fallow, nitrate migration occurs to a depth of 3–5 meters. In non-fallow crop rotations, nitrate leaching beyond the root zone is noted only with long-term application of high doses of nitrogen fertilizers. Nitrogen losses due to downward migration increase towards the south of the chernozem zone, where an excess of mineral nitrogen for plants is noted with lower crop yields[5].

Later, during further research, the possibility of nitrogen migration beyond the root-zone layer was established under an annual average nitrogen balance close to non-deficit. Thus, over 12 years of experiments in the Priobye under spring wheat with an annual N_{90} application in the 0–200 cm layer, an additional ≈350 kg $N\text{-}NO_3$/ha accumulated – approximately one-third of the total amount of nitrogen fertilizer applied to the soil. At the same time, the majority of nitrate nitrogen (≈270 kg N/ha) was located in the soil layer 100–200 cm. It was concluded that the pursuit of obtaining maximum crop yields on Siberian chernozems using intensive technologies should be justified not only from the standpoint of economic efficiency but also of environmental safety [1].

One of the ways to make agriculture more environmentally friendly is to minimize primary soil tillage, which significantly reduces nitrate leaching beyond the root zone by limiting the rate of mineralization processes[6]. At the same time, there are concerns that this process may lead to a worsening of nitrogen nutrition of cereals and, consequently, an increase in the need for nitrogen fertilizer. We have shown that under the conditions of the Priobye forest-steppe, when using intensive technology on stubble fields, the doses of nitrogen fertilizers that ensure the maximum possible wheat yield do not differ from the plowing background [2].

In connection with the relevance of the problem of the biologization of agriculture, a comparative assessment was carried out of the economic effect of using biological and chemical nitrogen in the cultivation of spring wheat. The nitrogen uptake coefficient of wheat from ammonium nitrate averaged 80%, and from legume biomass – 20%. The cost of biological nitrogen is 2–5 times lower compared to chemical nitrogen. However, due to the low absorption coefficient, in order to achieve the same increase in wheat yield as from ammonium nitrate, the costs of applying biological nitrogen were 1.1–1.6 times higher. A calculation method is proposed for comparing the efficiency of nitrogen forms under specific agro-technological conditions[7].

Further yield increase at the present stage is impossible without the combined use of nitrogen and phosphorus fertilizers. In this regard, the relevance of rationalizing the use of phosphorus fertilizers has increased. The novelty of this new stage of research lies in the comprehensive evaluation of the phosphate reserves of leached chernozem, in the comparative determination of available phosphorus by four methods, and in the assessment of the element's uptake by spring wheat under different hydrothermal conditions of the growing season.

[4]*Gamzikov G.P., Kostrik G.I., Emelyanova V.N.* Balance and transformation of fertilizer nitrogen. Novosibirsk: Nauka, 1985, 161 p.

[5]*Kiryushin V.I., Tkachenko G.I.* On the downward migration of nitrates in the chernozems of Siberia under agricultural use // Eurasian Soil Science, 1986, N 2, pp. 34–44.

[6]*Titlyanova A.A., Kiryushin V.I., Okhinko I.P.* Agrocenoses of the steppe zone. Novosibirsk: Nauka, 1984, 246 p.

[7]*Bashchuk A.G.* Economic assessment of the impact of biological and technical nitrogen on increasing the yield of spring wheat on leached chernozem in the forest-steppe conditions of Priobye // Bulletin of KrasSAU, 2010, N 3 (42), pp. 57–63.

For the first time in the Russian Federation, the number of organic phosphorus compounds available for enzymatic hydrolysis has been determined, and the response of the soil biota to the application of phosphorus fertilizer has been assessed [3]. On leached chernozems of the Novosibirsk Priobye region, differing in phosphate reserves, it was found that for periodic soil diagnostics of phosphorus nutrition, the most sensitive method is the Nikolov method (ammonium malate). It is advisable to assess the annual phosphorus availability in soil using the Karpinsky-Zamyatina method (0.3 N K_2SO_4). The method recommended for chernozems by Chirikov (0.5 N CH_3COOH) does not allow an adequate assessment of the soil's phosphorus available to plants [4]. Currently, the study of a biological method for diagnosing phosphorus nutrition in cereal crops has begun.

The high cost of phosphorus fertilizers necessitates the calculation of economically acceptable doses for specific conditions. Based on the analysis of long-term data, the need to calculate phosphorus fertilizer doses for cereals based on the amount of the element removed with the grain yield has been justified. With this approach, for the conditions of Priobye, a dose of $P_{40–60}$, recommended for the soils of the Russian Federation, is excessive and is not compensated by the yield [5]. It has been experimentally substantiated that it is advisable to apply phosphorus fertilizers in fractions to each field in the crop rotation compared to applying the entire dose at once [6].

Long-term studies continue on the influence of weather conditions on the productivity of the grain agrocenosis. A classification of years according to the weather conditions of Priobye has been proposed. It has been shown that the hydrothermal conditions formed during the June–July period have a primary influence on the formation of spring wheat yield, regardless of the level of nitrogen nutrition of the plants. The highest, and roughly equal, correlation coefficients (0.7–0.8) of wheat yield were obtained with the amount of precipitation in June–July, average daily air temperatures, and the Selyaninov hydrothermal coefficient. Grain increases from nitrogen fertilizer significantly increased with the improvement of hydrothermal conditions in June–July (increase in the Selyaninov HTC). The highest average annual return of nitrogen fertilizer by grain increase was obtained at N_{30} (30 kg of nitrogen per 1 ha of crop rotation area) and amounted to 17.3 kg/kg. At N_{60} and N_{90}, the indicator decreased significantly [7].

Research continues to assess the contribution of chemical treatment complexes to wheat yield. On average, over the years of research, a 13% increase in yield was due to the use of herbicides, 18% to fungicides, and 69% to mineral fertilizers, with a payback of 1 kg of active ingredient through 12.4 kg of grain. When calculated on an annual average, chemical treatments provided an income even at a minimum grain price of 10,000 rubles per ton. Income sharply increased across the range of field experiment options: herbicides – herbicides + fertilizers – herbicides + fertilizers + fungicide. However, when evaluating annual effects, income from chemical treatment in this range was obtained in only 42, 75, and 92% of the years, respectively. The probability of losses significantly decreased with an increase in grain prices. But even at prices of 13,000 and 16,000 rubles/ton, the use of the entire chemical treatment complex was unprofitable in 8% of the years due to severe drought during the growing season. At current prices for fertilizers and pesticides, the minimally sufficient grain price can be considered 13,000 rubles/ton [8].

The Agroten program has been created, designed to assess the economic feasibility of using intensification means (primarily fertilizers and pesticides) in crop cultivation technologies. The reliability of the assessment is based on the results of long-term field experiments conducted in the Priobye. The program calculates the minimum price of agricultural products that covers the costs of using an intensification agent. A farmer will decide to use this agent only if the market price significantly exceeds this minimum price. The program can also be useful at the industry level for adjusting the prices of ag-

ricultural products and the intensification agents purchased for this purpose[8].

Systematic research is being conducted on the testing of various types of fertilizers. At the end of the 20th century, an assessment was carried out of the effectiveness of using nitric acid, obtained by the plasma-chemical method, as a fertilizer[9]. In recent years, due to the expanded use of liquid fertilizers, the specifics of using UAN in production conditions have been clarified [9].

The task of the soil biology group is the microbiological support of comprehensive studies of the laboratory on the matter cycle in agrocenoses. The soil-microbiological foundations of minimizing primary soil cultivation have been formulated. Soil properties have been studied with 24 years of the use of four conservation tillage methods compared to plowing. The increase in differentiation of the 0–40 cm soil layer, the decrease in the amplitude of the temporal dynamics of biological activity, and the shift of its maximum by 30–40 days towards autumn contributed to the formation of microbiological prerequisites for the deterioration of nitrogen nutrition in cereals. The accumulation of mortmass on stubble backgrounds combined with the use of pesticides contributed to a decrease in the sensitivity threshold of the soil microbial community to pesticide exposure and an increase in the phytotoxicity of the microflora. The application of fertilizers and clean fallow were effective measures to overcome these negative processes [10].

As is known, the main regulator of soil biodynamics is soil organic matter. Research on the problem in the Priobye conditions has begun with long-term experiments modeling soil profiles with different humus content, where quantitative parameters of the decrease in CFU as soil humus content decreases have been determined. It has been shown that against the background of fertilizers, this process does not affect grain crop yields[10]. Subsequently, this line of research was continued in long-term field experiments, and it was shown that a decrease in soil organic matter content affects the stability of soil microbial community functioning under conditions of anthropogenic stress, which in turn reflects on its ability to detoxify pesticides.

New methods for assessing the stability of agricultural soils to the impact of stress factors[11–13] have been developed and patented in the Russian Federation. A scale for assessing the likelihood of residual amounts of pesticides accumulating in the soil has been proposed. It is justified that straw is an inherent resource of the agrocenosis, ensuring its ecotoxicological well-being [11]. At the same time, it is necessary to monitor the pesticide content in the components of the agrocenosis.

For the first time in Siberia, we have studied the content of residual amounts of glyphosate in grain and straw after crop desiccation. A significantly higher content of glyphosate residues was found in straw and weed biomass compared to grain (up to 9 mg/kg versus 4.4), i.e., post-harvest residues can be a significant source of pesticide contamination in the environment [12]. The next section of the research is related to finding approaches to assess the contribution of microbial preparations in reducing the residual phytotoxicity of pesticides applied to cereal crops.

[8]Certificate of registration of a computer program RU 2019662573, 26.09.2019. Computer program Agroten for assessing the feasibility of using intensification means in agrotechnologies / I.N. Sharkov, O.D. Sorokin, S.A. Kolbin. Application No. 2019617265 dated 18.06.2019.

[9]*Kiryushin V.I., Samokhvalova L.M.* The use of nitric acid as a fertilizer on leached chernozem // Methods of fertilizer application in Siberia: collection of scientific works of the SB VASKhNIL, Novosibirsk, 1985, pp. 47–54.

[10]*Lebedeva I.N., Karvan G.V.* The influence of humus content on the biogenicity of leached chernozem // Soil fertility management in intensive agriculture: collection of scientific papers, SibNIIZKhim, Novosibirsk: EBCA SB VASKhNIL, 1988, pp. 121–131.

[11]Patent No. 2525677 C1 Russian Federation. The method for assessing the detoxification activity of chernozems in agrocenoses / Danilova A.A.; filed 20.09.2013; published 20.08.2014; bulletin No. 23.

[12]Patent No. 2562855 C1 Russian Federation. The method for assessing the functional stability of a saprotrophic soil microbial community / Danilova A.A., Savvinov G.N., Danilov P.P., Petrov A.A.; filed 22.05.2014; published 10.09.2015; bulletin No. 25.

[13]Patent for Invention RU 2678876 C2 Russian Federation. The method for assessing the stability of a saprotrophic soil microbial community using a multisubstrate test / Danilova A.A., Legostaeva Y.B., Sivtseva N.E., Petrov A.A.; filed 03.07.2017; published 04.02.2019; bulletin No. 4.

At present, a new stage of research is beginning in the laboratory, related to the metagenomic analysis of the microbiome of Siberian soils. Based on metagenomic sequencing of total DNA using the shotgun method in a series of options: long-term continuous pair (20 years) – plowing – surface treatment, functional genes involved in metabolic pathways of carbon (accA, argG, acsA, mphE, miaB), nitrogen (queC, amiF, pyrG, guaA, guaB, napA) and phosphorus (phoB, ppa, pstB, pnp, phnJ) have been identified. To account for changes in the taxonomic structure of the soil microbiome, both the full 16S rRNA gene sequence (V1–V9) and its individual regions (V4, V3–V4) were studied in these same experimental variants using platforms Pacific Bioscience (PacBiO), Oxford Nanopore Technologies (ONT) Illumina. Significant differences in the functional potential and taxonomic composition of the soil microbiome between land use types are demonstrated, and approaches to interpreting these results are being sought [13, 14].

The accumulated experimental material and ongoing field observations in long-term field experiments will allow transitioning to the assessment of the contribution of agrotechnological factors (crop rotation, fertilizers, plant protection products) in ensuring the stability of the cereal agrocenosis under changing hydrothermal conditions of the growing season. A large amount of work is ahead in bioinformatic processing of the already available results of metagenomic soil analysis in order to develop approaches for using these data for applied purposes, in particular, for the search for metagenomic markers of agrochemical soil degradation. The difficulty of this work lies in the fact that there is a shortage of specialists capable of carrying out such analysis from the perspective of agrosoil science problems in the Russian Federation.

CONCLUSION

The founder of the Soil Fertility Laboratory, Academician V.I. Kiryushin, is an opponent of ill-conceived short-sighted research and recommendations in agriculture based on it. This position remains the foundation of the research work of the Soil Fertility Laboratory team at the Siberian Research Institute of Fodder Crops of the SFSCA RAS. All the provisions formulated by the laboratory are always based on many years of systematic, carefully thought-out experiments. The scientists participated in solving many controversial problems in agro-soil science. Often, their conclusions did not coincide with established views on a particular problem. For example, this concerns the problem of humus in agriculture, when they had to defend their position for many years.

The Soil Fertility Laboratory has always supported the differentiation of recommendations depending on the region. According to our data, the method for assessing plant-available phosphorus by Chirikov, which is mandatory for use in the agrochemical service of the Russian Federation, does not reflect the situation for the soils of Western Siberia; the phosphorus fertilizer dose recommended for Russian soils, P_{40-60}, proved excessive for the cereal agrocenoses of the Priobye and does not pay off with the yield.

When developing the fundamental principles of intensive crop cultivation technologies in Siberia, consideration of the economic efficiency of the technologies is always accompanied by an assessment of environmental risks. For the first time in Siberia, scientists from the soil fertility laboratory paid attention to the migration of nitrates beyond the root zone. It has been shown that in the forest-steppe of the Priobye region, this is possible even with a nitrogen balance close to non-deficient, especially in dry years. Priority studies have been conducted in the laboratory to assess the impact of pesticides on the state of the agrocenosis. An accessible method for accounting for the dynamics of their decomposition in the soil has been proposed, based on which a renewable resource of the agrocenosis has been established, the proper use of which ensures the ecotoxicological well-being of the agrocenosis.

Currently, the Soil Fertility Laboratory at the Siberian Research Institute of Fodder Crops, with the financial support of the leadership of SFSCA RAS, is taking the first steps in a new

direction of research – in refining and deepening our knowledge based on metagenomic studies.

СПИСОК ЛИТЕРАТУРЫ

1. *Шарков И.Н., Колбин С.А., Самохвалова Л.М.* Проблема азота при использовании чернозема выщелоченного по интенсивной технологии в лесостепи Западной Сибири // Агрохимия. 2021. № 2. С. 3–10. DOI: 10.31857/S0002188121020101.
2. *Шарков И.Н., Колбин С.А., Прозоров А.С., Самохвалова Л.М.* Влияние минимизации обработки чернозема выщелоченного на вынос яровой пшеницей почвенного азота в лесостепи Западной Сибири // Агрохимия. 2019. № 9. С. 67–73. DOI: 10.1134/S0002188119090114.
3. *Данилова А.А.* Оптимальные дозы фосфорных удобрений (к почвенно-биохимическим аспектам проблемы) // Сибирский вестник сельскохозяйственной науки. 2019. № 49 (3). С. 5–15. DOI: 10.26898/0370-8799-2019-3-1.
4. *Ткаченко Г.И.* Сравнение методов почвенной диагностики фосфора на чернозёмах Новосибирского Приобья // Сибирский вестник сельскохозяйственной науки. 2024. Т. 54. № 12. С. 15–24. DOI: 10.26898/0370-8799-2024-12-2.
5. *Колбин С.А., Данилова А.А., Рахленко А.Г.* Оптимальные дозы фосфорных удобрений для зерновых агроценозов Приобья // Агрохимия. 2024. № 8. С. 19–26. DOI: 10.31857/S0002188124080032.
6. *Колбин С.А., Ткаченко Г.И., Данилова А.А., Рахленко А.Г.* Способы применения фосфорного удобрения: в запас или ежегодно? // Агрохимия. 2025. № 9. С. 25–33. DOI: 10.7868/S3034496425090038.
7. *Шарков И.Н., Колбин С.А.* Влияние погодных условий вегетационного периода на урожайность яровой пшеницы и эффективность азотного удобрения в лесостепи Приобья // Вестник НГАУ. 2020. № 1 (54). С. 33–41. DOI: 10.31677/2072-6724-2020-54-1-33-41.
8. *Шарков И.Н., Колбин С.А., Васильева Н.В.* Возможности интенсификации технологии выращивания яровой пшеницы в лесостепи Западной Сибири // Агрохимия. 2023. № 6. С. 3–11. DOI: 10.31857/S0002188123060108.
9. *Колбин С.А., Ткаченко Г.И., Самохвалова Л.М.* Эффективность разных форм азотных удобрений на черноземе обыкновенном в южной лесостепи Барабы // Почва и окружающая среда. 2025. Т. 8. № 2. DOI: 10.31251/pos.v8i2.303.
10. *Данилова А.А.* Сочетание естественных и антропогенных факторов в формировании свойств выщелоченного чернозема при почвозащитной обработке // Агрохимия. 2013. № 11. С. 45–53.
11. *Данилова А.А.* Биодинамика почвы при различном содержании органического вещества: монография. Новосибирск: РАСХН., 2018. 150 с.
12. *Данилова А.А., Итэсь Ю.В., Колбин С.А.* Содержание глифосата в зерне при десикации посевов в Приобье // Сибирский вестник сельскохозяйственной науки. 2021. Т. 51. № 3. С. 24–30. DOI: 10.26898/0370-8799-2021-3-3.
13. *Galanova O.O., Mitkin N.A., Danilova A.A., Pavshintsev V.V., Tsybizov D.A., Zakharenko A.M., Golokhvast K.S., Grigoryeva T.V., Markelova M.I., Vatlin A.A.* Assessment of Soil Health Through MetagenomicAnalysis of Bacterial Diversity in Russian Black Soil // Microorganisms. 2025. N 13. P. 854. DOI: 10.3390/microorganisms1304085.
14. *Veselovsky V., Romanov M., Zoruk P., Larin A., Babenko V., Morozov M., Strokach A., Zakharevich N., Khamidova S., Danilova A., Vatlin A., Pavshintsev V., Chenguang F., Tsybizov D., Mitkin N., Galanova O., Zakharenko A., Golokhvast K., Klimina K.* Comparative evaluation of sequencing platforms: Pacific Biosciences, Oxford Nanopore Technologies, and Illumina for 16S rRNA-based soil microbiome profiling // Frontiers in Microbiology. 2025. Vol. 16. P. 1633360. DOI: 10.3389/fmicb.2025.1633360.

REFERENCES

1. Sharkov I.N., Kolbin S.A., Samokhvalova L.M. Problem of nitrogen when using leached chernozem on intensive technology in forest-steppe of western Siberia. *Agrokhimia = Agricultural Chemistry*, 2021, no. 2, pp. 3–10. (In Russian). DOI: 10.31857/S0002188121020101.
2. Sharkov I.N., Kolbin S.A., Prozorov A.S., Samokhvalova L.M. Influence of minimization of autumn cultivation of leached chernozem on wheat removal of soil nitrogen in the Western Siberia forest-steppe. *Agrokhimia = Agricultural Chemistry*, 2019, no. 9, pp. 67–73. (In Russian). DOI: 10.1134/S0002188119090114.
3. Danilova A.A. Optimal doses of phosphorous fertilizers (soil biochemical aspects of the problem). *Sibirskiy vestnik sel'skokhozyaystvennoy nauki = Siberian Herald of Agricultural Science*, 2019, no. 49 (3), pp. 5–15. (In Russian). DOI: 10.26898/0370-8799-2019-3-1.

4. Tkachenko G.I. Comparison of the methods of soil phosphorus diagnostics on the chernozems of the Novosibirsk Priobye. *Sibirskiy vestnik sel'skokhozyaystvennoy nauki = Siberian Herald of Agricultural Science*, 2024, vol. 54, no. 12, pp. 15–24. (In Russian). DOI: 10.26898/0370-8799-2024-12-2.
5. Kolbin S.A., Danilova A.A., Rakhlenko A.G. Optimal dose of phosphorus fertilizers for grain agrocenoses in the Ob Region. *Agrokhimia = Agricultural Chemistry*, 2024, no. 8, pp. 19–26. (In Russian). DOI: 10.31857/S0002188124080032.
6. Kolbin S.A., Tkachenko G.I., Danilova A.A., Rakhlenko A.G. Methods of application of phosphorus fertilizer: in stock or annually? *Agrokhimia = Agricultural Chemistry*, 2025, no. 9, pp. 25–33. (In Russian). DOI: 10.7868/S3034496425090038.
7. Sharkov I.N., Kolbin S.A. The influence of weather conditions of the growing season on the yield of spring wheat and the effectiveness of nitrogen fertilizer in the forest-steppe of the Ob river region. *Vestnik NGAU = Bulletin of NSAU*, 2020, no. 1 (54), pp. 33–41. (In Russian). DOI: 10.31677/2072- 6724-2020-54-1-33-41.
8. Sharkov I.N., Kolbin S.A., Vasileva N.V. Possibilities of intensification of spring wheat growing technology in the Western Siberia forest-steppe. *Agrokhimia = Agricultural Chemistry*, 2023, no. 6, pp. 3–11. (In Russian). DOI: 10.31857/S0002188123060108.
9. Kolbin S.A., Tkachenko G.I., Samokhvalova L.M. Efficiency of nitrogen fertilizer forms on the ordinary chernozem in the southern forest-steppe of Baraba. *Pochva i okruzhaiushaya sreda = The Journal of Soils and Environment*, 2025, vol. 8, no. 2. (In Russian). DOI: 10.31251/pos.v8i2.303.
10. Danilova A.A. Contribution of natural and anthropogenic factors to the development of leached chernozem properties under conservation tillage systems. *Agrokhimia = Agricultural Chemistry*, 2013, no. 11, pp. 45–53.
11. Danilova A.A. *Biodynamics of agricultural soil at various content of organic substance*. Novosibirsk: SFSCA RAS Publ., 2018, 156 p. (in Russian).
12. Danilova A.A., Ites Yu.V., Kolbin S.A. Glyphosate residues in grain after desiccation of crops in the Ob Region. *Sibirskiy vestnik sel'skokhozyaystvennoy nauki = Siberian Herald of Agricultural Science*, 2021, vol. 51, no. 3, pp. 24–30. (In Russian). DOI: 10.26898/0370-8799-2021-3-3.
13. Galanova O.O., Mitkin N.A., Danilova A.A., Pavshintsev V.V., Tsybizov D.A., Zakharenko A.M., Golokhvast K.S., Grigoryeva T.V., Markelova M.I., Vatlin A.A. Assessment of Soil Health Through MetagenomicAnalysis of Bacterial Diversity in Russian Black Soil. *Microorganisms*, 2025, no. 13, p. 854. DOI: 10.3390/microorganisms1304085.
14. Veselovsky V., Romanov M., Zoruk P., Larin A., Babenko V., Morozov M., Strokach A., Zakharevich N., Khamidova S., Danilova A., Vatlin A., Pavshintsev V., Chenguang F., Tsybizov D., Mitkin N., Galanova O., Zakharenko A., Golokhvast K., Klimina K. Comparative evaluation of sequencing platforms: Pacific Biosciences, Oxford Nanopore Technologies, and Illumina for 16S rRNA-based soil microbiome profiling. *Frontiers in Microbiology*, 2025, vol. 16, p. 1633360. DOI: 10.3389/fmicb.2025.1633360.

ИНФОРМАЦИЯ ОБ АВТОРАХ

(✉)**Данилова Альбина Афанасьевна,** главный научный сотрудник, доктор биологических наук; ORCID 0000-0002-2212-3074, SPIN-код 8815-2297; **адрес для переписки:** Россия, 630501, р.п. Краснообск, ул. Центральная, 26; e-mail: Danilovaaa@sfsca.ru

Ткаченко Галина Ивановна, ведущий научный сотрудник, кандидат биологических наук; ORCID 0000-0002-5793-7529, SPIN-код 4272-6588

Колбин Сергей Александрович, ведущий научный сотрудник, кандидат сельскохозяйственных наук; SPIN-код 5753-6978, ORCID 0009-0009-3744-6907,

AUTHOR INFORMATION

(✉)**Albina A. Danilova,** Head Researcher, Doctor of Science in Biology; ORCID 0000-0002-2212-3074, SPIN-code 8815-2297; **address:** 26, Tsentralnaya St., Krasnoobsk, 630501, Russia; e-mail: Danilovaaa@sfsca.ru

Galina I. Tkachenko, Lead Researcher, Candidate of Science in Biology; ORCID 0000-0002-5793-7529, SPIN-code 4272-6588

Sergey A. Kolbin, Lead Researcher, Candidate of Science in Agriculture; SPIN-code 5753-6978, ORCID 0009-0009-3744-6907

Дата поступления статьи / Received by the editors 04.08.2025
Дата принятия к публикации / Accepted for publication 27.08.2025
Дата публикации / Published 19.12.2025

AUTHOR GUIDELINES

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

The journal publishes original articles on fundamental and applied issues by the following directions:

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;

food systems.

The article sent to the editorial board must correspond to the thematic sections of the journal "Siberian Herald of Agricultural Science":

Section name	Code and name of the scientific specialty in accordance with the Nomenclature of Scientific Specialties, for which academic degrees are awarded
Agriculture and chemicalization	4.1.1. General agriculture and crop production 4.1.3. Agrochemistry, soil science, plant protection and quarantine
Plant growing and breeding	4.1.1. General agriculture and crop production 4.1.2. Plant breeding, seed production and biotechnology
Plant protection	4.1.3. Agrochemistry, soil science, plant protection and quarantine
Fodder production	4.1.1. General agriculture and crop production 4.1.2. Plant breeding, seed production and biotechnology 4.1.3. Agrochemistry, soil science, plant protection and quarantine
Zootechnics and veterinary medicine	4.2.3. Infectious diseases and animal immunology 4.2.4. Private zootechnics, feeding, technology of feed preparation and production of livestock products 4.2.5. Breeding, selection, genetics, and animal biotechnology
Mechanization, automation, modelling and dataware	4.3.1. Technologies, machinery and equipment for the agro-industrial complex
Agriproducts processing	4.3.3. Food systems
Problems. Opinions Scientific relations From the history of agricultural science Brief reports From dissertations	4.1.1. General agriculture and crop production 4.1.2. Plant breeding, seed production and biotechnology 4.1.3. Agrochemistry, soil science, plant protection and quarantine 4.2.3. Infectious diseases and animal immunology 4.2.4. Private zootechnics, feeding, technology of feed preparation and production of livestock products 4.2.5. Breeding, selection, genetics, and animal biotechnology 4.3.1. Technologies, machinery and equipment for the agro-industrial complex 4.3.3. Food systems

RECOMMENDATIONS TO THE AUTHOR BEFORE SUBMITTING AN ARTICLE

Submission of an article to the journal "Siberian Herald of Agricultural Science" implies that:

an article has not been published before in any other journal;

an article is not subject to review in any other journal;

all co-authors agree with the publication of the current version of the article.

Before submitting an article, it is necessary to make sure that the file (files) contains all the information required in Russian and English, tables and figures provide the source of the information presented, all references are written correctly.

PROCEDURE FOR SENDING MANUSCRIPTS OF ARTICLES

1 Submission of the article is carried out through the electronic editorial board on the journal's website https://sibvest.elpub.ru/jour/index. After preliminary registration of the author, choose the option "Send a manuscript" in the upper right corner of the page. Then download the manuscript (in *.doc or *.docx format) and the accompanying documents. When you have finished uploading, be sure to select the option "Send a Letter", in which case the editorial board will be automatically notified of the receipt of the new manuscript.

Accompanying documents to the manuscript of an article:

a scanned copy of a letter from the organization confirming authorship and permission to publish (sample cover letter);

a scanned copy of the author's note in the form provided (sample author's note), in which consent must be expressed for the open publication of the article in the printed version of the journal and its electronic copy in the Internet;

a scanned copy of the manuscript with the authors' signatures. The author, by signing the manuscript and sending it to the editorial office, thereby transfers the copyright for the publication of this article to SFSCA RAS;

author questionnaires in Russian and English (sample author questionnaire);

a scanned copy of your post-graduate school transcript (for full-time postgraduate students).

2. All manuscripts received by the editorial board are registered via the electronic editorial system. The author's personal account shows the current status of the manuscript.

3. Non-reviewed materials (scientific chronicles, reviews, book reviews, materials on the history of agricultural science and activities of institutions and scientists) are sent to the e-mail: sibvestnik@sfsca.ru and are registered by the executive secretary.

ARTICLE DESIGN PROCEDURE

The text of the manuscript is printed in Times New Roman font, type size 14 with 1.5 spacing, all margins 2.0 cm, page numbering at the bottom. The size of a manuscript should not exceed 15 pages (including tables, illustrations and bibliography); the articles placed in the sections "From dissertations" and " Brief reports" should not exceed 7 pages.

Article design structure:

UDC

2. Title of an article in Russian and English (no more than 70 characters).

3. Surnames and initials of the authors, full official name of the scientific institution where the research was conducted in Russian and English.

If authors from different institutions took part in the preparation of the article, it is necessary to indicate the affiliation of each author to a particular institution using the superscript index.

4. Abstract in Russian and English. The size of the abstract should not be less than 200-250 words. The abstract is a brief and consistent presentation of the material of the article on the main sections and should reflect the main content, follow the logic of the presentation of the material and description of the results in the article with the provision of specific data. The abstract should not include the newly introduced terms, abbreviations (with the exception of common knowledge), references to the literature. The abstract should not emphasize the novelty, relevance and personal contribution of the author; the place of research should be indicated to the district (region), specific organizations should not be mentioned.

5. Keywords in Russian and English. There should be up to 5–7 words by the topic of the article. It is desirable that the keywords support the abstract and the title of the article.

6. Information on the conflict of interests or its absence. The author should notify the editor on the real or potential conflict of interests by including the information in the appropriate section of the article. If there is no conflict of interests, the author should also inform the editor about it.

Example wording: "The author declares no conflict of interest".

7. Acknowledgements in Russian and English. This section lists all sources of funding for the study, as well as acknowledgements to people who contributed to the article but are not the authors.

8. The main body of the article. When presenting original experimental data, it is recommended to use subheadings:

INTRODUCTION (problem statement, goal and tasks of the study)

MATERIAL AND METHODS (conditions, methods (methodology) of research, object description, place and time of research)

RESULTS AND DISCUSSION

CONCLUSION

REFERENCES. The number of sources must be at least 12. The list of references includes only peer-reviewed sources: articles from scientific journals and monographs. Self-citation of no more than 10% of the total number. The bibliography list should be designed as a general list in the order of mention in the text, it is desirable to refer to sources 2-3 years old. The rules for the list of references are in accordance with GOST R 7.05-2008 (requirements and rules for compiling a bibliographical reference). In the text the reference to the source is marked by a serial number in square brackets, for example [1]. Literature in the list is given in the languages in which it was published. In the bibliographic description of the publication, it is necessary to include all authors, without abbreviating them by one, three, etc. It is unacceptable to abbreviate the names of articles, journals, publishing houses.

1. If it is necessary to refer to abstracts, dissertations, collections of articles, textbooks, recommendations, manuals, GOSTs, information from websites, statistical reports, articles in socio-political newspapers, etc., such information should be placed in a footnote at the end of the page. Footnotes are numbered in Arabic numerals and placed page by page through continuous page numbering.

Attention! Theoretical, review and problem articles can have any structure, but must contain an abstract, keywords, list of references.

EXAMPLE OF REFERENCES IN RUSSIAN AND ENGLISH AND FOOTNOTES

REFERENCES (in Russian):

Monograph

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

Part of a book

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

Periodical publication

Pakul A.L., Lapshinov N.A., Bozhanova G.V., Pakul V.N. Technological grain qualities of spring common wheat depending on the system of soil tillage // Siberian Herald of Agricultural Science. 2018. vol. 48. № 4. pp. 27-35. DOI: 10.26898/0370-8799-2018-4-4.

REFERENCES (in English):

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

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

Example: Author A.A., Author B.B., Author C.C. Title of article.

Transliteration of the authors. English title of the article.

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

Transliteration of the source = English name of the source

Monograph

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

Part of a book

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

Periodical publication

Pakul A.L., Lapshinov N.A., Bozhanova G.V., Pakul V.N. Technological grain qualities of spring common wheat depending on the system of soil tillage. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2018, vol. 48, no. 4, pp. 27–35. (In Russian). DOI: 10.26898/0370-8799-2018-4-4.

FOOTNOTES:

Quated text$_1$.

1*Klimova E.V., Andreeva O.T., Temnikova G.P.* Ways to stabilize food production in Transbaikalia // Problems and prospects of perfecting zonal farming systems in modern conditions: materials of the scientific and practical conf. (Chita, October 16-17 2008). Chita, 2009, pp.36-39.

Digital Object Identifier – DOI (when the cited material has it) should be indicated at the end of the bibliographic reference.

Example:

Chu T., Starek M.J., Brewer M.J., Murray S.C., Pruter L.S. Assessing lodging severity over an experimental maize (Zea mays L.) field using UAS images // Remote Sensing. 2017. Vol. 9. P. 923. DOI: 10.3390/rs9090923.

The DOI of the article should be checked on the website http://search.crossref.org/ or https://www.citethisforme.com. To do this, enter the title of the article in English in the search bar.

FIGURES, GRAPHS, TABLES, SCREENSHOTS, PHOTOGRAPHS AND FORMULAS

The figures must be of good quality, suitable for printing. All figures must have captions. The caption must be translated into English. Figures should be numbered in Arabic numerals according to the order in the text. If there is only one figure in the text, it is not numbered. References to figures should be formatted as follows: “Fig. 3 indicates that ...” or “It is indicated that ... (see Fig. 3)”. The caption under the figure includes a figure number and its title. “Figure 2. Description of vital processes.” The translation of the figure caption should be placed after the figure caption in Russian.

Tables should be of good quality, suitable for printing. Tables suitable for editing are preferred, not scanned or

as figures. All tables should have headings. The title of the table should be translated into English. Tables should be numbered in Arabic numerals according to the order in the text. If there is only one table in the text, it is not numbered. References to tables should be formatted as follows: “Table 3 states that ...” or “It is stated that ... (see Table 3)”. The title of the table includes a table number and its title: “Table 2. Description of Vital Processes.” The translation of the table title should be placed after the table title in Russian.

Photos, screenshots must be uploaded separately as files of the following format*.jpeg files (*.doc and *.docx if the image has additional marks). The resolution of the image should be >300 dpi. The image files should be given a name corresponding to the figure number in the text. In the description of the file a caption should be given separately, which should correspond to the name of the picture placed in the text.

Graphs, charts, histograms, etc. should be attached as a separate file in Microsoft Excel program.

Attention should be paid to the spelling of formulas in the article. All formulas must be editable, i.e. it must be possible to make changes to them. To avoid confusion, it is necessary to write Greek (α, β, π, etc.), Russian (A, a, B, b, etc.) letters and numbers in straight font, Latin letters in italics (*W, Z, m, n*, etc.). Mathematical signs and symbols should also be written in straight font. It is necessary to clearly indicate upper and lower superscript characters (W_1, F_1, etc.).

INTERACTION BETWEEN THE JOURNAL AND THE AUTHOR

The Editorial Board asks the authors to be guided by the above stated rules when preparing the article.

All the articles submitted to “Siberian Herald of Agricultural Science” go through preliminary check for compliance with formal requirements. At this stage the Editorial Board reserves the right to:

• accept the article for review;

• return the article to the author (authors) for revision with a request to correct the mistakes or add the missing data;

• return the article which is designed not according to the journal’s requirements to the author (authors) without consideration;

• 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.