



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

SIBERIAN HERALD OF AGRICULTURAL SCIENCE

Volume 54 No 5 2025

SIBERIAN HERALD OF AGRICULTURAL SCIENCE



No 5

Volume 55

MAY 2025



НАУЧНЫЙ ЖУРНАЛ
**СИБИРСКИЙ ВЕСТНИК
СЕЛЬСКОХОЗЯЙСТВЕННОЙ НАУКИ**
SIBIRSKII VESTNIK SEL'SKOKHOZYAISTVENNOI NAUKI

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

ОСНОВАН В 1971 г.

ВЫХОДИТ 12 РАЗ В ГОД

Том 55, № 5 (318)

DOI: 10.26898



2025

май

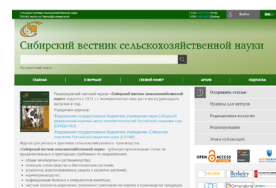
Цель создания журнала – оперативное информирование ученых и практиков сельскохозяйственного производства о новейших достижениях сельскохозяйственной науки. «Сибирский вестник сельскохозяйственной науки» публикует оригинальные статьи по фундаментальным и прикладным проблемам по направлениям: общее земледелие и растениеводство; селекция, семеноводство и биотехнология растений; агрохимия, агропочвоведение, защита и карантин растений; кормопроизводство; инфекционные болезни и иммунология животных; частная зоотехния, кормление, технологии приготовления кормов и производства продукции животноводства; разведение, селекция, генетика и биотехнология животных; технологии, машины и оборудование для агропромышленного комплекса.

Главный редактор – Донченко Александр Семенович, академик РАН, доктор ветеринарных наук, главный научный сотрудник, руководитель Института экспериментальной ветеринарии Сибири и Дальнего Востока Сибирского федерального научного центра агrobiотехнологий Российской академии наук, Новосибирск, Россия

Заместитель главного редактора – Ломбанина Татьяна Александровна, заведующая издательством «Агронаука» Сибирского федерального научного центра агrobiотехнологий Российской академии наук, Новосибирск, Россия

Редакционная коллегия:

В.В. Азаренко	д-р техн. наук, член-корреспондент НАН Беларуси, Минск, Беларусь
В.В. Альт	академик РАН, д-р техн. наук, Новосибирск, Россия
О.С. Афанасенко	академик РАН, д-р биол. наук, Санкт-Петербург, Россия
Г.П. Гамзиков	академик РАН, д-р биол. наук, Новосибирск, Россия
К.С. Голохваст	член-корреспондент РАО, д-р биол. наук, Новосибирск, Россия
Н.П. Гончаров	академик РАН, д-р биол. наук, Новосибирск, Россия
М.И. Гулюкин	академик РАН, д-р вет. наук, Москва, Россия
В.Н. Делягин	д-р техн. наук, Новосибирск, Россия
С.А. Джохари	профессор, PhD, Санандадж, Иран
И.М. Донник	академик РАН, д-р биол. наук, Москва, Россия
А.Т. Жунушов	д-р вет. наук, академик НАН Киргизской Республики, Бишкек, Киргизия
Н.М. Иванов	член-корреспондент РАН, д-р техн. наук, Новосибирск, Россия
А.Ю. Измайлов	академик РАН, д-р техн. наук, Москва, Россия
Н.И. Кашеваров	академик РАН, д-р с.-х. наук, Новосибирск, Россия
В.И. Кирюшин	академик РАН, д-р биол. наук, Москва, Россия
А.К. Куришбаев	д-р с.-х. наук, академик НАН Республики Казахстан, иностранный член РАН, Алма-Ата, Казахстан
С.Н. Магер	д-р биол. наук, Новосибирск, Россия
М.А. Наваз	профессор, PhD, Томск, Россия
А.М. Наметов	д-р вет. наук, член-корреспондент НАН Республики Казахстан, Уральск, Казахстан
В.С. Николов	д-р вет. наук, София, Болгария
С.П. Озорнин	д-р техн. наук, Чита, Россия
В.Л. Петухов	д-р биол. наук, Новосибирск, Россия
Р.И. Полюдина	д-р с.-х. наук, Новосибирск, Россия
А.Ф. Салимзода	д-р с.-х. наук, член-корреспондент ТАСХН, Душанбе, Таджикистан
М.И. Селионова	д-р биол. наук, Москва, Россия
В.А. Солошенко	академик РАН, д-р с.-х. наук, Новосибирск, Россия
Н.А. Сурин	академик РАН, д-р с.-х. наук, Красноярск, Россия
А.М. Тсатсакис	д-р биол. наук, иностранный член РАН, Крит, Греция
А.А. Шпедт	д-р с.-х. наук, Красноярск, Россия
С. Эркисли	профессор, PhD, Эрзурум, Турция
С.Х. Янг	профессор, PhD, Кванджу, Корея



www.sibvest.elpub.ru

Редакторы *Е.М. Исаевич, Е.В. Мосунова, Г.Н. Ягунова*. Корректор *В.Е. Селянина*.

Оператор электронной верстки *Н.Ю. Борisko*. Переводчик *М.Ш. Гаценко*.

Свидетельство о регистрации средств массовой информации ПИ ФС77-64832 выдано Федеральной службой по надзору в сфере связи, информационных технологий и массовых коммуникаций 2 февраля 2016 г.

Издатель: Сибирский федеральный научный центр агrobiотехнологий Российской академии наук

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

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

Вышел в свет 16.06.2025. Формат 60 × 84¹/₈. Бумага тип. № 1. Печать офсетная. Печ. л. 16,75

Уч.-изд. л. 17. Тираж 500 экз. Цена свободная.

Отпечатано в Сибирском федеральном научном центре агrobiотехнологий Российской академии наук

© ФГБУ «Сибирский федеральный научный центр агrobiотехнологий Российской академии наук», 2025

© ФГБУ «Сибирское отделение Российской академии наук», 2025



СОДЕРЖАНИЕ

CONTENTS

РАСТЕНИЕВОДСТВО И СЕЛЕКЦИЯ

PLANT GROWING AND BREEDING

Заремук Р.Ш., Копнина Т.А. Засухоустойчивость сортов вишни (*Cerasus vulgaris* Mill.) в условиях южного региона

5 Zaremuk R.Sh., Koptina T.A. Drought tolerance of cherry (*Cerasus vulgaris* Mill.) varieties in the conditions of the southern region

ЗАЩИТА РАСТЕНИЙ

PLANT PROTECTION

Шаманин А.А., Берим М.Н., Корелина В.А., Попова Л.А. Оценка степени распространения тлей – переносчиков вирусов картофеля на юге Архангельской области

13 Shamanin A.A., Berim M.N., Korelina V.A., Popova L.A. Assessment of the aphids-potato virus vectors distribution in the south of the Arkhangelsk region

Агасьева И.С., Исмаилов В.Я., Петрищева М.В., Голобородько Е.О., Петрищев В.С. Изучение биоэкологических особенностей акациевой огневки *Etiella zinckenella* Tr. и оценка эффективности энтомопатогенных биопрепаратов в защите сои от этого вредителя

22 Agasyeva I.S., Ismailov V.Ya., Petrishcheva M.V., Goloborodko E.O., Petrishchev V.S. Study of bioecological features of the lima bean pod borer *Etiella zinckenella* Tr. and evaluation of the effectiveness of entomopathogenic biopreparations in protecting soybean from this pest

- Фещенко Е.С., Торопова Е.Ю.** Фитосанитарное и экономическое обоснование элементов технологии возделывания яровой пшеницы в лесостепи Новосибирского Приобья
- 32 Feshchenko E.S., Toropova E.Yu.** Phytosanitary and economic justification of the elements of technology for cultivation of spring wheat in the Novosibirsk Ob Region forest-steppe
- Пимохова Л.И., Яговенко Г.Л., Царапнева Ж.В., Хараборкина Н.И., Мисникова Н.В.** Влияние климатических условий Брянской области на развитие и распространение фузариоза в посевах люпина узколистного
- 42 Pimokhova L.I., Yagovenko G.L., Tsarapneva Zh.V., Kharaborkina N.I., Misnikova N.V.** Influence of climatic conditions of the Bryansk region on the development and spread of fusariosis in narrow-leaved lupine crops

*ЗООТЕХНИЯ
И ВЕТЕРИНАРИЯ*

*ZOOTECHNICS
AND VETERINARY MEDICINE*

- Макаров В.В., Стекольников А.А., Донченко А.С., Сочнев В.В.** Этиопатогенетические «загадки» факторной патологии (к 50-летию приоритетной концепции факторных болезней С.И. Джупины)
- 55 Makarov V.V., Stekolnikov A.A., Donchenko A.S., Sochnev V.V.** Etio-pathogenetic “mysteries” of factor pathology (to the 50th anniversary of S.I. Dzhupina's priority concept of factor diseases)
- Солошенко В.А., Бабаков В.Ю., Храмова И.А., Инербаева А.Т., Байфорт П.Я., Плешаков В.А., Адушинов Д.С., Третьяков А.М.** Качество говядины мясных пород крупного рогатого скота, районированных в Сибири
- 70 Soloshenko V.A., Babakov V.Yu., Khramtsova I.A., Inerbaeva A.T., Bayfort P.Ya., Pleshakov V.A., Adushinov D.S., Tretyakov A.M.** Beef quality of meat breeds of cattle released in Siberia
- Рязанов В.А., Дускаев Г.К., Курилкина М.Я., Муслюмова Д.М.** Влияние растительных лактонов и флавоноидов на структуру микрофлоры кишечника и концентрацию жирных кислот у крупного рогатого скота
- 83 Ryazanov V.A., Duskaev G.K., Kurilkina M.Ya., Muslyumova D.M.** Effect of plant lactones and flavonoids on intestinal microflora structure and fatty acid concentration in cattle

- Афанасьева Ю.Г., Колодина Е.В., Руппель И.А.** Создание экспериментальных образцов пробиотического препарата для сельскохозяйственных животных и определение содержания в них витамина В₁₂ **99**
- Afanaseva Yu.G., Kolodina E.V., Ruppel I.A.** Creation of experimental samples of a probiotic preparation for farm animals and measurement of vitamin B₁₂ content in them

*МЕХАНИЗАЦИЯ, АВТОМАТИЗАЦИЯ,
МОДЕЛИРОВАНИЕ
И ИНФОРМАЦИОННОЕ ОБЕСПЕЧЕНИЕ*

*MECHANISATION, AUTOMATION,
MODELLING AND DATAWARE*

- Назаров Н.Н., Некрасова И.В.** Качество распределения жидких форм минеральных удобрений по обрабатываемой поверхности **106**
- Nazarov N.N., Nekrasova I.V.** Quality of distribution of liquid forms of mineral fertilizers over the working surface
- Рубцов А.А., Немущенко Д.А.** Подходы к численному моделированию работы биореакторов анаэробного сбраживания: обзор **115**
- Rubcov A.A., Nemuschenko D.A.** Approaches to numerical modeling of anaerobic digestion bioreactor operation: a review



<https://doi.org/10.26898/0370-8799-2025-5-1>
УДК 634.23:581.1.036(471.63)

Тип статьи: оригинальная
Type of article: original

Засухоустойчивость сортов вишни (*Cerasus vulgaris* Mill.) в условиях южного региона

Заремук Р.Ш.¹, ✉ Копнина Т.А.²

¹Кубанский государственный аграрный университет им. И.Т. Трубилина
Краснодар, Россия

²Северо-Кавказский федеральный научный центр садоводства, виноградарства, виноделия
Краснодар, Россия
✉ e-mail: tatjanakopnina@rambler.ru

В последние годы засуха и высокотемпературный стресс являются причинами снижения адаптивного и продуктивного потенциала плодовых косточковых культур на юге Российской Федерации. Представлены результаты комплексной оценки засухоустойчивости разных по происхождению сортов вишни обыкновенной (*Cerasus vulgaris* Mill.) в условиях прикубанской зоны садоводства Краснодарского края. Исследования проведены в 2021–2023 гг. Объекты изучения – 10 сортов вишни: Краснодарская сладкая, Ивановна, Ходоса, Фея, Тимати, Призвание, Тамарис, Ассоль, Светлая, Памяти Евстратова. Схема посадки 5 × 3 м, подвой – сеянцы антипки. Контроль – Краснодарская сладкая, засухоустойчивый сорт вишни отечественной селекции. На фоне воздействия стрессовых факторов проанализированы основные физиологические показатели сортов вишни: содержание общей воды, сухих веществ и потеря воды в листьях. В годы исследований сорта вишни находились в условиях недостаточного увлажнения, подтвержденных низким гидротермическом коэффициентом, варьировавшим по годам от 0,4 до 1,2. Оводненность листьев в среднем по сортам составляла 60,0%, незначительно варьировала в пределах 57,2–62,7%, о чем свидетельствует коэффициент вариации ($C_v = 3,5\%$). Потеря воды была высокой, на уровне 11,4%, и значительно варьировала ($C_v = 26,3\%$) по сортам от 8,1 (Светлая) до 17,0% (Краснодарская сладкая). Содержание сухих веществ, свидетельствующее об определенной степени устойчивости растений к недостатку влаги, составляло 39,9%, при этом его динамика по сортам в зависимости от условий года была незначительной ($C_v = 5,3\%$). По комплексу оптимальных физиологических показателей, подтверждающих достаточно высокую засухоустойчивость, выделены сорта вишни обыкновенной отечественной селекции Ивановна, Ходоса, Фея и Призвание, рекомендуемые для создания устойчивых и продуктивных агроценозов вишни в условиях южного региона Российской Федерации.

Ключевые слова: вишня, сорта, засухоустойчивость, оводненность, потеря воды, сухие вещества

Drought tolerance of cherry (*Cerasus vulgaris* Mill.) varieties in the conditions of the southern region

Zaremuk R.Sh.¹, ✉ Kopnina T.A.²

¹Kuban State Agrarian University named after I.T. Trubilin
Krasnodar, Russia

²North Caucasian Federal Scientific Centre of Horticulture, Viticulture, Winemaking
Krasnodar, Russia
✉ e-mail: tatjanakopnina@rambler.ru

In recent years, drought and high temperature stress have caused a decrease in the adaptive and productive potential of stone fruit crops in the south of the Russian Federation. The results of a comprehensive assessment of the drought resistance of common cherry varieties (*Cerasus Vulgaris* Mill.)

of different origins in the conditions of the Prikuban horticultural zone of the Krasnodar Territory are presented. The studies were conducted in 2021–2023. The objects were 10 cherry varieties: Krasnodarskaya Sladkaya, Ivanovna, Khodosa, Feya, Timati, Prizvanie, Tamaris, Assol, Svetlaya, Pamyati Evstratova. The planting pattern was 5x3 m, the rootstock – Mahaleb cherry seedlings. The control – Krasnodarskaya sladkaya, a drought-resistant cherry variety of domestic selection. The main physiological indices of cherry varieties were analyzed against the background of stress factors exposure: content of total water, dry matter and water loss in leaves. During the years of research, the cherry varieties were in conditions of insufficient moisture, confirmed by a low hydrothermal coefficient, varying from 0.4 to 1.2 over the years. The average water content of the leaves across the varieties was 60.0%, varying slightly within the range of 57.2 – 62.7%, as evidenced by the coefficient of variation ($C_v = 3.5\%$). Water loss was high, at the level of 11.4%, and varied significantly ($C_v = 26.3\%$) among the varieties from 8.1 (Svetlaya) to 17.0% (Krasnodarskaya sladkaya). The content of dry matter, indicating a certain degree of resistance of the plants to lack of moisture, was 39.9%, while their dynamics by variety depending on the conditions of the year was not significant ($C_v = 5.3\%$). Based on a set of optimal physiological indicators confirming a sufficiently high drought resistance, domestic cherry varieties were identified – Ivanovna, Khodosa, Feya and Prizvanie, which are recommended for creating stable and productive cherry agrocenoses in the southern regions of the Russian Federation.

Keywords: cherry, varieties, drought resistance, water content, water loss, dry matter

Для цитирования: Заремук Р.Ш., Копнина Т.А. Засухоустойчивость сортов вишни (*Cerasus vulgaris* Mill.) в условиях южного региона // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 5. С. 5–12. <https://doi.org/10.26898/0370-8799-2025-5-1>

For citation: Zaremuk R. Sh., Kopnina T.A. Drought tolerance of cherry (*Cerasus vulgaris* Mill.) varieties in the conditions of the southern region. *Sibirskii vestnik sel'skhozvaystvennoi nauki = Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 5..., pp 5–12. <https://doi.org/10.26898/0370-8799-2025-5-1>

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

Благодарность

Исследование выполнено в рамках государственного задания ФГБНУ СКФНЦСВВ (№ 0498-2022-0001).

Acknowledgments

The study was carried out within the framework of the state assignment of the Federal State Budgetary Scientific Institution "North Caucasian Federal Scientific Centre of Horticulture, Viticulture, Winemaking" (No. 0498-2022-0001).

INTRODUCTION

Many scientists note that in recent decades there has been a shift in weather and climate conditions towards warming [1–4]. This trend necessitates deeper study of perennial fruit plants, including stone fruit crops, and the identification of varieties more resistant to temperature stressors.

When assessing plants' ability to withstand a complex of abiotic stresses, special attention is given to drought tolerance. Currently, approximately a quarter of all arable land on

Earth is subject to drought, underscoring the importance of research on plant resistance to this factor^{1, 2}.

In the summer period, southern regions of the Russian Federation more frequently experience abnormally high positive temperatures. In the Krasnodar Territory, in recent years, temperatures have reached 38–40 °C and above. Longer periods of drought and heat have also been recorded, which are highly likely to limit the full realization of the productive potential of fruit crops and varieties. This leads to poor fruit bud formation during the differentiation period,

¹Kruzhkov A.V., Dubrovsky M.L., Lyzhin A.S., Kirillov R.E. Drought resistance of cherry genotypes // Pomiculture and small fruits culture in Russia, 2015, vol. 42, pp. 232–234.

²Zhuchenko A.A. Adaptive system of plant breeding (ecological and genetic foundations). Moscow: Agrorus, 2001, vol. 2, 708 p.

reduced yield and quality, and in some years, complete flower loss^{3,4} [5].

Stone fruit crops, including the common cherry, respond differently to high-temperature stress due to their biological characteristics [6]. It is known that the common cherry, belonging to the genus *Cerasus* Mill., is a relatively drought-tolerant stone fruit species.⁵ [6, 7] (see footnote 1). Despite this, many cherry cultivars poorly tolerate drought and exposure to anomalously high temperatures. Studies by several scientists have shown that unfavorable summer temperature conditions more frequently have a significant negative impact on the realization of the biological potential of fruit crops, including cherry, leading to reduced yield and quality⁶ (see footnotes 1, 2).

Long-term studies have shown that against the background of annual stress factors, primarily high temperatures, many cherry cultivars experience reduced adaptability to temperature fluctuations, of which drought tolerance is a component. Drought decreases the activity of phytohormones and causes numerous abnormalities in embryonic tissues during the differentiation of generative organs. Prolonged dry and hot winds and heat lead to changes in plant metabolism, photosynthesis processes, and water balance. They also cause fruit drop and weak leaf development, which overall reduces plant resistance to different types of stress and lowers the productivity of cherry cultivars [8, 9] (see footnote 5).

Currently, comprehensive studies of drought resistance of cherry varieties by phenotype in field conditions and based on physiological methods of its diagnostics in laboratory conditions are of particular importance, which is a relevant and timely scientific direction in research on the adaptability of both fruit crops in general and specific varieties⁷ [8].

One of the most commonly used physiological criteria for assessing the drought tolerance of perennial fruit plants is their water regime, which characterizes their ability to tolerate heat and drought. Key indicators of plant water status include tissue water content, water-retaining capacity, dry matter content, and other parameters that allow for an adequate characterization of varieties and the identification of those most resilient to the stresses identified [8, 10].

The goal of the research is to conduct a physiological assessment of the resistance of various cherry cultivars under high-temperature stress and to identify the most drought-tolerant ones for creating adaptive agrocenoses.

MATERIAL AND METHODS

Research was conducted during 2021–2023. The study objects were 10 cultivars of common cherry of various ecological and geographical origins, concentrated in the genetic collection of fruit crops at the Shared Use Center of the North Caucasus Federal Scientific Center for Horticulture, Viticulture, and Winemaking (NCFSCHVW), located at the second division of the experimental production farm "Central" in the Prikubanskaya horticultural zone of the Krasnodar Territory. The planting scheme was 5 × 3 meters. As a control, the regional drought-resistant cherry cultivar "Krasnodarskaya Sladkaya" of domestic selection was used. The replication was threefold. The rootstock consisted of the Mahaleb cherry seedling rootstocks.

The soils of the experimental plot are leached chernozems, with a pH_{water} of 6.8–7.22 in the 0–30 cm soil layer and a humus horizon density of 1.30–1.42 g/cm³. Leached chernozems have a neutral soil pH in the 0–30 cm soil layer, making them well suited for growing cherries. The plant water regime was assessed using a gravimetric

³Doroshenko T.N., Zakharchuk N.V., Maksimov D.V. Resistance of fruit and ornamental plants to temperature stressors: diagnostics and ways of improvement. Krasnodar: KubSAU, 2014, 118 p.

⁴Koshkin E.I. Physiology of crop stability: textbook. Moscow: Drofa, 2010, 638 p.

⁵Kolesnikova A.F. Breeding of common cherry in the past and present. Orel: OSU, 2014, 352 p.

⁶Upadysheva G.Yu. The influence of summer stress factors on the productivity of modern stone fruit varieties in the Moscow region // Pomiculture and small fruits culture in Russia, 2012, vol. 31, P. 2, pp. 277–283.

⁷Belous O.G., Klemeshova K.V., Pashchenko O.I. Comparative analysis of photosynthetic indicators in freesia hybrids on the Black Sea coast of Krasnodar region // Horticultural Science, 2017, vol. 44 (2), pp. 99–104. DOI: 10.17221/189/2015-HORTSCI.

method: leaves with petioles were weighed on electronic scales and subjected to wilting for 2 and 4 hours, then the leaves were weighed again and placed in a drying cabinet for final drying at a temperature of 105 °C according to a modified method of M.D. Kushnerenko⁸. Drought resistance in field conditions was carried out according to the “Program and methodology for variety study of fruit, berry and nut crops”⁹. Statistical processing of the obtained data was carried out according to the Dospikhov method¹⁰. The hydrothermal coefficient was calculated using the Selyaninov method¹¹.

RESULTS AND DISCUSSION

One of the most informative methods for physiological assessment of fruit crops drought resistance is the water regime of leaves based on their water content, the rate of water loss over a certain period of time, the dynamics or content of dry matter in the leaves during periods of exposure to high positive temperatures, which allows one to identify plants with a higher response to temperature stress and drought, i.e., to identify more drought-resistant varieties.

Physiological studies of drought resistance in common cherry varieties were conducted in the second ten-day period of July 2021–2023, when the highest (abnormal) positive air temperatures were recorded. In July 2021, the maximum air

temperature reached 38.1°C. Precipitation was minimal, at 28.4 mm, compared to the long-term average of 56 mm. Air humidity averaged 60%.

In July 2022, the maximum air temperature was lower than in 2021, at 34.8°C. Precipitation during the month was 62.6 mm, in line with the long-term average. Humidity was quite high at 65%.

Weather conditions in July 2023 were similar to those in 2022. The maximum air temperature reached 37.2°C, 2.4°C higher than in 2022. Precipitation totals were within the long-term average of 61.7 mm. Humidity in July was 63% (see Table 1).

One of the relative indicators of the humidity of the territory is the hydrothermal coefficient (HTC) of Selyaninov, which was used as an additional one for the analysis of the developing weather conditions in the Prikubansky horticultural zone of the Krasnodar Territory during the period of the research.

It was established that the summer period in 2021 and 2022 was characterized by insufficiently humid conditions, which is confirmed by a hydrothermal coefficient of 1.1–1.2. The summer period of 2023 was very dry (HTC = 0.4) (see Table 2).

Thus, the period of research in the Prikubansky horticultural zone was characterized as dry and insufficiently moist, i.e. the assessment of

Табл. 1. Основные метеорологические показатели летнего периода
Table 1. Main meteorological indicators of the summer period

Indicator	Year								
	2021			2022			2023		
	June	July	August	June	July	Август	June	July	August
Average air temperature, °C	21,7	26,2	25,6	23,0	23,7	26,3	21,8	24,5	27,2
Maximum air temperature, °C	33,0	38,1	37,7	33,7	34,8	35,3	33,6	37,2	38,5
Precipitation, mm	108,3	28,4	75,0	161,0	62,6	91,2	40,9	61,7	0,0

⁸Kushnirenko M.D., Goncharova E.A., Bondar E.M. Methods for studying water exchange and drought resistance of plants. Chisinau, 1970, 79 p.

⁹Program and methodology for variety study of fruit, berry and nut crops / edited by E.N. Sedov, T.P. Ogoltsova. Orel: Publishing house of the All-Russian Research Institute of Fruit Crop Breeding, 1999, 608 p.

¹⁰Dospikhov B.A. Methodology of field experiment (with the basics of statistical processing of research results). Moscow: Alliance, 2014, 351 p.

¹¹Selyaninov G.T. Methodology of agricultural climate characteristics. Moscow: Gidrometeoizdat, 1977, 220 p.

the physiological resistance of cherry varieties was carried out against the backdrop of annual abnormally high temperatures and a lack of moisture in the soil and air.

Leaf water content is known to be a fairly effective indicator of plant water balance, which can be used to assess the status of a variety [11]. A comparative analysis of the leaf water content of the studied cherry varieties showed that in 2021, most of them exceeded 60% and were at the control level. Thus, the Svetlaya, Prizvanie, Timati, Feya, Khodosa, and Ivanovna varieties had high leaf water content, ranging from 60.2 to 65.2%. The highest water content (65.2%) was observed in the control variety Krasnodarskaya Sladkaya. Lower values (57.7 to 57.2%) were observed in the Tamaris and Assol cherry varieties. A comparatively low water content was observed in the

Pamyati Evstratova variety, amounting to 55.5% (see the figure).

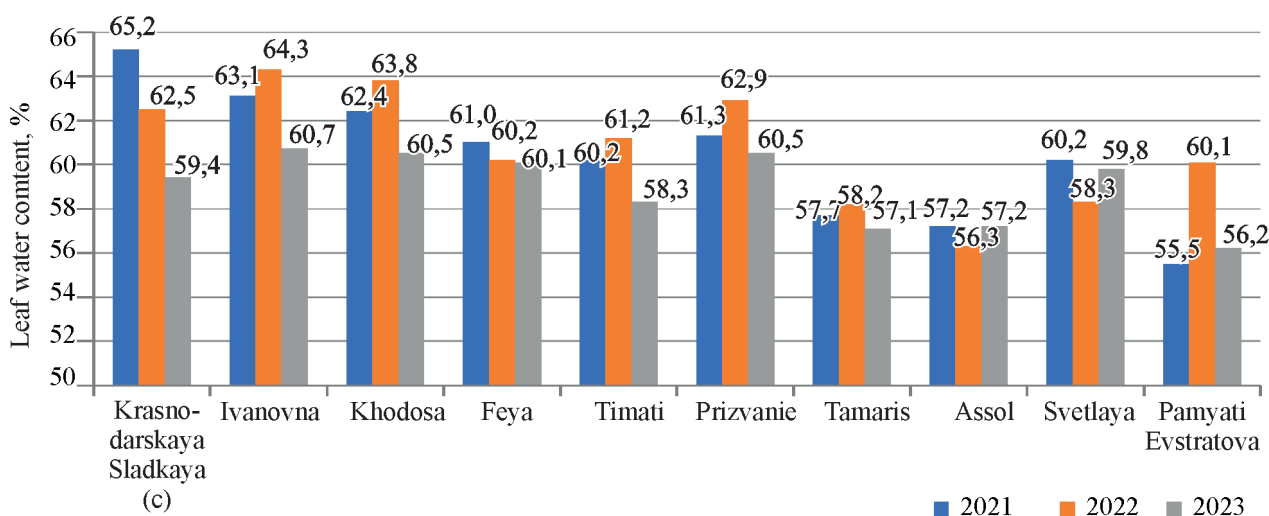
In 2022, leaf water content for different cherry varieties ranged from 56.3% to 64.3%. The Ivanovna, Khodosa, Feya, Timati, Prizvanie, and Pamyati Evstratova varieties had relatively high leaf water content (ranging from 60.1% to 64.3%). It was slightly lower (58.2% to 58.3%) for the Tamaris and Svetlaya varieties. The Assol cherry variety had the lowest leaf water content (56.3%).

In the drier 2023, average leaf water content for different cherry varieties ranged from 60.1% to 60.7%. High values were observed for the Ivanovna (60.7%), Khodosa (60.5%), Feya (60.1%), and Prizvanie (60.5%) varieties, whose leaf water content exceeded that of the control variety. Slightly lower values were observed for the Tamaris (57.1%), Assol (57.2%), Tima-

Табл. 2. Сумма активных температур и осадков, гидротермический коэффициент (по Селянинову), июнь – август 2021–2023 гг.

Table 2. Sum of active temperatures and precipitation, hydrothermal coefficient (according to Selyaninov), June–August 2021–2023

Year	The sum of the temperatures higher than 10 °C, °C	Total precipitation, mm	HTC	Drought class
2021	2258,3	265,7	1,1	Insufficient hydration
2022	2234,7	314,8	1,2	» »
2023	2254,3	102,6	0,4	Extremely arid



Динамика показателей оводненности листьев у сортов вишни в зависимости от условий года (июль 2021–2023 гг.)

Dynamics of leaf water content indices in cherry cultivars depending on the conditions of the year (July 2021–2023)

ti (58.3%), and Svetlaya (59.8%) varieties. The Pamyati Evstratova cherry cultivar had a leaf water content of 56.2% (see figure). It was found that under annual adverse temperature conditions, the Ivanovna, Khodosa, Feya, and Prizvanie cherry cultivars exhibited high leaf water content, which to some extent confirms their drought tolerance and is consistent with field surveys. No significant differences in leaf water content were observed for the Timati, Tamaris, Assol, and Svetlaya cherry cultivars depending on the growing conditions (see the figure).

Analysis of the obtained data allowed us to identify cherry varieties with the most stable annual leaf water content: Feya with indicators of 60.1–61.0%, Tamaris with 57.1–58.2%, and the Assol variety, whose water content varied from 56.3 to 57.2%. The dynamics by variety indicate the manifestation of certain varietal specificity of the studied varieties in terms of leaf water content.

Thus, on average for 2021–2023, the highest leaf tissue water content at the control level was observed in the cherry varieties Ivanovna (62.7%), Khodosa (62.2%), Feya (60.4%), and Prizvanie (61.5%) (see Table 3). It was comparatively lower for the Assol (56.9%), Pamyati Evstratova (57.2%), Svetlaya (59.4%), Tamaris (57.6%), and Timati (59.9%) varieties.

One of the indicators of drought resistance is the dry matter content in leaves, which determines the optimal water regime and characterizes the metabolic processes occurring in the plant during periods of stress [12]. It was found that the dry matter content in cherry varieties was at the level of 39.6%, while the variability of this trait across the varieties was insignificant ($Cv = 5.3\%$) (see Table 3).

Dry matter content from 37.3 to 39.6% was noted in the Ivanovna (37.3%), Khodosa (37.8%), Feya (39.6%), and Prizvanie (38.5%) varieties, which were conditionally classified as having a low dry matter content and a high total water content in the leaves. Overall, these cherry varieties are classified as drought-resistant based on these two indicators.

Cherry varieties Timati, Svetlaya, Tamaris, Pamyati Evstratova and Assol, whose indicators varied from 40.1 to 43.1%, were characterized by a high content of dry substances, but a lower amount of total water in the leaves, which gave grounds to classify them as a group of moderately drought-resistant varieties.

Based on the fact that the higher the water-holding capacity of leaves, the lower the water loss under stress, the variation parameters were set from 8.1 to 17.0% depending on the va-

Табл. 3. Основные физиологические показатели водного режима вишни в условиях Прикубанской зоны садоводства (2021–2023 гг.), %

Table 3. Main physiological indicators of water regime of cherry under conditions of the Prikuban horticultural zone (2021–2023), %

Variety	Water loss, in 2 h	Dry matter content	Total water
Krasnodarskaya Sladkaya (control)	17,0	37,6	62,4
Ivanovna	9,7	37,3	62,7
Khodosa	9,8	37,8	62,2
Feya	8,9	39,6	60,4
Timati	9,4	40,1	59,9
Prizvanie	9,6	38,5	61,5
Tamaris	13,6	42,4	57,6
Assol	16,4	43,1	56,9
Svetlaya	8,1	40,6	59,4
Pamyati Evstratova	11,8	42,8	57,2
Average	11,4	39,9	60,0
Cv , %	26,3	5,3	3,5
LSD_{05}	3,2	2,2	2,2

riety with a variation coefficient (C_v) of 26.3% (see Table 3).

The following cherry varieties were found to have the highest water-holding capacity: Khodosa (9.8%), Ivanovna (9.7%), Feya (8.9%), Timati (9.4%), Svetlaya (8.1%), and Prizvanie (9.6%). Slightly lower water loss was observed in the Pamyati Evstratova (11.8%) and Tamaris (13.6%) varieties. The Assol and Krasnodarskaya Sladkaya (control) varieties had comparatively low water-holding capacity (16.4–17.0%).

CONCLUSIONS

1. The average water content of cherry leaves across different cultivars was 60.0%; its parameters varied slightly between the cultivars, from 57.2 to 62.7%. Cherry cultivars with annually high leaf water content exceeding 60% were identified: Ivanovna (62.7%), Khodosa (62.2%), Feya (60.4%), and Prizvanie (61.5%).

2. The maximum water-holding capacity was found in the Khodosa, Ivanovna, Feya, Timati, Svetlaya and Prizvanie varieties; water loss varied within the range of 8,1–9,7%.

3. The dry matter content in the leaves of different cherry varieties averaged 39.9%. Cherry varieties Ivanovna, Khodosa, Feya, and Prizvanie, which are classified as more drought-resistant, had a comparatively low level (37.3–39.6%).

4. Based on the studied parameters of drought resistance, cherry varieties Khodosa, Ivanovna, Feya and Prizvanie were identified with optimal physiological indicators of water regime, confirming their high drought resistance, which can be recommended for the creation of stable agrocenoses in the conditions of southern horticulture and as sources of drought resistance for further breeding work.

СПИСОК ЛИТЕРАТУРЫ

1. Бондаренко Л.В., Маслова О.В., Белкина А.В., Сухарева К.В. Глобальное изменение климата и его последствия // Вестник Российского экономического университета им. Г.В. Плеханова. 2018. № 2. С. 84–93. DOI: 10.21686/2413-2829-2018-2-84-93.
2. Драгавцева И.А., Ахматова З.П., Моренец А.С. Особенности и тенденции вари-

бельности лимитирующих факторов среды для плодовых культур Северного Кавказа в зимне-весенний период с учетом изменения климата (на примере абрикоса) // Садоводство и виноградарство. 2018. № 4. С. 38–43. DOI: 10.31676/0235-2591-2018-4-38-43.

3. Salama A.M., Ezzat A, El-Ramady H., Alam-El-dein S.M., Okba S., Elmenofy H.M., Hassan I.F., Illés A., Holb I.J. Temperate Fruit Trees under Climate Change: Challenges for Dormancy and Chilling Requirements in Warm Winter Regions // Horticulturae. 2021. Vol. 7. N 86. DOI: 10.3390/horticulturae7040086.
4. Chawla R., Sheokand A., Roop Rai M., Kumar Sadawarti R. Impact of climate change on fruit production and various approaches to mitigate these impacts // The Pharma Innovation Journal. 2021. N 10 (3). P. 564–571.
5. Юшков А.Н. Селекция плодовых растений на устойчивость к абиотическим стрессорам: монография. Мичуринск: Федеральный научный центр им. И.В. Мичурина, 2019. 332 с.
6. Коваленко Н.Н. Микровишня. Использование в селекции косточковых плодовых культур и озеленении: монография. Краснодар: Просвещение-Юг, 2021. 391 с.
7. Гуляева А.А. Вишня и черешня. Орел: Всероссийский научно-исследовательский институт селекции плодовых культур, 2022. 44 с.
8. Ожерельева З.Е., Ефремов И.Н. Изучение жаро- и засухоустойчивости *Prunus cerasus* L. // Плодоводство и ягодоводство России. 2020. Т. 63. С. 77–88. DOI: 10.31676/2073-4948-2020-63-77-88.
9. Ненько Н.И., Киселева Г.К., Ульяновская Е.В., Яблонская Е.К., Караваева А.В. Физиолого-биохимические критерии устойчивости яблони к абиотическим стрессам летнего периода // Сельскохозяйственная биология. 2019. Т. 54. № 1. С. 158–168. DOI: 10.15389/agrobiology.2019.1.158rus.
10. Ожерельева З.Е., Галашева А.М., Красова Н.Г. Изучение устойчивости яблони в условиях теплового шока // Современное садоводство. 2018. № 2 (26). С. 1–7.
11. Реут А.А., Денисова С.Г. Устойчивость декоративных травянистых к изменяющимся условиям окружающей среды // Экобиотех. 2019. Т. 2. № 4. С. 456–461. DOI: 10.31163/2618-964X-2019-2-4-456-461.
12. Ожерельева З.Е., Красова Н.Г., Галашева А.М. Изучение засухоустойчивости летних сортов яблони // Достижения науки и техники АПК. 2019. Т. 33. № 2. С. 31–33. DOI: 10.24411/0235-2451-2019-10209.

REFERENCES

1. Bondarenko L.V., Maslova O.V., Belkina A.V., Sukhareva K.V. Global climate changing and its after-effect. *Vestnik Rossiiskogo ekonomicheskogo universiteta im.G.V. Plekhanova = Vestnik of the Plekhanov Russian University of Economics*, 2018, no. 2, pp. 84–93. (In Russian). DOI: 10.21686/2413-2829-2018-2-84-93.
2. Dragavtseva I.A., Akhmatova Z.P., Morenets A.S. Peculiarities and tendencies of variability of limiting factors of environment for fruit crops of the North Caucasus in the winter-spring period, taking into account climate change (on the example of apricot). *Sadovodstvo i vinogradarstvo = Horticulture and viticulture*, 2018, no. 4, pp. 38–43. (In Russian). DOI: 10.31676/0235-2591-2018-4-38-43.
3. Salama A.M., Ezzat A., El-Ramady H., Alam-Eldein S.M., Okba S., Elmenofy H.M., Hassan I.F., Illés A., Holb I.J. Temperate Fruit Trees under Climate Change: Challenges for Dormancy and Chilling Requirements in Warm Winter Regions. *Horticulturae*, 2021, vol. 7, no. 86. DOI:10.3390/horticulturae7040086.
4. Chawla R., Sheokand A., Roop Rai M., Kumar Sadawarti R. Impact of climate change on fruit production and various approaches to mitigate these impacts. *The Pharma Innovation Journal*, 2021, no. 10 (3), pp. 564–571.
5. Yushkov A.N. *Breeding fruit plants for resistance to abiotic stressors*. Michurinsk, Michurinsk-science city of the Russian Federation, 2019, 332 p. (In Russian).
6. Kovalenko N.N. *Microcherry. Use in the selection of stone fruit crops and landscaping*. Krasnodar, Prosveshchenie-Yug Publ., 2021, 391 p. (In Russian)
7. Gulyaeva A.A. *Cherries and sweet cherries*. Orel, All-Russian Research Institute of Fruit Crop Breeding, 2022. 44 p. (In Russian).
8. Ozherel'eva Z.E., Efremov I.N. Study of heat and drought resistance of *Prunus Crataegus* L. *Plodovodstvo i yagodovodstvo Rossii = Pomiculture and small fruits culture in Russia*, 2020, vol. 63, pp. 77–88. (In Russian). DOI: 10.31676/2073-4948-2020-63-77-88.
9. Nen'ko N.I., Kiseleva G.K., Ulyanovskaya E.V., Yablonskaya E.K., Karavaeva A.V. Physio-biochemical criteria for apple tree tolerance to summer abiotic stresses. *Sel'skokhozyaistvennaya biologiya = Agricultural biology*, 2019, vol. 54, no. 1, pp. 158–168. (In Russian). DOI: 10.15389/agrobiology.2019.1.158rus.
10. Ozherel'eva Z.E., Galasheva A.M., Krasova N.G. The study of apple resistance under conditions of heat shock. *Sovremennoe sadovodstvo = Contemporary horticulture*, 2018, no. 2 (26), pp. 1–7. (In Russian).
11. Reut A.A., Denisova S.G. Resistance of decorative herbaceous plants to changing environmental conditions. *Ekobiotekh = EcoBioTech*, 2019, vol. 2, no. 4, pp. 456–461. (In Russian). DOI: 10.31163/2618-964X-2019-2-4-456-461.
12. Ozherel'eva Z.E., Krasova N.G., Galasheva A.M. Investigation of drought tolerance of summer apple tree cultivars. *Dostizheniya nauki i tekhniki APK = Achievements of Science and Technology of AIC*, 2019, vol. 33, no. 2, pp. 31–33. (In Russian). DOI: 10.24411/0235-2451-2019-10209.

ИНФОРМАЦИЯ ОБ АВТОРАХ

Заремук Р.Ш., профессор кафедры, доктор сельскохозяйственных наук, профессор; SPIN-код 6244-5259

✉ **Копнина Т.А.**, научный сотрудник, кандидат сельскохозяйственных наук; SPIN-код 5261-5672; **адрес для переписки:** Россия, 350901, Краснодар, ул. им. 40-летия Победы, 39; e-mail: tatjanakopnina@rambler.ru

AUTHOR INFORMATION

Rimma Sh. ZaremuK, Chair Professor, Doctor of Science in Agriculture, Professor; SPIN-code 6244-5259

✉ **Tatyana A. Kopnina**, Researcher, Candidate of Science in Agriculture; SPIN-code 5261-5672; **address:** 39, 40 let Pobedy St., Krasnodar, 350901, Russia; e-mail: tatjanakopnina@rambler.ru

Дата поступления статьи / Received by the editors 17.12.2024
Дата принятия к публикации / Accepted for publication 21.02.2025
Дата публикации / Published 16.06.2025



Оценка степени распространения тлей – переносчиков вирусов картофеля на юге Архангельской области

✉ Шаманин А.А.¹, Берим М.Н.², Корелина В.А.¹, Попова Л.А.¹

¹Федеральный исследовательский центр комплексного изучения Арктики им. академика Н.П. Лаврова Уральского отделения Российской академии наук
Архангельск, Россия

²Всероссийский научно-исследовательский институт защиты растений
Санкт-Петербург, г. Пушкин, Россия

✉ e-mail: lexxik_1@mail.ru

В публикации приведены сведения по распространению комплекса афидофауны на посадках картофеля в южной части Архангельской области. Исследование проведено в 2018–2023 гг. В задачи исследования входили изучение видового состава, численности, активности лёта крылатых тлей, а также оценка степени распространения тлей – потенциальных переносчиков вирусов картофеля. Исследование проводили с использованием желтых водных ловушек, расставленных по периметру картофельных полей. Выявлено, что посадки картофеля посещали 13 видов тлей, способных к переносу вирусной инфекции: *Acyrtosiphum pisum* Harr., *Aphis fabae* Scop., *Aphis nasturtii* Kalt., *Aulacorthum solani* Kalt., *Brachycaudus helichrysi* Kalt., *Brevicoryne brassicae* L., *Cavariella aegopodii* Scop., *Hyperomyzus lactucae* L., *Lipaphis erysimi* Kalt., *Macrosiphum euphorbiae* Thomas, *Metopolophium dirhodum* Walk., *Rhopalosiphum padi* L., *Sitobion avenae* F. Данные виды отлавливали и идентифицировали на посадках на протяжении всего периода вегетации картофеля в количестве от 91 до 197 особей в разные годы, что составляет 71–92% от численности всей афидофауны. Отдельно отметим, что в отловах отсутствовали представители вида *Myzus persicae* Sulz., являющегося наиболее вредоносным для картофеля. В период наблюдений численность тлей – переносчиков вирусов в пересчете на одну водную ловушку колебалась в пределах 24–50 особей в год, что характеризует регион проведения исследования как территорию с низкой степенью распространения тлей, способных переносить вирусные инфекции картофеля. Незначительная распространенность тлей указывает на благоприятную фитосанитарную обстановку относительно вирусной инфекции картофеля, но полностью не исключает возможности ее распространения. В связи с этим система защиты растений картофеля в данном регионе должна включать как профилактические, так и истребительные мероприятия.

Ключевые слова: вирусы картофеля, крылатые тли, водные ловушки, мониторинг лёта тлей, *Myzus persicae* Sulz.

Assessment of the aphids-potato virus vectors distribution in the south of the Arkhangelsk region

✉ Shamanin A.A.¹, Berim M.N.², Korelina V.A.¹, Popova L.A.¹

¹N.P. Laverov Federal Center for Integrated Arctic Research
Arkhangelsk, Russia

²All-Russian Research Institute of Plant Protection
Pushkin, Saint-Petersburg, Russia

✉ e-mail: lexxik_1@mail.ru

The publication provides information on the distribution of the aphidofauna complex on potato plantings in the southern part of the Arkhangelsk region. The studies were conducted in 2018–2023.

The objectives of the research included studying the species composition, abundance, flight activity of winged aphids and assessing the prevalence of aphids-potential carriers of potato viruses. It was revealed that potato plantings are visited by 13 species of aphids capable of transmitting viral infection – *Acyrtosiphum pisum* Harr., *Aphis fabae* Scop., *Aphis nasturtii* Kalt., *Aulacorthum solani* Kalt., *Brachycaudus helichrysi* Kalt., *Brevicoryne brassicae* L., *Cavariella aegopodii* Scop., *Hyperomyzus lactucae* L., *Lipaphis erysimi* Kalt., *Macrosiphum euphorbiae* Thomas, *Metopolophium dirhodum* Walk., *Rhopalosiphum padi* L., *Sitobion avenae* F. These species were caught and identified in the plantings throughout the entire potato growing season in numbers from 91 to 197 individuals in different years, which is 71–92% of the total aphid fauna. It should be emphasized that no representatives of *Myzus persicae* Sulz. species, which is the most harmful to potatoes, were present in the catches. During the observation period, the number of aphid carriers per 1 water trap ranged from 24–50 individuals per year, which characterizes the study region as an area with a low prevalence of aphids capable of carrying potato virus infections. The low prevalence of aphid vectors indicates a favorable phytosanitary situation regarding potato viral infection, but does not completely exclude the possibility of the spread of viruses. Therefore, the potato plant protection system in this region should include both preventive and exterminatory measures.

Keywords: potato viruses, winged aphids, water traps, aphid flight monitoring, *Myzus persicae* Sulz.

Для цитирования: Шаманин А.А., Берим М.Н., Корелина В.А., Попова Л.А. Оценка степени распространения тлей – переносчиков вирусов картофеля на юге Архангельской области // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 5. С. 13–21. <https://doi.org/10.26898/0370-8799-2025-5-2>

For citation: Shamanin A.A., Berim M.N., Korelina V.A., Popova L.A. Assessment of the aphids-potato virus vectors distribution in the south of the Arkhangelsk region. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 5, pp. 13–21. <https://doi.org/10.26898/0370-8799-2025-5-2>

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Aphids are small insects (2–5 mm long) that feed on the phloem sap of plants. There are over 5,000 aphid species worldwide, of which approximately 250 are capable of transmitting viral infections of various agricultural crops. Aphids damage a wide range of both weeds and cultivated plants. Direct feeding by these insects causes leaf curling, stunted growth, decreased resistance to diseases and pests, and plant death. The honeydew secreted by aphids can reduce photosynthesis in leaves, attract ants, and create conditions for fungal growth, which also negatively impacts plants. Aphids have the greatest negative impact on plants by transmitting various viral diseases. Due to their high fecundity and ability to rapidly increase their numbers, coupled with their significant migratory activity, aphids can infect a large number of plants in a

short period of time. For example, potato crop losses due to aphid-borne viral infections can reach 80% [1].

One viroid, as well as approximately 50 viruses, can infect potatoes. However, only a few cause serious damage. The most damaging are PVY (Potato virus Y) and PLRV (Potato leafroll virus). PVX (Potato virus X) is also widespread worldwide, and its danger increases significantly when combined with PVY and PVA (Potato virus A). PVS (Potato virus S) is also quite common and belongs to a group of viruses with low pathogenicity, but mixed infections with PVX produce more pathogenic strains. PVA is less common but can cause yield losses of up to 40%. PVM (Potato virus M) is relatively rare in most countries. Typically, the damage it causes is minor, except when it interacts with other viruses [2, 3].

More than 25 aphid species have the ability to transmit potato virus infections, either persistently or non-persistently. The most harmful aphid species, primarily those capable of transmitting potato virus Y, include *Myzis persicae* Sulz., *Acyrtosiphon pisum* Harr., *Sitobion avenae* F., *Cavariella aegopodi* Scop., *Aphis nasturtii* Kalt., *Rhopalosiphum padi* L., *Metopolophium dirkhodum* Walk., *Brachucaudus helichrysi* Kalt., *Aulocarthum solani* Kalt., *Macrosiphum euphorbiae* Thomas, *Hyperomyzus lactucae* L., *Aphis fabae* Scop., *Brevicoryne brassicae* L., *Aphis frangulae* Kalt., *Aphis gossypii* Glov., *Myzus cerasi* F., *Phorodon humuli* Schrk., *Lipaphis erysimi* Kalt. Most species can spread several viruses at the same time^{1,2} [4, 5].

Aphids' dependence on food and climate conditions determines their distribution. Insect species diversity and abundance increase from north to south, from north to east, and from east to south. Thus, the Northwestern Federal District is considered an area with a relatively low prevalence of aphids, which carry viruses: there are 100–200 individuals per trap [6]. In the Moscow Region, Tatarstan, Kemerovo Region, and the Republic of Kazakhstan, aphid prevalence is average, with the maximum number of these insects being around 600 individuals per trap³ [7–9]. In the southern regions of Russia (Bryansk region), a high prevalence of aphids capable of transmitting viral diseases of potatoes has been noted, with the insect population here reaching 800–1,300 individuals per trap [10]. In the Far Eastern Federal District, aphid populations vary greatly: in the Magadan region and the Kamchatka Territory, a low prevalence of virus carriers has been recorded (less than 100 winged individuals per trap), in the Sakhalin region and the Khabarovsk Territory, a relatively low prevalence (100–250 individuals), in the

Amur region, a moderate prevalence (500 individuals), and in the Primorsky Territory, a high prevalence (1,100 individuals) [11].

Available data indicate low aphid populations in the Arkhangelsk region. Preliminary trapping conducted in 2017 identified 11 species, five of which are capable of transmitting potato viral infections [12]. To validate a system for protecting potatoes from pests and diseases, it is necessary to use long-term data, which can only be obtained through systematic annual monitoring.

The purpose of the study is to assess the extent of the spread of aphids, which are carriers of potato viruses, in the southern part of the Arkhangelsk region.

The research objectives are:

- 1) to study the species composition, abundance and flight activity of winged aphids – virus carriers in potato crops;
- 2) to assess the prevalence of aphids – carriers of potato viruses in the study area.

MATERIAL AND METHODS

A study examining the activity of aphids that transmit potato viral diseases was conducted from 2018 to 2023. The study focused on potato crops located in the southern Arkhangelsk region (Kotlas district).

Insects were captured using water traps. Four containers, painted yellow on the inside and filled with water (Mörike traps), were placed around the perimeter of the potato field⁴. Traps were set when the first potato shoots emerged (June 18). The last trapping was performed before top removal (August 27). Trapping frequency was once per week. The insect-containing filtrate obtained from the traps was preserved in a 70% alcohol solution. Insect identification was performed using morphometric characteristics^{5,6} in the Phytosanitary Diagnostics and Forecast-

¹Zykin A.G. Viral diseases of potatoes. L.: Kolos, 1976, 152 p.

²Kennedy J.S., Day M.F., Eastop V.F. A conspectus of aphids as vectors of plant viruses. London, 1962, 114 p.

³Lapshinov N.A. Spread of potato viral infection in the subtaiga zone of the foothills of the Kemerovo region // Achievements of Science and Technology of the AIC, 2011, N 1, pp. 32–33.

⁴Moericke V. Eine Farbfalle zur Kontrolle des Fluges von Blattläusen, insbesondere der Pflirsichblattlaus, *Myzodes persicae* (Zulz.) // Nachrichtenblatt des Deutschen Pflanzenschutzdienstes, 1951, Bd 3, pp. 23–24.

⁵Suborder Aphidinea – Aphids // Key to insects of the European part of the USSR: in 5 volumes / edited by G. Ya. Bey-Bienko. Moscow; Leningrad: Nauka, 1964, vol. 1, pp. 489–616.

⁶Remaudiee G., Seco Fernandez M.V. Claves de pulgones alados de la region Mediterranea. Leon, 1990, vol. 2, 206 p.

ing Laboratory of the All-Russian Research Institute of Plant Protection.

Potato plots were located more than 250 meters away from private farms and bordered forest stands, perennial grasses, and grain crops. In the crop rotation, potatoes were planted after spring grains.

The growing seasons during the study years were characterized by different meteorological conditions (see Table 1). The coldest and most humid year was 2019: the average daily air temperature was 0.5°C below the long-term average, and the hydrothermal coefficient (HTC) was 3.0 (according to Selyaninov). The warmest year was 2021: the average daily air temperature during the growing season exceeded the long-term average by 2.9°C. The driest year was 2018: the HTC was 1.1.

RESULTS AND DISCUSSION

The aphidofauna of the studied potato plantings is represented by 37 species of aphids with a total number of 165 individuals in 2018, 115 in 2019, 117 in 2020, 253 in 2021, 184 in 2022, and 259 individuals in 2023.

The following aphid species have been identified: *Acyrtosiphum pisum* Harr., *Amphorophora rubi* Kalt., *Anoecia corni* F., *Aphis fabae* Scop., *Aphis ideai* Goot, *Aphis nasturtii* Kalt., *Aphis pomi* De Geer, *Aphis sambuci* L., *Aulacorthum solani* Kalt., *Brachycaudus cardui* L., *Brachycaudus helichrysi* Kalt., *Brevicoryne brassicae* L., *Capitophorus elaeagni* Guerc., *Cavariella aegopodii* Scop., *Cavariella avenae* F., *Chaitophorus populeti* Panz., *Cinara costata* L., *Cryptomyzus ribis* L., *Dysaphis devector* Walk., *Euceraphis punctipennis* Zett., *Hyalopterus pruni* Geoffr., *Hyperomyzus lactucae* L., *Liosomaphis barberidis* Kalt., *Lipaphis erysimi* Kalt., *Macrosiphoniella tanacetaria* Gillette, *Macrosiphoniella absinthii* L., *Macrosiphum euphorbiae* Thomas, *Macrosiphum rosae* L., *Megoura viciae* Buck., *Metopolophium dirhodum* Walk., *Myzaphis rosarum* Kalt., *Pemphigus* spp., *Rhopalosiphoninus ribesinus* Goot., *Rhopalosiphum insertum* Walk., *Rhopalosiphum padi* L., *Sitobion avenae* F., *Tuberculatus annulatus* Hart.

Of the species listed above, only 13 are capable of spreading potato viruses: *A. pisum*, *A. fabae*, *A. nasturtii*, *A. solani*, *B. helichrysi*,

Табл. 1. Метеорологические условия вегетационных периодов в годы проведения исследования
Table 1. Meteorological conditions of the growing seasons during the years of research

Indicator	Long-time average annual	Year					
		2018	2019	2020	2021	2022	2023
Average daily air temperature, °C	13,7	14,8	13,2	14,3	16,6	15,4	14,9
May	8,4	10,4	11,4	9,9	11,8	7,7	11,8
June	14,6	13,1	14,8	14,1	19,1	15,6	13,2
July	17,3	19,3	14,9	19,3	18,9	19,6	17,7
August	14,5	16,4	11,6	13,8	16,5	18,6	16,9
Total precipitation, mm	256,0	226,9	398,2	238,9	337,0	270,2	259,4
May	48,0	36,3	69,1	62,7	119,3	43,5	52,4
June	68,0	85,3	64,3	48,6	23,4	81,3	53,0
July	73,0	54,6	129,8	73,2	69,9	106	121,4
August	67,0	50,7	135,0	54,4	124,4	39,4	32,6
HTC	–	1,1	3,0	1,4	1,7	1,7	1,3

B. brassicae, *C. aegopodii*, *H. lactucae*, *L. erysimi*, *M. euphorbiae*, *M. dirhodum*, *Rh. padi*, *S. avenae*. In the structure of the total number of aphids, these species accounted for 91% in 2018, 79% in 2019, 81% in 2020, 78% in 2021, 71% in 2022, and 73% in 2023.

The most numerous aphids capable of transmitting potato viruses, both through direct feeding and through test injections, were *A. fabae*, which was prevalent in crops in 2018, 2022, and 2023, and *Rh. padi*, which was dominant in the remaining years (see Table 2). *A. fabae* was captured in potato crops from the beginning of the potato growing season until the second ten-day period of August. The most active flight of this species occurred from late June to late July. Between 21 and 51 individuals of *A. fabae* were identified annually during the growing season. *Rh. padi* were trapped from the beginning of the potato growing season to early July and from late July to the end of the growing season. The most active flight of this species was recorded in the third ten-day period of June and from the second ten-day period of August until the end of observations. Between 22 and 105 individuals of *Rh. padi* were trapped annually. In 2021, outbreaks of mass reproduction of these species

occurred. For *A. fabae*, they were recorded in the second ten-day period of July, when the number of aphids in the catch was 30 individuals. Mass reproduction of *Rh. padi* occurred in two periods: in the third ten-day period of June, 40 winged insects were caught, and in the second ten-day period of August, their numbers increased sharply to 35 individuals.

The species *A. solani*, *C. aegopodii*, and *S. avenae* can be classified as the third-most abundant aphid vectors of viruses: a total of 70–79 individuals of each species were captured over six years of research. In various years, *A. solani* were trapped from the third ten-day period of June to the second ten-day period of August, meaning they were present on potato crops throughout the entire growing season. Their most active flight was observed in the second and third ten-day periods of July. The annual population was 2–21 individuals. Winged aphids of the species *C. aegopodii* were identified only in 2021–2023, with populations of 2–72 individuals. In the first two years, *C. aegopodii* representatives were present in potato crops from early July to the first ten days of August inclusive. In 2023, increased activity of the species was noted: they were trapped from the second half of June to the first

Табл. 2. Численность тлей, способных переносить вирусную инфекцию картофеля, шт./%

Table 2. The number of aphids capable of transmitting viral infection of potatoes, pcs./%

Species	Year						Total
	2018	2019	2020	2021	2022	2023	
<i>A. pisum</i> Harr.	4/2,7	5/5,5	3/3,2	3/1,5	11/8,5	10/5,3	36/4,2
<i>A. fabae</i> Scop.	44/29,3	21/23,1	25/26,3	51/25,9	30/23,1	41/21,7	212/24,9
<i>A. nasturtii</i> Kalt.	12/8,0	6/6,6	9/9,5	12/6,1	11/8,5	2/1,1	52/6,1
<i>A. solani</i> Kalt.	21/14,0	15/16,5	7/7,4	2/1,0	19/14,6	11/5,8	75/8,8
<i>B. helichrysi</i> Kalt.	0/0,0	0/0,0	2/2,1	0/0,0	0/0,0	0/0,0	2/0,2
<i>B. brassicae</i> L.	0/0,0	0/0,0	0/0,0	2/1,0	0/0,0	0/0,0	2/0,2
<i>C. aegopodii</i> Scop.	0/0,0	0/0,0	0/0,0	2/1,0	5/3,8	72/38,1	79/9,3
<i>H. lactucae</i> L.	23/15,3	7/7,7	4/4,2	7/3,6	7/5,4	6/3,2	54/6,3
<i>L. erysimi</i> Kalt.	0/0,0	0/0,0	0/0,0	0/0,0	2/1,5	0/0,0	2/0,2
<i>M. euphorbiae</i> Thomas	5/3,3	4/4,4	0/0,0	1/0,5	2/1,5	0/0,0	12/1,4
<i>M. dirhodum</i> Walk.	0/0,0	0/0,0	0/0,0	0/0,0	3/2,3	1/0,5	4/0,5
<i>Rh. padi</i> L.	26/17,3	26/28,6	34/35,8	105/53,3	22/16,9	39/20,6	252/29,6
<i>S. avenae</i> F.	15/10,0	7/7,7	11/11,6	12/6,1	18/13,8	7/3,7	70/8,2
Total	150/100,0	91/100,0	95/100,0	197/100,0	130/100,0	189/100,0	852/100,0

ten days of August, with a mass reproduction outbreak (up to 47 individuals per capture) recorded at the end of June. Aphids of the species *S. avenae* were present in traps annually. Their population fluctuated between 7 and 18 individuals per year. Winged individuals of this species were trapped from the first ten days of July to the third ten days of August, with the most active flight observed throughout July.

During the study, *H. lactucae* and *A. nasturtii* were found to be less abundant. *H. lactucae* were actively present in crops from the beginning of the growing season to the first ten days of July inclusive; in some years, single specimens were trapped from the second ten days of July to the second ten days of August. Between 6 and 23 individuals were identified annually during the growing season. *A. nasturtii* was not found to have an active flight during a specific period; in different years, representatives of this species were present in crops at different times from the beginning of the potato growing season to the beginning of the second ten days of August. Between 2 and 12 individuals were trapped annually.

Another aphid species that transmits potato virus infection is *A. pisum*. Pea aphids were present in potato crops annually, with a total population of 3–11 individuals during the growing season. The species was trapped from the third ten days of June through the second ten days of August. Active flight occurred in the second and third ten days of July.

M. euphorbiae is a species that primarily feeds on potatoes. It was present in crops in 2018, 2019, 2021, and 2022, and was captured in traps from the first ten days of July to the first ten days of August. Annual catches ranged from 1 to 5 individuals. Due to its extremely low population, no increased flight activity was observed.

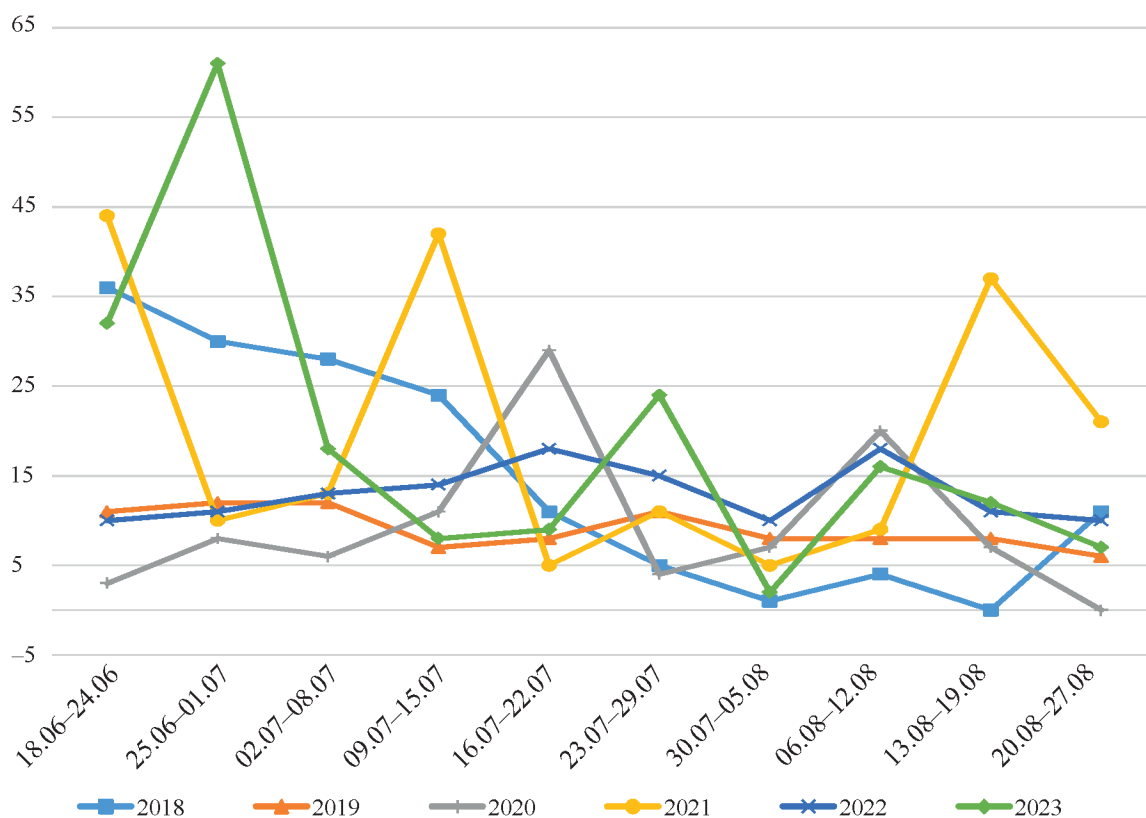
The remaining species were very low in abundance. *B. helichrysi*, *B. brassicae*, and *L. erysimi* were caught in just two individuals each, with the first species caught in late July, the second in mid-August, and the third in late July and early August. *M. dirhodum* aphids were identified in the second half of June.

A total of aphid species capable of transmitting potato viruses were present in the crops throughout the observation period, with varying intensities in individual years. A moderate correlation between the number of captured winged individuals and average daily air temperature ($r = 0.31$) and a weak correlation between this indicator and precipitation were observed ($r = 0.15$).

Given that potatoes are not a primary food source for most of the identified species, their visits to potato crops were primarily foraging for suitable primary food plants. Aphid activity on potato crops varied across all observation years (see the figure). The most consistent visitation patterns were recorded in 2019 and 2022. In 2018, the peak of aphid flight was observed at the beginning of observations. Throughout the potato growing season, there was a gradual decrease in insect numbers in captures, with their numbers beginning to increase in the second ten-day period of August. In 2020, two periods of increased aphid numbers were observed – in the second ten-day period of July and the first ten-day period of August. In 2021, three population spikes occurred – large numbers of aphids visited potato crops at the beginning of the growing season, in mid-July, and in the second ten-day period of August. In 2023, the largest increase in numbers of all years was observed – the peak of flight occurred at the end of June, with two further increases recorded later in the year (at the end of July and the first half of August).

Knowledge of the species composition of potato plantings' aphid fauna and the number of aphids capable of transmitting potato viruses allows us to assess the risks of viral infection spread and formulate a plan for plant protection measures. During the 2018–2023 potato growing season, the number of virus-carrying aphids per water trap ranged from 24 to 50 individuals (see Table 3). The data in Table 3 characterize the study region as an area with a low prevalence of aphids capable of transmitting potato viruses.

It should be noted that during all the years of observation, not a single specimen of *M. persicae* Sulz. (peach aphid), which is the most harmful species for potatoes, was caught.



Динамика численности тлей, способных переносить вирусные инфекции картофеля, шт.
Dynamics of the number of aphids capable of transmitting viral infection of potatoes, pcs.

CONCLUSION

Monitoring aphid flight in potato crops in the southern Arkhangelsk region from 2018 to 2023 revealed that this area is characterized by a low prevalence of aphids, which carry potato viruses. The species composition of aphids, which are potential vectors of infection, includes 13 species: *A. pisum*, *A. fabae*, *A. nasturtii*, *A. solani*, *B. helichrysi*, *B. brassicae*, *C. aegopodii*, *H. lactucaae*, *L. erysimi*, *M. euphorbiae*, *M. dirhodum*, *Rh. padi*, *S. avenae*. These species were captured in traps in potato crops throughout the growing season, with numbers ranging from 91 to 197 individuals in different years, representing 71–91% of the total identified aphidofauna. No representatives of *M. persicae* were found in the traps.

The low prevalence of aphid vectors of viruses indicates a favorable phytosanitary situation with respect to potato virus infection, but does not completely eliminate the possibility of its spread. Therefore, the seed potato plant protection system in this area should include pre-

Табл. 3. Численность тлей на одну водную ловушку в годы наблюдений, шт.

Table 3. Number of aphids per water trap during the observation period, pcs.

Year	Aphid numbers
2018	38
2019	29
2020	24
2021	50
2022	33
2023	47

ventive and eradication measures, such as monitoring aphid flight, monitoring for the presence of virus infection in potato crops, maintaining spatial isolation and crop rotation, autumn tillage, weed control, creating shelterbelts, and using insecticides.

СПИСОК ЛИТЕРАТУРЫ

1. Ali J. The Peach Potato Aphid (*Myzus persicae*): ecology and management: monograph. Boca Raton, 2023. 132 p. DOI: 10.1201/9781003400974.
2. Анисимов Б.В., Марзоев З.А., Зебрин С.Н., Блинков Е.Г., Грачева И.А. Профилактика вирусных болезней, контролируемых в семеноводстве картофеля // Защита и карантин растений. 2022. № 9. С. 27–31. DOI: 10.47528/1026-8634_2022_9_27.
3. Kreuze J.F., Souza-Dias J.A.C., Jeevalatha A., Figueira A.R., Valkonen J.P.T., Jones R.A.C. Viral diseases in potato // The potato crop: collective monograph. Cham, 2020. P. 389–430. DOI: 10.1007/978-3-030-28683-5_11.
4. Ерохова М.Д. Мониторинг тлей – переносчиков вирусов: международный и российский опыт // Защита картофеля. 2016. № 2. С. 24–30.
5. Fox A., Collins L.E., Macarthur R., Blackburn L.F., Northing P. New aphid vectors and efficiency of transmission of Potato virus A and strains of Potato virus Y in the UK // Plant Pathology. 2016. Vol. 2. N 2. P. 325–335. DOI: 10.1111/ppa.12561.
6. Sukhoruchenko G.I., Ivanova G.P., Volgarrev S.A., Berim M.N. Species composition of aphids (Hemiptera, Aphididae) on seed potato planting in Northwest Russia // Entomological review. 2019. N 8. P. 1113–1124. DOI: 10.1134/S0013873819080050.
7. Зейрук В.Н., Белякова Н.А., Белов Г.Л., Васильева М.К., Деревягина М.К., Митина Г.В. Биологическая защита меристемного семенного картофеля от вредителей – переносчиков вирусов в закрытом грунте // Защита картофеля. 2017. № 4. С. 3–12.
8. Сабирова Р.М., Сафиуллина Г.Ф., Ахмадеева З.А., Паутова Г.Г. Векторная активность крылатых тлей на посадках картофеля в условиях Предкамской зоны Республики Татарстан // Вестник Казанского государственного аграрного университета. 2019. № 4. С. 96–101.
9. Екатеринбургская Е.М., Тайков В.В., Карпова О.В. Особенности лёта тлей на посадках оздоровленного картофеля, выращиваемого в Костанайском НИИСХ // Защита картофеля. 2016. № 1. С. 3–5.
10. Молякко А.А., Жевора С.В., Марухленко А.В., Борисова Н.П., Ториков В.Е. Мониторинг переносчиков вирусов картофеля // Вестник Брянской государственной сельскохозяйственной

11. Какарека Н.Н., Толкач В.Ф., Сапоцкий М.В., Волков Ю.Г., Щелканов М.Ю. Насекомые – переносчики вирусных заболеваний картофеля на Дальнем Востоке // Чтения памяти Алексея Ивановича Куренцова. 2019. № 30. С. 191–199. DOI: 10.25221/kurentzov.30.18.
12. Шаманин А.А., Берим М.Н. Результаты мониторинга крылатых тлей (Hemiptera: Aphididae) на посадках картофеля в условиях северного региона России // Аграрная наука Евро-Северо-Востока. 2022. № 5. С. 697–705. DOI: 10.30766/2072-9081.2022.23.5.697-705.

REFERENCES

1. Ali J. *The Peach Potato Aphid (Myzus persicae): ecology and management: monograph*. Boca Raton, 2023, 132 p. DOI: 10.1201/9781003400974.
2. Anisimov B.V., Marzoev Z.A., Zebrin S.N., Blinkov E.G., Gracheva I.A. Prevention for viral diseases, managed in seed potato growing. *Zashchita i karantin rasteniy = Plant protection and quarantine*, 2022, no. 9, pp. 27–31. (In Russian). DOI: 10.47528/1026-8634_2022_9_27.
3. Kreuze J.F., Souza-Dias J.A.C., Jeevalatha A., Figueira A.R., Valkonen J.P.T., Jones R.A.C. Viral diseases in potato. *The potato crop: collective monograph*. Cham, 2020, pp. 389–430. DOI: 10.1007/978-3-030-28683-5_11.
4. Yerokhova M.D. Monitoring of aphid vectors of viruses: international and Russian experience. *Zashchita kartofelya = Potato protection*, 2016, no. 2, pp. 24–30. (In Russian).
5. Fox A., Collins L.E., Macarthur R., Blackburn L.F., Northing P. New aphid vectors and efficiency of transmission of Potato virus A and strains of Potato virus Y in the UK. *Plant Pathology*, 2016, vol. 2, no. 2, pp. 325–335. DOI: 10.1111/ppa.12561.
6. Sukhoruchenko G.I., Ivanova G.P., Volgarrev S.A., Berim M.N. Species composition of aphids (Hemiptera, Aphididae) on seed potato planting in Northwest Russia. *Entomological review*, 2019, no. 8, pp. 1113–1124. DOI: 10.1134/S0013873819080050.
7. Zeyruk V.N., Belyakova N.A., Belov G.L., Vasil'eva M.K., Derevyagina M.K., Mitina G.V. Biological protection of nuclear seed potato from pests – vectors of viruses in greenhouses. *Zashchita kartofelya = Potato protection*, 2017, no. 4, pp. 3–12. (In Russian).

8. Sabirova R.M., Safiullina G.F., Ahmadeeva Z.A., Pautova G.G. Vector activity of winged aphids on potato landings in the conditions of Kama zone of the Republic of Tatarstan. *Vestnik Kazanskogo GAU = Vestnik of Kazan State Agrarian University*, 2019, no. 4, pp. 96–101. (In Russian).
9. Ekaterinskaya E.M., Taykov V.V., Karpova O.V. Peculiarities of volatile aphides flights at plantations of improved potato cultivated in Kostanay Agricultural Research Institute. *Zashchita kartofelya = Potato protection*, 2016, no. 1, pp. 3–5. (In Russian).
10. Molyavko A.A., Zhevora S.V., Marukhlenko A.V., Borisova N.P., Torikov V.E. Potato virus vector monitoring. *Vestnik Bryanskoy gosudarstvennoy sel'skokhozyaistvennoy akademii = Vestnik of the Bryansk state agricultural academy*, 2022, no. 2, pp. 27–34. (In Russian). DOI: 10.52691/2500-2651-2022-90-2-27-34.
11. Kakareka N.N., Tolkach V.F., Sapotsky M.V., Volkov Yu.G., Shchelkanov M.Yu. Insects-vectors of viral diseases of potatoes in the Far East. *Chiteniya pamyati Alekseye Ivanovicha Kurentsova = A.I. Kurentsov's Annual Memorial Meetings*, 2019, no. 30, pp. 191–199. (In Russian). DOI: 10.25221/kurentzov.30.18.
12. Shamanin A.A., Berim M.N. Results of monitoring winged aphids (Hemiptera: Aphididae) on potato plantations in the conditions of the Northern region of Russia. *Agrarnaya nauka Yevro-Severo-Vostoka = Agricultural Science Euro-North-East*, 2022, no. 5, pp. 697–705. (In Russian). DOI: 10.30766/2072-9081.2022.23.5.697-705.

ИНФОРМАЦИЯ ОБ АВТОРАХ

✉ **Шаманин А.А.**, научный сотрудник; SPIN-код 6148-8487; **адрес для переписки:** Россия, 163032, Архангельская область, п. Луговой, 10; e-mail: lexxik_1@mail.ru

Берим М.Н., старший научный сотрудник, кандидат биологических наук; SPIN-код 5511-6431

Корелина В.А., ведущий научный сотрудник, кандидат сельскохозяйственных наук; SPIN-код 6921-4070

Попова Л.А., ведущий научный сотрудник, кандидат экономических наук; SPIN-код 3447-1131

AUTHOR INFORMATION

✉ **Alexey A. Shamanin**, Researcher; SPIN-code 6148-8487; **address:** 10, Lugovoi, Arkhangelsk Region, 163032, Russia; e-mail: lexxik_1@mail.ru

Marina N. Berim, Senior Researcher, Candidate of Science in Biology; SPIN-code 5511-6431

Valentina A. Korelina, Lead Researcher, Candidate of Science in Agriculture; SPIN-code 6921-4070

Ludmila A. Popova, Lead Researcher, Candidate of Science in Economics; SPIN-code 3447-1131

Дата поступления статьи / Received by the editors 14.08.2024
Дата принятия к публикации / Accepted for publication 25.09.2024
Дата публикации / Published 16.06.2025

Изучение биоэкологических особенностей акациевой огневки *Etiella zinckenella* Tr. и оценка эффективности энтомопатогенных биопрепаратов в защите сои от этого вредителя

Агасьева И.С., Исмаилов В.Я., (✉)Петрищева М.В., Голобородько Е.О., Петрищев В.С.

Федеральный научный центр биологической защиты растений

Краснодар, Россия

(✉)e-mail: dollkasneba@yandex.ru

Соя – важнейшая белково-масличная культура мирового земледелия, выращиваемая более чем в 80 странах мира. Целью настоящих исследований являлось изучение биоэкологических особенностей акациевой огневки и биологической эффективности энтомопатогенных биопрепаратов. Исследования проводились на посевах сои сортов среднеспелого срока созревания Вилана, Вилана Бета и Веда. Изучаемые препараты – Биостоп, Ж; Аккар, Ж; Биослип БВ, Ж; Лепидоцид, СК. Учет поврежденности бобов вредителем проводили в период от начала бобообразования до полного созревания семян, для чего отбирали пробы по 100 бобов из разных ярусов в трехкратной повторности. Производственную оценку проводили на площади 10 га в двухкратной повторности с использованием препарата Аккар, Ж. Сроки обработки определяли по отлову самцов акациевой огневки феромонными ловушками. Установлено, что наибольшую вредоносность культуре наносят гусеницы второй и третьей генерации вредителя с I декады августа до конца вегетации сои. Акациевая огневка начинает повреждать сою с нижнего яруса с дальнейшим заселением среднего и верхнего ярусов, при этом возрастной состав гусениц меняется от младшего, среднего к старшему. Установлено, что биологическая эффективность биопрепаратов против акациевой огневки в среднем за два года составляла: Биослип БВ, Ж – 65,1–68,8%; Аккар, Ж – 77,5–80,6%; Биостоп, Ж – 71,9–74,1%; Лепидоцид, СК – 72,0–73,0%. Производственные испытания с биопрепаратом Аккар, Ж показали, что препарат эффективно сдерживал численность и вредоносность акациевой огневки во время созревания сои. На 19.08.2023 г. процент поврежденности бобов гусеницами на 100 бобов в контрольном варианте составил 14,6%, в опытном – 2,1%; в 2024 г. – 9,4 и 1,8% соответственно.

Ключевые слова: соя, акациевая огневка, феромоны, биологическая защита, биопрепараты

Study of bioecological features of the lima bean pod borer *Etiella zinckenella* Tr. and evaluation of the effectiveness of entomopathogenic biopreparations in protecting soybean from this pest

Agasyeva I.S., Ismailov V.Ya., (✉)Petrishcheva M.V., Goloborodko E.O., Petrishchev V.S.

Federal Research Center of Biological Plant Protection

Krasnodar, Russia

(✉)e-mail: dollkasneba@yandex.ru

Soybean is the most important protein and oilseed crop of world agriculture, grown in more than 80 countries. The purpose of the present research was to study the bioecological features of lima bean pod borer and the biological efficacy of entomopathogenic biopreparations. The studies were carried out on soybean crops of mid-season ripening varieties Vilana, Vilana Beta and Veda. The studied preparations were Biostop, L, Akkar, L; Bioslip BV, L; Lepidocid, SC. The damage to beans by the pest was recorded in the period from the beginning of bean formation to full seed ripening, for which 100 beans were sampled from different tiers three times. The production evaluation was carried out on an area of 10 hectares twice using the preparation Akkar, L. The timing of treatment was determined by catching lima bean pod borer males with pheromone traps. It was found that the greatest harm to the crop was caused by caterpillars of the second and third generation of the pest beginning from the first ten days of August until the end of soybean vegetation. Lima bean pod borer begins to damage soybeans from the lower tier with further colonization of the middle and upper tiers, while the age composition of the caterpillars changes from younger, middle, to older. It was established that the biological efficiency of biopreparations lima bean pod borer, on average over two years, was as follows: Bioslip BV, L – 65.1 – 68.8%; Akkar, L – 77.5– 80.6%; Biostop, L – 71.9 – 74.1%, Lepidocide, SC – 72.0 – 73.0%.

Production tests with the biopreparation Akkar, L showed that it effectively suppressed the number and harmfulness of the lima bean pod borer during soybean ripening. As of 19.08.2023, the percentage of bean harmfulness by caterpillars in the control option was 14.6% per 100 beans, in the experimental one – 2.1% per 100 beans, in 2024 it was 9.4% – 1.8% per 100 beans, respectively.

Keywords: soybeans, lima bean pod borer, pheromones, biological protection, biopreparations

Для цитирования: Агасьева И.С., Исмаилов В.Я., Петрищева М.В., Голобородько Е.О., Петрищев В.С. Изучение биоэкологических особенностей акациевой огневки *Etiella zinckenella* Tr. и оценка эффективности энтомопатогенных биопрепаратов в защите сои от этого вредителя // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 5. С. 22–31. <https://doi.org/10.26898/0370-8799-2025-5-3>

For citation: Agasyeva I.S., Ismailov V.Ya., Petrishcheva M.V., Goloborodko E.O., Petrishchev V.S. Study of bioecological features of the lima bean pod borer *Etiella zinckenella* Tr. and evaluation of the effectiveness of entomopathogenic biopreparations in protecting soybean from this pest. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 5, pp. 22–31. <https://doi.org/10.26898/0370-8799-2025-5-3>

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

Благодарность

Исследование выполнено за счет гранта Российского научного фонда № 24-26-00263, <https://rscf.ru/project/24-26-00263/>.

Acknowledgments

This research was funded by the Russian Science Foundation Grant No. 24-26-00263, <https://rscf.ru/project/24-26-00263/>.

INTRODUCTION

The expansion of soybean areas leads to an increase in its production, but at the same time creates a food base for specialized and secondary pests, including adventitious ones, the species composition and harmfulness of which increases every year.

One of the central challenges in achieving high yields in soybean crops is damage to plants by harmful entomofauna. It is known that phytophagous insects can reduce overall yields by 30 to 50%¹ [1, 2].

Phytophages that feed on soybeans are usually divided into the following groups: pests of nodules, roots, leaves and stems, and generative organs. Representatives of all these groups are found in Russia; more than 190 different species of arthropods are known to damage soybeans. The most dangerous are considered to be the spider mite *Tetranychus urticae* Koch. [3, 4], the cotton budworm *Helicoverpa armigera* Hb., and the lima-bean pod borer *Etiella zinckenella* Tr.; damage from soybean aphids *Aphis glycines* Matsuura is also frequently mentioned [5, 6].

Adults and larvae of the spider mite *T. urticae* damage soybean leaf blades, disrupting the natural water balance, reducing chlorophyll content,

and significantly increasing transpiration. The plant becomes covered in white spots, the leaves wilt and fall off, yields decrease by 15–20%. When pest infestations reach high levels, photosynthesis ceases, and the plant loses all leaf surface. During a growing season, the mite produces up to 12 generations. Its population increases dramatically during hot, dry weather. Also, due to its more efficient enzymatic detoxification system, *T. urticae* is more resistant to commonly used acaricides than other spider mite species. This adaptation leads to its widespread spread across vast territories [7–9].

Damage to soybeans by various members of the Aphididae family causes leaf curling and wrinkling, severe wilting, and, in some cases, complete plant death. Furthermore, viruses spread by soybean aphids, such as soybean mosaic virus, can reduce yields by up to 40%, as well as decrease seed protein content by 7–19% and oil content by up to 2.5%. Furthermore, soybean varieties resistant to damage by various pests experience limited cultivation due to the development of new aphid adaptations to host plant resistance [10–12].

Cotton budworm caterpillars (*Helicoverpa armigera* Hb.) burrow into the pod, partially or

¹Fedorova S.N. Harmful entomofauna of the soybean agrocenosis in the Oryol region // Legumes and Groat Crops, 2013, N 8, pp. 58–63.

completely consuming it. Like the larvae of the lima-bean pod borer, *H. armigera* caterpillars contaminate the seeds with excrement. Damage to soybeans by cotton bollworm is more severe, and in cases of co-infestation of the two species, yield reductions can reach 15–25% [13, 14].

In the steppe and forest-steppe zones of Russia, the lima-bean pod borer *Etiella zinckenella* Tr. causes significant damage to soybean crops. The second generation of moths emerges in the fields in the second and third ten-day periods of July, with peak activity observed in the evening and at night, and the active mating flight lasting 10 to 15 days. The hatched caterpillars feed inside the beans, contaminating them with their excrement, and are capable of moving from one bean to another. The caterpillar stage lasts 20–40 days, after which they pupate in the soil and overwinter in cocoons. High temperatures and low humidity promote mass reproduction of the pest. These conditions also increase the damage of the caterpillars due to their increased hydrophilicity [15].

Pest control of soybeans, grown on hundreds of millions of hectares worldwide, typically requires significant economic investment. However, protecting crops from pests while maintaining environmental quality through environmentally sound and economically sound methods is key to meeting the growing demand for food due to the rapidly growing global population [16–18].

The purpose of the research is to study the bioecological characteristics of the lima-bean pod borer and evaluate the effectiveness of entomopathogenic biopreparations against it on soybeans.

MATERIAL AND METHODS

A study of the effectiveness of entomopathogenic biopreparations and biorational insecticides against the lima-bean pod borer on soybean crops was conducted on soybean crops in an eight-field crop rotation at the Federal Research Center of Biological Plant Protection (FRCBPP) (Krasnodar), on the farm of V.N.

Chub, an individual entrepreneur, in the Korenovsky District of Krasnodar Krai over two years (2023 and 2024). The study was carried out on the mid-season soybean varieties Vilana, Vilana Beta, and Veda.

The extent of bean damage by the lima-bean pod borer was assessed from the initial pod formation stage until the seeds were fully ripened. Samples of 100 beans were collected from the lower, middle, and upper tiers of plants, in triplicate. The number of damaged beans was counted and the extent of damage was expressed as a percentage of undamaged beans.

Treatment timing was determined based on insect capture using pheromone traps. The biological efficacy of the applied products against the lima-bean pod borer was determined in accordance with the guidelines² based on damage to 100 beans randomly selected from different plants.

Bean damage was determined by opening the beans in each experimental variant. For the production evaluation, damage was recorded on 300 beans randomly selected from soybean plants.

In a small-plot experiment, the following preparations were tested: Biostop, L; Akkar, L; Bioslip BV, L; Lepidocide, SC. Treatments were carried out in the evening after 7:00 p.m.

The study material consisted of biological insecticides based on three entomopathogenic microorganisms Biostop, L (*Bacillus thuringiensis* BA-2000 EA/ml, titer not less than 10^9 , *Streptomyce* ssp. BA-2000 EA/ml, titer not less than 10^8 , *Beauveria bassiana* BA-2000 EA/ml, titer not less than 10^8 CFU/ml), Akkar, L (1,0 млн/мл *Verticillum lecanii* F 239 + 1,0 million/ml *Hirsutella thompsonii* AC-963 + 1,0 million/ml *Beauveria bassiana* F-1357 + 2,0 billion/ml *Bacillus thuringiensis* IVM B-7072 + 18,0 g/l abamectin); Bioslip BV, L (*Beauveria bassiana* OPB – 43 titer not less than $1-7 \times 10^8$ CFU/ml), Lepidocide, SC (*Bacillus thuringiensis* var. *kurstaki* BA-3000 EA/mg, titer not less than 60 billion spores).

²Guidelines for registration tests of insecticides, acaricides, pheromones, molluscicides, and rodenticides in plant growing: information publication / edited by V.I. Dolzhenko. Moscow: Federal State Budgetary Scientific Institution Rosinformagrotekh, 2022, 508 p.

The treatment was carried out using a PULVEREX hand sprayer equipped with a two-meter boom, with a spray rate of 300 l/ha. The experimental plots were 50 m² in size and randomly located. The experiment was conducted in quadruplicate.

The production evaluation was carried out on an area of 10 hectares in two replicates using the Akkar, L preparation. The treatment was carried out using a tractor-mounted sprayer ON-800.

Statistical processing of the research results was performed according to B.A. Dospekhov³.

RESULTS AND DISCUSSION

Throughout the study period, the greatest threat to soybean crops was posed by the lima-bean pod borer – *Etiella zinckenella* Tr. (Lepidoptera, Pyralidae), which damages more than 70 species of plants in the legume family (Fabaceae), including peas, soybeans, beans, chickpeas, lupines, and others. Potential pests of this family were recorded as single specimens. It was established that the main habitat of the lima-bean pod borer in agroecosystems are protective forest plantations, including white acacia (*Robinia pseudoacacia* Linnaeus) (primarily) and yellow acacia (*Caragana arborescens*

Lam.). Thus, in shelterbelts directly adjacent to soybean crops, damage to white acacia pods by this pest was approximately 90%.

Soybean yields are significantly reduced when lima-bean pod borer caterpillars damage soybeans, as they feed on the kernels inside the pod. The caterpillars can crawl from one pod to another, destroying the seeds and opening the way for fungal infections.

It has been established that the lima-bean pod borer begins feeding in the lower tiers of soybeans (see Fig. 1). Thus, damage to this tier of plants on August 12 was 15.4%, but starting on August 19, the pest spread to all tiers from the lower to the upper, and the maximum infestation of beans by the phytophage reached 38.6% in the upper tier on September 5, with it beginning to decrease in subsequent surveys. Thus, the damage caused by the lima-bean pod borer is observed from the first ten days of August until the end of the crop's growing season, and during this period, the second and third generations of the pest develop in the soybean community.

Results of studies on the age distribution of the lima-bean pod borer caterpillars in soybean communities show that the lima-bean pod borer colonizes plants from the lower tiers with younger larvae, and after flowering, in the middle and

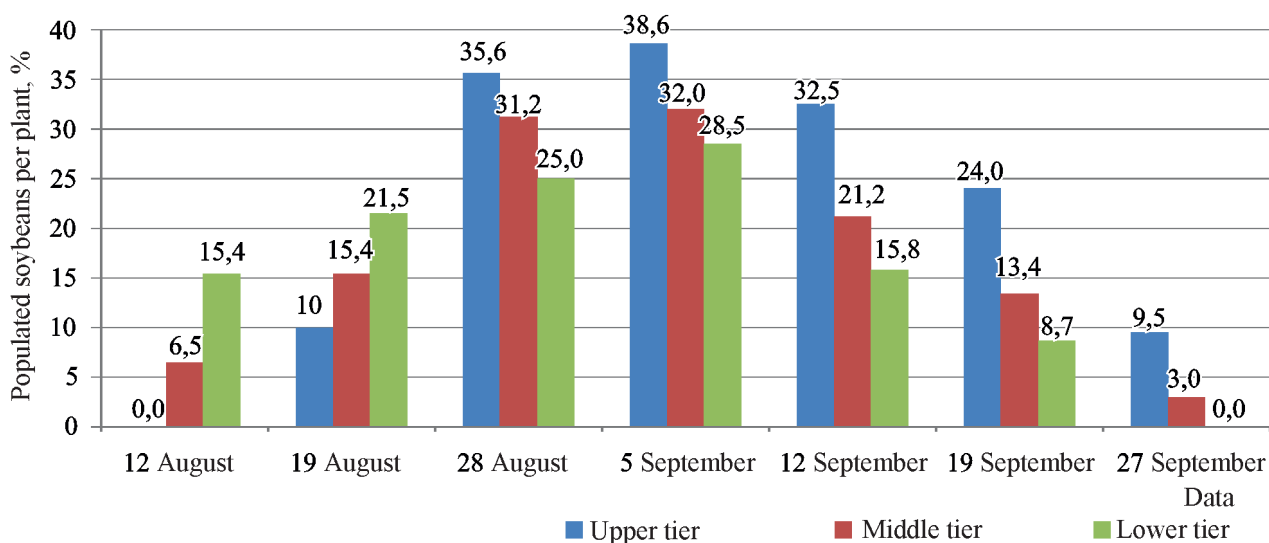


Рис. 1. Динамика заселения сои акациевой огневкой, ФНЦБЗР, 2023 г.

Fig. 1. Dynamics of soybean colonization by the lima bean pod borer, FRCBPP, 2023

³Dospekhov B.A. Methodology of field experiment (with the basics of statistical processing of research results). Moscow: ЕЁMedia, 2024, 349 p.

upper tiers. The pest lays eggs on newly formed pods, and the age distribution of the caterpillars simultaneously changes (see Fig. 2). Thus, on September 27, the proportion of middle-aged and older caterpillars in the middle and upper tiers was 97.3–100%, respectively. Thus, changes in the age structure of the lima-bean pod borer population occur over time. Data on the age structure and population dynamics of the acacia moth were used in planning protective measures using entomopathogenic biopreparations.

Similar results were obtained at the farm of V.N. Chub, an individual entrepreneur and state-owned farmer, in the Korenovsky District. Damage to soybeans by the the lima-bean pod borer amounted to 10.4% and 14.4% (2023 and 2024), respectively (see Table 1).

To monitor and determine the optimal timing of protective measures against *E. zinckenella*, pheromone traps were used. They were hung during the flowering phase of Zad.61-76 soybeans. These traps were used to determine pest population dynamics and optimize the timing of bioinsecticide applications (see Fig. 3).

As can be seen from the data presented in Fig. 3, the flight of males into pheromone traps began on July 4 (2.7 specimens/trap), by July 11 their numbers increased to 5.3 specimens/trap, and then decreased by August 1 to 0.3 specimens/trap. The maximum number of *E. zinckenella* was recorded in early September (09/05/2024) and amounted to 9.0 specimens/trap.

The first summer generation began flying in early July, gradually increasing its numbers. Treatment against lima-bean pod borer caterpillars was carried out on August 10 (plant development phase Zad.79 – bean formation); during this period, active hatching of caterpillars from egg clutches was observed. To prevent hatched caterpillars from penetrating into the beans, bioinsecticide treatments were applied (see Table 2).

The data presented in Table 2 show that the effectiveness of biological products against the lima-bean pod borer in 2023 was 65.1% for Bioslip BV, L, 77.5% for Akkar, L, 71.9% for

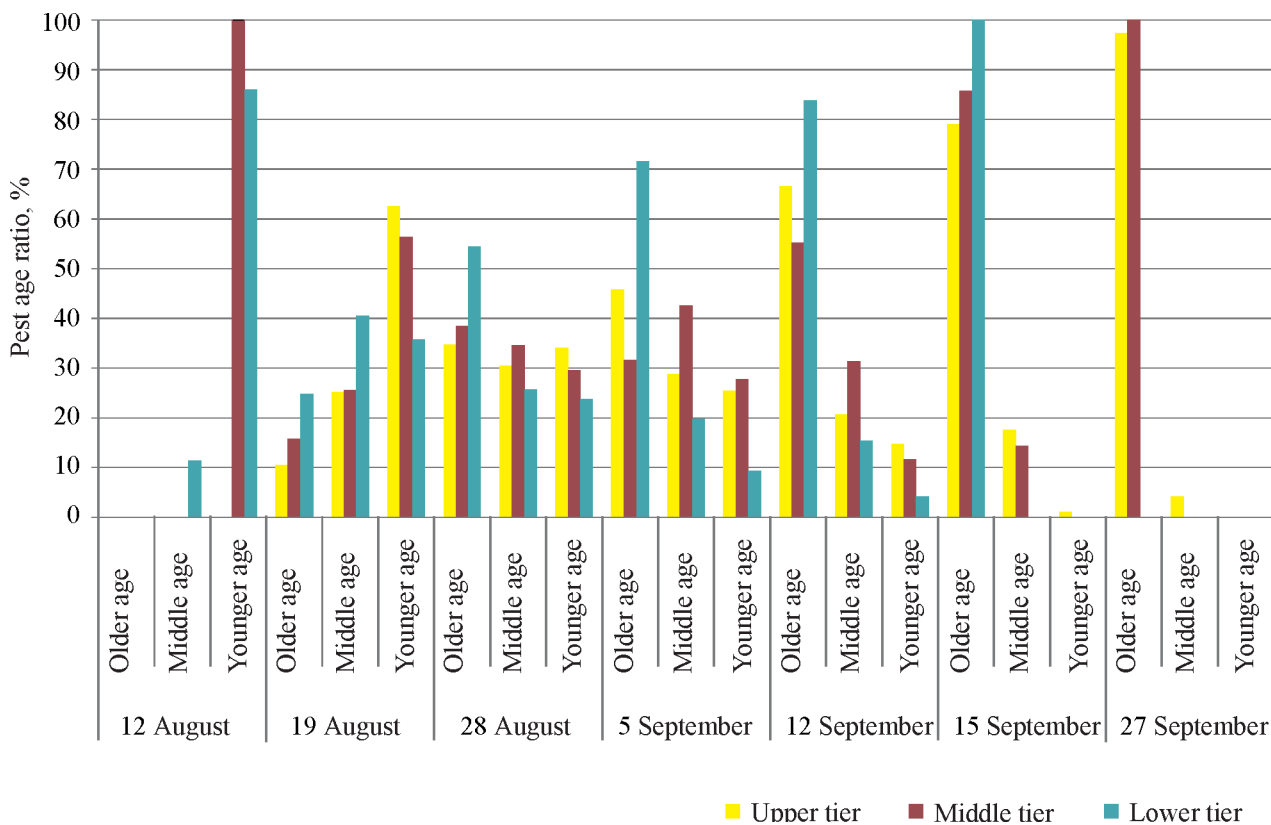


Рис. 2. Возрастная структура популяции акациевой огневки в период вегетации сои, ФНЦБЗР, 2023 г.
Fig. 2. Age structure of the lima bean pod borer population during soybean vegetation period, FRCBPP, 2023

Табл. 1. Повреждение бобов сои акациевой огневкой (ИП ГКФХ В.Н. Чуб Кореновского района)
Table 1. Damage to soybeans by lima bean pod borer (Individual Entrepreneur, head of a peasant farm V.N. Chub, Korenovsky district)

Year	Damage to soybeans by pests by plant layers, %			
	Upper	Middle	Lower	On average
2023	17,5	8	5,9	10,4
2024	29,0	10,5	3,7	14,4

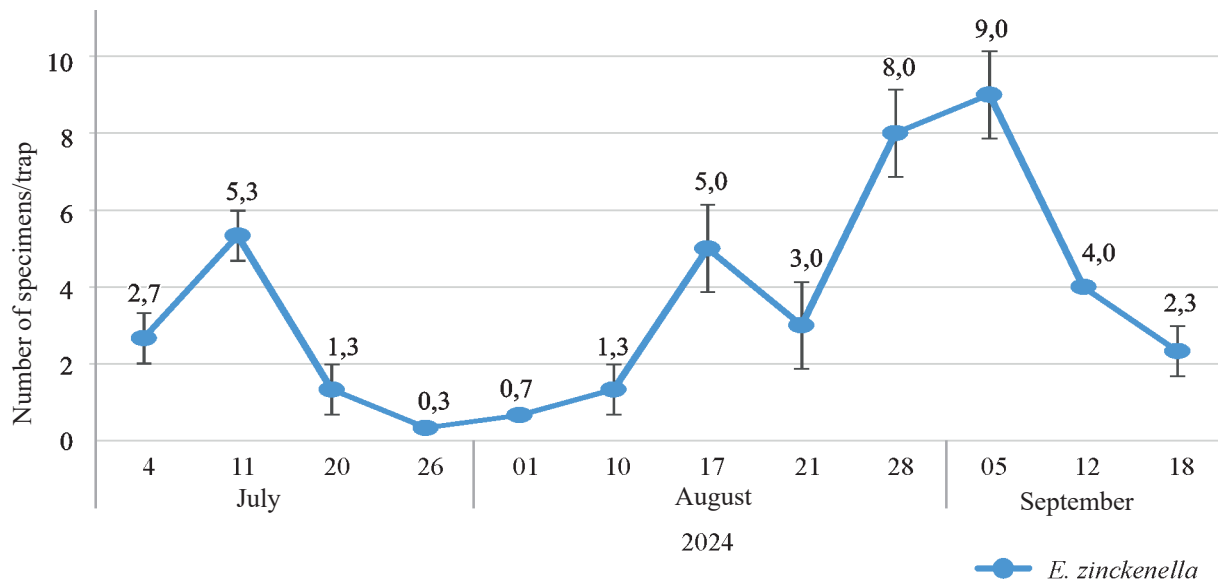


Рис. 3. Численность самцов акациевой огневки, отловленных с помощью феромонных ловушек на сое
Fig. 3. Number of male lima bean pod borers caught using pheromone traps on soybeans

Biostop, L, and 73.0% for Lepidocide, SC. Bean damage in the pre-harvest control was 31.5%.

Similar results were obtained in 2024: Biostop, BV, L – 68.8%, Akkar, L – 80.6%, Biostop, L – 74.1%, Lepidocid, SC – 72.0%, in the control, bean damage was 33.2%. It should be noted that the biological effectiveness of new bioinsecticides against the dangerous hidden-living soybean pest, the lima-bean pod borer, obtained as a result of field trials averaged 73.9%.

Treatment with biological preparations made it possible to protect soybean crops at critical stages of plant development during the bean formation period.

Industrial trials of the Akkar, L biopreparation confirmed its significant effectiveness in protecting soybean grain from the lima-bean pod borer. As of August 19, 2023, the percentage of caterpillar infestations per 100 beans was 14.6% in the control variant, 2.1% in the experimental variant, and 9.4% and 1.8% in 2024, respectively (see Table 3).

CONCLUSION

The conducted research examined the biological characteristics of the lima-bean pod borer and identified the period of greatest damage from the first ten days of August until the end of the soybean growing season. It was established that the second and third generations of the pest primarily develop in the soybean community. The lima-bean pod borer begins damaging soybeans from the lower tiers, then moves to the middle and upper tiers. Depending on the tier level, the age distribution of the caterpillars also changes, from younger and middle to older.

Incorporating pheromone monitoring and bioinsecticides into the soybean biological protection system against the lima-bean pod borer helps prevent hatched caterpillars from penetrating soybeans. The biological effectiveness of biopreparations reducing the lima-bean pod borer caterpillar population has been established: on average, over two years, it amounted to 65.1–

Табл. 2. Биологическая эффективность биопрепаратов в борьбе с акациевой огневкой *E. zinckenella* на сое в Краснодарском крае

Table 2. Biological efficiency of biological products against lima bean pod borer *E. zinckenella* on soybeans in the Krasnodar Territory

Option	Application rate of the preparation, l/ha	Number of seeds examined		Damage to beans, %	Reduction in damage relative to control, %	Weight of 1000 seeds, g
		total	of which damaged			
<i>2023</i>						
Bioslip BV, L	2,0	280	31	11,0	65,1	147,0
Akkar, L	4,0	282	20	7,0	77,5	149,3
Biostop, L	3,0	287	25	8,7	71,9	148,4
Lepidocid, SC	3,0	285	24	8,4	73,0	147,6
Control	–	282	89	31,5	–	134,9
<i>2024</i>						
Bioslip BV, L	2,0	287	29	10,1	68,8	146,8
Akkar, L	4,0	280	18	6,4	80,6	148,5
Biostop, L	3,0	285	24	8,4	74,1	147,8
Lepidocid, SC	3,0	274	26	9,4	72,0	147,0
Control	–	280	93	33,2	–	137,5

Табл. 3. Биологическая эффективность биорационального препарата Аккар, Ж против акациевой огневки в условиях производственных испытаний (ИП ГКФХ В.Н. Чуб Кореновского района)

Table 3. Biological efficiency of the biorational product Akkar against lima bean pod borer under production testing conditions, (Individual Entrepreneur, head of a peasant farm V.N. Chub, Korenovsky district)

Insect species	Infestation of beans by lima bean pod borer according to the dates of the surveys, %				
	10.08	19.08	27.08	06.09	19.09
<i>2023</i>					
Lima bean pod borer (treatment with Akkar, L)	1,7 ± 0,1	2,1 ± 0,4	0,7 ± 0,5	0,4 ± 0,4	0,2 ± 0,5
Lima bean pod borer (control without treatment)	6,8 ± 0,5	14,6 ± 0,5	18,5 ± 1,0	13,9 ± 0,9	7,4 ± 0,9
<i>2024</i>					
Lima bean pod borer (treatment with Akkar, L)	0,9 ± 0,1	1,8 ± 0,3	1,0 ± 0,5	0,5 ± 0,3	0,1 ± 0,3
Lima bean pod borer (control without treatment)	4,7 ± 0,3	9,4 ± 0,8	12,4 ± 1,0	10,9 ± 0,5	6,4 ± 0,7

68.8% (Bioslip BV, L), 77.5–80.6% (Akkar, L), 71.9–74.1% (Biostop, L), and 72.0–73.0% (Lepidocid, SC).

The conducted industrial tests of the biorational preparation Akkar, L have shown its high efficiency against the lima-bean pod borer during the ripening period of soybean grains.

СПИСОК ЛИТЕРАТУРЫ

1. *Ain Q., Mushtaq W., Shadab M., Siddiqui M.B.* Allelopathy: an alternative tool for sustainable agriculture // *Physiology and Molecular Biology of Plants*. 2023. Vol. 29. N 4. P. 495–511. DOI: 10.1007/s12298-023-01305-9.

2. *Adedayo A.A., Musser R., Aanaenson M., Babalola O.O.* The biochemical and molecular mechanisms of plants: a review on insect herbivory // *Plant Signaling and Behavior*. 2025. Vol. 20. N 1. P. 2439248. DOI: 10.1080/15592324.2024.2439248.
3. *Lee S.T., Li C., Davis J.A.* Predator-Pest Dynamics of Arthropods Residing in Louisiana Soybean Agroecosystems // *Insects*. 2022. Vol. 13. N 2. P. 154. DOI: 10.3390/insects13020154.
4. *Reichert M.B., Schneider J.R., Wurlitzer W.B., Ferla N.J.* Impacts of cultivar and management practices on the diversity and population dynamics of mites in soybean crops // *Experimental and Applied Acarology*. 2024. vol. 92. N 1. P. 41–59. DOI: 10.1007/s10493-023-00862-8.
5. *Menger J.P., Ribeiro A.V., Potter B.D., Valmorbida I., Hodgson E.W., Knodel J.J., Koch R.L.* Lack of Evidence for Fitness Costs in Soybean Aphid (Hemiptera: Aphididae) With Resistance to Pyrethroid Insecticides in the Upper Midwest Region of the United States // *Journal of Economic Entomology*. 2022. Vol. 115. N 4. P.1191–1202. DOI: 10.1093/jee/toac096.
6. *Gao B., Yang K., Tian Y., Bai B., Tian Z., Liu J.* Adaptability of the Soybean Aphid *Aphis glycines* (Hemiptera: Aphididae) to Temperature and Photoperiod in a Laboratory Experiment // *Insects*. 2024. Vol. 15. N 10. P. 816. DOI: 10.3390/insects15100816.
7. *Cao L.J., Guan T.B., Chen J.C., Yang F., Liu J.X., Jin F.L., Wei S.J.* Chromosome-level genome assembly of the two-spotted spider mite *Tetranychus urticae* // *Scientific Data*. 2024. Vol. 11. N 1. P. 798. DOI: 10.1038/s41597-024-03640-2.
8. *Hirata K., Kudo K., Amano T., Kawaguchi M.* Effects of the novel acaricide acynonapyr on the calcium-activated potassium channel // *Pesticide Biochemistry and Physiology*. 2024. Vol. 204. P. 106074. DOI: 10.1016/j.pestbp.2024.106074.
9. *Shumate S., Haylett M., Nelson B., Young N., Lamour K., Walsh D., Bradford B., Clements J.* Using targeted sequencing and TaqMan approaches to detect acaricide (bifenthrin, bifenazate, and etoxazole) resistance associated SNPs in *Tetranychus urticae* collected from peppermint fields and hop yards // *PLoS One*. 2023. Vol. 18. N 3. P. e0283211. DOI: 10.1371/journal.pone.0283211.
10. *Todd J.C., Stewart L.R., Redinbaugh M.G., Wilson J.R.* Soybean Aphid (Hemiptera: Aphididae) Feeding Behavior is Largely Unchanged by Soybean Mosaic Virus but Significantly Altered by the Beetle-Transmitted Bean Pod Mottle Virus // *Journal of Economic Entomology*. 2022. Vol. 115. N 4. P. 1059–1068. DOI: 10.1093/jee/toac060.
11. *Pozebon H., Marques R.P., Padilha G., O Neal M., Valmorbida I., Bevilacqua J.G., Tay W.T., Arnemann J.A.* Arthropod Invasions Versus Soybean Production in Brazil: A Review // *Journal of Economic Entomology*. 2020. Vol. 113. N 4. P. 1591–1608. DOI: 10.1093/jee/toaa108.
12. *Mou D.F., Kundu P., Pingault L., Puri H., Shinde S., Louis J.* Monocot crop-aphid interactions: plant resilience and aphid adaptation // *Current opinion in insect science*. 2023. Vol. 57. P. 101038. DOI: 10.1016/j.cois.2023.101038.
13. *Muraro D.S., Gonçalves T.M., Amado D., Lima M.F., Popham H.J.R., Marçon P.G., Omoto C.* Baseline Susceptibility and Cross-Resistance of HearNPV in *Helicoverpa armigera* (Lepidoptera: Noctuidae) in Brazil // *Insects*. 2022. Vol. 13. N 9. P. 820. DOI: 10.3390/insects13090820.
14. *Carpane P.D., Llebaria M., Nascimento A.F., Vivian L.* Feeding injury of major lepidopteran soybean pests in South America // *PLoS One*. 2022. Vol. 17. N 12. P. e0271084. DOI: 10.1371/journal.pone.0271084.
15. *Исмаилов В.Я., Пушня М.В., Родионова Е.Ю., Снесарева Е.Г., Команцев А.А., Цыгичко А.А.* Изучение возможности использования биопрепаратов и биологически активных веществ против доминантных вредителей сои // *Достижения науки и техники агропромышленного комплекса*. 2021. Т. 35. № 4. С. 2–28. DOI 10.24411/0235-2451-2021-10403.
16. *Bueno A.F., Panizzi A.R., Hunt T.E., Dourado P.M., Pitta R.M., Gonçalves J.* Challenges for Adoption of Integrated Pest Management (IPM): the Soybean Example // *Neotropical Entomology*. 2021. Vol. 50. N 1. P. 5–20. DOI: 10.1007/s13744-020-00792-9.
17. *Rowen E.K., Pearsons K.A., Smith R.G., Wicings K., Tooker J.F.* Early-season plant cover supports more effective pest control than insecticide applications // *Ecological Applications*. 2022. Vol. 32. N 5. P. e2598. DOI: 10.1002/eap.2598.
18. *Rios-Díez J.D., Meriño-Cabrera Y., Silva-Junior N.R., de Almeida Barros R., Aguilar de Oliveira J., Josué de Oliveira Ramos H., Gorette de Almeida Oliveira M.* Novel proteinase inhibitor from the hemolymph of soybean pest *Anticarsia gemmatilis* (Lepidoptera: Noctuidae):

Structural modeling and enzymatic kinetic // Archives of Insect Biochemistry and Physiology. 2022 Vol. 109. N 3. P. e21864. DOI: 10.1002/arch.21864.

REFERENCES

1. Ain Q., Mushtaq W., Shadab M., Siddiqui M.B. Allelopathy: an alternative tool for sustainable agriculture. *Physiology and Molecular Biology of Plants*, 2023, vol. 29, no. 4, pp. 495–511. DOI: 10.1007/s12298-023-01305-9.
2. Adedayo A.A., Musser R., Aanaenson M., Babalola O.O. The biochemical and molecular mechanisms of plants: a review on insect herbivory. *Plant Signaling and Behavior*, 2025, vol. 20, no. 1, p. 2439248. DOI: 10.1080/15592324.2024.2439248.
3. Lee S.T., Li C., Davis J.A. Predator-Pest Dynamics of Arthropods Residing in Louisiana Soybean Agroecosystems, *Insects*, 2022, vol. 13, no. 2, p. 154. DOI: 10.3390/insects13020154.
4. Reichert M.B., Schneider J.R., Wurlitzer W.B., Ferla N.J. Impacts of cultivar and management practices on the diversity and population dynamics of mites in soybean crops. *Experimental and Applied Acarology*, 2024, vol. 92, no 1, pp. 41–59. DOI: 10.1007/s10493-023-00862-8.
5. Menger J.P., Ribeiro A.V., Potter B.D., Valmorbidia I., Hodgson E.W., Knodel J.J., Koch R.L. Lack of Evidence for Fitness Costs in Soybean Aphid (Hemiptera: Aphididae) With Resistance to Pyrethroid Insecticides in the Upper Midwest Region of the United States. *Journal of Economic Entomology*, 2022, vol. 115, no. 4, pp. 1191–1202. DOI: 10.1093/jee/toac096.
6. Gao B., Yang K., Tian Y., Bai B., Tian Z., Liu J. Adaptability of the Soybean Aphid *Aphis glycines* (Hemiptera: Aphididae) to Temperature and Photoperiod in a Laboratory Experiment. *Insects*, 2024, vol. 15, no. 10, p. 816. DOI: 10.3390/insects15100816.
7. Cao L.J., Guan T.B., Chen J.C., Yang F., Liu J.X., Jin F.L., Wei S.J. Chromosome-level genome assembly of the two-spotted spider mite *Tetranychus urticae*. *Scientific Data*, 2024, vol. 11, no 1, p. 798. DOI: 10.1038/s41597-024-03640-2.
8. Hirata K., Kudo K., Amano T., Kawaguchi M. Effects of the novel acaricide acynonapyr on the calcium-activated potassium channel. *Pesticide Biochemistry and Physiology*, 2024, vol. 204, p. 106074. DOI: 10.1016/j.pestbp.2024.106074.
9. Shumate S., Haylett M., Nelson B., Young N., Lamour K., Walsh D., Bradford B., Clements J. Using targeted sequencing and TaqMan approaches to detect acaricide (bifenthrin, bifentazate, and etoxazole) resistance associated SNPs in *Tetranychus urticae* collected from peppermint fields and hop yards. *PLoS One*, 2023, vol. 18, no. 3, p. e0283211. DOI: 10.1371/journal.pone.0283211.
10. Todd J.C., Stewart L.R., Redinbaugh M.G., Wilson J.R. Soybean Aphid (Hemiptera: Aphididae) Feeding Behavior is Largely Unchanged by Soybean Mosaic Virus but Significantly Altered by the Beetle-Transmitted Bean Pod Mottle Virus. *Journal of Economic Entomology*, 2022, vol. 115, no. 4, pp. 1059–1068. DOI: 10.1093/jee/toac060.
11. Pozebon H., Marques R.P., Padilha G., O Neal M., Valmorbidia I., Bevilacqua J.G., Tay W.T., Arnemann J.A. Arthropod Invasions Versus Soybean Production in Brazil: A Review. *Journal of Economic Entomology*, 2020, vol. 113, no 4, pp. 1591–1608. DOI: 10.1093/jee/toaa108.
12. Mou D.F., Kundu P., Pingault L., Puri H., Shinde S., Louis J. Monocot crop-aphid interactions: plant resilience and aphid adaptation. *Current opinion in insect science*, 2023, vol. 57, p. 101038. DOI: 10.1016/j.cois.2023.101038.
13. Muraro D.S., Gonçalves T.M., Amado D., Lima M.F., Popham H.J.R., Marçon P.G., Omoto C. Baseline Susceptibility and Cross-Resistance of HearNPV in *Helicoverpa armigera* (Lepidoptera: Noctuidae) in Brazil. *Insects*, 2022, vol. 13, no. 9, p. 820. DOI: 10.3390/insects13090820.
14. Carpane P.D., Llebaria M., Nascimento A.F., Vivian L. Feeding injury of major lepidopteran soybean pests in South America. *PLoS One*, 2022, vol. 17, no. 12, p. e0271084. DOI: 10.1371/journal.pone.0271084.
15. Ismailov V.Ya., Pushnya M.V., Rodionova E.Yu., Snesareva E.G., Komantsev A.A., Tsygichko A.A. Possibility of using biological products and biologically active substances against dominant soybean pests. *Dostizheniya nauki i tekhniki agropromyshlennogo kompleksa = Achievements of Science and Technology of AIC*, 2021, vol. 35, no. 4, pp. 22–28. (In Russian). DOI: 10.24411/0235-2451-2021-10403.
16. Bueno A.F., Panizzi A.R., Hunt T.E., Dourado P.M., Pitta R.M., Gonçalves J. Challenges for Adoption of Integrated Pest Management (IPM): the Soybean Example. *Neotropical Entomology*, 2021, vol. 50, no. 1, pp. 5–20. DOI: 10.1007/

s13744-020-00792-9.

17. Rowen E.K., Pearsons K.A., Smith R.G., Wickings K., Tooker J.F. Early-season plant cover supports more effective pest control than insecticide applications. *Ecological Applications*, 2022, vol. 32, no. 5, p. e2598. DOI: 10.1002/eap.2598.
18. Rios-Díez J.D., Meriño-Cabrera Y., Silva-Junior N.R., de Almeida Barros R., Aguilar de

Oliveira J., Josué de Oliveira Ramos H., Goret de Almeida Oliveira M. Novel proteinase inhibitor from the hemolymph of soybean pest *Anticarsia gemmatalis* (Lepidoptera: Noctuidae): Structural modeling and enzymatic kinetic. *Archives of Insect Biochemistry and Physiology*, 2022, vol. 109, no. 3, p. e21864. DOI: 10.1002/arch.21864.

ИНФОРМАЦИЯ ОБ АВТОРАХ

Агасьева И.С., ведущий научный сотрудник, кандидат биологических наук; Spin-код 6325-6861

Исмаилов В.Я., ведущий научный сотрудник, кандидат биологических наук; Spin-код 2349-7368

✉ **Петрищева М.В.**, старший научный сотрудник, кандидат биологических наук; Spin-код 1691-2238; **адрес для переписки:** Россия, 350039, Краснодар, ул. Калинина, 62; e-mail: dollkasneba@yandex.ru

Голобородько Е.О., младший научный сотрудник; Spin-код 5132-9266

Петрищев В.С., младший научный сотрудник, аспирант; Spin-код 4146-9829

AUTHOR INFORMATION

Irina S. Agasyeva, Lead Researcher, Candidate of Science in Biology; Spin-code 6325-6861

Vladimir Ya. Ismailov, Lead Researcher, Candidate of Science in Biology; Spin-code 2349-7368

✉ **Maria V. Petrishcheva**, Senior Researcher, Candidate of Science in Biology; Spin-code 1691-2238; **address:** 62, Kalinina St., Krasnodar, 350039, Russia; e-mail: dollkasneba@yandex.ru

Ekaterina O. Goloborodko, Junior Researcher; Spin-code 5132-9266

Victor S. Petrishchev, Junior Researcher, Post-graduate Student; Spin-code 4146-9829

Дата поступления статьи / Received by the editors 07.02.2025
Дата принятия к публикации / Accepted for publication 13.03.2025
Дата публикации / Published 16.06.2025

Фитосанитарное и экономическое обоснование элементов технологии возделывания яровой пшеницы в лесостепи Новосибирского Приобья

Фещенко Е.С., ✉ Торопова Е.Ю.

Новосибирский государственный аграрный университет
Новосибирск, Россия
✉ e-mail: 89139148962@yandex.ru

Представлены результаты трехлетних исследований (2021–2023), проводившихся в лесостепной зоне Новосибирского Приобья с целью всесторонней (фитосанитарной, технологической, экономической) оценки эффективности предпосевной обработки семян и применения различных предшественников при возделывании яровой пшеницы. Исследования проводили по схеме двухфакторного опыта и согласно общепринятой методике. В качестве протравителей использовали фунгицид Дивиденд Стар, КС (норма применения – 0,9 л/т) и его баковую смесь с инсектицидом Контадор Макси, КС (норма – 0,5 л/т). Яровую пшеницу сорта Новосибирская 31 высевали по трем предшественникам: черный пар, вико-овсяная смесь на зеленую массу, озимая рожь на зерно. В каждый из годов исследования поврежденность посевов яровой пшеницы вредителями всходов (хлебной блошкой и злаковыми мухами) превышала пороговые значения. Применение инсектицидного протравителя семян продемонстрировало биологическую эффективность до 73,1% против хлебной блошки и до 42,7% против злаковых мух. Анализ элементов структуры урожайности показал, что в контрольных вариантах статистически достоверные различия отмечены по продуктивной кустистости и числу зерен в колосе. Протравливание оказало достоверно значимое влияние на число продуктивных колосьев (+ 43–49 шт./м², или 9,2–10,5%). Наибольшая биологическая урожайность контрольных вариантов получена по паровому предшественнику – 2,86 т/га. В среднем за три года зерно пшеницы по всем вариантам опыта (кроме контроля по озимой ржи) по качественным показателям соответствовало III классу. В среднем за три года наибольшая рентабельность по контрольным вариантам была выявлена при возделывании яровой пшеницы по однолетним травам (48,5%). Предпосевное протравливание семян по всем вариантам обеспечило увеличение как рентабельности производства, так и прибыли с 1 га.

Ключевые слова: яровая пшеница, предшественник, протравитель, элемент структуры урожайности, качество зерна, прибыль

Phytosanitary and economic justification of the elements of technology for cultivation of spring wheat in the Novosibirsk Ob Region forest-steppe

Feshchenko E.S., ✉ Toropova E.Yu.

Novosibirsk State Agrarian University
Novosibirsk, Russia
✉ e-mail: 89139148962@yandex.ru

The results of three years of research (2021–2023) conducted in the forest-steppe zone of the Novosibirsk region aiming at a comprehensive (phytosanitary, technological, economic) evaluation of the efficiency of pre-sowing seed treatment and application of different predecessors in spring wheat cultivation. The studies were conducted using a two-factor experiment scheme and according to the generally accepted methodology. Dividend Star, SC (application rate – 0.9 l/t) and its tank mixture with an insecticide Kontador Maxi, SC (application rate – 0.5 l/t) were used as the dressing agents. Spring wheat of the Novosibirskaya 31 variety was sown after three predecessors: black fallow, vetch-choat mixture for green mass, winter rye for grain. In each year of the study, damage to spring wheat crops by seedling pests (cereal flea beetle and corn flies) exceeded the threshold values. The use of an insecticidal disinfectant showed a biological effectiveness of up to 73.1% against cereal flea beetle and up to 42.7% against corn flies. Analysis of the yield structure elements showed that statistically significant differences in the control variants statistically reliable differences were observed in productive bushiness and number of grains per ear. Dressing had a significantly significant effect only on the

number of productive ears (+ 43–49 pcs/m² or 9.2–10.5%). The highest biological yield of the control variants was obtained with the fallow predecessor – 2.86 t/ha. On average over 3 years, the grain in all the experimental variants (except for the control for winter rye) in terms of quality indicators corresponded to class III grain. On average over 3 years, the highest profitability for the control options was identified when cultivating spring wheat with annual grasses (48.5%). Pre-sowing seed treatment for all the options increased both production profitability and profit per 1 hectare.

Keywords: spring wheat, predecessor, seed treatment, yield structure element, grain quality, profit

Для цитирования: Фещенко Е.С., Торопова Е.Ю. Фитосанитарное и экономическое обоснование элементов технологии возделывания яровой пшеницы в лесостепи Новосибирского Приобья // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 5. С. 32–41. <https://doi.org/10.26898/0370-8799-2025-5-4>

For citation: Feshchenko E.S., Toropova E.Yu. Phytosanitary and economic justification of the elements of technology for cultivation of spring wheat in the Novosibirsk Ob Region forest-steppe. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 5, pp. 32–41. <https://doi.org/10.26898/0370-8799-2025-5-4>

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Spring wheat is the main food crop grown by agricultural enterprises in the Novosibirsk Region. Its sown area in 2022 amounted to approximately 925.3 thousand hectares, or 60.3% of the grain area¹. From 2020 to 2022, wheat yields in the Novosibirsk Region did not exceed 2.2 tons/ha.

One of the ways to obtain stable grain crop yields is the biologization of agriculture based on the use of phytosanitary crop rotations [1], which allow removing of dormant structures of root rot pathogens from the soil by 62.1–89.2% [2–4]. At the same time, the cultivation of phytosanitary precursors reduces the number and harmfulness of specialized pests of cereal crops [5–7].

Pre-sowing treatment is the most effective, environmentally friendly and cost-effective method of using pesticides [2, 8]. However, it should be taken into account that its effectiveness depends on the choice of precursors, since they determine the species composition and abundance of destructive biota, and also affect the crop's resistance to it [9–11].

Currently, the grain processing industry in Russia is experiencing a shortage of high-quality

grain, which leads to the need to search for new ways of its stable production [12, 13]. Grain quality is an indicator of the intensification of grain production and depends on the genetic potential of the cultivated variety, the agricultural technologies used, and the natural and climatic resources of the growing zone [14, 15]. The introduction of scientifically based crop rotation and the rational use of plant protection products (including the selection of effective preparations for pre-sowing seed treatment) will bring us closer to solving the problem of obtaining high-quality wheat grain [16].

The purpose of the study was to comprehensively (phytosanitary, technological, economic) evaluate the effectiveness of pre-sowing treatment of spring wheat seeds and the use of various predecessors (black fallow, vetch-oat mixture, winter rye) in the forest-steppe conditions of the Novosibirsk Ob region.

MATERIAL AND METHODS

The study was conducted in 2021–2023 in the forest-steppe conditions of the Novosibirsk Ob region (Cherepanovsky District) at the Alva-Farm (OOO) farm using a two-factor experimental design. Spring wheat of the Novosibirskaya 31 variety was sown after three precu-

¹Cultivated area of the Russian Federation in 2022 / Federal State Statistics Service (Rosstat). Moscow, 2023, 36 p. (<http://ssl.rosstat.gov.ru/>).

sors: black fallow, a vetch-oat mixture for green fodder (grain silage), and winter rye for grain (the "predecessor" factor).

Pre-sowing wheat seed treatment was performed with the fungicide Dividend Star, SC (difeconazole, 30.0 g/l + cyproconazole, 6.3 g/l; application rate – 0.9 l/t), as well as a tank mix of the fungicide with the addition of the insecticide Kontador Maxi, SC (imidacloprid, 600 g/l; application rate – 0.5 l/t). The flow rate of the working fluid was 10 l/t. Untreated seeds served as a control ("treatment" factor).

The soil cover of the experimental plot is represented by leached medium-deep chernozem with small inclusions of podzolized medium-deep chernozem and dark-gray forest medium-deep soil.

The availability of nutrients varied depending on the preceding crops. Thus, the nitrate nitrogen content in the arable layer was: 9.9–23.5 (on average – 14.4) mg/kg – after fallow, 4.3–19.8 (9.5) mg/kg – after vetch-oat mixture, 5.2–13.2 (6.9) mg/kg – after winter rye. The availability of mobile forms of phosphorus (according to Nikonov) for all preceding crops was average – from 16.5 to 33.2 mg P₂O₅/kg. The average humus content for all variants was about 4.5% (from 3.2 to 7.6%). The reaction of the soil solution was close to neutral (pH_{salt} = 6,1).

The spring wheat cultivation technology was generally accepted for this zone [2, 3]. According to it, the mineral nutrition system included the application of ammonium nitrate in the row during sowing (the application rate was 120 kg/ha), as well as the combined use of urea along with chemical preparations during vegetation (the general rate was up to 20 kg/ha in physical weight). The area under each experimental variant was 50 hectares. Three replicates were performed.

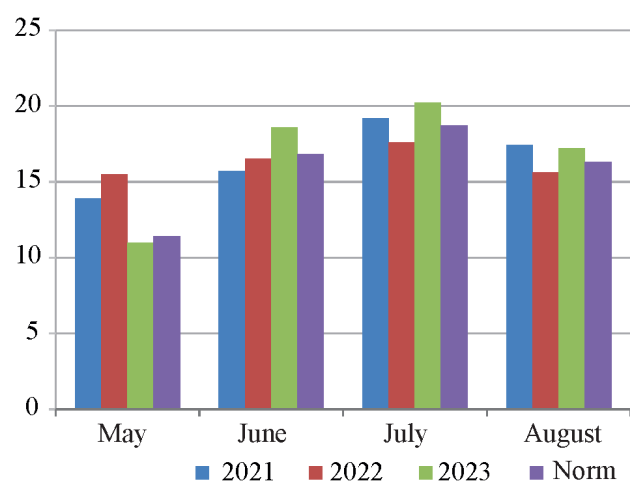
Leaf and stem diseases were recorded using proven methods², and leaf damage by cereal

flea beetles was assessed using a 5-point scale³. Wheat yield patterns were determined before harvesting, and biological yield was calculated based on these patterns. Statistical data processing was performed using variance and correlation analysis methods using the Snedekor software package.

During the years of study, hydrometeorological conditions were different (see the figure).

May 2021 was warm and rainy, with precipitation around normal and temperatures 2.5°C above the monthly average. June temperatures were 1.1°C below the long-term average, with precipitation 49.1% above normal (85 mm versus 57 mm). July and August experienced persistent drought, with precipitation totaling only 41% and 76% of normal, while temperatures exceeded the monthly average by 0.9°C and 1.1°C, respectively. The hydrothermal coefficient (HTC) for the growing season was 0.99, indicating slightly arid moisture conditions.

The beginning of the 2022 growing season was marked by warm (the average monthly air temperature in May was 4.1°C above normal) but dry conditions (precipitation was 21 mm, or 47% of normal). Hydrometeorological con-



Среднемесячная температура воздуха (по данным Посевнинской гидрометеостанции), °C
Average monthly air temperature (according to Posevinskaya HMS data), °C

²Chulkina V.A., Toropova E.Yu., Stetsov G.Ya., Kirichenko A.A., Marmuleva E.Yu., Grishin V.M., Kazakova O.A., Selyuk M.P. Phytosanitary diagnostics of agroecosystems: educational and practical manual. Barnaul, 2017, 210 p.

³Pospelov S.M., Arsenyeva M.V., Gruzdev G.S. Plant protection. L.: Kolos, 1979, 432 p.

ditions in June were close to long-term averages. Temperatures in July and August were 1.1°C and 0.7°C below normal, respectively, with precipitation deficits (28% and 14% below normal). Hydrothermal conditions during the growing season were characterized as arid (HTC = 0.92).

The 2023 growing season was marked by sharp fluctuations in hydrometeorological conditions. In May, precipitation was only 20% of the norm with a hydrothermal coefficient (HTC) of 0.15. From June to August, the average monthly air temperature exceeded the norm by 0.9–1.8°C. In July, a precipitation deficit was observed (16 mm below the norm), while in June and August, the long-term average was exceeded (by 9 and 60 mm, respectively, or 16 and 107%). The hydrothermal coefficient (HTC) for the 2023 growing season was 1.23, corresponding to moderate moisture.

RESULTS AND DISCUSSION

The results of recording damage to spring wheat leaves by cereal flea beetles and damage to stems by cereal flies in the full germination phase are presented in Table 1.

The data in Table 1 indicate significant annual damage to seedlings by pests. For example, damage to the leaf surface of wheat by the cereal flea beetle reached 70% or more, which is many times greater than the economic threshold of damage (ETD – first leaf damage of more than

15%). The greatest leaf damage was observed when grown over annual grasses (38.2%). The use of an insecticidal seed treatment reduced pest populations across all preceding crops, and consequently, damage to wheat leaves. The highest biological effectiveness was recorded for fallow: 73.1% (6.6% and 12.8% higher than for annual grasses and winter rye, respectively). Cereal fly infestations (spring fly, barley fry) were consistently above the economic threshold (ETD) for all preceding crops (6–10%). Thus, phytosanitary precursors (fallow and annual grasses) reliably reduce cereal fly infestations in crops compared to the grain precursor (winter rye). Insecticide treatments across all treatments demonstrated moderate biological effectiveness—from 31.9 to 42.7%.

Analysis of variance revealed that the influence of the "year" factor on leaf damage by cereal flea beetles was 24.6%, while the "treatment" factor was 40.1%, and the "predecessor" factor had no significant effect. The influence of the "year" factor on stem damage by cereal flies was 51.4%, while the "predecessor" factor was 23.3%, and the "treatment" factor was 18.6% (from here on, the reliability of the analysis results is at the 5% significance level).

The results of the survey of dark brown spot (helminthosporiosis) of spring wheat are shown in Table 2.

Analysis of Table 2 indicates a significant annual prevalence of dark brown leaf spot above

Табл. 1. Биологическая эффективность инсектицидного протравителя и предшественников в защите всходов яровой пшеницы от вредителей (в среднем за три года)

Table 1. Biological effectiveness of insecticidal disinfectant and precursors in protecting spring wheat seedlings from seedling pests (on average for 3 years)

Forecrop	Seed treatment	Leaf damage, %	Biological effectiveness, %	Damage to stems, %	Biological effectiveness, %
Black fallow	Control	26,4	–	9,0	–
	Insecticide	7,1	73,1	5,3	41,1
Annual grasses	Control	38,2	–	9,4	–
	Insecticide	12,8	66,5	6,4	31,9
Winter rye	Control	36,0	–	11,7	–
	Insecticide	14,3	60,3	6,7	42,7
LSD ₀₅ average quotients		6,8	–	1,4	–

the economic threshold (ETD) (20%). On average, over three years, the greatest leaf damage during the tillering stage (up to 4 ETD) was observed in the grain preceding crop. Black fallow reduced the prevalence of dark brown leaf spot by an average of 30.4%. During the heading stage of spring wheat, the prevalence of dark brown leaf spot did not significantly differ between preceding crops. Pre-plant seed treatment with a fungicide, as well as cultivation after winter rye and annual grasses, reduced the incidence of dark brown spot by 20% or more (biological effectiveness: 30%). However, cultivation after fallow had no significant effect on the incidence of the infection.

Analysis of variance showed that the influence of the “predecessor” factor on the prevalence of dark brown spot in the tillering phase was 16.8%, in the heading phase – 5.4%; the influence of the “year” factor in the tillering phase was 44.6%, in the heading phase – 66.1%; the influence of the “treatment” factor in the tillering phase was 16.2%, in the heading phase treatment did not have a reliable effect on the prevalence of the infection. Consequently, the degree of influence of predecessors and seed treatment on the prevalence of dark brown leaf spot of spring wheat during the growing season

decreased by 3.1 and 4.1 times, respectively, while the influence of year conditions, on the contrary, increased by 1.5 times, which confirms the additional nature of the ecological niche of the soil phytopathogen *Bipolaris sorokiniana* in the aboveground organs of host plants [17].

Analysis of the crop structure elements presented in Table 3 indicates that during the years of the study their value was lower than the optimal parameters for the zone or close to them.

The density of productive stems in all experimental variants was at or above the optimal level for the zone, with the exception of the control variants for winter rye and annual grasses (457.3 and 476.0 pcs/m², respectively). The maximum number of productive stems in the control variants was observed with the fallow predecessor – 522 pcs/m². Seed treatment with a tank mixture of fungicide and insecticide preparations ensured a significant increase in the number of productive stems by 43–49 pcs/m² (9,2–10,5%).

The grain content per ear across all experimental variants during the study years was 5–22% below the optimum. The decrease in grain content could be due to the formation of shortened ears during the tillering phase due to a lack of moisture and nutrients, root rot, and pest damage.

The 1,000-kernel weight was 5.4–14.3% below the optimal level for this zone, depending on the preceding crops and seed treatment options. Therefore, no statistically significant differences were found in this indicator.

In the control study, the maximum biological yield of spring wheat was achieved with fallow as a precursor crop – 2.86 t/ha, which is 0.47 and 0.69 t/ha higher than the yields for annual grasses and winter rye, respectively. The economic efficiency of fallow over the three years of the study was 31.8% (compared to winter rye). Seed treatment with a fungicide maintained average yields of 0.16–0.38 t/ha compared to previous crops, with economic efficiency ranging from 7.4–13.3%. Pre-sowing seed treatment with a tank mixture of fungicide and insecticide im-

Табл. 2. Распространенность темно-бурой пятнистости листьев по фазам развития яровой пшеницы, предшественникам и вариантам обработки семян (среднее за три года), %

Table 2. Prevalence of dark brown spot by development phases, predecessors and seed treatment options (on average for 3 years), %

Forecrop	Seed treatment	Development phase	
		tillering	earring
Black fallow	Control	49,3	68,3
	Fungicide	49,1	58,1
	Fungicide + insecticide	51,4	61,1
Annual grasses	Control	67,7	68,8
	Fungicide	47,2	48,3
	Fungicide + insecticide	49,3	49,8
Winter rye	Control	79,7	77,3
	Fungicide	60,0	53,3
	Fungicide + insecticide	55,6	55,9
LSD ₀₅ average quotients		13,3	9,9

Табл. 3. Хозяйственная эффективность и элементы структуры урожая (в среднем за три года)
Table 3. Economic efficiency and the yield structure elements (on average for 3 years)

Forecrop	Seed treatment	Number of ears, pcs/m ²	Number of grains per ear, pcs.	Weight of 1000 grains, g	Yield, t/ha	Economic efficiency, %
Optimal parameters for the zone		500,0	20,0	35,0	3,50	–
Black fallow	Control	522,0	17,4	31,0	2,86	–
	Fungicide	527,3	18,5	33,1	3,24	13,3
	Fungicide + insecticide	570,0	19,4	32,9	3,66	28,0
Annual grasses	Control	476,0	16,3	30,3	2,39	–
	Fungicide	486,8	16,3	32,4	2,59	8,4
	Fungicide + insecticide	525,8	17,7	30,4	2,84	18,8
Winter rye	Control	457,3	15,5	30,6	2,17	–
	Fungicide	477,2	15,8	30,8	2,33	7,4
	Fungicide + insecticide	500,3	16,2	30,0	2,45	12,9
LSD ₀₅ average quotients		12,3	0,9	1,1	0,13	–

proved economic efficiency. The highest yield was recorded for the fallow preceding crop (28.0%).

The analysis of variance shows that the influence of the "predecessor" factor on the density of productive stems was 11.1%, on the grain content of the ear – 45.2, on the weight of 1000 seeds – 8.4, and on the biological yield – 29.7%. The degree of influence of the "year" factor on the number of productive stems was 66.5%, on the grain content of the ear – 13.6, on the weight of 1000 seeds – 53.1, and on the biological yield – 47.9%. The "treatment" factor had a statistically significant effect only on the indicators of biological yield (9.2%) and the number of grains per ear (11.9%).

The quality of spring wheat grain varied greatly across years and variants (see Table 4).

The grain unit weight varied significantly across the experimental variants. On average, over the years of study, the lowest grain unit weight was observed for winter rye in the control variants – 720.0 g/l, which is 74.7 and 33.3 g/l less than for fallow and annual grasses, respectively. Seed treatment with a fungicide resulted in a significant increase in the grain unit weight for winter rye (+ 13.3 g/L) and annual grasses (+ 34.4 g/L), while treatment with a tank mixture of the preparations resulted only in winter rye (+ 43.7 g/L). The correlation coefficient between the grain unit weight and the 1,000-kernel weight was 0.757 ± 0.101 .

Табл. 4. Качественные показатели зерна пшеницы (в среднем за три года)
Table 4. Quality indicators of wheat grain (on average for 3 years)

Forecrop	Seed treatment	Grain unit, g/l	Vitreousness, %	Protein, %	Gluten		Grain class
					%	units (GDI-1)	
Black fallow	Control	794,7	56,0	15,3	27,5	63,3	III
	Fungicide	777,0	57,7	16,1	29,1	62,6	III
	Fungicide + insecticide	780,3	55,0	15,9	29,2	61,6	III
Annual grasses	Control	753,3	53,3	15,3	26,5	68,1	III
	Fungicide	787,7	59,0	16,4	28,5	66,1	III
	Fungicide + insecticide	751,3	56,3	14,9	26,1	64,7	III
Winter rye	Control	720,0	53,0	14,0	21,9	60,0	IV
	Fungicide	733,3	53,3	14,2	23,2	58,8	III
	Fungicide + insecticide	763,7	55,7	14,3	25,2	63,5	III
LSD ₀₅ average quotients		10,2	1,7	0,4	1,1	2,3	–

The grain vitreousness in all experimental variants (except for the control on winter rye) corresponded to class III grain and was within 50–60 units.

The highest wet gluten content in the control was observed in the fallow preceding crop – 27.5%, exceeding the values for annual grasses and winter rye by 1.0 and 5.6%, respectively. Seed treatment with a fungicide increased the gluten content by 1.3–2.0%. Adding an insecticide component to the tank mixture resulted in an additional gluten increase of 2.0% for winter rye.

The lowest protein content in the control treatments was recorded for the grain predecessor – 14.0%, which is 1.3% less than for the fallow and annual grasses. Treatment with a fungicide increased protein content by 0.2–1.1% for all treatments. Seed treatment with a tank mixture of fungicide and insecticide had different effects on the amount of protein in the grain: for the fallow predecessor, protein content significantly increased by 0.6% relative to the control, while for the grain predecessor and annual grasses, the value was statistically indistinguishable from the control.

Correlation analysis revealed a positive relationship ($r = 0.8671 \pm 0.147$) between the content of protein and crude gluten in grain ($p < 0,05$).

The results of the analysis of variance indicate that the degree of influence of the "predecessor" factor on the grain unit was 15.0%, on the crude gluten content – 56.1, the amount of protein in the grain – 41.0, the vitreousness index – 12.4%. The strength of the influence of the "year" factor on the grain unit was 54.4%, on the vitreousness of the grain – 16.6, the content of crude gluten and protein – 11.1% each. The "dressing agent" factor had a reliably significant effect only on the vitreousness of the grain (12,4%).

To calculate the economic efficiency of spring wheat cultivation using the stated predecessors and processing options, the average results of a field experiment over three years were taken as a basis (see Table 5).

Table 5 shows that the highest profitability for the control treatments, on average over three years, was achieved with annual grasses – 48.5%, which is 10.1% and 18.5% higher than with fallow and winter rye. The highest profit was obtained with the fallow predecessor –

Табл. 5. Экономическая эффективность возделывания яровой пшеницы по предшественникам и вариантам обработки семян (в среднем за три года)

Table 5. Economic efficiency of spring wheat cultivation by predecessors and seed treatment variants (on average for 3 years)

Indicator	Black fallow			Vetch-oat mixture			Winter rye		
	control	fungicide	fungicide + insecticide	control	fungicide	fungicide + insecticide	control	fungicide	fungicide + insecticide
Yield, t/ha	2,77	3,17	3,58	2,35	2,54	2,81	1,98	2,26	2,42
Production costs, rubles	27 422	28 868	30 175	21 682	22 299	22 758	20 869	21 754	22 530
Cost price of 1 ton of products, rubles	9900	9107	8429	9226	8779	8099	10 540	9626	9310
Average selling price of 1 ton of products, rubles	13 700	13 700	13 700	13 700	13 700	13 700	13 700	13 700	13 700
Cost of products at selling prices, rubles	37 949	43 429	49 046	32 195	34 798	38 497	27 126	30 962	33 154
Profit/loss, rubles	10 527	14 561	18 871	10 513	12 499	15 739	6257	9208	10 624
Profitability, %	38,4	50,4	62,5	48,5	56,1	69,2	30,0	42,3	47,2

10,527 rubles/ha, which is 14 and 4,270 rubles higher than with annual grasses and winter rye. Pre-sowing seed treatment for all experimental treatments increased both production profitability and profit per hectare. The greatest increase in profitability compared to the control was observed when treating seeds with a tank mixture of preparations for fallow – up to 62.5% (+24.1%). The highest net income in monetary terms was achieved when cultivating spring wheat after fallow with a tank mixture of fungicide and insecticide – 18,871 rubles/ha.

CONCLUSIONS

1. During the study years, the level of damage to spring wheat crops by seedling pests exceeded the ETD. Application of Contador Maxi, SC insecticide at a rate of 0.5 l/t demonstrated biological effectiveness of up to 73.1% against the cereal flea beetle and up to 42.7% against cereal flies.

2. An analysis of the yield structure of spring wheat showed that statistically significant differences were found in the control variants for productive tillering (maximum for the fallow predecessor – 522 pcs/m²) and the number of grains per ear (for the fallow predecessor – 17.4 pcs). Treatment had a significant effect only on the number of productive ears (+ 43–49 pcs./m², or 9,2–10,5%).

3. The maximum biological yield of spring wheat without seed treatment was obtained with a fallow predecessor – 2.86 t/ha. On average, over three years, the grain quality in all experimental variants (except for the control variant when grown after winter rye) corresponded to that of Class III grain.

4. The highest profitability of spring wheat cultivation without seed treatment was achieved with annual grasses (48.5%). Pre-sowing seed treatment increased not only production profitability (by 7.6–24.1%), but also profit per hectare (by 1986–8344 rubles) for all predecessor crops.

СПИСОК ЛИТЕРАТУРЫ

1. Зезин Н.Н., Постников П.А. Формирование и налив зерна с урожаем яровой пшеницы в различных метеоусловиях // *Зерновое хозяйство России*. 2021. № 1. С. 57–62. DOI: 10.31367/2079-8725-2021-73-1-57-62.
2. Торопова Е.Ю., Кириченко А.А., Стецов Г.Я. Защита всходов яровой пшеницы в Сибири // *Защита и карантин растений*. 2023. № 2. С. 20–28. DOI: 10.47528/1026-8634_2023_2_20.
3. Торопова Е.Ю., Кириченко А.А., Стецов Г.Я. Как повысить озерненность колоса и массу 1000 зерен яровой пшеницы // *Защита и карантин растений*. 2023. № 3. С. 16–25. DOI: 10.47528/1026-8634_2023_3_16.
4. Юшкевич Л.В., Щитов А.Г., Ющенко Д.Н., Кашиинская С.П. Агротехническая оценка зернобобового предшественника в плодосменном севообороте южной лесостепи Западной Сибири // *Вестник Красноярского государственного аграрного университета*. 2022. № 9. С. 87–94. DOI: 10.36718/1819-4036-2022-9-87-94.
5. Jambagi S.R., Kambrekar D.N., Mallapur C.P., Rudra Naik V. Novel insecticides for the management of shoot fly, *Atherigona approximate* Malloch (Diptera: Muscidae): an emerging insect pest of wheat in India // *International Journal of Tropical Insect Science*. 2023. Vol. 43. P. 989–998. DOI: 10.1007/s42690-023-01005-7.
6. Jasrotia P., Singh B., Nagpal M. Biology and management strategies of major insect-pests of wheat // *New horizons in wheat and barley research: collective monograph*. Singapore: Springer, 2022. P. 283–307. DOI: 10.1007/978-981-16-4134-3_9.
7. Schmid R., Hefley T., Lollato R., Mc Cornack B.P. Landscape effects on Hessian fly *Mayetiola destructor* (Diptera: Cecidomyiidae), distribution within six Kansas commercial wheat fields // *Agriculture, Ecosystems & Environment*. 2019. Vol. 274. P. 52–61. DOI: 10.1016/j.agee.2018.12.018.
8. Торопова Е.Ю., Фещенко Е.С. Эффективность протравителей семян яровой пшеницы при возделывании по разным предшественникам в лесостепи Новосибирской области // *Защита и карантин растений*. 2023. № 4. С. 15–18. DOI: 10.47528/1026-8634_2023_4_15.
9. Гришечкина Л.Д., Долженко В.И., Сухорученко Г.И., Буркова Л.А., Мартынушкин А.Н. Предпосевная обработка семян зерновых

- культур // Приложение к журналу «Защита и карантин растений». 2023. № 1. С. 33–80.
10. Долматова Л.С., Садовников Г.Г. Обработка семян – эффективный способ борьбы с личинками шведских мух в посевах яровой мягкой пшеницы // Вестник Алтайского государственного аграрного университета. 2019. № 7 (177). С. 22–27.
 11. Figueroa M., Hammond-Kosack K.E., Solomon P.S. A review of wheat diseases-a field perspective // *Molecular Plant Pathology*. 2018. Vol. 19. N 6. P. 1523–1536.
 12. Богдан П.М., Коновалова И.В., Клыков А.Г. Влияние абиотических факторов на урожайность и качество зерна яровой мягкой пшеницы в условиях Приморского края // *Достижения науки и техники АПК*. 2021. Т. 35. № 1. С. 16–20. DOI: 10.24411/0235-2451-2021-10103.
 13. Бахвалова С.А., Фёдорова А.В. Сидераты и урожайность яровой пшеницы // *Плодородие*. 2021. № 2 (119). С. 36–38. DOI: 10.25680/S19948603.2021.119.09.
 14. Горянин О.И., Щербинина Е.В. Совершенствование технологии возделывания яровой пшеницы в Поволжье // *Аграрный научный журнал*. 2020. № 6. С. 11–14. DOI: 10.28983/asj.y2020i6pp11-14.
 15. Скороходов В.Ю., Кафтан Ю.В., Зоров А.А., Скороходова Е.Н., Зенкова Н.А. Качество зерна яровой мягкой и твердой пшеницы в севооборотах Оренбургского Предуралья // *Животноводство и кормопроизводство*. 2023. Т. 106. № 4. С. 260–272. DOI: 10.33284/2658-3135-106-4-260.
 16. Кекало А.Ю., Заргарян Н.Ю., Немченко В.В. Распространение фитопатогенов на зерновых яровых культурах в Уральском регионе // *Аграрный вестник Урала*. 2022. № 11 (226). С. 14–24. DOI: 10.32417/1997-4868-2022-226-11-14-24.
 17. Торопова Е.Ю., Сухомлинов В.Ю., Кириченко А.А., Пискарев В.В. Паразитирование *Vipolaris sorokiniana* Sacc. Shoem. в системе органов сортов яровой пшеницы в северной лесостепи Приобья // *Вестник Новосибирского государственного аграрного университета*. 2022. № 1 (62). С. 76–87. DOI: 10.31677/2072-6724-2022-62-1-76-87.
 1. Zezin N.N., Postnikov P.A. Spring wheat grain formation and filling and its productivity under various weather conditions. *Zernovoe khozyaistvo Rossii = Grain Economy of Russia*, 2021, no. 1, pp. 57–62. (In Russian). DOI: 10.31367/2079-8725-2021-73-1-57-62.
 2. Toropova E.Yu., Kirichenko A.A., Stetsov G.Ya. Seedling protection for spring wheat in Siberia. *Zashchita i karantin rasteniy = Plant Protection and Quarantine*, 2023, no. 2, pp. 20–28. (In Russian). DOI: 10.47528/1026-8634_2023_2_20.
 3. Toropova E.Yu., Kirichenko A.A., Stetsov G.Ya. How to increase the grain content of an ear and the weight of 1000 grains of spring wheat. *Zashchita i karantin rasteniy = Plant Protection and Quarantine*, 2023, no. 3, pp. 16–25. (In Russian). DOI: 10.47528/1026-8634_2023_3_16.
 4. Yushkevich L.V., Shchitov A.G., Yushchenko D.N., Kashinskaya S.P. Leguminous precursor agrotechnical assessment in the crop rotation of the Western Siberian southern forest-steppe. *Vestnik KrasGAU = Bulletin KrasSAU*, 2022, no. 9, pp. 87–94. (In Russian). DOI: 10.36718/1819-4036-2022-9-87-94.
 5. Jambagi S.R., Kambrekar D.N., Mallapur C.P., Rudra Naik V. Novel insecticides for the management of shoot fly, *Atherigona* approximate Malloch (Diptera: Muscidae): an emerging insect pest of wheat in India. *International Journal of Tropical Insect Science*, 2023, vol. 43, pp. 989–998. DOI: 10.1007/s42690-023-01005-7.
 6. Jasrotia P., Singh B., Nagpal M. Biology and Management Strategies of Major Insect-Pests of Wheat. *New horizons in wheat and barley research: collective monograph*. Singapore: Springer, 2022, pp. 283–307. DOI: 10.1007/978-981-16-4134-3_9.
 7. Schmid R., Hefley T., Lollato R., Mc Cornack B.P. Landscape effects on Hessian fly *Mayetiola destructor* (Diptera: Cecidomyiidae), distribution within six Kansas commercial wheat fields. *Agriculture, Ecosystems & Environment*, 2019, vol. 274, pp. 52–61. DOI: 10.1016/j.agee.2018.12.018.
 8. Toropova E.Yu., Feshchenko E.S. Efficacy of fungicidal seed treaters for the seeds of spring wheat during cultivation after the different previous crops in the forest-steppe of the Novosibirsk region. *Zashchita i karantin rasteniy = Plant Protection and Quarantine*, 2023, no. 4, pp. 15–18. (In Russian). DOI: 10.47528/1026-8634_2023_4_15.
 9. Grishechkina L.D., Dolzhenko V.I., Sukhouchenko G.I., Burkova L.A., Martynushkin A.N. Pre-sowing treatment of grain seeds.

- Prilozhenie k zhurnalu "Zashchita i karantin rasteniy" = Appendix to the magazine "Plant Protection and Quarantine"*, 2023, no. 1, pp. 33–80. (In Russian).
10. Dolmatova L.S., Sadovnikov G.G. Seed treatment as an efficient technique to control frit fly (*Oscinella*) larvae on spring soft wheat. *Vestnik Altaiskogo gosudarstvennogo agrarnogo universiteta = Bulletin of Altai State Agricultural University*, 2019, no. 7 (177), pp. 22–27. (In Russian).
 11. Figueroa M., Hammond-Kosack K.E., Solomon P.S. A review of wheat diseases—a field perspective. *Molecular Plant Pathology*, 2018, vol. 19, no. 6, pp. 1523–1536.
 12. Bogdan P.M., Konovalova I.V., Klykov A.G. Influence of abiotic factors on yield and grain quality of spring common wheat under conditions of the Primorsky territory. *Dostizheniya nauki i tekhniki APK = Achievements of Science and Technology of AIC*, 2021, vol. 35, no. 1, pp. 16–20. (In Russian). DOI: 10.24411/0235-2451-2021-10103.
 13. Bakhvalova S.A., Fedorova A.V. Ciderates and spring wheat crop yield. *Plodorodie = Plodorodie*, 2021, no. 2 (119), pp. 36–38. (In Russian). DOI: 10.25680/S19948603.2021.119.09.
 14. Goryanin O.I., Shcherbinina E.V. Improving the technology of spring wheat cultivation in the Volga Region. *Agrarniy nauchnyy zhurnal = Agrarian Scientific Journal*, 2020, no. 6, pp. 11–14. (In Russian). DOI: 10.28983/asj.y2020i6pp11-14.
 15. Skorokhodov V.Yu., Kaftan Yu.V., Zorov A.A., Skorokhodova E.N., Zenkova N.A. Quality of spring soft and durum wheat grain in crop rotations of the Orenburg Cis-Urals. *Zhivotnovodstvo i kormoproizvodstvo = Animal Husbandry and Fodder Production*, 2023, vol. 106, no. 4, pp. 260–272. (In Russian). DOI: 10.33284/2658-3135-106-4-260.
 16. Kekalo A.Yu., Zargaryan N.Yu., Nemchenko V.V. Distribution of phytopatogens on spring grain crops in the Ural region. *Agrarniy vestnik Urala = Agrarian Bulletin of the Urals*, 2022, no. 11 (226), pp. 14–24. (In Russian). DOI: 10.32417/1997-4868-2022-226-11-14-24.
 17. Toropova E.Yu., Sukhomlinov V.Yu., Kirichenko A.A., Piskarev V.V. Parasitization of *Bipolaris sorokiniana* Sacc. Shoem. in the organ system of spring wheat varieties in the northern forest-steppe of Priobye region. *Vestnik NGAU = Bulletin of NSAU*, 2022, no. 1 (62), pp. 76–87. (In Russian). DOI: 10.31677/2072-6724-2022-62-1-76-87.

ИНФОРМАЦИЯ ОБ АВТОРАХ

Фещенко Е.С., аспирант; SPIN-код 9737-6714

✉ **Торопова Е.Ю.**, профессор кафедры, доктор биологических наук, профессор; SPIN-код 6909-0622; **адрес для переписки:** Россия, 630039, Новосибирск, ул. Добролюбова, 160; e-mail: 89139148962@yandex.ru

AUTHOR INFORMATION

Egor S. Feshchenko, Post-graduate Student; SPIN-code 9737-6714

✉ **Elena Yu. Toropova**, Chair Professor, Doctor of Science in Biology, Professor; SPIN-code 6909-0622; **address:** 160, Dobrolyubova St., Novosibirsk, 630039, Russia; e-mail: 89139148962@yandex.ru

Дата поступления статьи / Received by the editors 29.10.2024
Дата принятия к публикации / Accepted for publication 17.12.2024
Дата публикации / Published 16.06.2025

Влияние климатических условий Брянской области на развитие и распространение фузариоза в посевах люпина узколистного

Пимохова Л.И., Яговенко Г.Л., Царапнева Ж.В., Хараторкина Н.И., ✉ Мисникова Н.В.

Всероссийский научно-исследовательский институт люпина – филиал Федерального научного центра кормопроизводства и агроэкологии им. В.Р. Вильямса

Брянская область, п. Мичуринский, Россия

✉ e-mail: lupin_nvmisnikova@mail.ru

В статье представлены результаты изучения распространения в посевах люпина заболеваний корневой гнилью и увядания растений, вызванных грибами рода *Fusarium*. Цель исследования – изучить влияние метеорологических факторов Брянской области на поражение люпина фузариозной корневой гнилью и увяданием растений, их вредоносности и выработать предложения по сдерживанию. Работа проведена в 2019–2023 гг. Объект изучения – растения люпина узколистного сорта Белорозовый 144 в посевах с применением средств защиты и в контрольном посевах (без применения защитных средств). Идентификацию возбудителей заболеваний проводили по морфологическим признакам спороношения в течение вегетации с помощью влажных камер и светового микроскопа. Установлено, что корневая гниль люпина узколистного вызывается грибом *F. avenaceum*, а трахеомикозное увядание растений – *F. oxysporum*. Интенсивность их развития определялась количеством выпадения осадков и температурой воздуха в период вегетации. Наибольший вред посевам люпина узколистного наносило трахеомикозное увядание растений. За годы исследований в контрольном посевах поражение им растений за вегетацию варьировало от 9,1 до 29,0%, а корневой гнилью – 4,6...8,3%. В посевах с применением средств защиты поражение растений этими заболеваниями сократилось на 6,3...19,6% и на 4,5...7,2% соответственно. Среднее количество сохранившихся растений с бобами (5,8 бобов/растение) увеличилось по отношению к контрольному посевам на 33,4 шт./м². При этом масса 1000 семян увеличилась на 17,1 г, урожайность семян – на 0,97 т/га. Установлена достоверная обратная корреляционная связь ($r = -0,89$, $p = 0,039$) между урожайностью семян люпина узколистного и поражением растений грибом *F. oxysporum*. Выявлена высокая достоверная обратная зависимость ($r = -0,89$, $p = 0,039$) между среднесуточной температурой воздуха в июле и урожайностью семян. Таким образом, для уменьшения количества больных растений люпина узколистного, пораженных фузариозной корневой гнилью и увяданием, а также для снижения потерь урожайности семян необходимо проводить протравливание посевного материала и обработку посевов в фазы 2–3 настоящих листьев и бутонизации – начала цветения фунгицидами с высокой эффективностью против патогенных грибов *F. avenaceum* и *F. oxysporum*.

Ключевые слова: люпин узколистный, фузариоз, климатические факторы, средства защиты, урожайность

Influence of climatic conditions of the Bryansk region on the development and spread of fusariosis in narrow-leaved lupine crops

Pimokhova L.I., Yagovenko G.L., Tsarapneva Zh.V., Kharaborkina N.I., ✉ Misnikova N.V.

The All-Russian Research Institute of Lupine – Branch of the Federal Williams Research Center of Forage Production and Agroecology

Michurinsky, Bryansk region, Russia

✉ e-mail: lupin_nvmisnikova@mail.ru

The article presents the results of studying the spread of root rot and wilting diseases caused by fungi of the genus *Fusarium* in lupine crops. The purpose of the research was to study the influence of meteorological factors of the Bryansk region on the damage of lupine by fusarium root rot and wilting of plants, their harmfulness and to develop proposals to control them. The work was carried out in 2019–2023. The object of research was the plants of narrow-leaved lupine variety Belorozovy 144 in the sowing with application of protection means and in the control sowing (without application of protection means). Identification of the pathogens was carried out by morphological signs of sporulation

during the vegetation period using humidified chambers and light microscope. It was found that root rot of narrow-leaved lupine is caused by the fungus *F. avenaceum*, and tracheomycosis wilt of plants by *F. oxysporum*. The intensity of their development was determined by the amount of precipitation and the air temperature during the growing season. Tracheomycosis wilt caused the greatest damage to narrow-leaved lupine crops. During the years of research in the control crop, its affection of plants during vegetation varied from 9.1 to 29.0%, and root rot – 4.6...8.3%. In sowing with application of means of protection plant damage by these diseases decreased by 6.3...19.6% and by 4.5...7.2%, respectively. The average number of preserved plants with beans (5.8 beans/plant) increased by 33.4 units/m² in relation to the control crop. At the same time, the mass of 1000 seeds increased by 17.1 g and the seed yield increased by 0.97 t/ha. A reliable inverse correlation relationship ($r = -0.89$, $p = 0.039$) between narrow-leaved lupine seed yield and plant infestation by fungus *F. oxysporum* was found. A high significant inverse relationship ($r = -0.89$, $p = 0.039$) between the average daily air temperature in July and seed yield was found. Thus, to reduce the number of diseased narrow-leaved lupine plants affected by fusarium root rot and wilting, as well as to reduce seed yield losses, it is necessary to conduct seed dressing and treatment of crops in the phases of 2–3 true leaves and budding – beginning of flowering with fungicides with high efficacy against pathogenic fungi *F. avenaceum* and *F. oxysporum*.

Keywords: narrow-leaved lupine, fusariosis, climatic factors, protection means, yield

Для цитирования: Пимохова Л.И., Яговенко Г.Л., Царапнева Ж.В., Хараборкина Н.И., Мисникова Н.В. Влияние климатических условий Брянской области на развитие и распространение фузариоза в посевах люпина узколистного // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 5. С. 42–54. <https://doi.org/10.26898/0370-8799-2025-5-5>

For citation: Pimokhova L.I., Yagovenko G.L., Tsarapneva Zh.V., Kharaborkina N.I., Misnikova N.V. Influence of climatic conditions of the Bryansk region on the development and spread of fusariosis in narrow-leaved lupine crops. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 5, pp. 42–54. <https://doi.org/10.26898/0370-8799-2025-5-5>

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

Благодарность

Работа выполнена в рамках бюджетного финансирования Программы фундаментальных научных исследований Российской академии наук (№ FGGW-2022-0006).

Acknowledgements

The work was carried out within the framework of budgetary funding of the Basic Research Program of the Russian Academy of Sciences (No. FGGW-2022-0006).

INTRODUCTION

Narrow-leaved lupine (*Lupinus angustifolius* L.) is the earliest of all its cultivated varieties. For seed maturation, the sum of active temperatures should be 1600–1700 °C. In the Non-Black Earth regions north and east of Moscow, lupine is the only crop whose grain can compete with imported soybeans in the production of high-protein feed additives and bulk feeds balanced in energy and protein. The crude protein content in grain is 34–38%, in dry matter of green mass 17–20% [1, 2].

Diseases of narrow-leaved lupine reduce the yield of grain and green mass, reduce the nitrogen-fixing capacity of nodules, and worsen the sowing qualities of seeds. Of the many diseases

of lupine, fusariosis continues to be a widespread and harmful disease [3, 4].

Fusariosis is a dangerous disease of lupine caused by imperfect fungi of the genus *Fusarium*, widespread in all countries cultivating this crop. *Fusarium* species have a wide range of adaptive reactions. This determines their saprophytic growth phase in the soil of the rhizosphere, on dead cells and then on the surface of the roots, and when plants are weakened by the influence of many unfavorable factors - the transition to parasitism on their tissues or growth in their organs, the emergence of virulent races [5, 6].

The species composition of the mushroom is not constant. It changes over the years depend-

ing on the diversity of cultivated species and varieties¹.

Development and spread of fusariosis depend on both the type of pathogen and its biological characteristics, as well as on environmental factors: climatic, agronomic, soil, biocenotic and other changing living conditions of the pathogen and the host plant².

Different species and varieties of lupine form different species composition of the fungus differing in the percentage of species. Lupine diseases caused by different types of fusarium fungi include damage to the above-ground and root parts of the plant³.

The greatest damage to crops of narrow-leaved lupine in the Non-Black Earth Zone of Russia is caused by species such as *Fusarium avenaceum* Sacc. and *Fusarium oxysporum* Schl. [3, 4].

Root rot of narrow-leaved lupine is mainly caused by the fungus *F. Avenaceum* Sacc. The fungus penetrates the plant through root hairs, cracks in the surface tissues and insect damage. Root rot can develop on lupine plants throughout the growing season. Dark brown stripes form on the root neck and lower part of the stem. Plants lag in growth and development; leaves turn yellow and fall off. Such plants are easily pulled out of the soil [4, 5]. Yellow lupine plants affected by root rot do not form seeds in the germination and early flowering phases. When plants are affected at the beginning of bean formation, only 17% of the healthy plants are harvested, and 75% in the shiny bean formation phase [5, 6].

In Belarus, the number of narrow-leaved lupine plants affected by root rot in breeding nurseries reached 15–30%, in some years – 60–80% (see footnote 3). The root rot infestation of lupine is facilitated by the damage to seedlings by insect larvae – tuber weevils, shoot flies and click beetles [4].

Fusarium wilt of lupine plants is caused by the fungus *F. Oxysporum* Schl. This type of *Fusarium* fungus is more pathogenic and harmful to lupine. The disease manifests itself in foci, starting from the stage of stem formation and until ripening [4, 5]. In competitive variety trial, in the ripening bean stage, the incidence of Fusarium wilt of narrow-leaved lupine plants varied from 7.5 to 27.5%. With mass development of the disease, this leads to significant crop losses⁴.

Infection of lupine plants by the fungus *F. oxysporum* is associated with the ability of lupine to form nodules on the roots when symbiotic bacteria of the genus *Rhizobium* settle on them. Ruptures of the surface tissues during the formation of nodules accelerate the penetration of the fungus and the wilting of the plants (see footnote 3). The destructive effect of the fungus in tracheomycotic wilt of plants is associated with the blockage of blood vessels by the mycelium, viscous formations and the negative effect of the fungal toxins penetrating the conducting vessels (see footnote 2). As the temperature rises, the number of plant pathogens moving from south to north increases, which leads to an expansion of the range of heat-loving fungi species [7, 8]. Thus, the causative agent of fusariosis of grain crops *Fusarium graminearum* is historically localized in the North Caucasus and the Far East. However, since 2003, the causative agent has spread to the North-West of Russia. In 2008, the average degree of spread of the disease on grain crops reached 87.3%, which is explained by global warming [9].

There was an increase in the average annual air temperature by 2.1°C in the Bryansk region from 1976 to 2016 [10].

The development of fungi of the genus *Fusarium* largely depends on meteorological fac-

¹Saukova S.L., Antonova T.S., Ryzhenko E.N., Kumunzhieva K.O., Andreeva K.K., Belorutsky A.Yu. Species composition of fungi of the genus *Fusarium* on vegetative plants and sunflower seeds // Current directions of development of agricultural science: collection of scientific articles dedicated to the 50th anniversary of the breeding center of the FSBSI "Omsk Scientific Center". Omsk: publishing house of IP Maksheeva E.A., 2020, pp. 202–207.

²Serdyuk O.A., Trubina V.S., Gorlova L.A. Effect of Fusarium wilt on the productivity of spring rape and Sarepta mustard plants // Plant protection from pests: materials of the international. scientific and practical. conf. Krasnodar: KubSAU, 2023, pp. 350–352.

³Korneichuk N.S. Lupine fungal diseases. Kyiv, 2010, 374 p.

⁴Matyukhina M.V., Ageeva P.A. Identification of resistant varieties and accessions of narrow-leaved lupine to the main complex of diseases // Agroecological aspects of sustainable development of the agro-industrial complex: Proc. XVII International. scientific. conf. (Bryansk SAU, March 17-18, 2020). Bryansk, 2020, pp. 324–330.

tors – temperature and humidity. The optimal conditions are: temperature 18– 25 °C, soil moisture – 60–80% of field capacity, relative air humidity – 85– 90% (see footnote 3) [4]. The development of fusarium head blight in spring wheat and triticale crops was influenced by high daytime temperatures of the surface air layer during the period of milk ripeness ($r = 0.87$) and relative air humidity ($r = 0,89$) [11].

The purpose of the research was to study the influence of meteorological factors in the Bryansk region on the infestation of narrow-leaved lupine by fusarium root rot and plant wilting, their harmfulness and the development of proposals for their containment.

MATERIAL AND METHODS

The study of the prevalence of Fusarium root rot and wilting on narrow-leaved lupine plants of the Belorozovy 144 variety was conducted in the experimental field of the The All-Russian Research Institute of Lupine – Branch of the Federal Williams Research Center of Forage Production and Agroecology. The experimental design included a control variant without the use of pesticides and a variant where pesticides were used. The seeds were treated with Vitaros, WSC (thiram 198 + carbaxin 198 g/l) – 2.0 l/ha, in the phase of 2–3 true leaves of plants the first treatment was carried out with the fungicide Triaktiv Extra, SC (azoxystrobin-200 + cyproconazole – 80 g/l) – 0.8 l/ha, the second – in the phase of budding – beginning of flowering with the fungicide Kolossal Pro, SC (propiconazole-300 + tebuconazole 200 g/l) – 0.4 l/ha in a tank mixture with the insecticide Borey Neo, SC – 0.2 l/ha. The area of the experimental plot is 32 m², fourfold repetition. CH-16 seeder was used for sowing. The seeding rate was 1.2 million viable seeds/ha. Agricultural technology is generally accepted for the conditions of the Bryansk region. The spread of root rot was recorded in accordance with the methodology adopted in phytopathology⁵.

Identification of pathogens was carried out using humid chambers and a light microscope based on morphological signs of sporulation. Isolation of pathogens of fusarium root rot and plant wilting was carried out throughout the growing season from the material collected in the field using generally accepted methods^{6, 7}.

The number of beans per plant was determined using a test sheaf of 40 plants. Before harvesting, the number of plants with beans per 1 m² was recorded. The seed yield was determined from each plot by continuous threshing of beans with a Sampo-500 combine. Statistical data processing was performed using the method of dispersion and correlation analysis⁸.

RESULTS AND DISCUSSION

The weather conditions in 2019 were warm and slightly dry (HTC 1.22). May was humid, with 32.1 mm of precipitation above the norm. The air temperature was 1.4 °C above the long-term average. In June and July, there was an acute lack of moisture, with 32.6 and 49.7 mm of precipitation, with the norm being 79 and 86 mm, respectively. The air temperature in June was 4.3 °C (20.9 °C) above the norm, and in July it was at the level of long-term averages.

In general, vegetation conditions in 2020 were warm and excessively humid (HTC 2.2). However, May was cool and excessively humid (HTC 4.1). June and July were characterized by sufficient heat (20.3 and 18.8 °C) and precipitation (104.7 and 75.9 mm), which contributed to the development and spread of plant diseases, including anthracnose.

The vegetation period of 2021 was characterized by warm and humid weather (HTC 1.97). At the same time, climatic conditions in May were characterized by a lack of heat (13.3 °C) and excess precipitation (143.3 mm), which negatively affected the emergence of lupine seedlings. In June, the conditions were warm (19.9 °C) and excessively humid (153.7 mm). Weather conditions in July were noted as dry. The air tempera-

⁵Chumakov A.E. Basic methods of phytopathological research. M.: L., 1974, 109 p.

⁶Khokhryakov M.K. Methods of experimental study of phytopathological fungi. L., 1976, 21 p.

⁷Naumov N.A. Methods of microbiological and phytopathological studies. L.: Selkhozgiz, 1937, 270 p.

⁸Dospekhov B.A. Methods of field experiment. Moscow: Agropromizdat, 1985, 351 p.

ture (22.1 °C) was 4.4 °C higher than the long-term average. In August, the weather conditions were warm and moderately humid (HTC 0,99).

Climate conditions in 2022 were warm and humid (HTC 1.43). However, May was cold and excessively humid (HTC 2.35). Air temperature was 2.1 °C below the long-term average, precipitation was 30.5 mm above normal. June was hot and humid (HTC 1.57). Air temperature was 2.8 °C above the long-term average. Precipitation (89.8 mm) exceeded the norm by 10.8 mm. Growing conditions in July were also warm and humid (HTC 1.52). August was warm and dry (HTC 0.26). The average daily air temperature was 4.2 °C (20.8 °C) higher than the long-term average.

The vegetation period of 2023 was characterized by warm and humid weather conditions (HTC 1.15). May was cold and dry (HTC 0.38). Air temperature was 1.0 °C below the long-term average, precipitation was 54.6 mm below the norm. In June, air temperature was 0.5 °C below the norm. Precipitation was 66.3 mm. HTC totaled 1.28 units. The vegetation conditions in July were warm and humid (HTC 1.44). The air temperature was 18.6 °C, precipitation was 82.4 mm. August was hot and excessively humid (HTC 1.50). Analysis of meteorological parameters showed that the development of fungi of the genus *Fusarium* (*F. avenaceum* and *F. oxysporum*) and the diseases of lupine caused by them was largely determined by the air temperature and precipitation during the vegetation period.

The greatest damage to narrow-leaved lupine plants by fusarium root rot was observed in 2019 during the growing season in the control crop, where protective agents were used at 8.3 and 0.8%, respectively (see Table 1).

In May, precipitation exceeded the norm by 60.5% (85.1 mm), the average daily air temperature was 14.9 °C. These conditions were favorable for the intensive growth and development of the fungus *F. avenaceum*, the causative agent of root rot disease of lupine seedlings. Since the growth of the mycelium of this fungus begins at a temperature of 5...6 °C, at a temperature of

10...12 °C the growth intensity increases. The optimum temperature for the development of the fungus is within the range of 18...25 °C (see footnote 3). The infestation of soybean plants by fusarium root rot increases when it is sown in unheated soil⁹.

The first signs of lupine root rot in crops (3.8 and 0.3%) were noted during the period of the beginning of the stem formation of plants (third ten-day period of May). Dark brown oblong spots were observed on the roots, on which white fluffy mycelium with abundant sporulation of the fungus in the form of colorless sickle-shaped conidia with three and five partitions was formed in a humid chamber (see Fig. 1).

In June 2019, there was a sharp decrease in soil moisture due to a decrease in precipitation (32.6 mm) and an increase in average daily air temperature (20.9 °C). The onset of soil and air drought weakened the resistance of plants to the disease and contributed to the manifestation of its external signs. The leaves withered and eventually fell off on affected plants, The root and lower part of the stem acquired a brown color. Over time, the main and lateral roots died off. Such plants withered and could be easily pulled out of the soil.

The influence of average daily air temperature and amount of precipitation on the incidence of root rot of narrow-leaved lupine in June 2019 is shown in the graphs (see Fig. 2, 3).

Plants were also affected by root rot later. Some plants were observed to form new roots above the site of damage to the main root. Plants affected by root rot at the beginning of flowering did not form seeds. Fusarium root rot killed narrow-leaved lupine plants mainly before pod formation. The largest number of diseased lupine plants (4.5 and 0.8%) in the studied crops was noted during the period of booting – beginning of flowering. In general, root rot did not have a significant effect on the yield. On average, over the years of research, pre-sowing seed treatment with Vitaros seed treatment agent (2.0 l/t) reduced plant damage by root rot in the sprouts –

⁹Maui A.A., Anuarova L.E. Species composition and biological characteristics of pathogens of soybean fusarium in the south and south-east of Kazakhstan // Formation and development of science on plant protection and quarantine in the Republic of Kazakhstan: collection of materials of the international scientific conf., dedicated to the 60th anniversary of the founding of the institute and the 100th anniversary of scientific research on plant protection in Kazakhstan. Almaty, 2018, pp. 429–435.

Табл. 1. Поражаемость растений люпина узколистного фузариозом по фазам развития (2019–2023 гг.)
Table 1. Fusariosis infestation of narrow-leafed lupine plants by development phases (2019–2023)

Year	Infestation, %						
	Fusarium root rot			Fusarium wilt			
	Development phase		For the vegetation period	Development phase			For the vegetation period
	Sprouting – booting	Booting – flowering		Budding – flowering	Flowering – shiny bean	Ripening bean	
<i>Control variant – without using protective means</i>							
2023	2,1	2,5	4,6	1,7	6,5	0,9	9,1
2022	2,6	3,1	5,7	3,2	12,5	4,1	19,8
2021	3,5	4,2	7,7	4,7	17,1	5,3	27,1
2020	2,3	2,8	5,1	5,3	18,2	5,5	29,0
2019	3,8	4,5	8,3	2,1	8,3	2,6	13,0
<i>Option with the use of protective means</i>							
2023	0,0	0,1	0,1	0,4	2,0	0,4	2,8
2022	0,1	0,3	0,4	0,7	4,7	1,3	6,7
2021	0,2	0,7	0,9	1,3	5,3	1,7	8,3
2020	0,0	0,2	0,2	1,3	5,8	2,3	9,4
2019	0,3	0,8	1,1	0,6	3,0	0,9	4,5

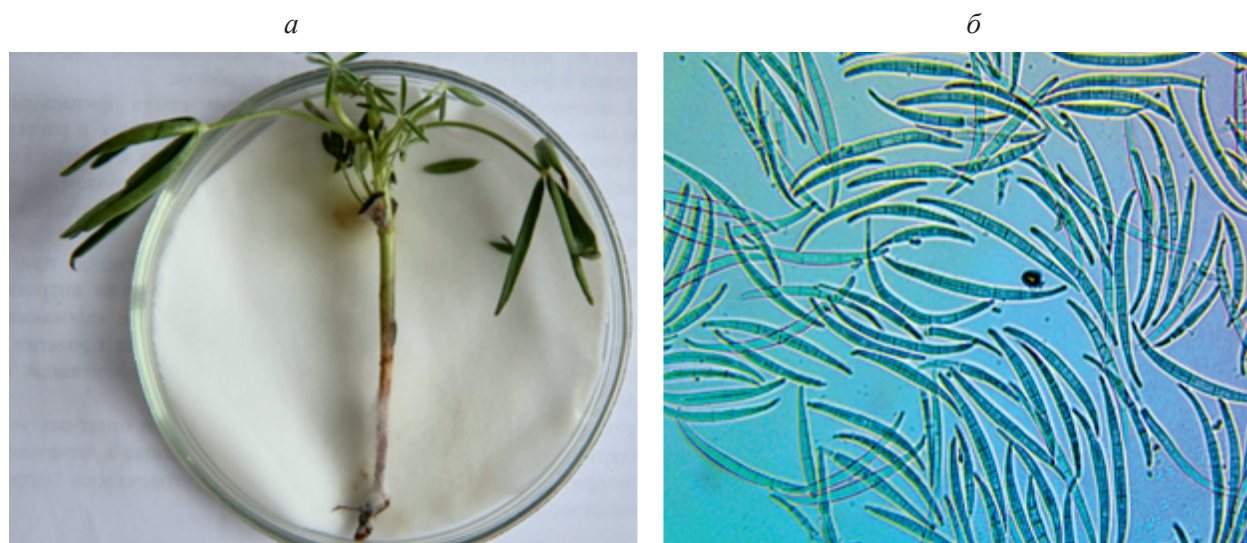


Рис. 1. Фузариозная корневая гниль (*F. avenaceum*) люпина узколистного: а) пораженный корень, фаза стеблевания; б) макроконидии гриба

Fig. 1. Fusarium root rot (*F. avenaceum*) of narrow-leafed lupine: а) infected root, stem formation stage; б) macroconidia of the fungus

booting phases from 2.9% in the control crop to 0.1%.

The conducted correlation analysis of the relationship between the infestation of narrow-leafed lupine plants by Fusarium root rot and the yield revealed a weak relationship ($r = 0.32$, $p = 0.69$) between these parameters. There is data in the literature on a weak correlation

between the infestation of narrow-leafed lupine plants by root rot and grain yield [12].

It should be noted that in our conditions, the greatest harm to narrow-leafed lupine crops is caused by fusarium wilt (tracheomycosis) of plants, which is caused by the fungus *F. oxysporum*. The maximum number (29.0%) of plants affected by this disease during the growing season

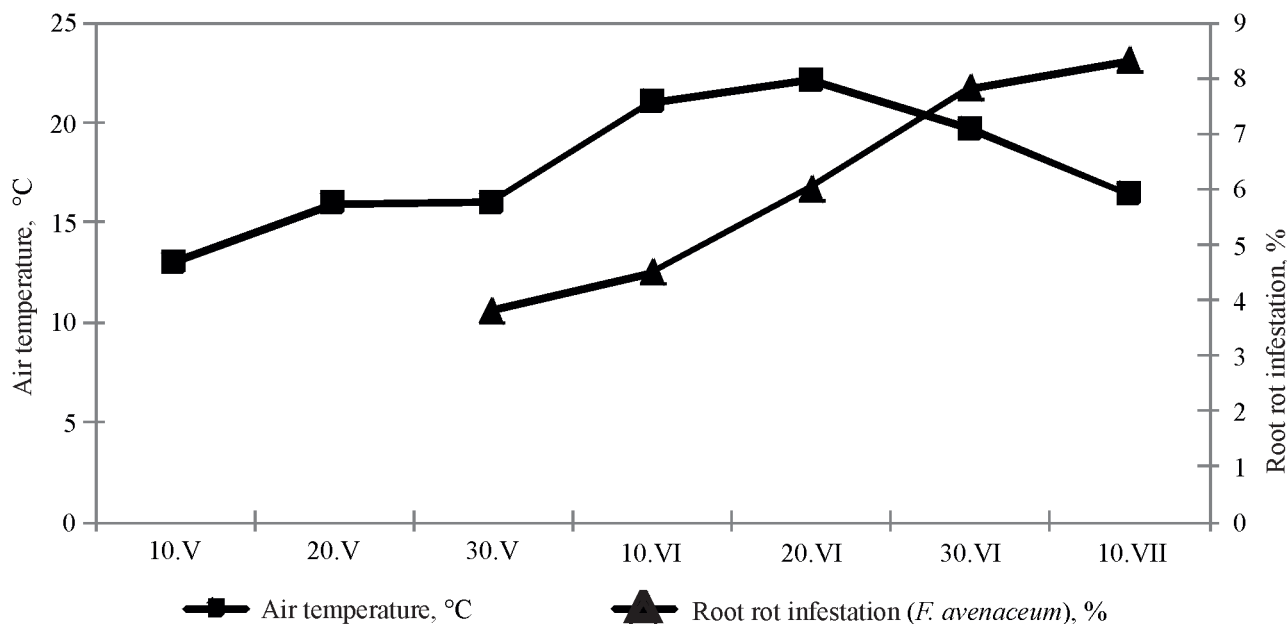


Рис. 2. Влияние температуры воздуха на поражение фузариозной корневой гнилью люпина узколистного (*F. avenaceum*) в условиях вегетации 2019 г.

Fig. 2. The effect of air temperature on Fusarium root rot infection (*F. avenaceum*) of the narrow-leaved lupine under the growing season 2019

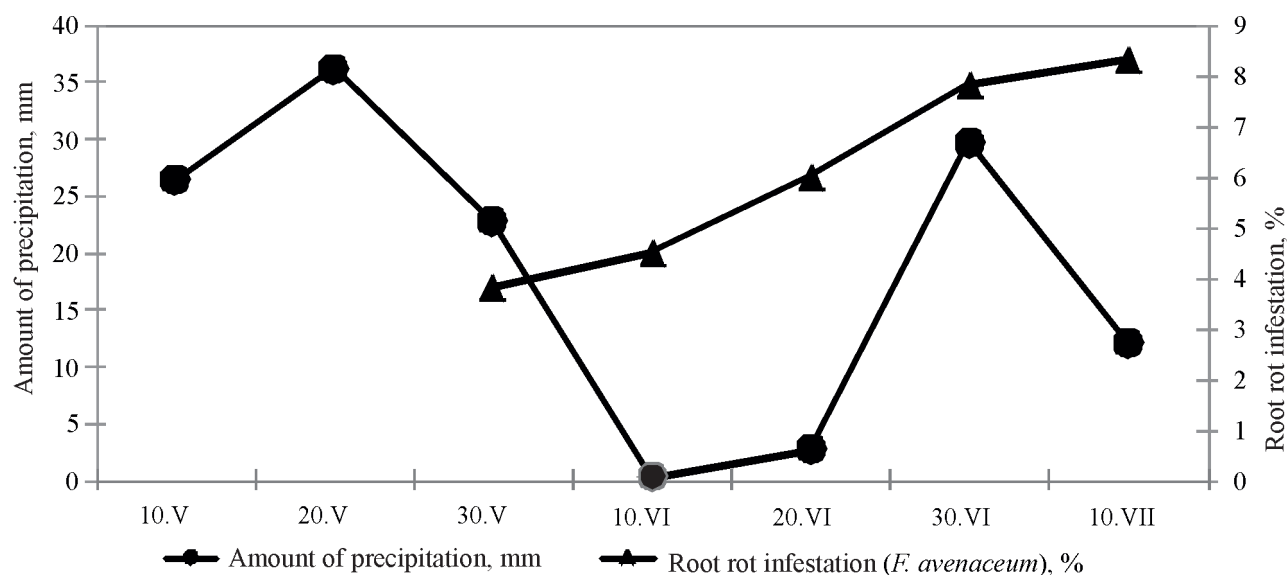


Рис. 3. Влияние количества осадков на поражение люпина узколистного фузариозной корневой гнилью (*F. avenaceum*) в условиях вегетации 2019 г.

Fig. 3. The effect of rain amount on Fusarium root rot infection (*F. avenaceum*) of the narrow-leaved lupin under the growing season 2019

was observed in the weather conditions of 2020. The first signs of fusarium wilt began to appear at the end of the first ten days of June (5.3%) during the period from the end of budding to the beginning of flowering of the plants. The tops of the plants withered, the leaves turned yellow and dried out, while the roots were healthy. When

the affected stem was cut, browning of the conducting vessels was observed. On such parts of the stems in a humid chamber (Petri dishes), the fungus *F. oxysporum*, the causative agent of the disease, formed a white aerial mycelium with colorless, fan-shaped, slightly curved macroconidia with three to five septa (see Fig. 4).

Temperature and humidity are of primary importance for the development of the fungus *F. oxysporum*. It has been established that the optimum temperature for the growth of the mycelium of the fungus *F. oxysporum* is in the range from 18 to 25 °C. Temperatures of 31...33 °C sharply limit the growth, and mycelial growth slows down at temperatures below 14 °C. At the same time, intensive development of the fungus occurs at soil moisture of 80% of the field moisture capacity. A decrease in humidity to 60% and below slows down the development of the fungus (see footnote 3).

In June 2020, favorable conditions for the development of the fungus were established. The average daily air temperature was 20.3 °C, the amount of precipitation was 61.7 mm (78.1%) higher than the norm. Inspection at the end of June of control lupine crops and lupine with the use of protective agents showed that the damage to plants by fusarium wilt was 14.0 and 4.7%, respectively.

The onset of soil and air drought in the first and second ten-day periods of July increased the manifestation of external signs of the disease. By the end of July, the number of plants with fusarium wilt increased in these crops to 24.0

and 7.3%, respectively. In the dry conditions of August, the incidence of this disease increased to 29.0 and 9.4%, respectively. Affected plants withered in groups, leaf blades hung on petioles, dried up and fell off, their roots died off after some time (see Fig. 5).

Intensive infection of arrow-leaved lupine plants by the fungus *F. oxysporum* was preceded by weather conditions when a period with sufficient heat and moisture was followed by soil and air drought. It has been established that high temperatures provoke accelerated plant growth, which leads to a decrease in the content of calcium and microelements in tissues and high susceptibility to diseases [8].

The influence of average daily air temperature and precipitation on the increase in the incidence of lupine plants with Fusarium wilt in 2020 is shown in the graphs (see Fig. 6, 7).

The defeat of narrow-leaved lupine plants by the fungus of the genus *Fusarium* by the wilting type causes more significant damage than by the root rot type. During the vegetation period in the crop without the use of protective agents, the number of plants with signs of fusarium wilt exceeded the number of plants with root rot in a similar crop by 13.3%. The dynamics of the

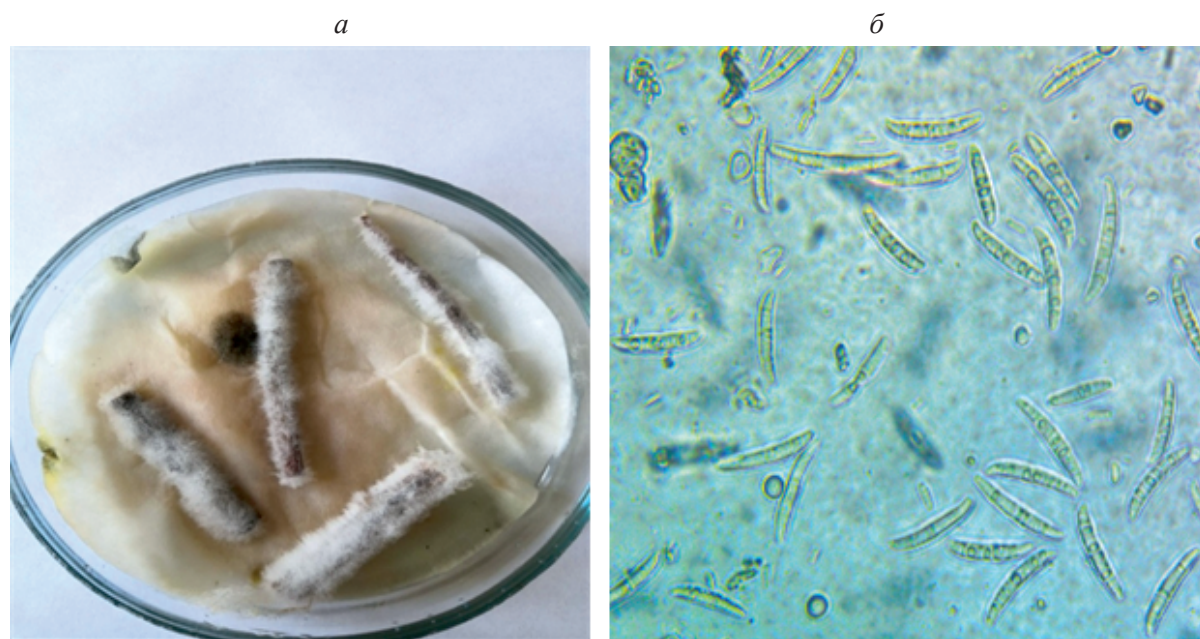


Рис. 4. Фузариозное (*F. oxysporum*) увядание люпина узколистного:
а) грибница гриба на частях стебля во влажной камере; б) макроконидии и микроконидии

Fig. 4. Fusarium wilt (*F. oxysporum*) of narrow-leaved lupine:
а) mycelium on stem parts in a humidified chamber; б) macro- and microconodia

spread of wilting of narrow-leaved lupine from fusarium showed that the greatest number of diseased plants were noted in the flowering phase - shiny bean.

The use of protective agents does not fully protect lupine plants from damage by this disease. However, in the crop where fungicides were used, there was a significant decrease in the number of plants with fusarium root rot and tracheomycotic wilt. On average, over five years, the damage to plants by these diseases decreased by 5.8 and 13.3%, respectively. At the same time, the number of surviving plants with beans increased in relation to the control crop by 33.4 pcs./m². On average, the number of beans increased by 1.4 pcs./plant (see Table 2).

Fusarium wilt reduced the 1000-seed weight of narrow-leaved lupine. Compared to the crop plants treated with pesticides, the 1000-seed weight in the control crop decreased by an average of 17.1 g, which reduced the seed yield by 0.97 t/ha, or 54.8%. In general, the greatest impact on the seed yield of narrow-leaved lupine is exerted by tracheomycotic wilt of plants

caused by the fungus *F. oxysporum*. A reliable inverse correlation ($r = -0.89$, $p = 0.039$) was established between the seed yield of lupine and plant damage by the fungus *F. oxysporum*. A high reliable inverse relationship ($r = -0.89$, $p = 0.039$) was found between the average daily air temperature in July and the seed yield.

CONCLUSION

In the Bryansk region, lupine is dominated by fungi of the genus *Fusarium* – *F. avenaceum* and *F. oxysporum*. Root rot is caused by the fungus *F. avenaceum*. The causative agent of (tracheomycotic) wilting of plants is the fungus *F. oxysporum*. At the same time, the fungus *F. oxysporum* has the greatest pathogenic properties. The intensity of the development of fungi *F. avenaceum* and *F. oxysporum* and the diseases of narrow-leaved lupine caused by them is largely determined by meteorological factors during the growing season. The greatest damage to crops of this culture is caused by tracheomycotic wilt. Over the years of research, the damage to plants by fusarium wilt in the control crop with-

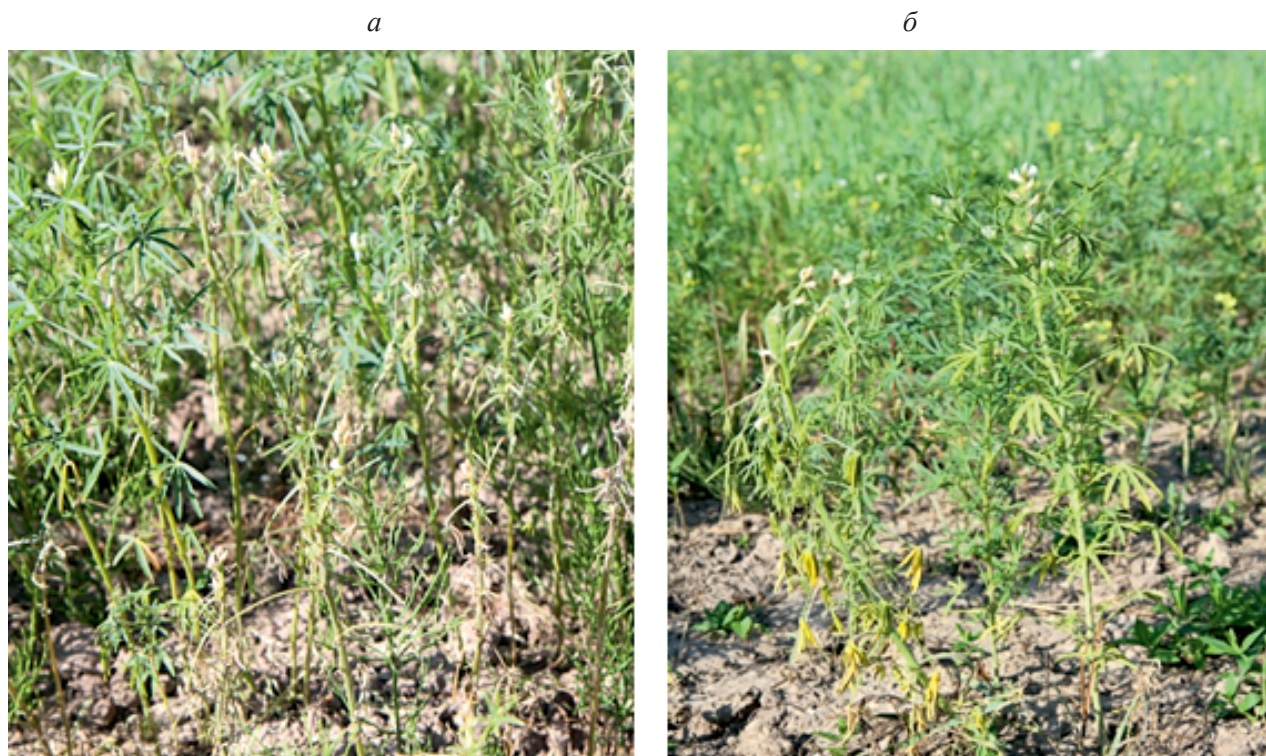


Рис. 5. Фузариозное (*F. oxysporum*) увядание растений люпина узколистного: а) фаза цветения; б) начало образования бобов

Fig. 5. Fusarium wilt (*F. oxysporum*) of narrow-leaved lupine plants: а) flowering stage; б) beginning of bean formation

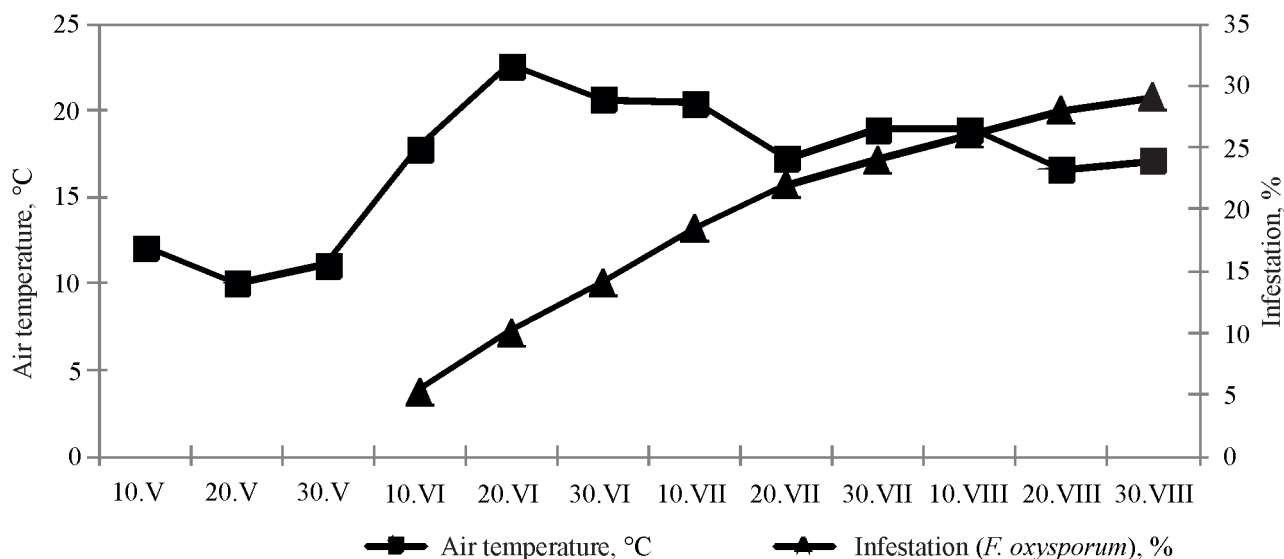


Рис. 6. Влияние температуры воздуха на поражение растений люпина узколистного фузариозным увяданием (*F. oxysporum*) в условиях вегетации 2020 г.

Fig. 6. The effect of air temperature on Fusarium wilt (*F. oxysporum*) infection of the narrow-leaved lupine plants under the growing season 2020

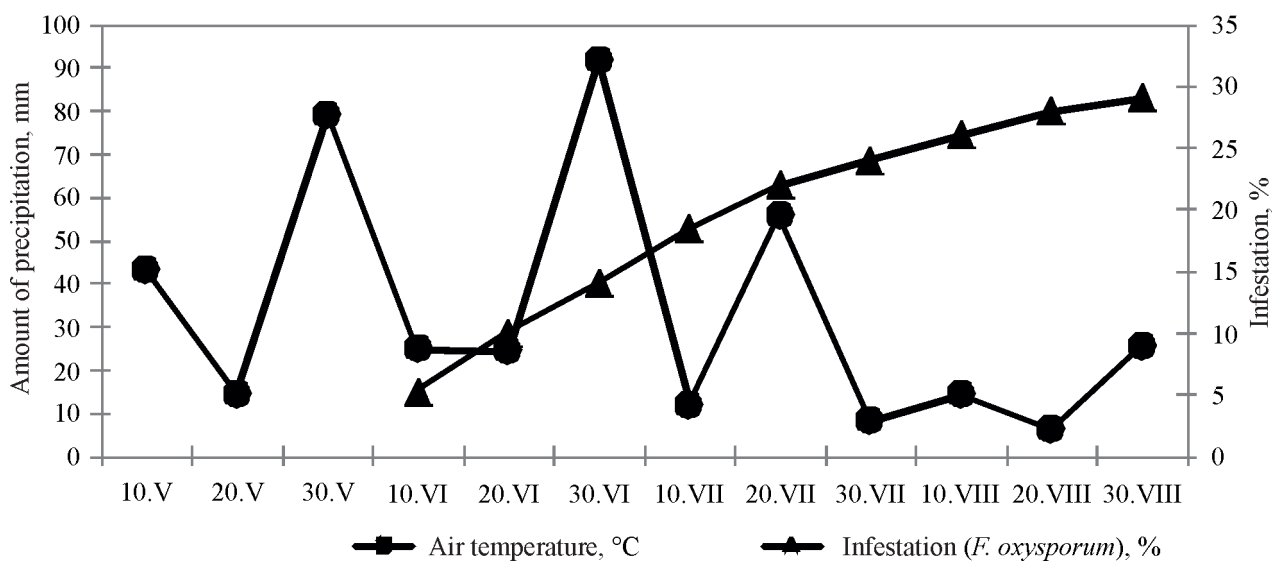


Рис. 7. Влияние количества осадков на поражение растений люпина узколистного фузариозным увяданием (*F. oxysporum*) в условиях вегетации 2020 г.

Fig. 7. The effect of rain amount on Fusarium wilt (*F. oxysporum*) infection of the narrow-leaved lupine plants under the growing season 2020

out the use of plant protection products varied from 9.1 to 29.0%, and by root rot 4.6 ... 8.3%. Seed treatment with Vitaros (2.0 l / t) reduced the damage to plants by root rot depending on the year of research by 4.5 ... 7.2%. Treatment of plants with fungicides Triaktiv Extra (0.8 l / ha) and Kolosal Pro (0.4 l / ha) reduced the number of plants affected by fusarium wilt by 6.3 ... 19.6%. On average, over the years of research,

the number of surviving plants with beans (5.8 pcs/m²) increased in relation to the control sowing by 33.4 pcs/m². At the same time, the weight of 1000 seeds increased by 17.1 g, the seed yield by 0.97 t/ha. A reliable inverse correlation ($r = -0.89, p = 0.039$) was established between the seed yield of narrow-leaved lupine and the damage of plants by the fungus *F. oxysporum*. A high reliable inverse relationship ($r = -0.89,$

Табл. 2. Влияние фузариоза на продуктивность растений и урожайность люпина узколистного Белорозовый 144 (2019–2023 гг.)

Table 2. The effect of fusariosis on plants productivity and yield of the narrow-leaved lupine variety Belorozovy 144 (2019–2023)

Year	Number of plants, pcs/m ²	Number of beans, pcs/plant	Weight of 1000 seeds, g	Yield, t/ha
<i>Sowing without the use of protection means</i>				
2023	67,0	2,7	135,1	0,94
2022	37,3	3,6	112,3	0,74
2021	36,0	5,2	94,9	0,53
2020	51,3	5,3	114,7	0,87
2019	49,0	4,9	118,2	0,93
LSD ₀₅	0,78	–	–	0,029
<i>Sowing with the use of protection means</i>				
2023	92,1	3,9	150,2	2,00
2022	62,3	5,0	129,8	2,10
2021	69,0	6,4	113,0	1,29
2020	93,0	7,0	133,6	1,59
2019	91,0	6,4	134,0	1,87
LSD ₀₅	0,81	–	–	0,032

$p = 0.039$) was revealed between the average daily air temperature in July and the seed yield. Thus, in order to reduce the number of narrow-leaved lupine plants affected by fusarium root rot and wilting of plants, as well as to reduce losses in seed yield, it is necessary to treat the seed material and process crops with fungicides with high efficiency against pathogenic fungi *F. avenaceum* and *F. oxysporum*, which are the causative agents of root rot and wilting of narrow-leaved lupine plants.

СПИСОК ЛИТЕРАТУРЫ

1. Конончук В.В., Тимошенко С.М., Назарова Т.О., Штырхунов В.Д., Меднов А.В. Ресурсосберегающая технология возделывания районированных в Центральном регионе Нечерноземной зоны сортов люпина узколистного в чистом виде и в смесях со злаковыми зерновыми культурами. М.: ФИЦ «Немчиновка», 2022. 48 с.
2. Агеева П.А., Почутина Н.А., Матюхина М.В. Люпин узколистный – источник ценных питательных веществ для использования в кормопроизводстве // Кормопроизводство. 2020. № 10. С. 29–32. DOI: 10.25685/KRM. 2020. 11.40.001.
3. Абдуллаев Р.А., Вишнякова М.А., Егорова Г.П., Радченко Е.Е. Фитосанитарный мониторинг коллекции люпина узколистного ВИР на северо-западе Российской Федерации // Труды по прикладной ботанике, генетике и селекции. 2021. Т. 182. № 3. С. 167–173. DOI: 10.30901/2227-8834-2021-3-167-173.
4. Пимохова Л.И., Яговенко Г.Л. Болезни и вредители люпина: система и средства защиты: монография. Брянск: «Читай-город», 2020. 88 с.
5. Карпиевич В.А., Анохина В.С., Саук И.Б., Романчук И.Ю. Полиморфизм возбудителей фузариоза растений и оценка устойчивости образцов люпина узколистного к наиболее агрессивным изолятам патогена // Новости науки в АПК. 2018. Т. 2. № 11. С. 64–67.
6. Косолапов В.М., Яговенко Г.Л., Лукашевич М.И., Агеева П.А., Новик Н.В., Мисникова Н.В., Слесарева Т.Н., Исаева Е.И., Такунов И.П., Пимохова Л.И., Яговенко Т.В. Люпин: селекция, возделывание, использование: монография. Брянск: ГУП «Брянское областное полиграфическое объединение», 2020. 304 с.
7. Логинов В.Ф., Хитриков М.А. Прогноз изменений биоклиматического потенциала территории Беларуси на период 2016–2035 гг. // Известия национальной академии наук Бела-

- русси. Серия аграрных наук. 2018. Т. 56. № 1. С. 51–64.
8. Игнатов А.Н., Кошкин Е.И., Андреева И.В., Гусейнов Г.Г., Гусейнов К.Г., Джалилов Ф.С. Влияние глобальных изменений климата на фитопатогены и развитие болезней растений // *Агрохимия*. 2020. № 12. С. 81–96. DOI: 10.31857/S0002188120120042
 9. Левитин М.М., Афанасенко О.С., Гаккаева Т.Ю., Ганнибал Ф.Б., Гултыяева Е.И., Мironenko Н.В. Популяционные исследования грибов – возбудителей болезней зерновых культур // *Вестник защиты растений*. 2019. Т. 4. № 102. С. 5–16.
 10. Мамеев В.В. Изменение агрометеорологических условий в юго-западной части центра России и их влияние на урожайность озимой пшеницы // *Вестник Алтайского государственного аграрного университета*. 2021. Т. 6. № 200. С. 5–13.
 11. Асеева Т.А., Зенкина К.В., Трифунова И.Б., Имтосими О.Ю., Тишкова А.Г., Савченко Н.Е. Грибные болезни на зерновых культурах в муссонном климате Дальнего востока // *Достижения науки и техники АПК*. 2020. Т. 34. № 12. С. 12–18. DOI: 10.24411/0235-2451-2020-11202.
 12. Рябова Т.Н., Ястребова А.В., Коконев С.И. Формирование урожайности зерна люпина узколистного в зависимости от предпосевной обработки семян и нормы высева // *АгроЭкоИнфо: Электронный научно-производственный журнал*. 2023. № 4. URL: http://agroe-coinfo.ru/STATYI/2023/4/st_421.pdf. DOI: 10.51419/202134421.
- ## REFERENCES
1. Kononchuk V.V., Timoshenko S.M., Nazarova T.O., Shtyrkhunov V.D., Mednov A.V. *Resource-saving cultivation technology for narrow-leaved lupin varieties adopted in the Central region of the Non-Chernozem zone as single and mixed with cereals crops*. Moscow, «Nemchinovka» Publ., 2022, 48 p. (In Russian).
 2. Ageeva P.A., Pochutina N. A., Matyuxina M.V. Blue lupine – source of valuable nutrients in forage production. *Kormoproizvodstvo = Kormoproizvodstvo*, 2020, no. 10, pp. 29–32. (In Russian). DOI: 10.25685/KRM. 2020. 11.40.001.
 3. Abdullaev R.A., Vishnyakova M.A., Egorova G.P., Radchenko E.E. Phytosanitary monitoring of the narrow-leaved lupine collection of VIR in the northwest of Russia. *Trudy` po prikladnoj botanike, genetike i selekcii = Proceedings on Applied Botany, Genetics and Breeding*, 2021, vol. 182, no. 3, pp. 167–173. (In Russian). DOI: 10.30901/2227-8834-2021-3-167-173.
 4. Pimoxova L.I., Yagovenko G.L. *Diseases and pests of lupin: system and protection*, Bryansk, Chitai-gorod Publ., 2020, 88 p. (In Russian).
 5. Karpievich V.A., Anoxina V.S., Sauk I.B., Romanchuk I.Yu. Polymorphism of agents of plants' fusarium and evaluation of resistant narrow-leaved lupin lines to the most aggressive isolates of the pathogen. *Novosti nauki v APK = Science news in AIC*, 2018, vol. 2, no. 11, pp. 64–67. (In Russian).
 6. Kosolapov V.M., Yagovenko G.L., Lukashevich M.I., Ageeva P.A., Novik N.V., Misnikova N.V., Slesareva T.N., Isaeva E.I., Taku-nov I.P., Pimohova L.I., Yagovenko T.V. *Lupin: breeding, cultivation and use*. Bryansk, Bryanskoe oblastnoe poligraficheskoe ob"edinenie Publ., 2020, 304 p. (In Russian).
 7. Loginov V.F., Xitrikov M.A. Predicting changes in bioclimatic potential in the territory of Belarus for the period of 2016–2035. *Izvestiya nacional'noj akademii nauk Belarusi. Seriya agrarny`x nauk = Proceedings of the National Academy of Sciences of Belarus. Agrarian Series*, 2018, vol. 56, no. 1. pp. 51–64. (In Russian).
 8. Ignatov A.N., Koshkin E.I., Andreeva I.V., Gusejnov G.G., Gusejnov K.G., Dzhililov F.S. Impact of global climate change on plant pathogens occurrence. *Agroximiya = Agricultural Chemistry*, 2020, no. 12, pp. 81–96. (In Russian). DOI: 10.31857/S0002188120120042.
 9. Levitin M.M., Afanasenko O.S., Gakkaeva T.Yu., Gannibal F.B., Gul'tyaeva E.I., Mironenko N.V. Population studies of fungi causing the diseases of grain crops. *Vestnik zashchity` rastenij = Plant Protection News*, 2019, vol. 4, no. 102. pp. 5–16. (In Russian).
 10. Mameyev V.V. The changes of agrometeorological conditions in the south-western part of the center of Russia and their influence on winter wheat yields. *Vestnik Altajskogo gosudarstvennogo agrarnogo universiteta = Bulletin of Altai State Agricultural University*, 2021, vol. 6, no. 200, pp. 5–13. (In Russian).
 11. Aseeva T.A., Zenkina K.V., Trifunova I.B., Imtosimi O.Yu., Tishkova A.G., Savchenko N.E. Fungal diseases on cereals in the monsoon climate of the Russian Far East. *Dostizheniya nauki i texniki APK = Achievements of Science and Technology of AIC*, 2020, vol. 34, no. 12,

pp. 12–18. (In Russian). DOI: 10.24411/0235-2451-2020-11202.

12. Ryabova T.N., Yastrebova A.V., Kokonov S.I. Formation of grain yield of narrow-leaved lupine depending on pre-sowing seed treatment

and seeding rate. *AgroE`koInfo: E`lektronny` nauchno-proizvodstvenny` zhurnal = AgroEcoInfo: Electronic scientific and production magazine*, 2023, no. 4. URL: http://agroecoinfo.ru/STATYI/2023/4/st_421.pdf. (In Russian). DOI: 10.51419/202134421.

ИНФОРМАЦИЯ ОБ АВТОРАХ

Пимохова Л.И., ведущий научный сотрудник, кандидат сельскохозяйственных наук; SPIN-код 8986-3416

Яговенко Г.Л., доктор сельскохозяйственных наук; SPIN-код 3245-6568

Царапнева Ж.В., старший научный сотрудник; SPIN-код 4568-8049

Хараборкина Н.И., научный сотрудник; SPIN-код 5474-1529

✉ **Мисникова Н.В.**, ученый секретарь, кандидат сельскохозяйственных наук; SPIN-код 1045-6982; **адрес для переписки:** Россия, 241524, Брянская область, Брянский район, п/о Мичуринский, ул. Березовая, 2; e-mail: lupin_nvmsnikova@mail.ru

AUTHOR INFORMATION

Ludmila I. Pimokhova, Lead Researcher, Candidate of Science in Agriculture; SPIN-code 8986-3416

German L. Yagovenko, Doctor of Science in Agriculture; SPIN-code 3245-6568

Zhanna V. Tsarapneva, Senior Researcher; SPIN-code 4568-8049

Nina I. Kharaborkina, Researcher; SPIN-code 5474-1529

✉ **Nadezhda V. Misnikova**, Academic Secretary; Candidate of Science in Agriculture; SPIN-code 1045-6982; **address:** 2, Berezovaya St., Michurinsky, Bryansk District, Bryansk Region, 241524, Russia; e-mail: lupin_nvmsnikova@mail.ru

Дата поступления статьи / Received by the editors 26.11.2024
Дата принятия к публикации / Accepted for publication 20.01.2025
Дата публикации / Published 16.06.2025



<https://doi.org/10.26898/0370-8799-2025-5-6>
УДК 619:616.9-02:636

Тип статьи: обзорная
Type of article: review

Этио-патогенетические «загадки» факторной патологии (к 50-летию приоритетной концепции факторных болезней С.И. Джупины)

(✉) Макаров В.В.¹, Стекольников А.А.², Донченко А.С.³, Сочнев В.В.⁴

¹Центр ветеринарии

Москва, Россия

²Санкт-Петербургский государственный университет ветеринарной медицины

Санкт-Петербург, Россия

³Сибирский федеральный научный центр агробиотехнологий Российской академии наук

Новосибирская область, р.п. Краснообск, Россия

⁴Нижегородский государственный агротехнологический университет

Нижний Новгород, Россия

(✉) e-mail: vvm-39@yandex.ru

Факторные и оппортунистические болезни без банальных источников инфекции, тривальной эпизоотической цепной трансмиссии и прочих тривиальных атрибутов «старой» эпизоотологии остаются в ее современной компетенции, способствуя прогрессу оппозитных направлений в данной сфере науки и практики. Их содержательное и смысловое определение предполагает неприемлемость устаревших представлений и догматов относительно эпизоотического процесса как единственно возможной формы существования инфекций. Приоритетная парадигма, сформулированная Шарлем Николлем (1930) и И.В. Давыдовским (1956) в контексте пророческих постулатов относительно эволюции инфекционной патологии, в самой идее дезавуирует архаику господствующих до сих пор ключевых положений эпизоотологии. При факторных инфекциях убиквитарность среды обитания патогенов абиотического и биотического типов переводит все явления в категорию случайных, факторная *causa prima* и последствия не предсказуемы, не контролируемы и не управляемы в принципе. В связи с этим возможности медицинского и ветеринарного обеспечения защиты весьма ограничены. Только специфическая профилактика и вакцинация как ее преимущественный элемент в ветеринарии по своей паллиативной сути не позволяют достичь искоренения инфекции. На фоне тотального применения мероприятия возникают такие неблагоприятные эпизоотические явления, как вакцинозависимость, проэпизоотичивание и эволюция возбудителей, адаптирующихся к персистенции на иммунном фоне. В настоящем сообщении обсуждена группа инфекций, характеризующихся неэпизоотическими причинами, – тяжелые, идиопатически обостряющиеся, но без атрибутов эпизоотичности маститы, мыт, некробактериоз, паратуберкулез, «новые» неканонические клостридиозы. Критическими факторами их этиологии и патогенеза служат совершенно неожиданные в канонической патологии «скоординированные» процессы и механизмы от условной патогенности микроорганизмов-комменсалов до нормальных физиологических отравлений и даже прямого вреда этиотропной терапии.

Ключевые слова: эпизоотология, факторные и оппортунистические инфекции, мастит, мыт, некробактериоз, паратуберкулез, *Clostridioides difficile*-ассоциированная диарея

Etiopathogenetic “mysteries” of factor pathology (to the 50th anniversary of S.I. Dzhupina's priority concept of factor diseases)

(✉) Makarov V.V.¹, Stekolnikov A.A.², Donchenko A.S.³, V.V. Sochnev⁴

¹Center for Veterinary Medicine

Moscow, Russia

²*Saint-Petersburg State University of Veterinary Medicine*
Saint-Petersburg, Russia

³*Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences*
Krasnoobsk, Novosibirsk region, Russia

⁴*Nizhny Novgorod State Agrotechnological University*
Nizhny Novgorod, Russia

✉ e-mail: vvm-39@yandex.ru

Factor and opportunistic diseases without trivial sources of infection, trizal epizootic chain transmission and other trivial attributes of “old” epizootology remain in its modern competence, contributing to the progress of opposite directions in this field of science and practice. Their substantive and semantic definition implies the unacceptability of outdated ideas and dogmas regarding the epizootic process as the only possible form of existence of infections. The priority paradigm formulated by Charles Nicolle (1930) and I.V. Davydovsky (1956) in the context of prophetic postulates regarding the evolution of infectious pathology, in the very idea disavows the archaic nature of the still dominant key provisions of epizootology. In case of factor infections, ubiquitousness of habitat of abiotic and biotic pathogens puts all phenomena in the category of accidental; factor *causa prima* and consequences are not predictable, not controllable and not manageable in principle. As such, medical and veterinary provision options are very limited. Solely specific prophylaxis and vaccination as its predominant element in veterinary medicine by its palliative nature do not achieve eradication of infection. Against the background of total application of the measures, such unfavorable epizootic phenomena as vaccine dependence, proepizooticization and evolution of pathogens adapting to persistence on an immune background occur. The present paper discusses a group of infections characterized by non-epizootic causes, severe, idiopathically exacerbated, but without the attributes of epizooticism mastitis, strangles, necrobacteriosis, paratuberculosis, and “new” non-canonical clostridiosis. Critical factors of their etiology and pathogenesis are absolutely unexpected in canonical pathology “coordinated” processes and mechanisms from conditional pathogenicity of microorganisms-commensals to normal physiological departures and even direct harm of etiotropic therapy.

Keywords: epizootology, factor and opportunistic infections, mastitis, strangles, necrobacillosis, paratuberculosis, *Clostridioides difficile*-associated diarrhea

Для цитирования: Макаров В.В., Стекольников А.А., Донченко А.С., Соцнев В.В. Этио-патогенетические «загадки» факторной патологии (к 50-летию приоритетной концепции факторных болезней С.И. Джупины) // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 5. С. 55–69. <https://doi.org/10.26898/0370-8799-2025-5-6>

For citation: Makarov V.V., Stekolnikov A.A., Donchenko A.S., Sochnev V.V. Etio-pathogenetic “mysteries” of factor pathology (to the 50th anniversary of S.I. Dzhupina's priority concept of factor diseases) // *Sibirskii vestnik sel'skhozaystvennoi nauki* = *Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 5, pp. 55–69. <https://doi.org/10.26898/0370-8799-2025-5-6>

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

Not knowing something is forgivable.
But not seeing something is stupid.
Jan Hulsen, "Cow Signals"

A substantive and meaningful definition of the category of factor diseases presupposes, first of all, the unacceptability of outdated provisions and dogmas of trivial epizootology and their opposition to the epizootic process as the only possible form of existence of infections in the form

of an inevitable, interdependent, alternative-free cycle of “emergence → spread → extinction”, contagiousness, three-element chain transmission, introduction and removal into farms, epizootic dynamics, focality, infectious and epizootological diagnostics [1].

The idea of dividing infectious diseases of veterinary significance into classical (epizootic) and factorial ones and classifying them on this basis was first formulated by S.I. Dzhupina at the

All-Union Conference on General Epizootology more than half a century ago (Ulyanovsk, 1972)¹ [2]. Although the latter also included all chronic, latent, and other infections with mild chain transmission, which was a significant distortion of the meaning of factoriality, this approach is undoubtedly innovative in the theory of epizootology. The fundamental differences between epizootic and non-epizootic infections (i.e., exogenous and endogenous) had long been theoretically substantiated by I.V. Davydovsky in the context of his prophetic postulates regarding the evolution of infectious pathology².

The priority paradigm in the idea itself disavows the archaic beliefs regarding the key provisions of epizootology that have dominated to this day – the definition of the *subject* of this sphere of professional scientific, practical activity and academic discipline, as well as the place of the *epizootic process* in epizootological phenomena. The objective role of the epizootic process in the form of the aforementioned indisputable cycle is transferred to *morbidity* (prevalence) as one of the fundamental dynamic characteristics of pathology - the mass nature of its manifestation, the mass coverage of susceptible groups and populations of varying sizes, the integrative reflection of the interaction of various etiological factors (or risk factors) with a heterogeneous population of animals in terms of susceptibility.

This is not simply a mechanical sum of individual diseases, but a distinct, independent phenomenon of animal pathology of a functionally integrated, population-level nature, expressed as a collection of disease cases with emergent, novel, and specific properties. The *epizootic process*, in its modern interpretation, is assigned a secondary role as a cyclical mechanism for the development of infectious diseases and the self-regulation of parasitic systems in action, the

emergence of a contagious disease in an animal population as a result of the interaction of the "pathogen population + susceptible animal population" dyad³ [1, 3, 4].

Thus, factorial and opportunistic diseases without banal sources of infection, three-element epizootic chain transmission and other trivial attributes of the "old" epizootology, nevertheless, remain in its modern competence, contributing to the progress of opposing directions in this area of science and, more importantly, practice in the directions and developments of S.I. Dzhupina, V.D. Belyakov, G.P. Somov [4]. In terms of etiopathogenetics, the parasit systemic essence of conditional pathogenicity, epizootology, economic significance and other indicators, they fully correspond to the provisions of new concepts in this area.

This report will discuss unresolved issues of factorial pathology using specific examples. This paper will examine a group of infections whose non-epizootic causes are still unclear; there are no specific *causa prima* provoking agents, but there is also no trivial epizootic process. These include severe, idiopathically aggravated mastitis, strangles, necrobacillosis, paratuberculosis, and "new" non-canonical clostridiosis.

The situation regarding common pathogens causing pneumoenteritis (viral diarrhea, infectious bovine rhinotracheitis (IBR), etc.) is beyond the scope of this discussion, as these problems have been successfully addressed using examples from international sources. Specifically, in Sweden, Germany, the United States, and other countries with highly developed dairy farming and epizootic safety requirements, the control of thoroughly studied viral diarrhea is directly regulated by developed national programs in consultation with farm owners. The strategy is based on voluntary participation and funding, determined by population density and

¹Dzhupina S.I. On the theory of the epizootic process // Dzhupina S.I. On the theory of the epizootic process // Current issues of general epizootology: Proceedings of the All-Union Conf. on General Epizootology, Moscow, 1974, vol. 74, pp. 74–85.

²Davydovsky I.V. The Doctrine of infection. Moscow, Medgiz, 1956, 108 p.

³Makarov V.V., Barsukov Yu.I. General epizootology. Terminology reference. Moscow: Publishing house of the FSBI "Veterinary Center", 2023, 200 p.

prevalence logic, primarily without vaccination, systematic ongoing screening, and certification. Similar approaches are being implemented in IBR monitoring, where the DIVA strategy is additionally applied in specific cases⁴ [5–9]. In domestic livestock farming, there are currently no programs or any kind of regulation for controlling these infections at the farm level, other than vaccination, which loses all meaning in the face of total seropositivity⁵.

Mastitis – inflammation of the parenchymatous tissue of the udder, is the most common disease of dairy cows and the main reason for their premature culling. It develops as a result of a decrease in the body's overall resistance, often in the first months of lactation after calving, as well as under the influence of any provoking factors resulting from thermal, mechanical or chemical damage (cooling, various udder injuries, poor animal hygiene, milking technology and techniques). It has an infectious nature due to the fact that ubiquitous representatives of opportunistic and saprophytic pyogenic microflora penetrate into the udder from the outside – *Streptococcus* spp., *Staphylococcus* spp. (mainly), *E. coli*, *Pseudomonas* and others. As a cisternal organ with an outlet to the external environment, the udder is exposed to infection through the teat canal (primarily), as well as through wounds and blood from other organs, for example, with endometritis^{6–9}.

The pathological development vector is stereotypical for factor-endogenous diseases: "violation of optimal conditions of existence as causa prima → provocation of infection due to ubiquitous opportunistic and other microorgan-

isms," in this case, the microbial environment. The logic of this conclusion is that it is precisely zoosocialization that causes the conditional susceptibility of animals to factor-induced diseases, which are not typically observed in private farming conditions or in free-range conditions [1].

In terms of causes, mastitis in human and veterinary obstetrics is rationally divided into idiopathic and environmental. The former (primarily in human medicine) ranges from an undetermined etiology to secondary complications of chronic infections, autoimmune processes, diabetes, and others.

The term "ecological" in the definition of animal mastitis as an infection in a broad sense emphasizes critical causality – the environment as the main reservoir and factor of transmission of pathogens, in contrast to the intraorganismal zones of normal habitat of opportunistic commensals. There are, however, certain specific differences between purely environmental and contagious pathogens, which are important in the epizootology and control of mastitis. The former exist in a manner similar to saprophytes and dead-end saprophytoses, with the environment serving as both a reservoir and a source of infection (*E. coli* and other enterobacteria, saprophytes, yeasts, and fungi). For the latter, the environment is only a transmission factor (*Staphylococcus aureus*, *Streptococcus agalactiae*, and other commensals) (see footnote 9).

The factor-endogenous epizootological interpretation of mastitis, based on global scientific and practical experience (more than 10.5 thousand publications registered in PubMed), indicates the only possible strategy for solving this

⁴The DIVA strategy is the differentiation of infected and vaccinated animals by discriminatory serological testing using marked vaccines devoid of immunologically irrelevant antigens.

⁵On the results of the work of the reference laboratory of cattle diseases of the FSBI "All-Russian Research Institute for Animal Protection" / <https://www.arriah.ru/press-sluzhba/news/o-rezultatakh-raboty-referentnoy-laboratorii-bolezney-krs-fgbu-vniizzh-zal-polugodie/>

⁶Bovine mastitis / <https://www.nita-farm.ru/publikatsii/metodic/mastit-krupnogo-rogatogo-skota/>

⁷Mastitis: etiology, prevention, diagnosis, treatment // https://animal-health.ru/wp-content/uploads/2020/01/zdoroviejivotnih_mastit_Obzor_preview.pdf

⁸Mastitis-in-cows-causes-types-treatment-prevention-and-control / <https://www.thevetexpert.com/mastitis-in-cows-causestypes-treatment-prevention-and-control/><https://www.thevetexpert.com/>

⁹Smith K., Todhunter D., Schoenberger P. Symposium: environmental effects on cow health and performance // Environmental Mastitis: Cause, Prevalence, Prevention // Journal of Dairy Science, 1985, vol. 68, N. 6.

significant problem of veterinary science and the economics of dairy farming, that is the effective implementation of the modern ideology of the "happy cow" in dairy farms, which provides for the complete provision of all its needs from physiology and hygiene to livestock management [10]. The focus of practice on the use of "autovaccines" (immunization against one's own and local opportunistic microflora) in such a situation is an obvious, falsely encouraging palliative, a passive approach in its preventive, warning focus on "defensive" protection, in essence, of the third driving force of the epizootic chain and, by definition, not providing for the eradication of the disease, which requires "offensive" action on reservoirs, sources, and transmission.

Bovine necrobacillosis is an infectious disease caused by the anaerobic bacterium *Fusobacterium necrophorum*. It is common on dairy farms and is associated with significant productivity declines and reproductive losses. Although livestock deaths are rare, the damage caused is enormous. The pathogen is relatively unstable but can persist for long periods in various environmental media.

The disease most often develops due to metabolic and other abnormalities and traumatic skin injuries to the lower hind limbs. The disruption of capillary integrity creates an anoxic environment favorable for the pathogen's anaerobic life. Its activity results in the release of a large number of toxic substances that block intracellular enzyme systems, causing tissue necrosis. In some cases, the infection spreads through the body hematogenously, leading to septicemia and metastases from secondary necrotic lesions, primarily liver abscesses (see Fig. 1). At this stage, necrobacillosis becomes malignant, and the animal often dies. Immunity in those who have recovered from the disease is virtually undeveloped¹⁰.

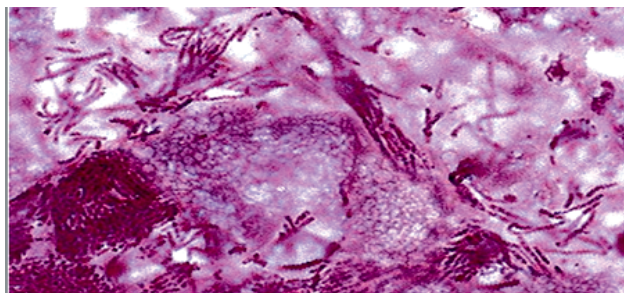


Рис. 1. Короткие цепочки *F. necrophorum* в очаге воспаления [afip.org/vetpath/WSC/WSC96/96wsc01.htm]

Fig. 1. Short chains of *F. necrophorum* in the focus of inflammation [afip.org/vetpath/WSC/WSC/WSC96/96wsc01.htm]

The factor-endogenous nature of necrobacillosis is due to the fact that *F. necrophorum* is a normal inhabitant of the bovine rumen. The microorganism's role in rumen fermentation involves the metabolism of lactic acid and the breakdown of feed and epithelial proteins. Its concentration in the rumen increases significantly with grain feeding. Normally, it is excreted from the body along with undigested waste during its natural transit through the gastrointestinal tract. However, in rumen pathologies (acidosis, rumenitis), the microorganism enters the portal circulation and lingers in the liver, causing abscesses. *F. necrophorum* is an opportunistic pathogen; some of its metabolic products are toxic and act as virulence factors. Specifically, hemagglutinin, endotoxin, and leukotoxin, which have antigenic properties, facilitate colonization of the rumen and penetration of the liver (see footnote 10) [11].

Environmental contamination occurs through feces (primarily) and other excretions from infected animals, including purulent ones. Typically, incidence within a herd manifests unevenly, in the form of small, sporadic, unrelated outbreaks, with no signs of trivial contagiousness¹¹.

¹⁰Bovine necrobacteriosis: causative agent and diagnostics. Description of the disease, symptoms, treatment / <https://techconfronts.com/17296383-necrobacteriosis-in-cattle-causative-agent-and-diagnosis-description-of-the-disease-symptoms-treatment>

¹¹The clinical picture, pathology, and epizootology of bovine necrobacteriosis have been studied in detail and described in fundamental publications by A.A. Samolovov and S.I. Dzhupina [13, 14].

Dairy cattle acidosis syndrome is a key factor in the etiopathogenesis of necrobacillosis, associated with the accumulation of lactic acid in the rumen due to an increase in the concentration of *F. necrophorum*, which synthesizes it, with a predominance over its consumers. This is a result of feeding a diet rich in rumen-available carbohydrates or a diet deficient in effective fiber. Depending on the level of lactic acid production, utilization, and absorption, the process affects two distinct anatomical regions: the gastrointestinal tract and body fluids. Systemic acidosis can have several pathophysiological consequences, including necrobacillosis laminitis—a diffuse aseptic inflammation of the laminae (cortex). The critical relationship between acidosis and laminitis, and the severity of the pathology, is determined by the frequency, intensity, and duration of systemic acidotic disturbances, which affect the mechanisms of vasoactive substance release and are caused by persistent hypoperfusion, leading to digital ischemia¹² [12].

In this regard, the factorial etio-pathogenetic interpretation of necrobacillosis and the resulting laminitis as a symptom complex of metabolic disorders in the works of A.A. Samolovov and S.I. Dzhupina [13–16] seems absolutely correct. An extensive excerpt from one of their publications should be cited. “This approach to laminitis and laminitis-related hoof damage significantly changes the approach to organizing and implementing measures to eliminate pathology and its prevention. What vaccinations are we talking about in this case?! Providing adequate, standardized, and balanced feeding is paramount. To successfully eliminate and prevent pathological processes in the hooves, it's necessary to not only treat the symptoms of the disease, such as laminitis and laminitis-related injuries, but also to address the underlying cause of the disease—the disruption of metabolic processes. This is why

there has been no progress in reducing lameness in dairy cows; on the contrary, it is constantly increasing. Treatment alone cannot solve the problem and cannot stabilize it. Vaccination in this case appears to be a purely commercial project, hidden in proposals to combine vaccine use with veterinary and sanitary measures, balanced feeding, and other measures. In our opinion, policymakers should simply remove necrobacillosis vaccines from production, as American researchers have done, which will encourage more in-depth study of the problem [16].

Overall, the vaccination of dairy cattle, which was intensively promoted in the recent past, offers a rather instructive example of professional incompetence. Among other justifications, a virtual threat of zoonotic necrobacillosis to humans was assumed, which was reflected in the discussion [15, 16]. The ephemeral positive effect was most likely simulated and was due to the fact that the measure was cleverly integrated into a set of well-known sanitary hoof treatment techniques, which in some way controlled the condition of the lower extremities of cows. However, by now, life itself has resolved this problem.

However, a general question remains: why, of all the many commensals, is *F. necrophorum* so pathogenic? The most likely reason is the natural history of its microecology and the powerful hydrolytic potential of fusobacteria, inherent in saprophytic decomposers in natural ecosystem balances, preserved during their transition to commensalism and “put in good use” there [17]. These are not obligate primary pathogens and not parasites as causative agents of canonical infections, interconnected by mutually beneficial parasit systemic relationships with the host, but also not yet the final “peaceful” commensals-members of eubiosis (see footnote 12), former saprophytes, for which the rumen is the only suitable place in the macroorganism, and pathogenicity is obviously conditionally dependent.

¹²Eubiosis is a microbiocenotic phenomenon, meaning the presence and existence in an animal organism of up to 10¹⁴ (100 trillion) eubiot microorganisms of 500 to 1000 species, a normal flora that performs at least 10 useful and even necessary functions for the latter as its own kind of extracorporeal organ; the most important of these are antagonistic resistance to exogenous and opportunistic pathogenic microbes, the synthesis of B vitamins, enzymatic breakdown of food products, strengthening of the immune defense, etc. (see footnote 3).

The logically probable vector of development of necrobacillosis appears to be as follows: *F. necrophorum* in the rumen as a useful element of rumen digestion → asymmetrical feeding ration with a predominance of grain and concentrates → subacute rumen acidosis → laminitis with a disorder of the barrier protection of the skin of the lower extremities (maceration, trauma) → local exogenous “autoinfection” → effective realization of the hydrolytic potential in the lesions.” Such an interpretation of the etiopathogenesis would explain the catabolic nature of the virulence factors of the pathogen, its localization primarily in the rumen, where they are naturally in demand under conditions close to saprophytism, damaged surfaces of the generally “weakened” lower parts of the hind limbs as a gateway for infection, primarily in contact with the source of infection, the absence of an immune response, the sporadic incidence of diseases caused by random *causa prima*, and other elements of the existence of necrobacillosis that have epizootological significance, as well as metabolic approaches to infection control, limiting the freedom of their existence only in the rumen, and the senselessness of immunoprophylaxis.

Strangles is a disease of solidungulates, first described in 1251. It is characterized by abscess formation in the lymphoid tissue of the upper respiratory tract, purulent lymphadenopathy, and nasopharyngitis. It is one of the most common equine infections worldwide, with a high morbidity (up to 100% of the susceptible population) and rare mortality. The causative agent is *Streptococcus equi* subsp. *equi*. The disease is most severe in horses aged 1–5 years. Infection is believed to occur through direct contact with infected horses or any number of contaminated objects. Asymptomatic carriers (up to 40% of naturally infected horses) and recovering animals are also sources of infection. Transmission from apparently healthy animals may be more

significant in causing new outbreaks or relapses in previously infected herds than from sick horses with purulent discharge, since the source of infection is not obvious^{13, 14}.

S. equi enters the upper respiratory tract through inhaled air or ingestion and colonizes regional lymph nodes. Replication of the pathogen and the influx of neutrophils contribute to the development of lymphadenopathy and lymph node abscesses, typical clinical signs of *S. equi*. Hematogenous and lymphogenous spread of infection beyond the upper respiratory tract is possible, leading to the formation of metastatic abscesses throughout the body. Several *S. equi* metabolites serve as virulence factors, the most important of which is the surface fibrillar protein SeM, which has adhesive and antiphagocytic properties and facilitates immune evasion (see footnote 14) [18, 19] (see Fig. 2).

Several vaccines are available for specific prevention: live attenuated vaccines for intranasal use and components for parenteral administration. However, the protective efficacy of vaccination is relative: protection against clinical manifestations of the disease is 50% [18, 19].

Along with the unconditional chain oronasal transmission as the main attribute of epizooticity, strangles is intriguingly characterized by a certain factorial specificity. Literally, *myt* (the Russian term for strangles also can mean a toll) and *mytar* (a derivative meaning toll collector) are common Slavic designations for obligatory tribute, taxes, and their collectors. Since biblical times, these concepts have signified something unpleasant, deception, cheating, and torment. Consequently, words of this series (such derivatives as *mytar*, *mytarit*, *mytarstvo*) are better known in their swearing and figurative meanings, primarily as everyday torments. When applied to animals in general, “myt” and “mytitsya” signify illness and relapse, primarily during early adolescence; molting is a peculiar semantic equivalent of the obligatory and pain-

¹³Strangles / <https://liphook.cylex-uk.co.uk/>

¹⁴Strangles in horses: <https://www.merckvetmanual.com/respiratory-system/respiratory-diseases-of-horses/strangles-in-horses>

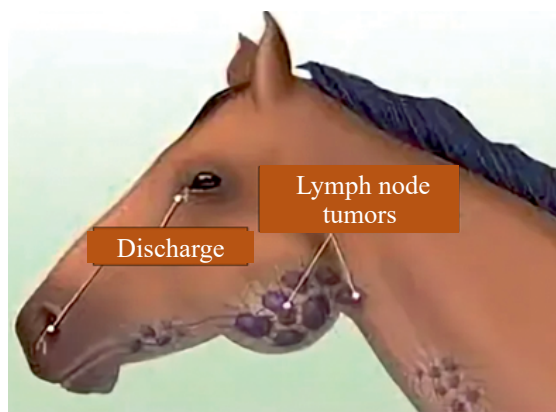


Рис. 2. Основные клинические признаки мыта лошадей: слизисто-гнойные выделения из глаз и носа и подчелюстная лимфаденопатия

Fig. 2. The main clinical signs of strangles: mucopurulent discharge from the eyes and nose and submandibular lymphadenopathy

ful "tax." Expressions such as "foals are mytized in their fourth or fifth year" and "a young horse is in myt" (V.I. Dahl) have survived. This is precisely why the term "myt"(strangles) has become ingrained in veterinary medicine for a specific equine disease.

The nature of the disease's clear dependence on age has not been studied. However, in medicine, there is a related phenomenon: acne (pustular rash, "acne vulgaris") – a skin pathology occurring in 90% of adolescents, on average, after 12–15 years of age, which correlates with the onset of puberty. This problem is polyetiologic, but the triggering factor and *causa prima* is endocrine – a rapid increase in androgenemia. The development of acne is facilitated by the activation of pyogenic eubiotic microorganisms of the skin and mucous membranes – the same epidermal staphylococci, streptococci, propionibacteria, yeasts, and others, also resistant to phagocytosis¹⁵. Therefore, in all etiopathogenetic conditions, acne is a factorial pathology.

Strangles and acne are not complete analogues. However, the similarity of the predominant age-dependent susceptibility, the common

stereotypical vector of pathology development from a factorial *causa prima* to a secondary, complicating infection, and the involvement of microorganisms that are conditionally rather than obligately pathogenic are undeniable. Their close ecological relationship with susceptible subjects (animals and humans, respectively), relative resistance to phagocytosis, determined local focality of pathology (abscesses), and the inadequacy of the immune response provide grounds for classifying equine strangles as a disease of the factorial category.

Paratuberculosis is a chronic, contagious granulomatous enteritis characterized by progressive weight loss, emaciation, and ultimately death in ruminants. The infection has been identified in omnivores, carnivores, and wild ruminants. It is also known as human Crohn's disease (inflammatory bowel disease). It is a serious infectious disease of dairy cattle worldwide, causing significant losses in the form of decreased productivity, culling/death, and control costs. The highest prevalence is observed in dairy cattle. Paratuberculosis is widespread worldwide. In most major dairy-producing countries, 20–90% of herds are affected. Paratuberculosis is of significant economic importance, is a priority for international trade, and is included in the OIE list¹⁶ [20].

The causative agent is *Mycobacterium avium* subsp. *paratuberculosis* (MAP), a member of the non-tuberculous mycobacteria saprophyte complex, widely distributed in the environment. It is a slow-growing mycobacterium, requiring 2 to 4 months to form visible colonies on solid media. Bacteria in this complex do not typically cause disease in healthy animals or humans, but they are among the main agents of opportunistic infections.

Pathological changes in paratuberculosis vary from a complete absence of visible lesions to thickening and pathognomonic folding of the

¹⁵Acne / <https://ru.wikipedia.org/wiki>

¹⁶Paratuberculosis in ruminants / <https://www.merckvetmanual.com/digestive-system/intestinal-diseases-in-ruminants/>

intestine with enlarged and edematous adjacent lymph nodes, diffuse granulomatous enteritis with progressive accumulation of epithelioid macrophages and giant cells in the intestinal mucosa and submucosa containing acid-fast microorganisms (see Fig. 3).

Mononuclear phagocytes, whose receptors participate in endocytosis, serve as the intracellular niche for MAP survival and proliferation. Virulence factors are the mechanisms responsible for MAP colonization, penetration, and persistence in macrophages, as well as for subsequent disease development—aggregation, adhesion, biofilm formation, colonization and adhesion, granulomatosis, invasiveness, immune evasion, etc. (see footnote 16).

There is no satisfactory treatment. Stereotypical protective responses of both innate and adaptive immunity are relatively weak. Vaccination has shown conflicting and unreliable results, as is common in the control of epizootic infections (foot-and-mouth disease, rinderpest), which may be due to chronic intracellular persistence of MAP of indefinite duration (see footnote 16).

Such etiopathogenetic characteristics, taking into account the generally recognized primary role of non-tuberculous mycobacteria, including MAP, in opportunistic pathology in acquired

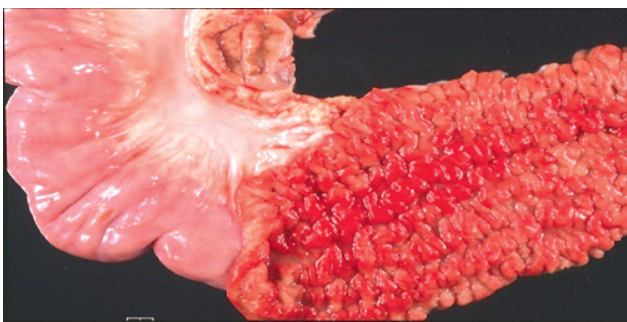


Рис. 3. Утолщенная и складчатая подвздошная кишка коровы с клиническим паратуберкулезом
Fig. 3. Thickened and folded ileum of a cow with clinical paratuberculosis

immunodeficiency syndrome (AIDS) caused by HIV infection¹⁷ and other human immunodeficiencies, provide sufficient grounds to consider paratuberculosis an opportunistic infection. MAP is not a parasite or an opportunistic commensal, but rather an opportunistic opportunist saprophyte existing in the environment, accidentally penetrating the macroorganism and remaining there asymptotically, exhibiting pathogenicity depending on the level of immunological suppression of the latter as *causa prima*.

The vector of the MAP infection cycle is similar to that of intestinal pathogens and other factor-mediated diseases: alimentary infection → uptake by subepithelial macrophages and asymptomatic intracellular persistence of indefinite duration → acquired immunodeficiency as a critical condition and sluggish chronic pathology against this background → feco-oral transmission, other attributes determined by the functioning of the gastrointestinal tract → resistance to environmental factors and survival.

Control of opportunistic infections in general *a priori* presents extreme difficulties due to the fatal cryptic nature of immunodeficiencies on a global scale, the stressful existence of humans and especially productive animals [1]. The well-known successful strategy against HIV infection, which ensures the salvation of many hundreds of thousands of infected people, allowing them to lead a relatively healthy lifestyle, is based on purely antiviral therapy, does not in any way affect the epidemic process and in this case is not a target¹⁸.

Of particular concern is the growing tension and interest in paratuberculosis in dairy cattle, indicating a large-scale, evolving infection. According to reports, infection control through veterinary and sanitary measures, monitoring and culling, farm biosecurity, and additional measures aimed at limiting the spread of infection within the herd, such as reducing calf exposure

¹⁷Panteleev A.M. Mycobacteriosis in the context of HIV infection / <https://congress-ph.ru/common/htdocs/upload/fm/cardiotorakal/prez/N20-02-3.pdf>

¹⁸AIDS / https://en.wikipedia.org/wiki/Management_of_HIV

to adult feces, more rapid culling after positive test results, and similar measures, have not and cannot produce the expected results due to the absolute extra- and intra-organismal ubiquity of MAP. The situation is complicated by the inherently low sensitivity of diagnostic tests, particularly in screening movements and trade of high-risk animals. One possible strategy involves tailoring a reliable set of measures to each specific affected farm [21, 22].

Non-canonical clostridioses are a relatively new pathology among infections caused by anaerobic microorganisms, generally unknown in Russian veterinary medicine. This term, within the category of known clostridioses of the neurotoxic, histotoxic, and enteric types (tetanus, botulism, blackleg, bradsot, enterotoxemia), refers to intestinal diseases of various animal species caused by *Clostridioides difficile*¹⁹ [23]. The infection of the new group is characterized by epizootological features common to clostridiosis (alimentary (or wound parenteral) infection, spore-forming pathogens (pathogenic saprophytes-anaerobes and the extreme activity of their catabolic ("destructive") enzymes in the processes of biodegradation (the potential of virulence), soil in a broad sense as a reservoir, amplifier and source of infection, abiotic and biotic habitat, in particular, the intestinal microbiota of animals, natural focality, seasonal sporadicity, the absence of trivial contagiousness and transmission from animal to animal or from animals to humans, a dead-end type of infection. Because clostridia and their infectious agents are ubiquitous, the diseases they cause have no natural limitations and are widespread worldwide. Animal defense mechanisms are virtually non-existent, and innate immunity is only relatively

developed. However, routine etiotropic antibiotic therapy is quite effective²⁰⁻²².

However, non-canonical clostridioses are distinguished by a radical feature: the critical condition for enteropathogenicity and *causa prima* is an obligatory imbalance of the intestinal microbiome²³ and a disruption of the protective potential of normal flora, leading to abnormal growth of *C. difficile*. The predominant cause of this is the detrimental effects of excessive antibiotic use (β -lactams, fluoroquinolones, macrolides, and others, regularly and widely used in animal husbandry) as a determining risk factor.

This infection leads to lower intestinal pathology, exacerbating many associated pathological processes, and even, as has been shown in medical practice, impacting brain function and mental health. The course of the infection ranges from asymptomatic colonization and mild symptoms to fulminant symptoms, including watery diarrhea, fever, nausea, and abdominal pain, complicated by pseudomembranous colitis, colonic perforation, and sepsis (see Fig. 4). Pathogenic effects are primarily caused by the massive elective proliferation of *C. difficile*, the production and accumulation in the intestine of potent entero- and cytotoxins, which cause several cytopathic effects and ultimately colonocyte death, inflammation, necrosis and loss of intestinal barrier function^{24, 25} [24].

Antibiotic-Associated Diarrhea (AAD) is a well-known phenomenon in human pathology. It represents a new challenge for civilization and represents one of the pressing challenges of modern medicine. Antibacterial agents affect the body's internal ecosystem, the microbial component of which includes the microbiota of the skin, respiratory tract, genitourinary organs, but

¹⁹In 2016, the species was transferred from the genus *Clostridium* to the genus *Clostridioides*, reflecting the taxonomic differences between these microbial taxa.

²⁰*Clostridia* / <https://en.wikipedia.org/wiki/Clostridia>

²¹*Clostridioides difficile* infection / https://en.wikipedia.org/wiki/Clostridioides_difficile_infection

²²*Clostridium difficile* and *C. perfringens* infections in animals / <https://www.merckvetmanual.com/infectious-diseases/clostridial-diseases/clostridium-difficile-and-c-perfringens-infections-in-animals>

²³Microbiome / <https://ru.wikipedia.org/wiki/Microbiome>

²⁴*Clostridioides difficile* / https://en.m.wikipedia.org/wiki/Clostridioides_difficile

²⁵*Uspensky Yu.P., Fominykh Yu.A.* Antibiotic-associated diarrhea – a new problem of civilization / <https://medi.ru/info/1471/>

primarily the gastrointestinal tract, where the greatest number of different microorganisms are present in the proctocaudal direction. Microbiota, or normal microflora, is a unique extracorporeal, supraorganismal structure that exists in a state of balanced equilibrium in a healthy body. However, maintaining this system's balance is a complex process and is heavily influenced by a variety of factors affecting the body and its microbiome (see footnote 25).

C. difficile-associated diarrhea and disease develop spontaneously in animals of various species, including calves, horses, pigs, dogs, cats, hamsters, guinea pigs, rats, and rabbits. It has been identified in young calves; 20–30% of cases of acute equine diarrhea are associated with *C. difficile*. The microorganism is excreted in low concentrations in the feces of 10% of healthy animals. In neonatal piglets aged one to seven days, *C. difficile* is the second most common cause of diarrhea; ileal edema is a characteristic feature of the disease in almost all affected animals.

C. difficile isolates from cattle, horses, pigs, and dogs share a number of characteristics with those isolated from humans, indicating the possibility of interspecies transmission. *C. difficile* has been detected in high numbers in calf meat during the early stages of veal production, and spores have been found in pig and cattle meat. Toxigenic strains from humans have been identified in rectal swabs of domestic dogs. Approximately 10% of asymptomatic dogs excrete toxigenic strains of *C. difficile* in their feces.

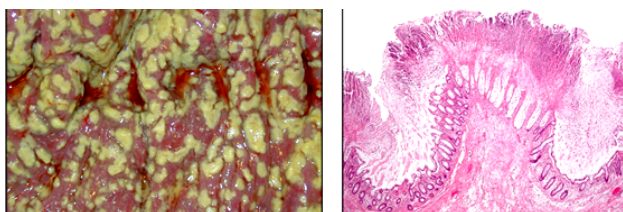


Рис. 4. Псевдомембраны в толстой кишке при колите, вызванном *C. difficile* – поверхность и гистосрез (см. сноски 20, 21)

Fig. 4. Pseudomembranes in the colon during colitis, caused by *C. difficile* – surface and histosection (see footnotes 20, 21)

As with the diseases listed above, control of *C. difficile*-associated pathology is extremely difficult due to the pathogen's fatal ubiquity, opportunistic, random, factor-dependent etiology, the specific pathogenesis, and its low immunogenicity. It is suggested that the most appropriate measures include simple isolation procedures in high-risk groups, the correct and judicious use of antimicrobials for both individual and mass therapy and prophylaxis, particularly antibiotics, to potentiate microbiome imbalances, and the use of probiotics as an alternative and, if unavoidable, concurrently with antibiotics, as is common practice in medical practice (see footnotes 22, 24, 25).

CONCLUSION

The facts presented are further evidence of the truly inexhaustible harmful potential of the animal world's habitat in all its diversity [25]. This, too, likely reflects the fatal significance of Darwinian selection for the survival of the most advanced life forms. This concerns not only the enormous number of nosological forms, replenished annually (if not daily!), but also, even more importantly, the diversity of sophisticated mechanisms of etiopathogenetic influence on the objects affected.

If for nosological forms of the classical epizootic type, the etiopathogenesis is relatively standard and is determined by well-established patterns of self-regulating balance of parasitic systems “parasite ↔ host” [3], then in factor infections, the ubiquity of the habitat of the pathogens of both abiotic, extraorganismal type and biotic type within the body, transfers all phenomena into the category of random, factorial *causa prima* and consequences are unpredictable, uncontrollable and unmanageable in principle.

Consequently, medical and veterinary protection capabilities remain extremely limited. Unfortunately, subjectivity or simply a lack of competence in approaches to solving emerging problems also predominates. As the brilliant Pasteur once prophetically wrote, “...to set one's first

task to finding the methods of treatment means, in most cases, condemning oneself to fruitless work. It is preferable to begin by studying the nature, cause, and development of the disease, with the long-term hope of discovering a method for preventing it".

Vaccination still holds the dominant position in infectious disease control, including factor-related ones, despite the fact that in the latter case, the full set of three canonical driving forces of the epizootic process, as in classic foot-and-mouth disease, influenza, CSF, and the like, is absent—no specific, unambiguous sources of infection, no transmission, only obvious targets and morbidity. Therefore, the usual, extremely primitive approach to solution begins not with initial positions as causes, but with final positions as consequences²⁶.

At the same time, the general logic of constructing anti-epidemic and preventive measures (APM), based on the canonical sequence "source → transmission → susceptibility," presupposes their target, chronological, and substantive specialization. Primary attention is paid to sources of infection, and APM include screening and monitoring, culling, stamping out, depopulation, quarantine, and isolation. To control transmission, biological protection measures, general and private hygiene of the environment, various barriers, zoning, the creation of free zones and territories, sentinelization, and import controls are used. These principles are active, "offensive," and are theoretically and practically substantiated by the principles of V.D. Belyakov's doctrine of self-regulation of parasitic systems (1983), the main conclusion of which indicates that focusing on clinically established morbidity is not only erroneous but also practically dangerous [3].

Ring, frontal, and total systematic vaccination are considered the last resort for protecting susceptible populations, the absolute basis for which is the obvious threat of introduction, emergence, and spread of infection. Such a mea-

sure, aimed at the final, third link of the epizootic chain, has a purely defensive purpose and can only be effective where this chain exists and is functioning. In this case, the targeting must be justified as a consequence of the primary causal factors—the actual source and transmission, the ineffectiveness of APM in the initial stages, and the ongoing threat.

Moreover, specific prevention and vaccination alone, as its primary element in veterinary medicine, where population-based protection and population protection are paramount, by definition and their palliative nature, do not achieve infection eradication. Post-vaccination sterilizing immunity is virtually nonexistent. There is not a single example of the complete well-being of any country or region achieved through vaccination (rather the opposite, as evidenced by the widespread "eradication versus vaccination" strategy, which has now become the standard for controlling the most dangerous infections) (see footnote 3). Moreover, against the backdrop of the widespread use of measures that limit protection only to the containment of infection and direct damage, such unfavorable epizootic phenomena as vaccine dependence, pro-epizootic development, and the evolution of pathogens adapting to persistence in the immune environment arise. In this case, the situation is not analogous to human vaccination, where everything is subordinated to individual protection with purely humanitarian goals [26].

СПИСОК ЛИТЕРАТУРЫ

1. Макаров В.В. Факторные болезни // Российский ветеринарный журнал. 2017. № 4. С. 22–27.
2. Джупина С.И. Эпизоотический процесс и его контроль при факторных инфекционных болезнях: монография. М.: Издательство Российского университета дружбы народов, 2002. С. 212.
3. Макаров В.В. Теория саморегуляции паразитарных систем В.Д. Белякова – парадигма в

²⁶Here it is appropriate to recall Chekhov's Vanka, who cleaned a herring from the tail, and what came of it.

- учении об эпидемическом процессе // Ветеринарная патология. 2004. № 10. С. 10–13.
4. Макаров В.В. Эволюция эпизоотологии: монография. М.: Издательство Российского университета дружбы народов, 2022, 118 с.
 5. Greiser-Wilke I., Grummer B., Moennig V. Bovine viral diarrhoea eradication and control programmes in Europe // *Biologicals*. 2003. Vol. 31. Is. 2. P. 113–118. DOI: 10.1016/S1045-1056(03)00025-3.
 6. Grooms L., Bartlett B., Bolin S. Review of the Michigan Upper Peninsula Bovine Viral Diarrhea Virus Eradication Project // *JAVMA*. 2024. Vol. 243. Is. 4. DOI: 10.2460/javma.243.4.548.
 7. Houe H., Lindberg A., Moennig V. Test Strategies in Bovine Viral Diarrhea Virus Control and Eradication Campaigns in Europe // *Journal of Veterinary Diagnostic Investigation*. 2006. Vol. 18 (5). P. 427–436. DOI: 10.1177/104063870601800501.
 8. Van Campen H. Epidemiology and control of BVD in the U.S. // *Veterinary Microbiology*. 2010. Vol. 21. N 142 (1-2). P. 94–98. DOI: 10.1016/j.vetmic.2009.09.049.
 9. Iscaro C., Cambiotti V., Petrini S. Control programs for infectious bovine rhinotracheitis (IBR) in European countries: an overview // *Animal Health Research Reviews*. 2021. Vol. 22. Is. 2. P. 136–146. DOI: 10.1017/s1466252321000116.
 10. Dirke K. 11 Happy cows? Unravelling contexts of Swedish farmed animals // In book: *Animal Industries*. 2024. P. 213–228. DOI: 10.1515/9783110787337-015.
 11. Tadepallia S., Narayanan S., Stewart G. Veterinary anaerobes and diseases *Fusobacterium necrophorum*: A ruminal bacterium that invades liver to cause abscesses in cattle // *Anaerobe*. 2009. Vol. 15. Is. 1-2. P. 36–43. DOI: 10.1016/j.anaerobe.2008.05.005.
 12. Plaizier J., Mulligan F., Nevill E. Invited review: Effect of subacute ruminal acidosis on gut health of dairy cows // *Journal of Dairy Science*. 2022. Vol. 105. P. 7141–7160. DOI: 10.3168/jds.2022-21960.
 13. Dzhupina S.I. Features of control over the epizootic process of necrobacteriosis in cattle // *Veterinary pathology*. 2016. N 2. P. 5–13.
 14. Samolovov A.A. Classification and mechanism of pathogenesis of hoof diseases in dairy cattle // *Innovations and food security*. 2018. N 3. P. 166–172.
 15. Dzhupina S.I. Response to opponents on the problem of necrobacteriosis in cattle // *Veterinary science*. 2006. N 12. P. 6–9.
 16. Samolovov A.A., Lopatin S.V. Theory and practice of vaccination against necrobacteriosis in dairy cattle // *Innovations and food security*. 2017. N 1. P. 28–34. DOI: 10.31677/2311-0651-2017-0-1-28-34.
 17. Makarov V.V. Pathogenic saprophytes and sapro-noses // *Pest-management*. 2024. No. 1. P. 10–19.
 18. Boyle A., Timoney J., Newton J. Streptococcus equi Infections in Horses: Guidelines for Treatment, Control, and Prevention of Strangles-Revised Consensus Statement // *Journal of Veterinary Internal Medicine*. 2018. Vol. 32. Is. 2. P. 611–878. DOI: 10.1111/JVIM.15043.
 19. Rendle D., de Brauwere V., Gayle-Hallowell G. Streptococcus equi infections: current best practice in the diagnosis and management of ‘strangles’ // *UK-Vet Equine*. 2021. Vol. 5 (2). P. 3–15. DOI: 10.12968/ukve.2021.5.2.S.3.
 20. Ssekitoleso J., Ojok L., Abd El Wahed A. Mycobacterium avium subsp. paratuberculosis Virulence // *A Review. Microorganisms*. 2021. Vol. 9. P. 2623. DOI: 10.3390/microorganisms9122623.
 21. Bastida F., Juste R. Paratuberculosis control: a review with a focus on vaccination Paratuberculosis control: a review with a focus on vaccination // *Journal of Immune Based Therapies and Vaccines*. 2011. Vol. 9. P. 8. DOI: 10.1186/1476-8518-9-8.
 22. Ezanno P., Arnoux S., Joly A. Rewiring cattle trade movements helps to control bovine paratuberculosis at a regional scale // *Preventive Veterinary Medicine*. 2022. Vol. 198. P. 105529. DOI: 10.1016/j.prevetmed.2021.105529.
 23. Lawson P., Citron D., Tyrrell K. Reclassification of Clostridium difficile as Clostridioides difficile (Hall and O’Toole 1935) Prévot 1938 // *Anaerobe*. 2016. Vol. 40. P. 95–99. DOI: 10.1016/j.anaerobe.2016.06.008.
 24. Kuehne S., Cartman S., Heap J. The role of toxin A and toxin B in Clostridium difficile infection // *Nature*. 2010. Vol. 467. N 7316. P. 711–713. DOI: 10.1038/nature09397.
 25. Макаров В.В. Инфекции как эмерджентная угроза биологическим популяциям и видам // *Пест-менеджмент*. 2022. № 4. С. 5–17.
 26. Lombard M., Pastoret P., Moulin A. A brief history of vaccines and vaccination // *Rev. sci. tech. Off. int. Epiz.* 2007. Vol. 26 (1). P. 29–48.

REFERENCES

1. Makarov V.V. Factor diseases. *Rossijskij veterinarnyj zhurnal = Russian Veterinary Journal*, 2017, no. 4, pp. 22–27. (In Russian).

2. Dzhupina S.I. *Epizootic process and its control in factor-based infectious diseases*. Moscow: Publishing House of Peoples' Friendship University of Russia, 2002, p. 212. (In Russian).
3. Makarov V.V. Belyakov's theory of self-regulation of parasitic systems is a paradigm in the doctrine of the epidemic process *Veterinarnaya patologiya = Russian Journal of Veterinary Pathology*, 2004, no. 10, pp. 10–13. (In Russian).
4. Makarov V.V. *Evolution of epizootology*. Moscow, Publishing House of Peoples' Friendship University of Russia, 2022, 118 p. (In Russian).
5. Greiser-Wilke I., Grummer B., Moennig V. Bovine viral diarrhoea eradication and control programmes in Europe. *Biologicals*, 2003, vol. 31, is. 2, pp. 113–118. DOI: 10.1016/S1045-1056(03)00025-3.
6. Grooms L., Bartlett B., Bolin S. Review of the Michigan Upper Peninsula Bovine Viral Diarrhea Virus Eradication Project. *JAVMA*, 2024, vol. 243, is. 4. DOI: 10.2460/javma.243.4.548.
7. Houe H., Lindberg A., Moennig V. Test Strategies in Bovine Viral Diarrhea Virus Control and Eradication Campaigns in Europe. *Journal of Veterinary Diagnostic Investigation*, 2006, vol. 18 (5), pp. 427–436. DOI: 10.1177/104063870601800501.
8. Van Campen H. Epidemiology and control of BVD in the U.S. *Veterinary Microbiology*, 2010, vol. 21, no. 142 (1-2), pp. 94–98. DOI: 10.1016/j.vetmic.2009.09.049.
9. Iscaro C., Cambiotti V., Petrini S. Control programs for infectious bovine rhinotracheitis (IBR) in European countries: an overview. *Animal Health Research Reviews*, 2021, vol. 22, is. 2, pp. 136–146. DOI: 10.1017/s1466252321000116.
10. Dirke K. 11 Happy cows? Unravelling contexts of Swedish farmed animals. *In book: Animal Industries*, 2024, pp. 213–228. DOI: 10.1515/9783110787337-015.
11. Tadepallia S., Narayanan S., Stewart G. Veterinary anaerobes and diseases *Fusobacterium necrophorum*: A ruminal bacterium that invades liver to cause abscesses in cattle. *Anaerobe*, 2009, vol. 15, is. 1-2, pp. 36–43. DOI: 10.1016/j.anaerobe.2008.05.005.
12. Plaizier J., Mulligan F., Nevill E. Invited review: Effect of subacute ruminal acidosis on gut health of dairy cows. *Journal of Dairy Science*, 2022, vol. 105, pp. 7141–7160. DOI: 10.3168/jds.2022-21960.
13. Dzhupina S.I. Features of control over the epizootic process of necrobacteriosis in cattle. *Veterinary pathology*, 2016, no. 2, pp. 5–13. (In Russian).
14. Samolovov A.A. Classification and mechanism of pathogenesis of hoof diseases in dairy cattle. *Innovations and food security*, 2018, no. 3, pp. 166–172. (In Russian).
15. Dzhupina S.I. Response to opponents on the problem of necrobacteriosis in cattle. *Veterinary science*, 2006, no. 12, pp. 6–9. (In Russian).
16. Samolovov A.A., Lopatin S.V. Theory and practice of vaccination against necrobacteriosis in dairy cattle. *Innovations and food security*, 2017, no. 1, pp. 28–34. DOI: 10.31677/2311-0651-2017-0-1-28-34.
17. Makarov V.V. Pathogenic saprophytes and saproscoses. *Pest-management*, 2024, no. 1, pp. 10–19.
18. Boyle A., Timoney J., Newton J. Streptococcus equi Infections in Horses: Guidelines for Treatment, Control, and Prevention of Strangles-Revised Consensus Statement. *Journal of Veterinary Internal Medicine*, 2018, vol. 32, is. 2, pp. 611–878. DOI: 10.1111/JVIM.15043.
19. Rendle D., de Brauwere V., Gayle-Hallowell G. Streptococcus equi infections: current best practice in the diagnosis and management of 'strangles'. *UK-Vet Equine*, 2021, vol. 5 (2), pp. 3–15. DOI: 10.12968/ukve.2021.5.2.S.3.
20. Ssekitoleko J., Ojok L., Abd El Wahed A. Mycobacterium avium subsp. paratuberculosis Virulence. *A Review. Microorganisms*, 2021, vol. 9, p. 2623. DOI: 10.3390/microorganisms9122623.
21. Bastida F., Juste R. Paratuberculosis control: a review with a focus on vaccination Paratuberculosis control: a review with a focus on vaccination. *Journal of Immune Based Therapies and Vaccines*, 2011, vol. 9, p. 8. DOI: 10.1186/1476-8518-9-8.
22. Ezanno P., Arnoux S., Joly A. Rewiring cattle trade movements helps to control bovine paratuberculosis at a regional scale. *Preventive Veterinary Medicine*, 2022, vol. 198, p. 105529. DOI: 10.1016/j.prevetmed.2021.105529.
23. Lawson P., Citron D., Tyrrell K. Reclassification of *Clostridium difficile* as *Clostridioides difficile*

- (Hall and O'Toole 1935) Prévot 1938. *Anaerobe*, 2016, vol. 40, pp. 95–99. DOI: 10.1016/j.anaerobe.2016.06.008.
24. Kuehne S., Cartman S., Heap J. The role of toxin A and toxin B in *Clostridium difficile* infection. *Nature*, 2010, vol. 467, no. 7316, pp. 711–713. DOI: 10.1038/nature09397.
25. Makarov V.V. Infections as an emergent threat to biological populations and species. *Pest-menedzhment = Pest Management*, 2022, no. 4, pp. 5–17. (In Russian).
26. Lombard M., Pastoret P., Moulin A. A brief history of vaccines and vaccination. *Rev. sci. tech. Off. int. Epiz*, 2007, vol. 26 (1), pp. 29–48.

ИНФОРМАЦИЯ ОБ АВТОРАХ

✉ **Макаров В.В.**, старший преподаватель, доктор биологических наук, профессор; SPIN-код 4905-4705; **адрес для переписки:** Россия, 29344, Москва, ул. Летчика Бабушкина, 20; e-mail: vvm-39@mail.ru

Стекольников А.А., профессор кафедры, академик РАН, доктор ветеринарных наук, профессор; SPIN-код 7509-9171

Донченко А.С., руководитель ИЭВСиДВ СФНЦА РАН, академик РАН, доктор ветеринарных наук, профессор; SPIN-код 3918-5688

Сочнев В.В., профессор кафедры, член-корреспондент РАН, доктор ветеринарных наук, профессор; SPIN-код 5499-9674

AUTHOR INFORMATION

✉ **Vladimir V. Makarov**, Senior Lecturer, Doctor of Science in Biology, Professor; SPIN-code 4905-4705; **address:** 20, Letchika Babushkina St., Moscow, 129344, Russia; e-mail: vvm-39@mail.ru

Anatoly A. Stekolnikov, Chair Professor, Doctor of Science in Veterinary Medicine, Professor, Academician RAS; SPIN-code 7509-9171

Alexandr S. Donchenko, Head of the IEVSSFE SFSCA RAS, Academician RAS, Doctor of Science in Veterinary Medicine, Professor, SPIN-code 3918-5688

Vasily V. Sochnev, Chair Professor, Corresponding Member RAS, Doctor of Science in Veterinary Medicine, Professor; SPIN-code 5499-9674

Дата поступления статьи / Received by the editors 27.02.2025
Дата принятия к публикации / Accepted for publication 19.03.2025
Дата публикации / Published 16.06.2025

Качество говядины мясных пород крупного рогатого скота, районированных в Сибири

Солошенко В.А.¹, Бабаков В.Ю.¹, Храмцова И.А.¹, (✉)Инербаева А.Т.¹,
Бейфорт П.Я.², Плешаков В.А.³, Адушинов Д.С.⁴, Третьяков А.М.¹

¹Сибирский федеральный научный центр агробиотехнологий Российской академии наук
Новосибирская область, р.п. Краснообск, Россия

²Госплемзавод ООО «ВИРТ»

Алтайский край, Целинный район, Россия

³Алтайский государственный аграрный университет

Барнаул, Россия

⁴Иркутский государственный аграрный университет им. А.А. Ежевского

Иркутск, Россия

(✉)e-mail: atinerbaeva@yandex.ru

В статье дана историческая справка о зарождении специализированного мясного скотоводства в России, в частности приводятся результаты мировых лидеров по формированию отрасли, состоянию и перспективах развития мясного скотоводства по регионам РФ, породный состав скота мясного направления в Сибири. Материал содержит данные по численности и биологическим особенностям каждой мясной породы крупного рогатого скота: абердин-ангусской, герефордской, казахской белоголовой и черно-пестрой. Породы разводятся в регионе и формируют основной объем производимой в регионе говядины. Представлены фото быков мясных пород крупного рогатого скота. Обсуждены результаты, полученные учеными из Оренбургской области, Ставропольского края, Московской области, Горного Алтая и Новосибирской области. В зависимости от регионов разведения, контрастно различающихся по рельефу, климату, кормовым условиям, оценены новые варианты сочетаний сибирских типов герефордов с канадскими, финскими, американскими экотипами, в которых использовались эмбрионы, племенные животные или их семя. Новые гибридные сочетания существенно отличаются друг от друга. Несмотря на имеющиеся исследования научных учреждений, прослеживается недостаточная изученность вопроса в области качества говядины, в частности его взаимосвязи с жирнокислотным составом и другими факторами, определяющими вкусовые качества этого ценного продукта питания. Нами представлены данные по живой массе и среднесуточному приросту подопытных животных четырех пород: черно-пестрой, абердин-ангусской, герефордской и казахской белоголовой, у которых в дальнейшем будет исследован биохимический и жирнокислотный состав мяса. Также будет проведена органолептическая оценка вареного мяса и бульона.

Ключевые слова: мясной скот, порода, живая масса, жирные кислоты

Beef quality of meat breeds of cattle released in Siberia

Soloshenko V.A.¹, Babakov V.Yu.¹, Khramtsova I.A.¹, (✉)Inerbaeva A.T.¹,
Bayfort P.Ya.², Pleshakov V.A.³, Adushinov D.S.⁴, Tretyakov A.M.¹

¹Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences
Krasnoobsk, Novosibirsk region, Russia

²State breeding farm ООО "VIRT"

Tselinniy district, Altai Territory, Russia

³Altai State Agricultural University

Barnaul, Russia

⁴Irkutsk State Agrarian University named after A.A. Yezhevsky

Irkutsk, Russia

(✉)e-mail: atinerbaeva@yandex.ru

The article provides historical information about the origin of specialized beef cattle breeding in Russia, in particular, the results of world leaders in the formation of the industry, the state and prospects of development of beef cattle breeding, by regions of the Russian Federation, the breed composition of meat cattle in Siberia. The material contains data on the abundance and biological

characteristics of each beef breed of cattle: Aberdeen Angus, Hereford, Kazakh white-headed and Black-and-White breeds. The breeds are raised in the region and form the bulk of the beef produced in the region. Photos of the bulls of meat breeds of cattle are presented. The results obtained by the scientists from the Orenburg Region, Stavropol Territory, Moscow Region, Gorny Altai and Novosibirsk regions are discussed. Depending on the breeding regions, which differ in contrast in relief, climate, and feeding conditions, new combinations of Siberian Hereford types with Canadian, Finnish, and American ecotypes using embryos, breeding animals, or their seeds were evaluated. The new hybrid combinations differ significantly from each other. Despite the available research by scientific institutions, there is a lack of understanding of the issue of beef quality, in particular its relationship with the fatty acid composition and other factors that determine the taste of this valuable food product. We present data on the live weight and average daily gain of experimental animals of four breeds: Black-and-White, Aberdeen-Angus, Hereford and Kazakh white-headed, in which the biochemical and fatty acid composition of meat will be further studied. An organoleptic evaluation of boiled meat and broth will also be carried out.

Keywords: beef cattle, breed, live weight, fatty acids

Для цитирования: Солошенко В.А., Бабаков В.Ю., Храмцова И.А., Инербаева А.Т., Бейфорт П.Я., Плешаков В.А., Адушинов Д.С., Третьяков А.М. Качество говядины мясных пород крупного рогатого скота, районированных в Сибири // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 5. С. 70–82. <https://doi.org/10.26898/0370-8799-2025-5-7>

For citation: Soloshenko V.A., Babakov V.Yu., Khramtsova I.A., Inerbaeva A.T., Bayfort P.Ya., Pleshakov V.A., Adushinov D.S., Tretyakov A.M. Beef quality of meat breeds of cattle released in Siberia. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 5, pp. 70–82. <https://doi.org/10.26898/0370-8799-2025-5-7>

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

The origin of specialized beef cattle breeding as a distinct branch of animal husbandry is difficult to pinpoint. The oldest breeds—Hereford and Aberdeen Angus, which pioneered the production of "marbled" beef using a special technology—turned 150 years old at the beginning of the 21st century. The sites of their origin and successful development are Great Britain, Canada, Australia, and Uruguay. The first mass import of the Hereford cattle to the USSR took place in 1928–1932 from Great Britain (612 heads) and Uruguay (895 heads), and the second in 1963–1965 from Great Britain and Canada. The first batch of beef cattle was distributed in the steppe region of the southern USSR and the Volga region, the second in the Urals and Siberia [1, 2]. The breeding of beef cattle was initially aimed at producing early-maturing, compact animals that fatten quickly on pastures, with a daily growth rate of 800–900 g. By 13–15 months of age, commercial young animals were ready for

slaughter. Beef cattle breeding in Siberia began with compact Herefords, characterized by high adaptability to pasture management and excellent maternal qualities (see Fig. 1).

Increased demand for leaner beef, driven by changing lifestyles, led to a shift in beef cattle breeding toward a more vigorous type with a daily growth rate of 1,000–1,200 g. This resulted in the creation of the "Sonsky" Hereford type, followed by the "Sadovsky" type. These differed



Рис. 1. Фото быка герефордской породы компактного типа

Fig. 1. Photo of a compact Hereford bull

from the previous imported Herefords in their polled nature, even greater daily growth rate of 1,100–1,300 g, and a calm disposition (see Fig. 2) [3].

New Hereford breeds required changes in feeding and management practices, as average daily gains reached 1,200–1,300 g per day, with periods reaching 1,500 g, which was impossible to achieve with pasture feed alone. Newborn calves were nursed with their mothers in holding pens or pastures until they were 6–7 months old, after which they were reared and finished in feedlots.

Following the change in energy prices in Russia, breeding efforts to create new meat breeds and types continued for some time. This resulted in the development of the Kazakh white-headed breed, the “Andrianovsky” type in the Hereford breed, and the “Bagansky” beef type in the Simmental breed [3].

In order to realize the productive potential of new breeds and types, projects were developed for inexpensive feedlots with free-range housing of young animals on deep, permanent litter in light-type buildings, which have become widespread in Siberia (see Fig. 3).

At the same time, 61 industrial fattening complexes using Italian technology were built in many regions of the USSR. They utilized confinement and a single-feed system (concentrate-silage ratio 65:35) with a capacity of 10,000–12,000 head at a time. Over the course of

several years of operation, it became clear that raising young animals without active exercise and sunlight on mono-rations led to metabolic disorders and low-quality beef. The products proved to be of little demand, and as a result, all of the facilities were closed. Thus, the question of livestock product quality and its relationship with the environment has suddenly arisen, yet our understanding of the decisive role of breed in determining meat quality remains incomplete. While the number of exploratory scientific papers on the relationship between livestock quality and feeding conditions, housing, breed compatibility, and other environmental factors has increased significantly abroad over the past two decades, this area of research is only just beginning in Russia. Despite government programs and decrees to increase the number of specialized beef cattle by 2.8–3.0 times, they have not been implemented (with the exception of the “Miratorg” company). [4].

Japan has made significant progress in beef quality management, creating one of the best breeds, Wagyu, recognized as the standard for meat “marbling” (see Fig. 4).

In order to increase the tenderness of the meat and its taste, castrated bulls were placed in darkened rooms during the final fattening period, were played calm classical music, were given massages, and were given beer or red wine to drink [5].



Рис. 2. Фото высокорослого растянутого типа герефордов

Fig. 2. Photo of a tall, stretched Hereford



Рис. 3. Фото откормочной площадки для молодняка

Fig. 3. Photo of a feedlot for young animals



Рис. 4. Фото быка породы Vagyu
Fig. 4. Photo of a Vagyu breed bull

Depending on consumer demand, three types of fattening have emerged: grass-fed, grain-fed, and combined. Grass-fed castrated beef is characterized by a rich flavor, grain-fed beef is distinguished by tenderness, and combined fattening combines both qualities, but to a lesser degree. Thanks to the superior taste of "marbled" beef, the number of beef cattle has increased sharply in a number of countries (France, Uruguay, Australia, the USA, Canada), surpassing the number of dairy cattle [6].

Russia began producing beef cattle in the 1960s and 1970s. Beef was obtained primarily from over-replacement or culled dairy cattle. Significant structural changes occurred in the Russian agro-industrial complex: the cattle population declined, their productive longevity decreased, and consequently, livestock production fell. To adequately feed the population, Russia needs to produce 4.67 million tons of beef annually from its own resources to ensure food independence. The problem of sufficient and rational utilization of meat production exists in all countries with developed beef cattle farming, regardless of ownership structure or economic system. One of the key factors in increasing the volume and efficiency of meat and meat product production is the comprehensive improvement of production technology and product quality, and beef cattle farming is becoming a more important branch of animal husbandry. The share of specialized beef and crossbred cattle amounted to 16% in the structure of cattle production

for slaughter in the farms of all categories in the Russian Federation. In the livestock industry as a whole, over the past 12 years, the share of specialized beef and crossbred cattle has increased by 11.3 times compared to the 2005 level [6].

Several beef cattle breeds are bred in Western Siberia, each with its own characteristics and advantages. The Aberdeen Angus is one of the most popular beef breeds in the world, distinguished by its early maturity and excellent meat quality. Its meat is considered one of the most delicious and tender. Its drawbacks include its demanding housing and feeding conditions, and its increased aggressiveness [7–9].

The Hereford breed is distinguished by its good endurance and adaptability to various climatic conditions. Herefords produce high-quality, marbled meat, prized for its tenderness and flavor. However, they are not as precocious as Aberdeen Angus cattle. This breed is the most numerous of the imported specialized meat breeds bred in Siberia. Over the 62 years of purebred Hereford breeding, Siberia has established its own breeding base, stud farms, and reproduction facilities, where champions and record-breakers of the breed have been produced. Three breeding lines (Mayer-Verne, Shalun, and Yarlyk) and three breeding types ("Sonsky", "Sadovsky", and "Andrianovsky") are officially registered [10–15].

New hybrid combinations of Siberian Hereford types with Canadian, Finnish, and American ecotypes were evaluated, using embryos, breeding animals, or their semen, depending on breeding regions with contrasting topography, climate, and feeding conditions. These new hybrid combinations differ significantly from each other. Of particular interest are crosses of Siberian Herefords with the meat-type Simmental breed, which boasts high growth rates of 1,400–1,600 g per day, reaching 2,000 g during finishing in fixed feedlots. The Gorno-Altai and Buryat ecotypes are well-adapted: the former to mountain pastures, the latter to year-round steppe pastures. It is believed that all of these

Siberian Hereford ecotypes differ in beef taste, and their genetic determination will help provide vast regions of Siberia with domestic breeding stock of Hereford cattle adapted to local conditions [16–19].

The Kazakh white-headed breed was developed in Kazakhstan specifically for breeding in the arid, continental steppe climate. Kazakh white-headed bulls and cows are distinguished by their hardiness and good meat production [20–25]. However, their meat can be slightly tougher than that of other breeds (see Fig. 5).

Each of these breeds has its own advantages and disadvantages, which must be taken into account when choosing one for breeding in Siberia.

Beef is one of the finest natural animal products in the world, and "marbled" beef is a source of vitamin B₁₂ and easily digestible iron, improves metabolism in human nerve tissue, and normalizes lipid metabolism. "Marbled" beef contains choline, which has membrane-protective, anti-sclerotic, and calming properties. With increasing demand for beef, the issue of meat quality is becoming increasingly important. The most sought after "marbled" meat, sold in restaurants and supermarkets, costs 800-1300 rubles per kilogram and is imported primarily from abroad (Australia, the United States). In Russia, this type of meat is not yet produced on a large scale, as domestic breeding efforts have not been focused on producing meat with such



Рис. 5. Фото быка казахской белоголовой породы
Fig. 5. Photo of a Kazakh white-headed bull

qualities, but research is nonetheless underway.

The biological value of meat depends not only on its protein content but also on the ratio of essential and non-essential amino acids. The nutritional value of muscle tissue lipids, which determine the structure of meat, its marbling, and many organoleptic characteristics, is a source of highly beneficial fatty acids, the composition of which also depends on the type of feeding.

The purpose of the study is a comparative analysis of the quality of beef in regionalized Siberian breeds of beef and dairy cattle.

MATERIAL AND METHODS

The subjects of the study are the most common beef and dairy cattle breeds in Siberia: Aberdeen Angus, Hereford, Kazakh white-headed and Black-and-White. The studies are conducted on the animals of various beef cattle breeds from the "VIRT" stud farm. Four groups of animals were formed for the study, each consisting of 8–10 animals, based on the same age, live weight, and physiological condition. Statistical data processing was performed using Snedecor software, and the reliability of the results was determined using the Student's t-test.

The research methods are comparative analysis of qualitative and quantitative indicators of beef of different breeds obtained under the same feeding and housing conditions: physiological, biochemical, organoleptic.

RESULTS AND DISCUSSION

Providing our country's population with meat and meat products through domestic production, as well as overcoming dependence on imported supplies, are the main priorities of our country's agro-industrial complex. At the current stage (1990–2025), various Russian livestock research institutes conducted research on the raising and fattening of cattle using various feeds and additives.

Currently, the state and prospects for the development of beef cattle breeding in the Russian Federation are described: monitoring of

the number of livestock, breed composition and productivity of cattle in all categories of farms was carried out, the scale and volume of appraisals for 2010-2018 were studied. A total of 15 breeds and types of beef cattle bred in 57 regions of the Russian Federation were identified, the most common were Aberdeen Angus (417,545 heads), Kalmyk (137,262 heads), Hereford (87,278 heads) and Kazakh white-headed (52,563 heads). The breeding base of beef cattle breeding in the country is represented by 270 breeding herds, including 46 breeding plants and 224 pedigree breeding unit^{1,2} [6].

A comparative assessment of the slaughter qualities and meat productivity of various genotypes of the Kazakh white-headed cattle was conducted. The genetic characteristics of the breeding bulls were determined, the slaughter qualities of young bulls at various ages were studied, carcass quality was assessed, the morphological composition of the anatomical parts of the carcass halves was analyzed, and the quality parameters of the longissimus dorsi muscle were examined. High-yielding linear breeding bulls with beneficial genes controlling meat productivity and beef quality in beef cattle were identified, which will contribute to increased production of "marbled" beef [21].

In the Stavropol Territory, where the Kazakh white-headed breed is bred and selected, a comprehensive assessment has been made. It possesses highly adaptable properties, inheriting meat qualities from the Hereford breed, and inheriting resistance to infectious diseases from the Kalmyk breed, as well as the ability to withstand both summer heat and winds, and winter frosts and snowstorms [22].

In the Altai Republic, the history of the creation of specialized beef cattle breeding was studied, where Kazakh white-headed animals (59.2%) and Galloway (11.8%), Simmental

dairy and meat productivity in almost all zones, as well as Hereford (17.4%) and Aberdeen Angus (1.4%), Gray Ukrainian (1.4%) breeds are bred in the zones where grain farms are developed and forage production is established [16].

Scientists studied the nutritional value, chemical composition, amino acid, and fatty acid composition of muscle tissue in grain-fed and conventionally fed Aberdeen Angus cattle. The results showed that the total amino acid content in grain-fed beef was 23.4% lower than in conventionally fed beef, and the total PUFA (polyunsaturated fatty acid) content was 2.8 times lower than in conventionally fed beef. Fat increased 5.0-fold, and protein decreased 23.5% in grain-fed beef. Concentrated feeding is recommended for optimal protein and fat balance [26, 27].

In the Orenburg region, the meat productivity of Hereford bulls was assessed. The morphological composition of carcasses, the chemical composition of the average meat sample (ground meat), the nutrient and energy content of the test animals' carcasses, and the chemical composition of the longissimus dorsi muscle were analyzed [18].

The value of beef cattle meat lies in its lower content of incomplete proteins than that of dairy and mixed breeds. The relative amount of incomplete proteins increases with age. The meat of older cattle, especially stud bulls, is stringy, difficult to cook and chew, making it primarily used for canned goods and sausages. Complete proteins in beef meat are particularly valuable for human nutrition. They contain amino acids such as arginine, histidine, lysine, leucine, isoleucine, methionine, phenylalanine, and tryptophan. The latter plays a vital role in metabolism. When tryptophan is consumed, the human body produces biologically active substances that promote the activation of the nervous system. Therefore, the need for tryptophan

¹Yearbook on breeding work in beef cattle breeding on farms of the Russian Federation (2022). Moscow: Publishing House of the FSBSI All-Russian Research Institute of Breeding, 2023, 218 p.

²Shichkin G.I., Tyapugin S.E., Amerhanov Kh.A., Dunin I.M., Myshkina M.S., Gerasimova E.V., Semenova N.V., Tyapugin E.E., Danyuk I.V. The state of beef cattle breeding in the Russian Federation // Yearbook on breeding work in beef cattle breeding on farms of the Russian Federation (2021), Lesnye Polyany, 2022, pp. 3–16.

increases with technological progress, which increases nervous tension in humans, and should be satisfied primarily by consuming the required amount of high-quality beef [28].

The biological value of meat is determined by its content of the essential amino acid tryptophan and the less valuable amino acid hydroxyproline. Their ratio characterizes protein quality. The SFSCA RAS scientists are currently studying the productive potential of Siberian Hereford cattle of various ecogenesis. The development of a new intrabreed type is being carried out through the targeted use of a range of breeding techniques to enhance the breeding and productive qualities of cattle and improve feeding for all age and sex groups. As a result, the vast majority of elite animal herds meet the requirements of the highest grading classes. According to generally accepted methods of research institutions (the All-Russian Research Institute of Animal Husbandry, the All-Russian Research Institute of the Meat Industry, the Siberian Research and Design and Technological Institute of Animal Husbandry (1965, 1968, 1977, 1990)) the meat qualities of young bulls are studied, the removable and pre-slaughter weight, the weight of the hot and chilled carcass, the morphological and varietal composition of the carcass, and its fat content are determined [29].

The “Mogoytuysky” variety of the Kazakh white-headed breed was developed in 2009 for extended grazing in the steppe zone of the Trans-Baikal Territory. The “Bagansky” beef variety of the Simmental cattle was registered in 2013 and is designed for intensive fattening, providing 1,100–1,400 g of growth energy per day, producing lean meat, and is resistant to the extreme conditions of Siberia. A new variety of the Hereford cattle for the arid zone of Siberia, the “Andrianovskiy” variety, was registered in 2014 in Khakassia and is suitable for crossbreeding with the Kazakh white-headed cattle. Hybrid young animals exhibit excellent adaptability, providing 1,200–1,300 g of growth energy per day and producing good-quality beef [30].

The above indicates a high level of breeding work on individual farms in our region, but not across the Siberian Federal District as a whole. However, with the increasing demand for beef, the issue of meat quality is becoming increasingly important. Meat “marbling” is determined by the content of intramuscular fat (IMF – the sum of intracellular, intercellular, and interfibrous fat components) and primarily characterizes its tenderness, flavor, and richness of broth, among other qualities. A correlation between IMF and the traits such as marbling (0.81) and lean meat content (-0.47) has been reported. The heritability coefficient of intramuscular fat content is low (38–55%), so in European beef cattle breeds, coupled with the low variability of this trait, the use of traditional breeding methods does not allow for significant success.

Due to the urgency of improving beef performance in cattle, driven by market demands, the need for genetic selection methods to meet high meat quality standards is emphasized worldwide. There are reports of a high correlation between the degree of “marbling” and the percentage of intramuscular fat (0.70–0.90). In addition to quantity and distribution, the “marbling” assessment includes the pattern of fat inclusions, while intramuscular fat is the amount of integrated fat in the eye of the muscle.

One of the standard indicators studied in specialized beef cattle breeding, characterizing the industry's specificity, is meat productivity. Breeders working with beef cattle breeds have long favored animals with the most pronounced meat qualities. Animals with the most developed muscles, a rounded, barrel-shaped body, and a lower bone content were selected. When assessing meat productivity, slaughter quality is of primary importance. The highest-quality beef, both culinary and nutritional, is obtained primarily from young animals, but its quality largely depends on the intensity of their rearing, taking into account breed characteristics and the specifics of feeding and housing.

In Russia, the pace of development of the beef cattle industry was slow, and only thanks

to massive public investment in the purchase of breeding and commercial young animals from abroad was it possible to produce premium-quality “marbled” beef at a high price, with production located in the western regions of the country. As a result, “marbled” beef is now available not only in Russia's major cities but also in medium-sized towns and villages. Unfortunately, Siberia and the Far East, which occupy 66% of the Russian Federation's total area and boast vast tracts of natural pasture and arable land for feed grain production, could produce elite livestock products (beef, young horse meat, lamb) from local and adapted breeds and types, the semen of which is available at the remaining active breeding farms and pedigree breeding units. There is confidence that such products will be in demand in the international markets of China, India, and several other densely populated countries, offering higher returns than simply trading in mediocre grain.

With fluctuating energy prices, livestock production is facing challenges: butter, meat, milk, and cheese have become unprofitable. For example, the profitability of the beef cattle industry in 2023 was negative across Russia, and at the best farms in Altai, it did not exceed 20%. To address this situation, it is advisable to increase the production of global brands of livestock products in the east of the country.

We were tasked with assessing the quality of beef from regionalized beef breeds, comparing it to the Black-and-White breed, whose numbers reached 1.9 million as of January 1, 2017, and which was the main supplier of beef in the country. Over the following six years, a decline in dairy herd numbers was observed, but the global trend of replacing dairy cattle with beef cattle has not yet been observed in Russia.

We have provided data on the live weight of experimental animals of four breeds at birth, at 9 months of age when they were put into the experiment, and at slaughter at 19 months (see Table 1).

Overall, based on the data in Table 1, live weight by 9 months of age increased significant-

ly only in the Hereford breed, and by 19 months in all experimental groups compared to the control group. Only Black-and-White calves were significantly heavier at birth, as this is typical of Holsteinized dairy cattle breeds. Average daily weight gains by period are presented below (see Table 2).

In general, no significant difference was found in the average daily gains in all periods compared to the 1st experimental group.

CONCLUSION

Having reviewed and analyzed available scientific and technical information both in Russia and abroad, we concluded that the quality characteristics of meat, particularly beef, have not been sufficiently studied, as the fatty acid and mineral composition presumably has a greater impact on taste. In both developed and developing countries, beef cattle genetics and husbandry technologies are constantly being improved, new feeding systems are being introduced, and their duration and variety are being modified, thereby increasing meat production.

All of the above methods for increasing the efficiency of animal reproduction and rearing can improve the quality of the finished product—beef. In our search for a solution to improve meat quality, we selected four cattle breeds. A scientific and farm experiment was conducted to study the growth dynamics of the experimental animals during the final fattening period, the amino acid, chemical, and fatty acid composition of the meat of the breeds studied was analyzed, and an organoleptic evaluation will be conducted.

In recent years, scientific literature has reported that the taste of meat, including beef, is determined by fatty acids. It is hypothesized that the organoleptic properties of the finished product can be altered, either deteriorating or improving, depending on the fatty acid composition. To answer this question, we are conducting extensive and in-depth scientific research in this area.

Табл. 1. Динамика роста живой массы опытных животных
Table 1. Dynamics of live weight growth of experimental animals

Group	Breed	Live weight, kg		
		at birth	9 months	19 months
1st	Black-and-White	37,0 ± 0,5	231,1 ± 7,5	553,0 ± 8,2
2nd	Aberdeen Angus	27,3 ± 0,5	232,6 ± 7,4	628,0 ± 19,4
3rd	Hereford	29,7 ± 0,7	241,7 ± 3,6	640,6 ± 8,0
4th	Kazakh white-headed	27,4 ± 0,5	242,8 ± 4,3	644,0 ± 7,2

Табл. 2. Среднесуточный прирост подопытных животных, г
Table 2. Average daily gain in experimental animals, g

Breed	Average daily increase by periods, g		
	0–9	9–19	0–19
Black-and-White	718,9 ± 8,2	1072,9 ± 13,86	905,1 ± 14,2
Aberdeen Angus	760,6 ± 26,5	1317,8 ± 69,60	1053,8 ± 34,3
Hereford	784,8 ± 12,3	1329,6 ± 28,60	1071,5 ± 14,4
Kazakh white-headed	798,0 ± 15,5	1337,0 ± 25,70	1081,5 ± 12,7

СПИСОК ЛИТЕРАТУРЫ

1. Амерханов Х.А. Роль и место животноводства в обеспечении продовольственной безопасности России // Молочное и мясное скотоводство. 2024. № 4. С. 3–6. DOI: 10.33943/MMS.2024.65.11.001.
2. Дускаев Г.К., Харламов А.В., Левахин Г.И., Ажмулдинов Е.А., Амерханов Х.А., Мирошников С.А., Рысаев А.Ф. Краткий обзор систем производства говядины в России и мире (обзор) // Животноводство и кормопроизводство. 2022. Т. 105. № 3. С. 78–94. DOI: 10.33284/2658-3135-105-3-78.
3. Солошенко В.А., Магер С.Н., Инербаев Б.О. Основные принципы создания модели эффективной отрасли мясного скотоводства на северных территориях РФ // Животноводство и кормопроизводство. 2020. Т. 103. № 3. С. 46–57. DOI: 10.33284/2658-3135-103-3-46.
4. Магер С.Н., Солошенко В.А. Развитие животноводства в Сибири // Сибирский вестник сельскохозяйственной науки. 2024. Т. 54. № 1. С. 12–19. DOI: 10.26898/0370-8799-2024-1-2.
5. Портной А.И., Липский К.А. Проблемы и перспективы производства говядины в специализированном мясном скотоводстве // Актуальные проблемы интенсивного развития животноводства. 2021. № 2. С. 17–23.
6. Дунин И.М., Дунин М.И., Аджибиков В.К. Породная и генетико-селекционная база отечественного животноводства // Зоотехния. 2021. № 1. С. 2–6. DOI: 10.25708/ZT.2020.66.16.001.
7. Дунин И.М., Герасимов А.А., Никитина С.В., Матвеева Е.А. Определение племенной ценности абердин-ангусского скота Российской Федерации по методике Евразийского Экономического Союза // Животноводство и кормопроизводство. 2024. Т. 107. № 3. С. 36–46. DOI: 10.33943/MMS.2020.40.30.001.
8. Шевхужев А.Ф., Погодаев В.А., Ковалева Г.П. Химический состав, физико-химические свойства мышечной и жировой ткани бычков абердин-ангусской породы при разной интенсивности производства говядины // Проблемы развития АПК региона. 2018. № 4 (36). С. 154–160.
9. Шевелёва О.М., Бахарев А.А., Терещенко И.Я. Экстерьерные особенности крупного рогатого скота абердин-ангусской породы в условиях северного Зауралья // Животноводство и кормопроизводство. 2024. Т. 107. № 2. С. 38–48. DOI: 10.33284/2658-3135-106-3-35.
10. Дубовскова М.П. Герефордская порода в России: современное состояние и перспективы

- развития // Молочное и мясное скотоводство. 2019. № 3. С. 23–27.
11. Шевелева О.М., Криницина Т.П. Откормочные и мясные качества бычков герефордской породы разного происхождения // Вестник Курганской ГСХА. 2020. № 4 (36). С. 43–46.
 12. Джуламанов К.М., Дубовскова М.П., Герасимов Н.П., Ворожейкина С.А., Найманов Д.К. Племенная ценность бычков герефордской породы // Известия Оренбургского государственного аграрного университета. 2018. № 6 (74). С. 191–194.
 13. Рагимов Г.И., Телешев В.М. Влияние разного уровня концентратов на конверсию кормов, откормочные и мясные качества бычков-кастратов герефордской породы // Кормление сельскохозяйственных животных и кормопроизводство. 2018. № 2. С. 23–30.
 14. Шевелёва О.М., Криницина Т.П. Экстерьерные особенности и живая масса герефордского скота разного происхождения // Агропродовольственная политика России. 2020. № 3. С. 36–39.
 15. Инербаев Б.О., Храмцова И.А., Инербаева А.Т. Генотипическая и фенотипическая характеристика популяции герефордского скота Западной Сибири // Сибирский вестник сельскохозяйственной науки. 2023. № 3 (53). С. 97–105. DOI: 10.26898/0370-8799-2023-3-11.
 16. Бахтушкина А.И., Подкорытов А.Т. Мясное скотоводство Республики Алтай // Вестник Алтайского государственного аграрного университета. 2019. № 1 (171). С. 92–95.
 17. Джуламанов К.М., Герасимов Н.П., Сурундаева Л.Г., Елемесов Б.К., Явнова М.С. Биохимическая и экологическая оценка качества мяса от чистопородного и помесного молодняка // Вестник Бурятской государственной сельскохозяйственной академии им. В.Р. Филиппова. 2023. № 4 (73). С. 63–71. DOI: 10.34655/bgsha.2023.73.4.008.
 18. Джуламанов К.М., Бактыгалиева А.Т., Колпаков В.И., Джуламанов Е.Б. Качество мяса бычков и кастратов разных генотипов // Вестник Бурятской государственной сельскохозяйственной академии им. В.Р. Филиппова. 2021. № 4 (65). С. 54–60. DOI: 10.34655/bgsha.2021.65.4.008.
 19. Джуламанов К.М., Колпаков В.И., Герасимов Н.П., Бактыгалиева А.Т. Продуктивность и интерьерные особенности молодняка мясного скота разных генотипов в связи с возрастом и сезоном года // Животноводство и кормопроизводство. 2022. Т. 105. № 2. С. 37–48.
 20. Насамбаев Е.Г., Ахметалиева А.Б., Нугманова А.Е., Досжанова А.О., Амерханов Х.А., Дунин И.М., Каюмов Ф.Г. Влияние типов кормления на продуктивные качества животных казахской белоголовой породы // Животноводство и кормопроизводство. 2020. Т. 103. № 4. С. 150–159.
 21. Макаев Ш.А., Ляпин О.А., Тайгузин Р.Ш. Убойные качества и мясная продуктивность бычков различных генотипов казахской белоголовой породы // Известия Оренбургского государственного аграрного университета. 2020. № 2 (82). С. 212–217.
 22. Ковалева Г.П., Бобрышова Г.Т. Казахская белоголовая порода мясного скота на Ставрополье // Сельскохозяйственный журнал. 2020. № 4 (13). С. 36–41. DOI: 10.25930/2687-1254/005.4.13.2020.
 23. Хаинацкий В.Ю., Гонтюров В.А., Джуламанов К.М., Искандерова А.П., Тюлебаев С.Д. Казахская белоголовая – первая отечественная специализированная порода мясного скота // Молочное и мясное скотоводство. 2020. № 2. С. 7–10.
 24. Ковалева Г.П., Лапина М.Н., Сулыга Н.В., Витол В.А. Результаты оценки мясной продуктивности животных казахской белоголовой породы // Сельскохозяйственный журнал. 2023. № 4 (16). С. 118–129. DOI: 10.48612/FARC/2687-1254/012.4.16.2023.
 25. Тищенко П.И., Васильев А.А., Быков Д.В. Влияние различных типов кормления на питательность, аминокислотный и жирнокислотный состав мяса говядины // Зоотехния. 2023. № 12. С. 17–19.
 26. Тищенко П.И., Васильев А.А., Быков Д.В. Жирнокислотный состав говядины и свинины при различных типах откорма животных // Аграрный научный журнал. 2023. № 6. С. 97–101.
 27. Кабанов В.Д., Тищенко П.И., Тимошенко Ю.И., Шевяков А.Н., Хасанова Л.В., Кожаринова Ю.С. Изменение аминокислотного состава говядины при концентратном откорме крупного рогатого скота // Вестник российской сельскохозяйственной науки. 2019. № 3. С. 63–67. DOI: 10.30850/vrsn/2019/3/63-67.
 28. Хакимов И.Н., Власова Н.И., Бухвалова Е.Г., Зайцева Е.С. Мясные качества и морфологический состав туш кроссбредного молодняка мясного скота // Известия Самарской государственной сельскохозяйственной академии. 2023. № 4. С. 126–133. DOI: 10.55170/199732_25_2023_8_4_126.
 29. Бандеев И.В., Шевченко Н.И., Рагимов Г.И. Мясо бычков чёрно-пёстрой породы: морфо-

логический и химический состав // Мясная индустрия. 2020. № 12. С. 28–31.

30. Себежко О.И., Коновалова Т.В., Короткевич О.С., Петухов В.Л., Себежко А.Н., Зайко О.А., Тарасенко Е.И. Межпородные различия показателей холестерина профиля у крупного рогатого скота в Западной Сибири // Вестник НГАУ. 2023. № 2 (67). С. 237–250. DOI: 10.31677/2072-6724-2023-67-2-237-250.

REFERENCES

- Amerkhanov Kh.A. Role and place of animal husbandry in ensuring food security in Russia. *Molochnoe i myasnoe skotovodstvo = Dairy and Beef Cattle Farming*, 2024, no. 4, pp. 3–6. (In Russian). DOI: 10.33943/MMS.2024.65.11.001.
- Duskaev G.K., Kharlamov A.V., Levakhin G.I., Azhmuldinov E.A., Amerkhanov Kh.A., Miroshnikov S.A., Rysaev A.F. Brief overview of beef production systems in Russia and the world. *Zhivotnovodstvo i kormoproizvodstvo = Animal Husbandry and Fodder Production*, 2022, vol. 105, no. 3, pp. 78–94. (In Russian). DOI: 10.33284/2658-3135-105-3-78.
- Soloshenko V.A., Mager S.N., Inerbaev B.O. Basic principles of creating a model of effective beef cattle breeding industry in the northern territories of the Russian Federation. *Zhivotnovodstvo i kormoproizvodstvo = Animal Husbandry and Fodder Production*, 2020, vol. 103, no. 3, pp. 46–57. (In Russian). DOI: 10.33284/2658-3135-103-3-46.
- Mager S.N., Soloshenko V.A. Livestock breeding development in Siberia. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2024, vol. 54, no. 1, pp. 12–19. (In Russian). DOI: 10.26898/0370-8799-2024-1-2.
- Portnoy A.I., Lipsky K.A. Problems and prospects of beef production in specialized beef cattle breeding. *Aktual'nye problemy intensivnogo razvitiya zhivotnovodstva = Current problems of intensive development of animal husbandry*, 2021, no. 2, pp. 17–23. (In Russian).
- Dunin I.M., Dunin M.I., Adjibekov V.K. Breed and genetic breeding base of domestic animal husbandry. *Zootekhnika = Zootechnika*, 2021, no. 1, pp. 2–6. (In Russian). DOI: 10.25708/ZT.2020.66.16.001.
- Dunin I.M., Gerasimov A.A., Nikitina S.V., Matveeva E.A. Estimation of breeding values of Aberdeen-Angus cattle of the Russian Federation according to the methodology of the Eurasian Economic Union. *Zhivotnovodstvo i kormoproizvodstvo = Animal Husbandry and Fodder Production*, 2024, vol. 107, no. 3, pp. 36–46. (In Russian). DOI: 10.33943/MMS.2020.40.30.001.
- Shevkhuzhev A.F., Pogodaev V.A., Kovaleva G.P. Chemical composition, physico-chemical properties of muscle and adipose tissue of Aberdeen-Angus bull calves at different beef production rates. *Problemy razvitiya APK regiona = Problems of development of the agro-industrial complex of the region*, 2018, no. 4 (36), pp. 154–160. (In Russian).
- Sheveleva O.M., Bakharev A.A., Tereshchenko I.Ya. Exterior features of the Angus cattle in the conditions of the northern Trans-Urals. *Zhivotnovodstvo i kormoproizvodstvo = Animal Husbandry and Fodder Production*, 2024, vol. 107, no. 2, pp. 38–48. (In Russian). DOI: 10.33284/2658-3135-106-3-35.
- Dubovskova M.P. The Hereford breed in Russia: current state and development prospects. *Molochnoe i myasnoe skotovodstvo = Dairy and Beef Cattle Farming*, 2019, no. 3, pp. 23–27. (In Russian).
- Sheveleva O.M., Krinitsyna T.P. Fattening and meat qualities of Hereford bull calves of different origin. *Vestnik Kurganskoi GSKhA = Bulletin of the Kurgan State Agricultural Academy*, 2020, no. 4 (36), pp. 43–46. (In Russian).
- Dzhulamanov K.M., Dubovskova M.P., Gerasimov N.P., Vorozheikina S.A., Naimanov D.K. Breeding value of Hereford bulls. *Izvestiya Orenburgskogo gosudarstvennogo agrarnogo universiteta = Izvestia Orenburg State Agrarian University*, 2018, no. 6 (74), pp. 191–194. (In Russian).
- Ragimov G.I., Teleshev V.M. The influence of different levels of concentrates in the feed conversion, fattening and meat traits of steers of Hereford breed. *Kormlenie sel'skokhozyaistvennykh zhivotnykh i kormoproizvodstvo = Feeding of Agricultural Animals and Feed Production*, 2018, no. 2, pp. 23–30. (In Russian).
- Sheveleva O.M., Krinitsyna T.P. Exterior features and live weight of Hereford cattle of different origin. *Agroprodovol'stvennaya politika Rossii = Agro-food policy in Russia*, 2020, no. 3, pp. 36–39. (In Russian).
- Inerbaev B.O., Khrantsova I.A., Inerbaeva A.T. Genotypic and phenotypic characteristics of the Western Siberian Hereford cattle population.

- Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2023, no. 3 (53), pp. 97–105. (In Russian). DOI: 10.26898/0370-8799-2023-3-11.
16. Bakhtushkina A.I., Podkorytov A.T. Beef cattle breeding of the Republic of Altai. *Vestnik Altai-skogo gosudarstvennogo agrarnogo universiteta = Bulletin of Altai State Agricultural University*, 2019, no. 1 (171), pp. 92–95. (In Russian).
 17. Dzhulamanov K.M., Gerasimov N.P., Surundaeva L.G., Yelemesov B.K., Yavnova M.S. Biochemical and ecological evaluation of meat quality from purebred and crossbred young cattle. *Vestnik Buryatskoi gosudarstvennoi sel'skokhozyaistvennoi akademii im. V.R. Filippova = Vestnik of Buryat State Academy of Agriculture named after V. Philippov*, 2023, no. 4 (73), pp. 63–71. (In Russian). DOI: 10.34655/bgsha.2023.73.4.008.
 18. Dzhulamanov K.M., Baktygalieva A.T., Kolkpakov V.I., Dzhulamanov E.B. Meat quality of steers and castrates of different genotypes. *Vestnik Buryatskoi gosudarstvennoi sel'skokhozyaistvennoi akademii im. V.R. Filippova = Vestnik of Buryat State Academy of Agriculture named after V. Philippov*, 2021, no. 4 (65), pp. 54–60. (In Russian). DOI: 10.34655/bgsha.2021.65.4.008.
 19. Dzhulamanov K.M., Kolkpakov V.I., Gerasimov N.P., Baktygalieva A.T. Productivity and interior features of young beef cattle of different genotypes in association with age and season. *Zhivotnovodstvo i kormoproizvodstvo = Animal Husbandry and Fodder Production*, 2022, vol. 105, no. 2, pp. 37–48. (In Russian).
 20. Nasambaev E.G., Akhmetalieva A.B., Nugmanova A.E., Doszhanova A.O., Amerkhanov Kh.A., Dunin I.M., Kayumov F.G. Influence of feeding types on productive qualities of animals of the Kazakh white-headed breed. *Zhivotnovodstvo i kormoproizvodstvo = Animal Husbandry and Fodder Production*, 2020, vol. 103, no. 4, pp. 150–159. (In Russian).
 21. Makaev S.A., Lyapin O.A., Taiguzin R.S. Slaughter qualities and meat productivity of Kazakh white-headed steers of different genotypes. *Izvestiya Orenburgskogo gosudarstvennogo agrarnogo universiteta = Izvestia Orenburg State Agrarian University*, 2020, no. 2 (82), pp. 212–217. (In Russian).
 22. Kovaleva G.P., Bobrysheva G.T., Kazakh white-headed breed of beef cattle in the Stavropol Territory. *Sel'skokhozyaistvennyi zhurnal = Agricultural Journal*, 2020, no. 4 (13), pp. 36–41. (In Russian). DOI: 10.25930/2687-1254/005.4.13.2020.
 23. Khainatsky V.Yu., Gontyurev V.A., Dzhulamanov K.M., Iskanderova A.P., Tyulebaev S.D. The Kazakh white-headed breed - the first domestic specialized breed of beef cattle. *Molochnoe i myasnoe skotovodstvo = Dairy and Beef Cattle Farming*, 2020, no. 2, pp. 7–10. (In Russian).
 24. Kovaleva G.P., Lapina M.N., Sulyga N.V., Vitol V.A. Results of beef productivity assessment of the Kazakh white-headed animals. *Sel'skokhozyaistvennyi zhurnal = Agricultural Journal*, 2023, no. 4 (16), pp. 118–129. (In Russian). DOI: 10.48612/FARC/2687-1254/012.4.16.2023.
 25. Tishenkov P.I., Vasiliev A.A., Bykov D.V. Influence of different types of feeding on nutrition, amino acid and fatty acid composition of beef meat. *Zootekhnika = Zootechniya*, 2023, no. 12, pp. 17–19. (In Russian).
 26. Tishenkov P.I., Vasiliev A.A., Bykov D.V. Fatty acid composition of beef and pork with different types of animal fattening. *Agrarnyi nauchnyi zhurnal = Agrarian Scientific Journal*. 2023, no. 6, pp. 97–101. (In Russian).
 27. Kabanov V.D., Tishenkov P.I., Timoshenko Yu.I., Shevyakov A.N., Khasanova L.V., Kozharinova Yu.S. Change in the amino acid composition of beef with concentrated fattening of cattle. *Vestnik rossiiskoi sel'skokhozyaistvennoi nauki = Vestnik of the Russian Agricultural Science*, 2019, no. 3, pp. 63–37. (In Russian). DOI: 10.30850/vrsn/2019/3/63-67.
 28. Khakimov I.N., Vlasova N.I., Bukhvalova E.G., Zaitseva E.S. Meat qualities and morphological composition of carcasses of crossbred young beef cattle. *Izvestiya Samarskoi gosudarstvennoi sel'skokhozyaistvennoi akademii = Bulletin Samara State Agricultural Academy*, 2023, no. 4, pp. 126–133. (In Russian). DOI: 10.55170/19973_225_2023_8_4_126.
 29. Bandedev I.V., Shevchenko N.I., Ragimov G.I. Meat of Black-and-White young bulls: morphological and chemical composition. *Myasnaya industriya = Meat industry*, 2020, no. 12, pp. 28–31.
 30. Sebezshko O.I., Konovalova T.V., Korotkevich O.S., Petukhov V.L., Sebezshko A.N., Zaiko O.A., Tarasenko E.I. Interbreed differences in the cholesterol profile in cattle in Western Siberia. *Vestnik NGAU = Bulletin of NSAU*, 2023, no. 2 (67), pp. 237–250. (In Russian). DOI: 10.31677/2072-6724-2023-67-2-237-250.

ИНФОРМАЦИЯ ОБ АВТОРАХ

Солошенко В.А., руководитель научного направления, академик РАН, доктор сельскохозяйственных наук; SPIN-код: 8842-5580

Бабakov В.Ю., младший научный сотрудник, аспирант

Храмцова И.А., ведущий научный сотрудник, кандидат сельскохозяйственных наук; SPIN-код: 8172-3513

✉ **Инербаева А.Т.**, ведущий научный сотрудник, кандидат технических наук; SPIN-код: 5488-7062; **адрес для переписки:** Россия, 630501, Новосибирская область, р.п. Краснообск, а/я 463; e-mail: atinerbaeva@yandex.ru

Бейфорт П.Я., директор

Плешаков В.А., вр. и. о. ректора, кандидат сельскохозяйственных наук; SPIN-код: 9957-7092

Адушинов Д.С., профессор кафедры, доктор сельскохозяйственных наук; SPIN-код: 3740-6450

Третьяков А.М. директор НИИ ветеринарии Восточной Сибири СФНЦА РАН, доктор ветеринарных наук, SPIN-код: 1647-5649

AUTHOR INFORMATION

Vladimir A. Soloshenko, Head of Research Group, Academician RAS, Doctor of Science in Agriculture; SPIN-code: 8842-5580

Vyacheslav Yu. Babakov, Junior Researcher, Post-graduate Student

Irina A. Khramtsova, Lead Researcher, Candidate of Science in Agriculture; SPIN-code: 8172-3513

✉ **Aigul T. Inerbaeva**, Lead Researcher, Candidate of Science in Engineering; SPIN-code: 5488-7062; **address:** PO Box 463, Krasnoobsk, Novosibirsk Region, 630501, Russia; e-mail: atinerbaeva@yandex.ru

Pavel Ya. Beifort, Director

Vladimir A. Pleshakov, Acting Rector, Candidate of Science in Agriculture; SPIN-code: 9957-7092

Dmitry S. Adushinov, Chair Professor, Doctor of Science in Agriculture; SPIN-code: 3740-6450

Alexei M. Tretyakov, Director of the Research Institute of Veterinary Science of Eastern Siberia SFSCA RAS, Doctor of Science in Veterinary Medicine; SPIN-code: 1647-5649

Дата поступления статьи / Received by the editors 28.03.2025

Дата принятия к публикации / Accepted for publication 24.04.2025

Дата публикации / Published 16.06.2025

Влияние растительных лактонов и флавоноидов на структуру микрофлоры кишечника и концентрацию жирных кислот у крупного рогатого скота

Рязанов В.А., Дускаев Г.К., (✉)Курилкина М.Я., Муслюмова Д.М.

Федеральный научный центр биологических систем и агротехнологий

Российской академии наук

Оренбург, Россия

(✉)e-mail: K_marina4@mail.ru

Проведена оценка воздействия растительной композиции полыни горькой (*Artemisia absinthium*) отдельно и в сочетании с хлоридом кобальта (II) в хелатной форме (CoCl_2I) на изменение таксономического профиля микробиома рубца жвачных в эксперименте *in vivo*. В исследованиях определяли изменение бактериального состава рубцовой жидкости путем применения метода секвенирования на приборе MiSeq. Объект исследований – бычки ($n = 4$) казахской белоголовой породы в возрасте 12–13 мес со средней живой массой 336–340 кг. Во время исследования животным опытных групп задавали *A. absinthium herbal* и хлорид кобальта (II) (CoCl_2I): 1-й опытной группе – *A. absinthium* в дозе 2,0 г/кг сухого вещества, 2-й опытной – *A. absinthium* в дозе 2,0 г/кг СВ с дополнительным CoCl_2I (1,5 мг/кг/СВ), 3-й опытной – только CoCl_2I (1,5 мг/кг/СВ). Подготовительный период составлял 14 дней, основной – 7 дней. По истечении основного периода для анализа концентраций жирных кислот производили отбор проб содержимого рубца через фистулу. Образцы кишечного содержимого отбирали в стерильные контейнеры методом ректальной пальпации, для метагеномного секвенирования – в микропробирки типа «Eppendorf» объемом 1,5 мл. Анализ данных показал, что введение *A. absinthium* и хлорида кобальта (II) в форме, наиболее близкой к природной, способно модулировать микробное сообщество кишечника, влияя на концентрацию и усвоение жирных кислот. Полученные результаты указывают на перспективность применения в кормлении крупного рогатого скота композиции *A. absinthium* и CoCl_2I с целью естественной альтернативы улучшения систем производства жвачных животных.

Ключевые слова: крупный рогатый скот, флавоноиды, лактоны, рубец, микробиом, переваримость, жирные кислоты

Effect of plant lactones and flavonoids on intestinal microflora structure and fatty acid concentration in cattle

Ryazanov V.A., Duskaev G.K., (✉)Kurilkina M.Ya., Muslyumova D.M.

Federal Research Center of Biological Systems and Agrotechnologies
of the Russian Academy of Sciences

Orenburg, Russia

(✉)e-mail: K_marina4@mail.ru

The effect of plant composition of common wormwood (*Artemisia absinthium*) alone and in combination with cobalt (II) chloride in chelate form (CoCl_2I) on the changes in the taxonomic profile of rumen microbiome of ruminants in the *in vivo* experiment was evaluated. The studies determined the changes in the bacterial composition of rumen fluid by using the sequencing method on the MiSeq device. The object of the research were young bulls ($n=4$) of the Kazakh White-headed breed at the age of 12–13 months with an average live weight of 336–340 kg. During the study, animals in the experimental groups were given *Artemisia absinthium herbal* (*A. absinthium*) and cobalt (II) chloride (CoCl_2I): experimental group I – *A. absinthium* at a dose of 2.0 g/kg dry matter, experimental group II – *A. absinthium* in dose of 2.0 g/kg DM with additional CoCl_2I (1.5 mg/kg/DM), experimental group III – only CoCl_2I (1.5 mg/kg/DM). The preparatory period lasted for 14 days; the main period was 7 days. At the end of the baseline period, rumen contents were sampled through a fistula to analyze fatty acid concentrations. Samples of intestinal contents were taken into sterile containers by rectal palpation, and for metagenomic sequencing – into 1.5 ml Eppendorf microtubes. Data analysis showed

that administration of *A. absinthium* and cobalt (II) chloride in the form closest to the natural one was able to modulate the intestinal microbial community, affecting the concentration and assimilation of fatty acids. The results obtained indicate the potential of using *A. absinthium* and (CoCl₂) compositions in cattle nutrition as a natural alternative to improve ruminant production systems.

Keywords: cattle, flavonoids, lactones, rumen, microbiome, digestibility, fatty acids

Для цитирования: Рязанов В.А., Дускаев Г.К., Курилкина М.Я., Муслимова Д.М. Влияние растительных лактонов и флавоноидов на структуру микрофлоры кишечника и концентрацию жирных кислот у крупного рогатого скота // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 5. С. 83–98. <https://doi.org/10.26898/0370-8799-2025-5-8>

For citation: Ryazanov V.A., Duskaev G.K., Kurilkina M.Ya., Muslyumova D.M. Effect of plant lactones and flavonoids on intestinal microflora structure and fatty acid concentration in cattle. *Sibirskii vestnik sel'skhozyastvennoi nauki = Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 5. pp. 83–98. <https://doi.org/10.26898/0370-8799-2025-5-8>

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

Благодарность

Работа выполнена при финансовой поддержке Российского научного фонда (проект № 21-76-10014).

Acknowledgments

This work was carried out with financial support from the Russian Science Foundation (project No. 21-76-10014).

INTRODUCTION

Following the ban on antibiotics as growth promoting feed additives, plant extracts and secondary plant metabolites have been considered as alternatives to rumen fermentation management to improve animal productivity and reduce environmental impacts. Among the secondary plant metabolites, polyphenolic compounds such as tannins and flavonoids have recently attracted interest due to their broad spectrum of biological activities [1, 2]. The influence of flavonoids on rumen fermentation has not been evaluated in detail [3]. In addition, of their great diversity in structure (more than 9,000 different compounds have been identified), only a small number of flavonoid-rich plant extracts or pure compounds have been tested so far [4]. Some flavonoids or derivatives formed as a result of microbial degradation in the rumen affect its microbial activity, causing a decrease in intestinal methane production [5–7]. Flavonoids have also been shown to be effective in mitigating the effects of excessive grain feeding on rumen hydrogen ion concentrations [8, 9].

The use of plant materials containing high levels of secondary metabolites may serve as an alternative to improve animal productivity without compromising food security. The develop-

ment and testing of feed additives in combination with essential microelements in a form closest to natural, associated with amino acids and peptides, is considered an excellent alternative drug system for the treatment of animals due to the increase in therapeutic effect.

This study tested the effect of the medicinal plant *A. absinthium* on the bacterial community structure and fatty acid concentrations of intestinal and rumen contents in an *in vivo* experiment. The main active substances responsible for the biological activity in this plant are essential oil, bitter sesquiterpenoid lactones, flavonoids, other bitter compounds, azulenes, phenolic acids, tannins and lignans. The testing was carried out alone and in combination with cobalt (II) chloride in the chelated form (CoCl₂) closest to the natural one, bound to amino acids and peptides. This will allow to expand the knowledge on the possibility of using this drug as a natural alternative for improving ruminant production systems [10–12].

The purpose of the study is to study the effect of additional introduction of wormwood and CoCl₂ into the diet of cattle on the bacterial structure of the intestine, the concentration of fatty acids in the rumen and intestinal contents and their digestibility by the body of young cattle.

MATERIAL AND METHODS

The study was conducted in 2023 under the conditions of the Federal Research Center of Biological Systems and Agrotechnologies of the Russian Academy of Sciences named after Professor S.G. Leushin on the basis of the Department of Feeding Agricultural Animals and Feed Technology. The object of the study was 12–13-month-old Kazakh White-Headed bulls ($n = 4$) with an average live weight of 336–340 kg. During the study, the animals of the experimental groups were given *Artemisia absinthium herbal* (*A. absinthium*) (JSC Krasnogorskleksredstva, Krasnogorsk) and cobalt (II) chloride in chelated form ($\text{CoCl}_2 \cdot l$) (OOO SIC Askont+, Moscow). The animals were implanted with rumen fistulas (ANKOM Technology, $d = 80$ mm) using the method of A.A. Aliyev. All efforts were made to minimize harm to them. The experiment was conducted in four surfaces using a 4×4 Latin square. The animals' diet consisted of 80% roughage (legume hay – 33%, mixed grass hay – 47), forage grain (crushed barley – 19%), commercial premix used for fattening beef cattle (Ca – 18.0%, Mg – 23.5%, vitamins: A – 0.4 mg, D3 – 5.0, E – 3.4 mg, as well as vitamin B complex and microelements). Animals had free access to water. The difference was that animals of the 1st experimental group were additionally given *A. absinthium* at a dose of 2.0 g/kg dry matter (DM), animals of the 2nd experimental group were given *A. absinthium* at a dose of 2.0 g/kg DM with additional $\text{CoCl}_2 \cdot l$ (1.5 mg/kg DM), and animals of the 3rd experimental group were given only $\text{CoCl}_2 \cdot l$ (1.5 mg/kg DM).

Average daily consumption of nutrients in the diet of bulls based on requirements per 100 kg of live weight with a weight gain of 850 g/day, g: dry matter – 2920.0 ± 110.0 , crude protein – 510.9 ± 52.3 , crude fiber – 2100.0 ± 142.0 , crude fat – 241.4 ± 15.0 , organic matter – 2730.0 ± 95.0 , nitrogen-free extractive substances – 1570.0 ± 87.0 , crude ash – 112.6 ± 22.0 .

The preparatory period lasted 14 days, the main period – 7 days. After the main period, samples of the rumen contents were collected through the fistula for analysis of fatty acid

concentrations. Samples of intestinal contents were collected in sterile containers by rectal palpation. For metagenomic sequencing, samples of intestinal contents were collected in 1.5 ml Eppendorf microtubes containing DNA/RNA Shield preservative (Zymo Research, USA), placed in a thermal container and delivered to the laboratory.

Fatty acids determination method

The fat from the samples was obtained in a SER 148 extractor using a solvent (petroleum ether, volume 50 ml) with the following program parameters: temperature 120 °C, immersion 20 min, irrigation – 25, drying 20 min. After finishing the work, the extractor was cooled to 100 °C, glass cups were placed in a drying cabinet for 1 hour at a temperature of 105 °C. After the time had elapsed, the cups were transferred to a desiccator until completely cooled, then weighed (drying was carried out to a constant weight so that the difference between the previous weighing did not exceed 0.001 g).

2 ml of hexane and 0.1 ml of sodium methylate were added to a 0.1 g sample of fat, left for 5 min, then filtered and 0.1 μl of the hexane layer containing fatty acid methyl esters was collected for analysis. The resulting methyl esters were analyzed on a gas chromatograph with FID and a ZB-WAX capillary column $60 \text{ m} \times 0.32 \text{ mm} \times 0.5 \mu\text{m}$. The sample was analyzed for 50 min at a temperature of 80 to 220 °C. The evaporator temperature was 250 °C, the detector temperature – 260 °C, the carrier gas flow rate (nitrogen) – 25 ml/min, hydrogen – 25, air – 250 ml/min, the flow split was 1/40. The fatty acid separation was identified by comparison with a fatty acid mixture from Supelco TM Component FAME Mix. The equipment used: CE 224-C electronic scales, Agilent 7900 ICP-MS inductively coupled plasma mass spectrometer, Chromatec-Crystal 5000.2 gas chromatograph, VM153 laboratory scales.

DNA library preparation and high-throughput sequencing

Total DNA was isolated from intestinal content samples using the FastDNA® SPIN Kit for Faeces (MP Biomedicals Inc., Solon, OH, USA)

using the Lysing Matrix E. The samples were homogenized using a TissueLyser LT (Qiagen, Venlo, Netherlands). The homogenization time was increased to 5 min compared to the manufacturer's protocol. The quality of the isolated DNA was checked by horizontal electrophoresis in 1% agarose gel and spectrophotometrically using a Nanodrop 8000 (Thermo Fisher Scientific, Waltham, MA, USA). DNA concentration was measured using a Qubit 4 Fluorometer (Life Technologies, Carlsbad, CA, USA) using the dsDNA High Sensitivity Assay Kit.

DNA libraries were prepared according to the Illumina protocol (Part #15044223, Rev. B). Amplicons of the V3-4 region of the 16S SSU rRNA gene were obtained using primers S-D-Bact-0341-b-S-17 and S-D-Bact-0785-a-A-21¹. The reaction mixture (25 µL) contained 10 ng of template; forward and reverse primers, 0.2 µM each; 80 µM dNTPs; 0.2 units of Q5 High-Fidelity DNA polymerase activity (New England Biolabs, Ipswich, MA, USA). DNA libraries were purified by solid-phase immobilization on paramagnetic particles using Agencourt AMPure XP beads (Beckman Coulter, Brea, CA, USA). The quality of the libraries was checked by capillary electrophoresis on a Qiaxcel Advanced System (Qiagen, Hilden, Germany) using a QIAxcel DNA Screening Kit cartridge. Paired-end sequencing of amplicon DNA libraries was performed on the Illumina MiSeq platform using the MiSeq Reagent Kit v.3 (600-cycle) (Illumina, San Diego, CA, USA).

DNA extraction, preparation of DNA libraries, sequencing and bioinformatics processing were performed at the Center for Collective Use "Persistence of Microorganisms" of the Institute for Cellular and Intracellular Symbiosis of the Ural Branch of the Russian Academy of Sciences (Orenburg, Russia).

Bioinformatic processing of the sequencing data

The quality of the original reads was checked using the FastQC (V. 0.11.9)² program. Adapters were trimmed using the cutadapt 1.9.1³ program. After removing the adapters, the reads were re-processed using the FastQC (V. 0.11.9) program to determine the parameters for subsequent processing. All subsequent processing steps were performed by the USEARCH V. 11.0.667 program using the UPARSE algorithm (Edgar, 2013). Merging of left and right reads was performed using the `-fastq_mergepairs` command. The following parameters were used for this: `-fastq_maxdiffs 10`, `-fastq_pctid 80`. Filtering was performed using the `-fastq_filter` command with the parameters `-fastq_maxee 1.0` (the maximum expected reading error does not exceed 1 in 100 nucleotides), `-fastq_minlen 400` (the minimum sequence length is 400 bp). The filtered reads were dereplicated using the `-fastx_uniques` command to determine the unique sequences and their number. Clustering and removal of chimeric sequences according to the UPARSE algorithm were performed using the `-cluster_otus` command, operational taxonomic units (OTUs) were obtained at a similarity level of 97%. To determine the representation of certain OTUs in the samples, a global alignment was performed using the `-usearch_global` command. The taxonomic identification of the obtained OTUs was determined using the RDP database (release 11.6) (Kerkhof et al. 2022). For OTUs with low support, identification according to the specified database was performed in the NCBI database using the BLAST⁴ program. Singletons and doubletons (sequences occurring once or twice) were removed from further analysis.

¹Klindworth A., Pruesse E., Schweer T., Peplies J., Quast C., Horn M., Glockner F.O. Evaluation of general 16S ribosomal RNA gene PCR primers for classical and next-generation sequencing-based diversity studies // *Nucleic Acids Res.*, 2013, vol. 41, N 1, p. e1. DOI: 10.1093/nar/gks808.

²<https://www.bioinformatics.babraham.ac.uk/projects/fastqc/>

³Martin M. Cutadapt removes adapter sequences from high-throughput sequencing reads // *EMBnet.journal*, 2011, vol. 17, N 1, pp. 10–12. DOI: 10.14806/ej.17.1.200.

⁴<https://blast.ncbi.nlm.nih.gov/Blast.cgi>

Statistical analysis

The sequencing results were processed using the Microsoft Excel 16 data analysis package and Microsoft Office software (USA). Numerical data were processed using the SPSS Statistics 20 program (IBM, USA). The mean (M), standard deviations ($\pm\sigma$), and standard deviation errors ($\pm SE$) were calculated. A nonparametric analysis method was used to compare the variants. Differences were considered statistically significant at $p \leq 0.05$; 0.01; 0.001. Recommendations were used [13] for calculating the main Shannon (H), Simpson (D) biodiversity indices, the Pielou evenness index (E) in the PAST 4.03 program, and the community and distance indices using the PRIMER 6 software. The graphic material was built on the RAWGraphs 2.0 open-source data visualization platform⁵.

RESULTS AND DISCUSSION

Results of calculations of α -biodiversity indices for the intestinal microbiome

Based on the results of next-generation sequencing (NGS) of the intestinal contents of the experimental animals, the indices of α -diversity were calculated. Comparing the Shannon index

and the Simpson index by groups, it was found that their values changed depending on the feed additive used. During the calculations, large values were obtained for the number of species in the experimental groups. Reliable differences were found for the 1st experimental group in relation to the control. The Shannon biodiversity index was 16.7% higher than in the control group, the Student's criterion was $t = 3.8$ at a significance level of $p = 0.00015$, which indicates a difference in the indices of these groups. A similar picture was for the Simpson index (direct) between the control and the 1st experimental group: the Student's criterion was $t = -3.7$ at the significance level of $p = 0.00016$, which also indicates a high statistical difference between the indices. A reliable significance of differences in the Shannon and Simpson biodiversity indices was established in the 3rd experimental group in relation to the control. The Shannon biodiversity index was higher by 0.5%, the Student's criterion was $t = 4.9$ at the significance level of $p = 8.2052E-07$, the Simpson biodiversity index was lower by 6.7%, the Student's criterion $t = -4.9$ at the significance level of $p = 6.9029E-07$. A greater diversity of the intestinal bacterial community was noted in the 1st–3rd experimen-

Индексы α -биоразнообразия бактериального сообщества кишечника крупного рогатого скота под влиянием кормовых веществ ($n = 4$), $M \pm SE$
Indices of α -biodiversity of bacterial community of bovine intestine under the influence of feed substances ($n = 4$), $M \pm SE$

Biodiversity Index	Group			
	control	experimental		
		1st	2nd	3rd
Number of species	465 ± 59,8	550,1 ± 82,7*	471,3 ± 64,2	509,4 ± 29,9
Individual microorganisms	10326,0 ± 2504,6	14273,3 ± 4454,9*	10912 ± 2851,5	13955,6 ± 1465,7
Index:				
Simpson (D)	0,015 ± 0,002	0,018 ± 0,001***	0,020 ± 0,004*	0,014 ± 0,001***
Shannon (H)	5,21 ± 0,077	5,28 ± 0,094***	5,09 ± 0,149	5,24 ± 0,056***
Pielou (E)	0,399 ± 0,029	0,363 ± 0,031	0,349 ± 0,013	0,371 ± 0,011
Chao-1	469,5 ± 60,5	554,9 ± 82,9**	476,0 ± 64,5*	513,8 ± 30,4*

Note. * $p \leq 0,05$; ** $p \leq 0,01$; *** $p \leq 0,001$ when compared with the control group; 1st experimental group – A. absinthil; 2nd experimental – A. absinthil + $CoCl_2$; 3rd experimental – $CoCl_2$ (cobalt chloride II).

⁵Mauri M., Elli T., Caviglia G., Uboldi G., Azzi M. RAWGraphs: A Visualisation Platform to Create Open Outputs // In: Proceedings of the 12th Biannual Conference on Italian SIGCHI Chapter, 2017, N 28, pp. 1–5. DOI: 10.1145/3125571.3125585.

tal groups. The Chao-1 index had values higher than in the control by 15.3% ($p \leq 0.01$), 1.4 ($p \leq 0.01$) and 8.7% ($p \leq 0.05$), respectively (see the table).

Taxonomic structure of the bacterial community of the intestine of animals when taking feed additives

After metagenomic sequencing of the 16s rRNA gene of intestinal content samples, 148,401 sequences were obtained. These sequences were grouped into 5991 OTUs with 97% clustering. Metagenomic analysis of intestinal content in experimental groups 1 and 2 using *A. absinthium* revealed a decrease in the proportion of *Akkermansia* bacteria by 61.7 and 63.0% relative to the control group. In experimental group 3 using only CoCl_2l , on the contrary, the proportion of *Akkermansia* increased by 40.0% relative to the control group. The use of only *A. absinthium* in experimental group 1 resulted in a decrease in the abundance of *Clostridium* XIVa bacteria by 43.3%.

The use of the combination (*A. absinthium* + CoCl_2l) in the 2nd experimental group and only CoCl_2l in the 3rd led to an increase in the proportion of bacteria of the genus unclassified *Bacteroidales* by (7.2–8.3%) and the genus unclassified *Lachnospiraceae* by (15.1–26.9%) (see Fig. 1).

The most similar in structure were the bacterial communities in the 1st and 2nd experimental groups, in which *A. absinthium* was used separately and in combination with CoCl_2l (see Fig. 2). In these groups, the bacteria present in a greater proportion were those involved in the fermentation and fixation of complex organic substances containing nitrogen, as well as those producing short-chain fatty acids, including acetate and propionate, which ferment complex carbohydrates and disaccharides to the final product – acetate. In the 3rd experimental group, when only CoCl_2l was added to the animals' diet, the proportion of bacteria capable of effectively destroying the cell wall of plants increased. Also, the proportion of bacteria capable of improving the intestinal mucosa increased in the intestinal

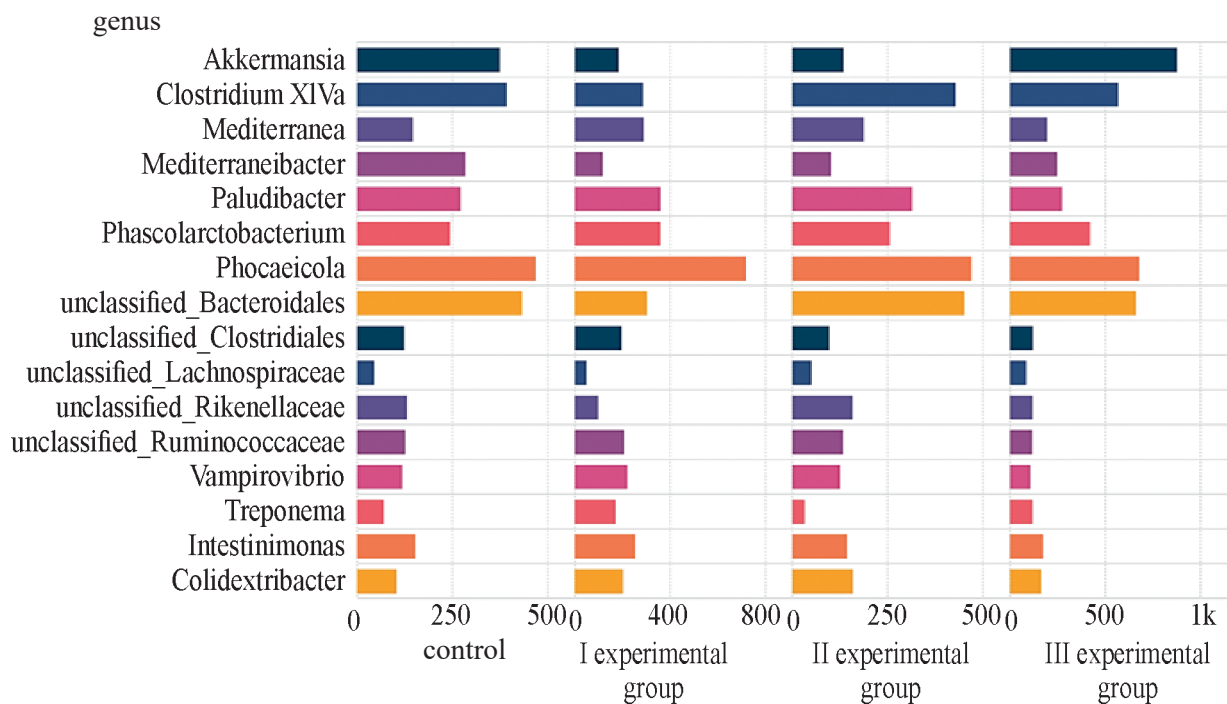


Рис. 1. Таксономическое обилие наиболее изменяемых родов ($\geq 5\%$) бактерий кишечного содержания при использовании кормовых добавок. Нижняя ось – доля определенных OTU

Fig. 1. Taxonomic abundance of the most variable genera ($\geq 5\%$) of bacteria in the intestinal contents when using feed additives. The lower axis represents the proportion of identified OTUs

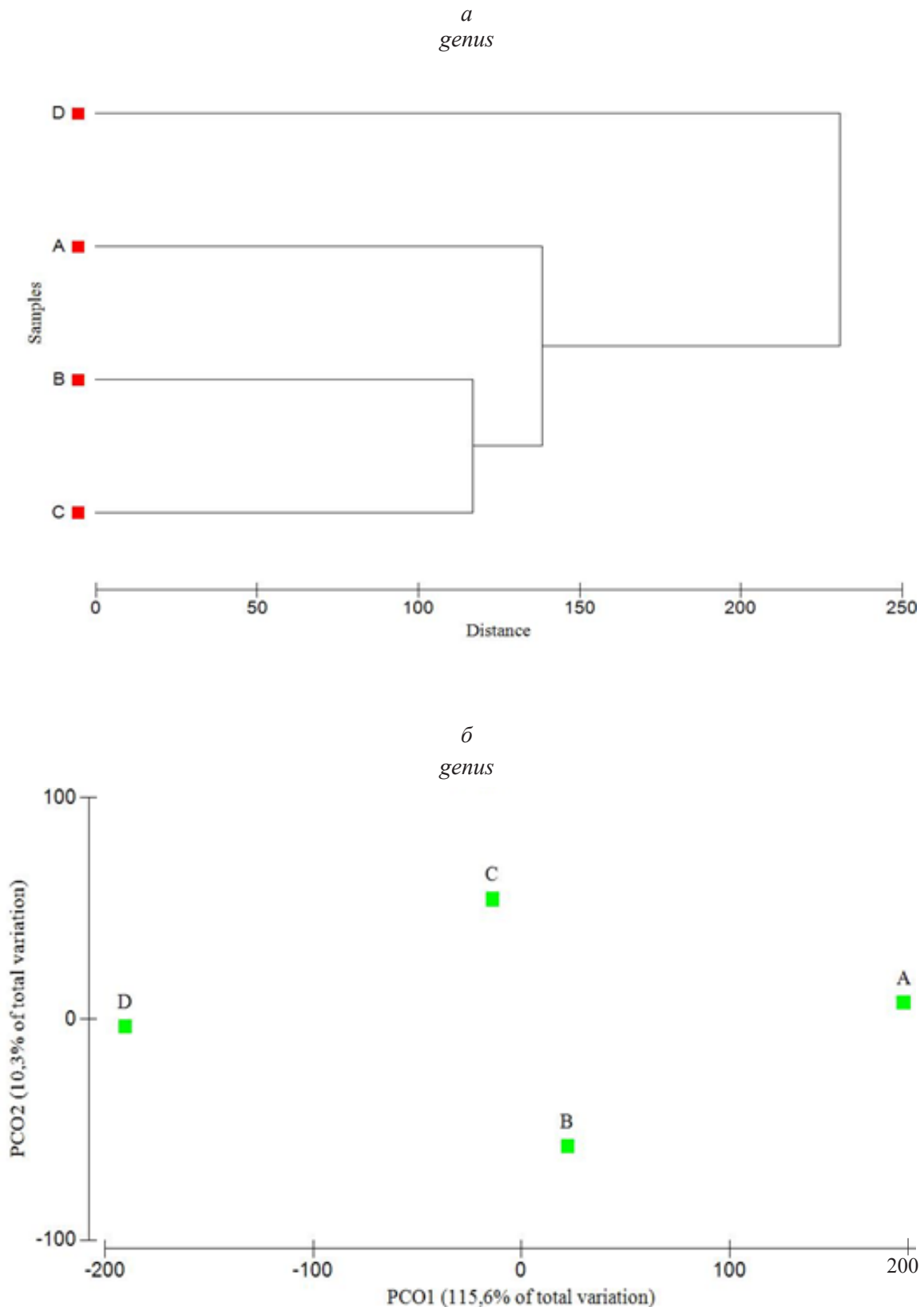


Рис. 2. Анализ бактериального сообщества кишечника: *a* – иерархический кластерный анализ схожести бактериальных сообществ на уровне рода кишечного содержимого по группам; *b* – анализ PCoA β -разнообразия по индексу Брея-Кертиса; А – контрольная группа; В – 1-я опытная; С – 2-я опытная; D – 3-я опытная

Fig. 2. Intestinal bacterial community analysis: *a* – hierarchical cluster analysis of the similarity of bacterial communities at the genus level of intestinal contents by groups, *b* – PCoA analysis of beta diversity using the Bray-Curtis index, А – control group, В – experimental group I, С – experimental group II, D – experimental group III

contents. In the same group, the proportion of bacteria capable of producing free hydrogen also decreased (see Fig. 2).

*Experimental data (metabolome)
of liquid chromatography: fatty acid
composition, composition of liquid and solid
medium of the rumen and intestinal contents*

During the analysis to determine the difference in the concentrations of fatty acids in the rumen chyme and feces in all experimental groups, a characteristic change was found for linoleic and linolenic acids. In feces, there was a tendency for their concentrations to decrease. Also, an increase in the content of palmitoleic and oleic acids in feces was found in all experimental groups, myristic acid was not detected. In the 1st experimental group, an increase in the concentration of palmitoleic and oleic acids in feces by 79.4 and 16.9%, respectively, was reliably established with a simultaneous decrease in the proportion of palmitic, stearic, linoleic, linolenic acids by 0.7; 15.6; 8.5 and 6.3%, respectively. The reliability of these values is confirmed by the Fisher's test ($F = 5.81$ at $p = 0.05$) and the Student's t-test ($t = 2.1$ at $p = 0.05$). In the 2nd experimental group, the content of palmitic, linoleic, linolenic acids in feces decreased by 3.1; 33.0 and 65.5%, respectively ($F = 5.81$ at $p = 0.05$, $t = 2.1$ at $p = 0.05$). The content of stearic, oleic and palmitoleic acids increased significantly by 10.9; 45.5 and 57.6%, respectively. In the 3rd experimental group, a decrease in the content of linoleic and linolenic acids in feces was noted by 12.7 and 55.5%, respectively. In contrast to the 2nd experimental group, an increase in the content of palmitic acid in feces by 5.7% and a decrease in stearic acid by 9.8% were detected ($F = 7.1$ at $p = 0.05$, $t = 2.2$ at $p = 0.05$) (see Fig. 3).

*Results of calculations of the digestibility
of fatty acids in the body of animals*

The conducted studies established that the introduction of the experimental feed additives into the diet significantly affects the bioavailability of fatty acids in the body of experimental animals (see Fig. 4).

Differences in the digestibility of saturated fatty acids in the organism of experimental animals were revealed between the groups. High digestibility of stearic acid (C 18:0) was noted in all experimental groups, while its lowest value was recorded in the control group. Inclusion of *A. absinthium* with additional $\text{CoCl}_2 \cdot 1$ (2nd experimental group) in the diet resulted in a significant (2.1%) increase in the digestibility of palmitic acid (C 16:0). A decrease in its digestibility was noted only in the 3rd experimental group, which received a diet containing $\text{CoCl}_2 \cdot 1$ (1.5 mg/kg DM), by 0.6% relative to the control values. The digestibility of myristic acid (C 14:0) in the organism of experimental animals in animals of all studied groups was 100%.

The compared groups differed in the level of unsaturated fatty acid digestibility. The inclusion of experimental feed additives was accompanied by an increase in the digestibility of palmitoleic acid (C 16: 1) in all experimental groups by 6.4–13.3% relative to the control, with a prevailing value in the 2nd experimental group. Analysis of the digestibility of linoleic (C 18: 2) and linolenic (C 18: 3) fatty acids indicated an increase in the indicators in the 2nd experimental group by 0.9 and 8.9% relative to the control. In the 1st and 3rd experimental groups, a decrease in the digestibility of linoleic acid was noted by 6.8 and 5.5%, respectively, as well as linolenic in the 3rd experimental group by 9.6%. The inclusion of experimental feed additives in the diets contributed to an increase in the absorption of oleic acid (C 18: 1) in the 1st and 3rd experimental groups by 1.2 and 0.8%, respectively, and a decrease of 7.7% in the 2nd experimental group.

The results of the study indicate that the addition of *A. absinthium* with additional $\text{CoCl}_2 \cdot 1$ to the diet of the experimental animals has a more significant effect on the digestibility of SFA and PUFA in the fatty acid pool compared to control values.

Gut microbes play an important role in maintaining host gastrointestinal homeostasis, nutrient digestion and absorption, performance, immune health, and behavior [14]. The rumen is the natural fermenter of ruminants and a unique organ whose main feature is that nutrient ab-

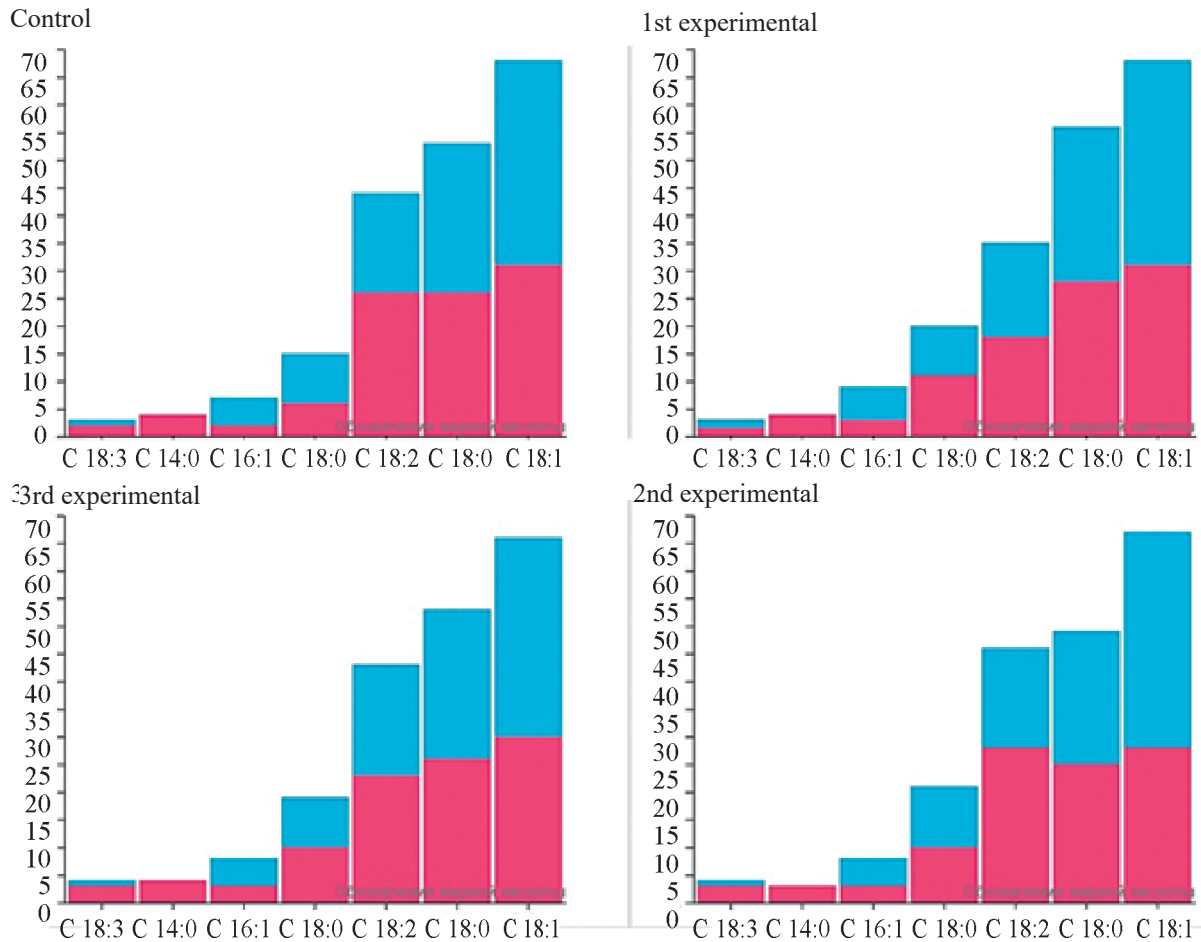


Рис. 3. Массовая доля жирных кислот в рубцовом (красный цвет) и кишечном (голубой) содержимом животных, отображенная в пропорции, %

Fig. 3. Mass fraction of fatty acids in the rumen (red) and intestinal (blue) contents of animals, mapped in proportion, %

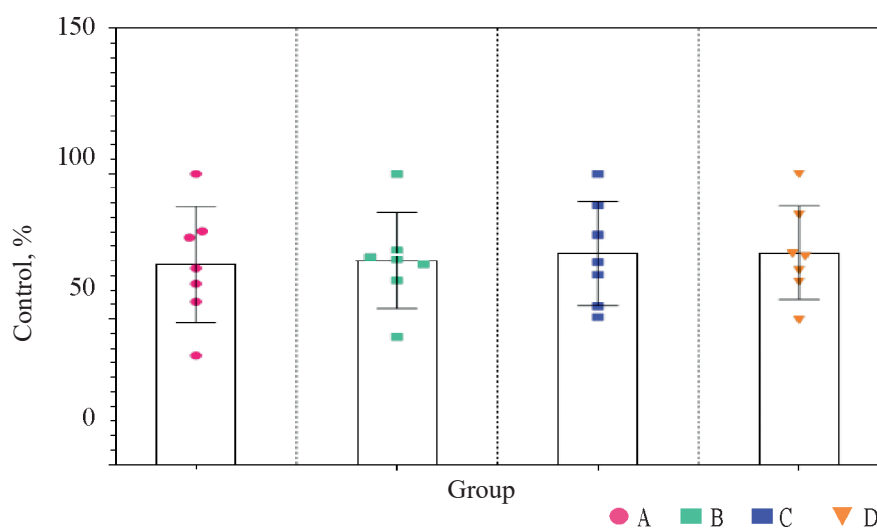


Рис. 4. Усвояемость жирных кислот в организме молодняка крупного рогатого скота при использовании кормовых добавок, %;

A – контрольная группа; B – 1-я опытная; C – 2-я опытная; D – 3-я опытная

Fig. 4. Digestibility of fatty acids in the body of young cattle when using feed additives, %;

A – control group, B – experimental group I, C – experimental group II, D – experimental group III

sorption is achieved through the catabolic effect of rumen microbes. The various components of the cattle diet are primarily digested in the rumen. It contains a variety of microbes that degrade cellulose, hemicellulose, and non-protein nitrogen in the diet to form metabolites such as short chain fatty acids (SCFA), which can be directly utilized by the host [15–17].

The rumen microbial community is complex and consists of bacteria, protozoa, archaea and fungi. The composition and activity of the rumen microbiota have been shown to have profound effects on host performance, health and immune system [18, 19]. An earlier study [20] reported a strong association between rumen amino acid concentrations and bacterial community structure.

Firmicutes and *Bacteroidetes* account for about 90% of the total microflora in the rumen of cattle, with high interindividual variability and an inverse correlation between the abundance of both types [21]. In our experiment, the phyla *Bacteroidetes* and *Firmicutes* were more important in all groups. Their ratio directly depended on the use of the studied additives in the diet. It is known that *Bacteroides* is a gram-negative microorganism. It uses plant glycans as the main energy sources and is considered one of the main bacteria that participate in the production of short-chain fatty acids and participate in the breakdown of complex compounds into simple molecules necessary for the growth and development of animals [22]. The data obtained in our experiment indicate that the diversity of the bacterial composition relative to the control group changed depending on the feed additive used.

Dietary interventions have historically been used to improve ruminant phenotypes due to their impact on the rumen microbiome. As a result, animals fed high grain diets tend to have lower bacterial diversity and lower concentrations of fibrolytic microbes (i.e. protozoa and anaerobic fungi), which is usually associated with lower rumen proteolysis and ultimately higher feed efficiency [23].

Earlier studies have shown that low rumen microbial levels are strongly associated with higher feed efficiency in dairy cows. This may

be because lower rumen saturation in animals results in a simpler metabolic pathway, which results in higher concentrations of certain enzymatic substances that are used to support the animals' energy needs [24].

Nutritional strategies can influence the interactions between microbial groups and, as a consequence, the production and quality of products. This is perhaps best illustrated by the quality of products derived from ruminants in terms of fatty acid profile [25]. Bacteria are known to be largely responsible for the biohydrogenation of fatty acids in the rumen, while protozoa are not thought to be actively involved in this process. However, protozoa influence the composition of the bacterial population in the rumen and thus potentially influence biohydrogenation. In addition, they directly incorporate unsaturated fatty acids, protecting them in the rumen from biohydrogenation and allowing direct passage into milk and meat [26].

Carvacrol in herbs and essential oils has been reported to have a stimulating effect on pancreatic secretion, increasing the secretion of digestive enzymes. Herbs and plant products can control and limit the growth and colonization of numerous pathogenic and non-pathogenic bacterial species in the gut of chickens. This can lead to greater efficiency in the utilization of food, leading to faster growth and improved feed efficiency. There are studies showing that supplementing the diet with essential oils can improve the digestive process [27].

Fatty acids are the most important determinants of the nutritional value of fat [28]. The abundance of several bacteria from the *Firmicutes* and *Spirochaetes* phyla, including cellulolytic bacteria such as *Acetivibrio cellulolyticus*, *Clostridium stercorarium*, and *Clostridium cellulosi*, was found to be negatively associated with the amount of dietary SFA. Only eight bacteria were positively associated with high SFA intake, including proteobacteria and oral and skin bacteria. These findings are consistent with their effect on α -diversity. Bacteria negatively associated with MUFA intake partially overlapped with bacteria associated with SFA intake, but the number of correlations and fold

change differences were smaller. Only two bacterial species were significantly associated with PUFA intake. SFAs were found to have a stronger effect on gut microbiota than MUFAs and PUFAs, and low SFA intake was associated with higher α -diversity of gut microbiota and higher abundance of specialized bacteria capable of breaking down dietary fiber.

Fatty acid absorption is thought to be a key determinant of the effect of the diet on the microbiota in the distal gut. Dietary fatty acid composition has also been found to influence the gut microbiota profile. The interaction between dietary fatty acids and gut microbiota may be used to improve dietary recommendations for metabolic health in animals [29].

In ruminants, dietary fatty acids are hydrogenated by rumen microorganisms [30]. Stearic acid (C 18:0), the end product of this reaction, passes from the rumen to the abomasum, where it is digested and absorbed [31]. Rumen fatty acids are precursors for plasma triglyceride synthesis, which are mainly incorporated into milk and adipose tissue lipids. Due to the hydrogenating activity of bacteria, ruminant plasma triglycerides result in a low PUFA content. In ruminants, to bypass the rumen, PUFA must be protected for further absorption in the duodenum [32, 33].

Summarizing the above, the rumen microbiome plays a central role in addressing significant challenges in animal production. A better understanding of the role of constituent microbes is critical to developing best practices for managing the rumen microbiome in ways that improve ruminant performance while reducing environmental impacts [34].

CONCLUSION

Thus, *A. absinthium* and cobalt (II) chloride in the form closest to the natural one, bound to amino acids and peptides (CoCl_2I), have the ability to modulate the intestinal microbial community, affecting the concentration and absorption of fatty acids. The obtained results indicate the prospects for the use of a composition of *A. absinthium* and (CoCl_2I) in cattle feeding for the purpose of a natural alternative for improving ruminant production systems.

СПИСОК ЛИТЕРАТУРЫ

1. Ramos-Morales E., Tibble-Howlings J., Lyons L., Ogbu M.O., Murphy P.J., Braganca R., Newbold C.J. Slight changes in the chemical structure of haemanthamine greatly influence the effect of the derivatives on rumen fermentation *in vitro* // Scientific Reports. 2019. Vol. 9. N 1. P. 2440. DOI: 10.1038/s41598-019-38977-x.
2. Sarnataro C., Spanghero M., Lavrenčič A. Supplementation of diets with tannins from Chestnut wood or an extract from Stevia rebaudiana Bertoni and effects on *in vitro* rumen fermentation, protozoa count and methane production // Journal of animal physiology and animal nutrition (Berl). 2020. Vol. 104. N 5. P. 1310–1316. DOI: 10.1111/jpn.13414.
3. Ku-Vera J.C., Jiménez-Ocampo R., Valencia-Salazar S.S., Montoya-Flores M.D., Molina-Botero I.C., Arango J., Gómez-Bravo C.A., Aguilar-Pérez C.F., Solorio-Sánchez F.J. Role of Secondary Plant Metabolites on Enteric Methane Mitigation in Ruminants // Frontiers in Veterinary Science. 2020. Vol. 7. P. 584. DOI: 10.3389/fvets.2020.00584.
4. Shen N., Wang T., Gan Q., Liu S., Wang L., Jin B. Plant flavonoids: Classification, distribution, biosynthesis, and antioxidant activity // Food Chemistry. 2022. Vol. 383. P. 132531. DOI: 10.1016/j.foodchem.2022.132531.
5. Albores-Moreno S., Alayón-Gamboa J.A., Miranda-Romero L.A., Alarcón-Zúñiga B., Jiménez-Ferrer G., Ku-Vera J.C., Piñeiro-Vázquez A.T. Effect of tree foliage supplementation of tropical grass diet on *in vitro* digestibility and fermentation, microbial biomass synthesis and enteric methane production in ruminants // Tropical Animal Health and Production. 2019. Vol. 51. N 4. P. 893–904. DOI: 10.1007/s11250-018-1772-7.
6. Yejun L., Su Kyoung L., Shin Ja L., Jong-Su E., Sung Sill L. Effects of Lonicera japonica extract supplementation on *in vitro* ruminal fermentation, methane emission, and microbial population // Journal of Animal Science. 2019. Vol. 90. N 9. P. 1170–1176. DOI: 10.1111/asj.13259.
7. Hassan F.U., Arshad M.A., Li M., Rehman M.S., Loor J.J., Huang J. Potential of Mulberry Leaf Biomass and Its Flavonoids to Improve Production and Health in Ruminants: Mechanistic Insights and Prospects // Animals (Basel). 2020. Vol. 10. N 11. P. 2076. DOI: 10.3390/ani10112076.

8. Li Y., Wang Y., Lv J., Dou X., Zhang Y. Effects of Dietary Supplementation with *Clostridium butyricum* on the Amelioration of Growth Performance, Rumen Fermentation, and Rumen Microbiota of Holstein Heifers // *Frontiers in Nutrition*. 2021. Vol. 11. N 8. P. 763700. DOI: 10.3389/fnut.2021.763700.
9. Castillo-Lopez E., Rivera-Chacon R., Ricci S., Petri R.M., Reisinger N., Zebeli Q. Short-term screening of multiple phytochemical compounds for their potential to modulate chewing behavior, ruminal fermentation profile, and pH in cattle fed grain-rich diets // *Journal of Dairy Science*. 2021. Vol. 104. N 4. P. 4271–4289. DOI: 10.3168/jds.2020-19521.
10. Batiha G.E., Olatunde A., El-Mleeh A., Hetta H.F., Al-Rejaie S., Alghamdi S., Zahoor M., Magdy Beshbishy A., Murata T., Zaragoza-Bastida A., Rivero-Perez N. Bioactive Compounds, Pharmacological Actions, and Pharmacokinetics of Wormwood (*Artemisia absinthium*) // *Antibiotics (Basel)*. 2020. Vol. 9. N 6. P. 353. DOI: 10.3390/antibiotics9060353.
11. Ahamad J., Mir S.R., Amin S. A pharmacognostic review on *Artemisia absinthium* // *International Research Journal of Pharmacy*. 2019. Vol. 10. P. 25–31. DOI: 10.7897/2230-8407.10015.
12. Nazeri M., Mirzaie-Asl A., Saidijam M., Moradi M. Methanolic extract of *Artemisia absinthium* prompts apoptosis, enhancing expression of Bax/Bcl-2 ratio, cell cycle arrest, caspase-3 activation and mitochondrial membrane potential destruction in human colorectal cancer HCT-116 cells // *Molecular Biology Reports*. 2020. Vol. 47. N 11. P. 8831–8840. DOI: 10.1007/s11033-020-05933-2.
13. Liu Y.X., Qin Y., Chen T., Lu M., Qian X., Guo X., Bai Y. A practical guide to amplicon and metagenomic analysis of microbiome data // *Protein Cell*. 2021. Vol. 12. N 5. P. 315–330. DOI: 10.1007/s13238-020-00724-8.
14. Yang J., Yang Y., Ishii M., Nagata M., Aw W., Obana N., Tomita M., Nomura N., Fukuda S. Does the Gut Microbiota Modulate Host Physiology through Polymicrobial Biofilms? // *Microbes Environ*. 2020. Vol. 35. N 3. P. ME20037. DOI: 10.1264/jsme2.ME20037.
15. Duskaev G., Nurzhanov B.S., Rysaev A.F., Rahmatulin Sh.G. Changing of the composition of the rumen microflora to improve the efficiency of feed use by ruminants // *January IOP Conference Series Earth and Environmental Science*. 2021. Vol. 624. N 1. P. 012022. DOI: 10.1088/1755-1315/624/1/012022.
16. Clemmons B.A., Voy B.H., Myer P.R. Altering the Gut Microbiome of Cattle: Considerations of Host-Microbiome Interactions for Persistent Microbiome Manipulation // *Microbial Ecology*. 2019. Vol. 77. N 2. P. 523–536. DOI: 10.1007/s00248-018-1234-9.
17. Morais S., Mizrahi I. The Road Not Taken: The Rumen Microbiome, Functional Groups, and Community States // *Trends in Microbiology*. 2019. Vol. 27. N 6. P. 538–549. DOI: 10.1016/j.tim.2018.12.011.
18. Lilian M., Rawlynce B., Charles G., Felix K. Potential role of rumen bacteria in modulating milk production and composition of admixed dairy cows // *Letters in Applied Microbiology*. 2023. Vol. 76. N 2. P. ovad007. DOI: 10.1093/lambio/ovad007.
19. Newbold C.J., Ramos-Morales E. Review: Ruminant microbiome and microbial metabolome: effects of diet and ruminant host // *Animal*. 2020. Vol. 14. N S1. P. 78–86. DOI: 10.1017/S1751731119003252.
20. Ryazanov V., Tarasova E., Duskaev G., Kolpakov V., Miroshnikov I. Changes in the Concentration of Amino Acids and Bacterial Community in the Rumen When Feeding *Artemisia absinthium* and Cobalt Chloride // *Fermentation*. 2023. Vol. 9. P. 751. DOI: 10.3390/fermentation9080751.
21. Nawab A., Li G., An L., Nawab Y., Zhao Yi., Xiao M., Tang S., Sun C. The potential effect of dietary tannins on enteric methane emission and ruminant production, as an alternative to antibiotic feed additives – a review // *Annals of Animal Science*. 2020. Vol. 20. N 2. P. 355–388. DOI: 10.2478/aoas-2020-0005.
22. Takeshita N., Watanabe T., Ishida-Kuroki K., Sekizaki T. Transition of microbiota in chicken cecal droppings from commercial broiler farms // *BMC Veterinary Research*. 2021. Vol. 17. N 1. P. 10. DOI: 10.1186/s12917-020-02688-7.
23. Kameshwar A.K.S., Ramos L.P., Qin W. Meta-data Analysis Approaches for Understanding and Improving the Functional Involvement of Rumen Microbial Consortium in Digestion and Metabolism of Plant Biomass // *Journal of Genomics*. 2019. Vol. 7. P. 31–45. DOI: 10.7150/jgen.32164.
24. Montano M.F., Carvalho P.H.V., Chirino-Romero J.O., Latack B.C., Salinas-Chavira J., Zinn R.A. Influence of supplemental condensed tannins on initial 112-d feedlot growth-perfor-

- mance and characteristics of digestion of calf-fed Holstein steers // *Translational animal science*. 2022. Vol. 6. N 1. P. txac024. DOI: 10.1093/tas/txac024.
25. Carreño D., Toral P.G., Pinloche E., Belenguer A., Yáñez-Ruiz D.R., Hervás G., McEwan N.R., Newbold C.J., Frutos P. Rumen bacterial community responses to DPA, EPA and DHA in cattle and sheep: a comparative in vitro study // *Scientific Reports*. 2019. Vol. 9. P. 11857. DOI: 10.1038/s41598-019-48294-y.
26. Hackmann T.J., Sen A., Firkins J.L. Culture techniques for ciliate protozoa from the rumen: Recent advances and persistent challenges // *Anaerobe*. 2024. Vol. 87. P. 102865. DOI: 10.1016/j.anaerobe.2024.102865.
27. Nehme R., Andrés S., Pereira R.B., Ben Jemaa M., Bouhallab S., Cecilian F., López S., Rahali F.Z., Ksouri R., Pereira D.M., Abdennebi-Najar L. Essential Oils in Livestock: From Health to Food Quality // *Antioxidants (Basel)*. 2021. Vol. 10. N 2. P. 330. DOI: 10.3390/antiox10020330.
28. Wang L., Zhou J., Gao T., Liang X., Hu Q., Huang B., Lyu Z., Johnston L.J., Lai C. Comparison of regression and fat-free diet methods for estimating ileal and total tract endogenous losses and digestibility of fat and fatty acids in growing pigs // *Journal of Animal Science*. 2020. Vol. 98. N 12. P. skaa376. DOI: 10.1093/jas/skaa376.
29. Schoeler M., Ellero-Simatos S., Birkner T., Mayneris-Perxachs J., Olsson L., Brolin H., Loeber U., Kraft J.D., Polizzi A., Martí-Navas M., Puig J., Moschetta A., Montagner A., Gourdy P., Heymes C., Guillou H., Tremaroli V., Fernández-Real J.M., Forslund S.K., Burcelin R., Caesar R. The interplay between dietary fatty acids and gut microbiota influences host metabolism and hepatic steatosis // *Nature Communications*. 2023. Vol. 14. N 1. P. 5329. DOI: 10.1038/s41467-023-41074-3.
30. Cartoni Mancinelli A., Mattioli S., Twining C., Dal Bosco A., Donoghue A.M., Arsi K., Angelucci E., Chiattelli D., Castellini C. Poultry Meat and Eggs as an Alternative Source of n-3 Long-Chain Polyunsaturated Fatty Acids for Human Nutrition // *Nutrients*. 2022. Vol. 14. N 9. P. 1969. DOI: 10.3390/nu14091969.
31. Ibrahim N.A., Alimon A.R., Yaakub H., Samsudin A.A., Candyrine S.C.L., Wan Mohamed W.N., Md Noh A., Fuat M.A., Mookiah S. Effects of Vegetable Oil Supplementation on Rumen Fermentation and Microbial Population in Ruminant: A Review // *Tropical Animal Health and Production*. 2021. Vol. 53. P. 422. DOI: 10.1007/s11250-021-02863-4.
32. Costa F.S., Cabral A.R., Silva S.L., Silva M.A.I., Henrique W., Mazalli M.R., Baldi F.S., Mueller L.F., Ferrinho A.M., Corte R.R.P.S., Pereira A.S.C. Effects of n-3 and n-6 feeding sources on the quality and lipid oxidation of meat from feedlot-finished *Bos indicus* steers // *Meat Science*. 2020. Vol. 161. P. 107966. DOI: 10.1016/j.meatsci.2019.107966.
33. Pereira G., Simões P., Bexiga R., Silva E., Mateus L., Fernandes T., Alves S.P., Bessa R.J.B., Lopes-da-Costa L. Effects of Feeding Rumen-Protected Linseed Fat to Postpartum Dairy Cows on Plasma n-3 Polyunsaturated Fatty Acid Concentrations and Metabolic and Reproductive Parameters // *Journal of Dairy Science*. 2022. Vol. 105. P. 361–374. DOI: 10.3168/jds.2021-20674.
34. Woodruff K.L., Hummel G.L., Austin K.J., Lake S.L., Cunningham-Hollinger H.C. Calf rumen microbiome from birth to weaning and shared microbial properties to the maternal rumen microbiome // *Journal of Animal Science*. 2022. Vol. 100. N 10. P. skac264. DOI: 10.1093/jas/skac264.

REFERENCES

- Ramos-Morales E., Tibble-Howlings J., Lyons L., Ogbu M.O., Murphy P.J., Braganca R., Newbold C.J. Slight changes in the chemical structure of haemanthamine greatly influence the effect of the derivatives on rumen fermentation in vitro. *Scientific Reports*, 2019, vol. 9, no. 1, p. 2440. DOI: 10.1038/s41598-019-38977-x.
- Sarnataro C., Spanghero M., Lavrenčič A. Supplementation of diets with tannins from Chestnut wood or an extract from *Stevia rebaudiana* Bertoni and effects on in vitro rumen fermentation, protozoa count and methane production. *Journal of animal physiology and animal nutrition (Berl)*, 2020, vol. 104, no. 5, pp. 1310–1316. DOI: 10.1111/jpn.13414.
- Ku-Vera J.C., Jiménez-Ocampo R., Valencia-Salazar S.S., Montoya-Flores M.D., Molina-Botero I.C., Arango J., Gómez-Bravo C.A., Aguilar-Pérez C.F., Solorio-Sánchez F.J. Role of Secondary Plant Metabolites on Enteric Methane Mitigation in Ruminants. *Frontiers in Veterinary Science*, 2020, vol. 7, p. 584. DOI: 10.3389/fvets.2020.00584.

4. Shen N., Wang T., Gan Q., Liu S., Wang L., Jin B. Plant flavonoids: Classification, distribution, biosynthesis, and antioxidant activity. *Food Chemistry*, 2022, vol. 383, p. 132531. DOI: 10.1016/j.foodchem.2022.132531.
5. Albores-Moreno S., Alayón-Gamboa J.A., Miranda-Romero L.A., Alarcón-Zúñiga B., Jiménez-Ferrer G., Ku-Vera J.C., Piñeiro-Vázquez A.T. Effect of tree foliage supplementation of tropical grass diet on in vitro digestibility and fermentation, microbial biomass synthesis and enteric methane production in ruminants. *Tropical Animal Health and Production*, 2019, vol. 51, no. 4, pp. 893–904. DOI: 10.1007/s11250-018-1772-7.
6. Yejun L., Su Kyoung L., Shin Ja L., Jong-Su E., Sung Sill L. Effects of *Lonicera japonica* extract supplementation on in vitro ruminal fermentation, methane emission, and microbial population. *Journal of Animal Science*, 2019, vol. 90, no. 9, pp. 1170–1176. DOI: 10.1111/asj.13259.
7. Hassan F.U., Arshad M.A., Li M., Rehman M.S., Loor J.J., Huang J. Potential of Mulberry Leaf Biomass and Its Flavonoids to Improve Production and Health in Ruminants: Mechanistic Insights and Prospects. *Animals (Basel)*, 2020, vol. 10, no. 11, p. 2076. DOI: 10.3390/ani10112076.
8. Li Y., Wang Y., Lv J., Dou X., Zhang Y. Effects of Dietary Supplementation with *Clostridium butyricum* on the Amelioration of Growth Performance, Rumen Fermentation, and Rumen Microbiota of Holstein Heifers. *Frontiers in Nutrition*, 2021, vol. 11, no. 8, p. 763700. DOI: 10.3389/fnut.2021.763700.
9. Castillo-Lopez E., Rivera-Chacon R., Ricci S., Petri R.M., Reisinger N., Zebeli Q. Short-term screening of multiple phytochemicals for their potential to modulate chewing behavior, ruminal fermentation profile, and pH in cattle fed grain-rich diets. *Journal of Dairy Science*, 2021, vol. 104, no. 4, pp. 4271–4289. DOI: 10.3168/jds.2020-19521.
10. Batiha G.E., Olatunde A., El-Mleeh A., Hetta H.F., Al-Rejaie S., Alghamdi S., Zahoor M., Magdy Beshbishy A., Murata T., Zaragoza-Bastida A., Rivero-Perez N. Bioactive Compounds, Pharmacological Actions, and Pharmacokinetics of Wormwood (*Artemisia absinthium*). *Antibiotics (Basel)*, 2020, vol. 9, no. 6, p. 353. DOI: 10.3390/antibiotics9060353.
11. Ahamad J., Mir S.R., Amin S. A pharmacognostic review on *Artemisia absinthium*. *International Research Journal of Pharmacy*, 2019, vol. 10, pp. 25–31. DOI: 10.7897/2230-8407.10015.
12. Nazeri M., Mirzaie-Asl A., Saidijam M., Moradi M. Methanolic extract of *Artemisia absinthium* prompts apoptosis, enhancing expression of Bax/Bcl-2 ratio, cell cycle arrest, caspase-3 activation and mitochondrial membrane potential destruction in human colorectal cancer HCT-116 cells. *Molecular Biology Reports*, 2020, vol. 47, no. 11, pp. 8831–8840. DOI: 10.1007/s11033-020-05933-2.
13. Liu Y.X., Qin Y., Chen T., Lu M., Qian X., Guo X., Bai Y. A practical guide to amplicon and metagenomic analysis of microbiome data. *Protein Cell*, 2021, vol. 12, no. 5, pp. 315–330. DOI: 10.1007/s13238-020-00724-8.
14. Yang J., Yang Y., Ishii M., Nagata M., Aw W., Obana N., Tomita M., Nomura N., Fukuda S. Does the Gut Microbiota Modulate Host Physiology through Polymicrobial Biofilms? *Microbes Environ*, 2020, vol. 35, no. 3, p. ME20037. DOI: 10.1264/jsme2.ME20037.
15. Duskaev G., Nurzhanov B.S., Rysaev A.F., Rahmatulin Sh.G. Changing of the composition of the rumen microflora to improve the efficiency of feed use by ruminants. *January IOP Conference Series Earth and Environmental Science*, 2021, vol. 624, no. 1, p. 012022. DOI: 10.1088/1755-1315/624/1/012022.
16. Clemmons B.A., Voy B.H., Myer P.R. Altering the Gut Microbiome of Cattle: Considerations of Host-Microbiome Interactions for Persistent Microbiome Manipulation. *Microbial Ecology*, 2019, vol. 77, no. 2, pp. 523–536. DOI: 10.1007/s00248-018-1234-9.
17. Morais S., Mizrahi I. The Road Not Taken: The Rumen Microbiome, Functional Groups, and Community States. *Trends in Microbiology*, 2019, vol. 27, no. 6, pp. 538–549. DOI: 10.1016/j.tim.2018.12.011.
18. Lilian M., Rawlynce B., Charles G., Felix K. Potential role of rumen bacteria in modulating milk production and composition of admixed dairy cows. *Letters in Applied Microbiology*, 2023, vol. 76, no. 2, p. ovad007. DOI: 10.1093/lambio/ovad007.
19. Newbold C.J., Ramos-Morales E. Review: Ruminal microbiome and microbial metabolome: effects of diet and ruminant host. *Animal*, 2020, vol. 14, no. S1, pp. 78–86. DOI: 10.1017/S1751731119003252.
20. Ryazanov V., Tarasova E., Duskaev G., Kolpakov V., Miroshnikov I. Changes in the Concentration of Amino Acids and Bacterial Community in the Rumen When Feeding *Artemisia absinthium* and Cobalt Chloride. *Fermentation*,

- 2023, vol. 9, p. 751. DOI: 10.3390/fermentation9080751.
21. Nawab A., Li G., An L., Nawab Y., Zhao Yi., Xiao M., Tang S., Sun C. The potential effect of dietary tannins on enteric methane emission and ruminant production, as an alternative to antibiotic feed additives – a review. *Annals of Animal Science*, 2020, vol. 20, no. 2, pp. 355–388. DOI: 10.2478/aoas-2020-0005.
22. Takeshita N., Watanabe T., Ishida-Kuroki K., Sekizaki T. Transition of microbiota in chicken cecal droppings from commercial broiler farms. *BMC Veterinary Research*, 2021, vol. 17, no. 1, p. 10. DOI: 10.1186/s12917-020-02688-7.
23. Kameshwar A.K.S., Ramos L.P., Qin W. Meta-data Analysis Approaches for Understanding and Improving the Functional Involvement of Rumen Microbial Consortium in Digestion and Metabolism of Plant Biomass. *Journal of Genomics*, 2019, vol. 7, pp. 31–45. DOI: 10.7150/jgen.32164.
24. Montano M.F., Carvalho P.H.V., Chirino-Romero J.O., Latack B.C., Salinas-Chavira J., Zinn R.A. Influence of supplemental condensed tannins on initial 112-d feedlot growth-performance and characteristics of digestion of calf-fed Holstein steers. *Translational animal science*, 2022, vol. 6, no. 1, p. txac024. DOI: 10.1093/tas/txac024.
25. Carreño D., Toral P.G., Pinloche E., Belenquer A., Yáñez-Ruiz D.R., Hervás G., McEwan N.R., Newbold C.J., Frutos P. Rumen bacterial community responses to DPA, EPA and DHA in cattle and sheep: a comparative in vitro study. *Scientific Reports*, 2019, vol. 9, p. 11857. DOI: 10.1038/s41598-019-48294-y.
26. Hackmann T.J., Sen A., Firkins J.L. Culture techniques for ciliate protozoa from the rumen: Recent advances and persistent challenges. *Anaerobe*, 2024, vol. 87, p. 102865. DOI: 10.1016/j.anaerobe.2024.102865.
27. Nehme R., Andrés S., Pereira R.B., Ben Jemaa M., Bouhallab S., Cecilian F., López S., Rahali F.Z., Ksouri R., Pereira D.M., Abdennebi-Najar L. Essential Oils in Livestock: From Health to Food Quality. *Antioxidants (Basel)*, 2021, vol. 10, no. 2, p. 330. DOI: 10.3390/antiox10020330.
28. Wang L., Zhou J., Gao T., Liang X., Hu Q., Huang B., Lyu Z., Johnston L.J., Lai C. Comparison of regression and fat-free diet methods for estimating ileal and total tract endogenous losses and digestibility of fat and fatty acids in growing pigs. *Journal of Animal Science*, 2020, vol. 98, no. 12, p. skaa376. DOI: 10.1093/jas/skaa376.
29. Schoeler M., Ellero-Simatos S., Birkner T., Mayneris-Perxachs J., Olsson L., Brolin H., Loeber U., Kraft J.D., Polizzi A., Martí-Navas M., Puig J., Moschetta A., Montagner A., Gourdy P., Heymes C., Guillou H., Tremaroli V., Fernández-Real J.M., Forslund S.K., Burcelin R., Caesar R. The interplay between dietary fatty acids and gut microbiota influences host metabolism and hepatic steatosis. *Nature Communications*, 2023, vol. 14, no. 1, p. 5329. DOI: 10.1038/s41467-023-41074-3.
30. Cartoni Mancinelli A., Mattioli S., Twining C., Dal Bosco A., Donoghue A.M., Arsi K., Angelucci E., Chiattelli D., Castellini C. Poultry Meat and Eggs as an Alternative Source of n-3 Long-Chain Polyunsaturated Fatty Acids for Human Nutrition. *Nutrients*, 2022, vol. 14, no. 9, p. 1969. DOI: 10.3390/nu14091969.
31. Ibrahim N.A., Alimon A.R., Yaakub H., Samsudin A.A., Candyne S.C.L., Wan Mohamed W.N., Md Noh A., Fuat M.A., Mookiah S. Effects of Vegetable Oil Supplementation on Rumen Fermentation and Microbial Population in Ruminant: A Review. *Tropical Animal Health and Production*, 2021, vol. 53, p. 422. DOI: 10.1007/s11250-021-02863-4.
32. Costa F.S., Cabral A.R., Silva S.L., Silva M.A.I., Henrique W., Mazalli M.R., Baldi F.S., Mueller L.F., Ferrinho A.M., Corte R.R.P.S., Pereira A.S.C. Effects of n-3 and n-6 feeding sources on the quality and lipid oxidation of meat from feedlot-finished *Bos indicus* steers. *Meat Science*, 2020, vol. 161, p. 107966. DOI: 10.1016/j.meatsci.2019.107966.
33. Pereira G., Simões P., Bexiga R., Silva E., Mateus L., Fernandes T., Alves S.P., Bessa R.J.B., Lopes-da-Costa L. Effects of Feeding Rumen-Protected Linseed Fat to Postpartum Dairy Cows on Plasma n-3 Polyunsaturated Fatty Acid Concentrations and Metabolic and Reproductive Parameters. *Journal of Dairy Science*, 2022, vol. 105, pp. 361–374. DOI: 10.3168/jds.2021-20674.
34. Woodruff K.L., Hummel G.L., Austin K.J., Lake S.L., Cunningham-Hollinger H.C. Calf rumen microbiome from birth to weaning and shared microbial properties to the maternal rumen microbiome. *Journal of Animal Science*, 2022, vol. 100, no. 10, p. skac264. DOI: 10.1093/jas/skac264.

ИНФОРМАЦИЯ ОБ АВТОРАХ

Рязанов В.А., старший научный сотрудник, кандидат сельскохозяйственных наук; SPIN-код: 6076-5714

Дускаев Г.К., заместитель директора, ведущий научный сотрудник, доктор биологических наук, доцент, профессор РАН; SPIN-код: 7297-3319

✉ **Курилкина М.Я.**, старший научный сотрудник, кандидат биологических наук; SPIN-код: 8964-6042; **адрес для переписки:** Россия, 460000, Оренбург, ул. 9 Января, 29; e-mail: K_marina4@mail.ru

Муслюмова Д.М., старший научный сотрудник, кандидат биологических наук; SPIN-код: 5173-0859

AUTHOR INFORMATION

Vitaly A. Ryazanov, Senior Researcher, Candidate of Science in Agriculture; SPIN-code: 6076-5714

Galimzhan K. Duskaev, Deputy Director, Lead Researcher, Doctor of Science in Biology, Associate Professor, Professor RAS; SPIN-code: 7297-3319

✉ **Marina Ya. Kurilkina**, Senior Researcher, Candidate of Science in Biology; SPIN-code: 8964-6042; **address:** 29, January 9th St., Orenburg, 460000, Russia; e-mail: K_marina4@mail.ru

Dina M. Muslyumova, Senior Researcher, Candidate of Science in Biology; SPIN-code: 5173-0859

Дата поступления статьи / Received by the editors 16.08.2024
Дата принятия к публикации / Accepted for publication 21.10.2024
Дата публикации / Published 16.06.2025

Создание экспериментальных образцов пробиотического препарата для сельскохозяйственных животных и определение содержания в них витамина В₁₂

✉Афанасьева Ю.Г., Колодина Е.В., Руппель И.А.

Сибирский научно-исследовательский институт сыроделия – отдел Федерального Алтайского научного центра агробиотехнологий

Барнаул, Россия

✉e-mail: yuliya.afanaseva.9718@mail.ru

В современных реалиях особую значимость имеет идея здорового питания, что способствует увеличению спроса на экологически чистые и полноценные по своему составу продукты. В этой связи актуальными вопросами животноводства становятся снижение частоты использования антибиотиков и активное применение пробиотических добавок в основных рационах кормления. Также неотъемлемыми задачами отрасли являются сохранность молодняка и повышение продуктивности поголовья. Важнейший этап при создании пробиотика – выбор его состава. Наиболее частыми компонентами пробиотических добавок выступают лактобациллы и пропионово-кислые бактерии, поскольку данные микроорганизмы обладают необходимым набором технологически ценных свойств. Пропионовокислые бактерии являются продуцентами витамина В₁₂, который положительно влияет на белковый обмен и повышает усвояемость кормов. В полной мере потребность в витамине В₁₂ у животных не удовлетворяется, поэтому становится необходимым его включение в состав кормовых добавок. Лактобациллы обладают высокой биологической и антагонистической активностью, оказывают иммуностимулирующее действие. Во время предыдущих и текущих исследований, проведенных на базе Сибирского научно-исследовательского института сыроделия, была подобрана оптимальная питательная среда для накопления биомасс указанных микроорганизмов, а также оптимальная доза их внесения в пробиотический препарат. На основании этих данных составлены три экспериментальных образца биопрепарата для сельскохозяйственных животных. При создании образцов применено как совместное, так и раздельное культивирование. Также в ходе исследования определяли активную кислотность и содержание витамина В₁₂ во всех образцах. Содержание витамина В₁₂ варьировало от $0,70 \pm 0,01$ до $0,82 \pm 0,03$ мкг/мл. В результате проделанной работы установлено, что образец № 1 наиболее оптимален с точки зрения технологичности, а также количественного содержания витамина В₁₂.

Ключевые слова: пробиотик, витамин В₁₂, пробиотические микроорганизмы, пропионово-кислые бактерии, лактобациллы, сельскохозяйственные животные

Creation of experimental samples of a probiotic preparation for farm animals and measurement of vitamin В₁₂ content in them

✉Afanaseva Yu.G., Kolodina E.V., Ruppel I.A.

Siberian Research Institute of Cheese Making – Department of the Federal Altai Scientific Centre of Agro-BioTechnologies

Barnaul, Russia

✉e-mail: yuliya.afanaseva.9718@mail.ru

In modern realities the idea of healthy nutrition is of particular importance, this interest increases the demand of consumers for products that are ecologically clean and complete in their composition. In this regard, reduction of antibiotic use frequency and active application of probiotic additives in the main feed rations are becoming topical issues of livestock breeding. Also integral to the industry are the preservation of young stock and increasing the productivity of the herd. The most important step in creating a probiotic is choosing its composition. The most common components of probiotic supplements are lactobacillus and propionic acid bacteria, as these microorganisms have the necessary set of technologically valuable properties. Propionic acid bacteria are producers of vitamin В₁₂, which has a positive effect on protein metabolism and increases feed digestibility. Animals do not fully cover the need for vitamin В₁₂, so it becomes necessary to include it in the composition of the feed additives. Lactobacillus have high biological and antagonistic activity and exert immunostimulatory effect.

During previous and current studies conducted on the basis of the Siberian Research Institute of Cheese Making, the optimal nutrient medium for accumulation of biomasses of the above microorganisms was selected, as well as the optimal dose of their introduction into the probiotic preparation. Based on these data, three experimental samples of biopreparation for farm animals have been formulated. Both co-cultivation and separate cultivation were applied in the process of specimen creation. The study also determined the active acidity and vitamin B₁₂ content of all the samples. Vitamin B₁₂ content ranged from 0.70 ± 0.01 to 0.82 ± 0.03 µg/ml. As a result of the work done, it has been found that sample No. 1 is the most optimal in terms of processability, as well as the quantitative content of vitamin B₁₂.

Keywords: probiotic, vitamin B₁₂, probiotic microorganisms, propionic acid bacteria, lactobacillus, farm animals

Для цитирования: Афанасьева Ю.Г., Колодина Е.В., Руппель И.А. Создание экспериментальных образцов пробиотического препарата для сельскохозяйственных животных и определение содержания в них витамина B₁₂ // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 5. С. 99–105. <https://doi.org/10.26898/0370-8799-2025-5-9>

For citation: Afanaseva Yu.G., Kolodina E.V., Ruppel I.A. Creation of experimental samples of a probiotic preparation for farm animals and measurement of vitamin B₁₂ content in them. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 5, pp. 99–105. <https://doi.org/10.26898/0370-8799-2025-5-9>

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Consumer interest in environmentally friendly and nutritious products is currently growing rapidly due to the popularization of healthy eating. In this regard, the elimination of frequent antibiotic use and the active use of probiotic supplements in basic diets are becoming pressing issues in animal husbandry. Furthermore, the industry's most important tasks are ensuring the safety of young animals and maximizing livestock productivity [1]. At the same time, gastrointestinal diseases in animals, caused by an imbalance of normal microflora, cause the greatest losses.

Dysbacteriosis often occurs in animals as a result of various diseases [2, 3]. To prevent infections and gastrointestinal disorders caused by opportunistic microflora, and also as growth promoters, feed antibiotics are actively used. These drugs combat foreign microflora and help improve livestock survival. However, they destroy not only infectious agents but also normal intestinal microflora. Furthermore, animals develop drug resistance [4].

Currently, the abandonment of antibiotics and the use of various biological additives are becoming pressing issues in animal husbandry, as reflected in recent scientific studies. Much attention is being paid to the use of environmentally friendly products as feed additives. The use of probiotics in livestock feed is the most promising [1].

Probiotics are bacterial preparations containing cultures of live microorganisms that are part of the normal microflora of the gastrointestinal tract. They do not cause allergic reactions in animals and have a positive effect on the body¹. The use of probiotics in livestock feed helps normalize natural digestion and nutrient absorption processes and helps manage the effects of antibiotic treatment. Probiotic feed supplements help increase livestock productivity while maintaining high product quality².

Most often, probiotic preparations contain lactobacilli (*Lactobacillus plantarum*) and pro-

¹Kononenko S.I. Increasing the biological potential of poultry through the use of probiotics // Polythematic online electronic scientific journal of the Kuban State Agrarian University, 2017, No. 127, pp. 527–545.

²Sokolenko G.G., Lazarev B.P., Minchenko S.V. Probiotics in rational animal feeding // Technologies for the Food and Processing Industry of AIC – Healthy Food, 2015, No. 1 (5), pp. 72–78.

propionic acid bacteria (*Propionibacterium freudenreichii* spp.)³.

Lactobacilli are non-motile, gram-positive rods that do not form spores. They are widely used in the creation of probiotic preparations [5, 6] because they are harmless, possess high biological and antagonistic activity, and exert an immunostimulating effect. These bacteria synthesize lactic acid, which helps lower the pH of the small intestinal contents, which is considered optimal for the functioning of other microflora.

Propionibacterium are among the most beneficial microorganisms. The most common representatives of propionibacterium are *P. freudenreichii* subsp. *shermanii* and *P. freudenreichii* subsp. *freudenreichii* [7].

P. freudenreichii spp. have the safety status GRAS (Generally Recognized as Safe). This indicates the possibility of their addition to food and feed products in the absence of genetically modified microorganisms [8]. In addition, propionic acid bacteria are highly biocompatible with lacto- and bifidobacteria, which promotes the growth of obligate microflora in the gastrointestinal tract of animals⁴ [9].

One of the most significant properties of propionic acid bacteria is their ability to synthesize vitamin B₁₂ (cobalamin). Vitamin B₁₂ is a growth factor for farm animals and poultry, has a beneficial effect on amino acid absorption and protein metabolism, improves the digestibility of plant feed, and, as a result, significantly increases productivity [10].

In cattle, some vitamin B₁₂ is synthesized by intestinal microflora. However, the body's need for vitamin B₁₂ is not fully met, so additional amounts must be obtained through feed supplements. Vitamin B₁₂ deficiency reduces protein digestibility, resulting in anemia, accompanied by stunted growth and inanition of the body [7, 10].

Cobalt, a component of vitamin B₁₂, is essential for animal life, but can be toxic in excess.

In the gastrointestinal tract, cobalt stimulates the growth of microorganisms that synthesize B vitamins [11]. One option for obtaining vitamin B₁₂ is microbial synthesis, using propionic acid bacteria.

Thus, the listed beneficial properties of lactobacilli and propionic acid bacteria allow us to recommend them as the basis for probiotic preparations used in agriculture.

The purpose of the study was to create experimental samples of a probiotic preparation for farm animals and determine the content of vitamin B₁₂ in them.

The research objectives are:

- 1) the creation of samples of a probiotic preparation for farm animals using various cultivation methods;
- 2) quantitative determination of vitamin B₁₂ and technologically valuable properties (active acidity) in all experimental samples of the drug.

MATERIAL AND METHODS

The study was conducted at the Siberian Research Institute of Cheese Making (SibNIIS). The subjects of the study were three experimental samples of a probiotic preparation for farm animals based on *L. plantarum* and *P. freudenreichii* spp. from the Siberian Collection of Microorganisms at SibNIIS.

Optimal nutrient media for accumulating the biomass of the probiotic cultures used and the probiotic as a whole were previously selected. The most valuable nutrient media based on their properties: a whey-based medium for propionic acid bacteria, and a grain bran-based medium for lactobacilli were selected. The probiotic microorganism addition rate of 1.0% was also selected.

During the study, both joint and separate cultivation were used, since in order to select a sample with the best manifestation of the required characteristics, it makes sense to consider both cultivation options.

³Morozova L.A., Mikolaychik I.N., Dostovalov E.V. Hematological parameters and microbiocenosis of the gastrointestinal tract of calves when feeding the feed additive "Laktur" // Bulletin of the South Ural state university. Series: Food and biotechnology, 2015, vol. 3, No. 1, pp. 76–82.

⁴Dracheva L.V., Dorozhko E.V., Avramchuk O.A., Korotkova E.I., Ryzhkova E.P., Hao Li, Danilova I.V. Study of antioxidant activity of propionic acid bacteria // Food industry, 2009, No. 2, pp. 12–13.

The presence of vitamin B₁₂ synthesized by propionic acid bacteria in the test samples was determined by a quantitative diffusion method using a test organism - mutant *Escherichia coli* 113-3 DSM 1900 (All-Russian collection of industrial microorganisms of the Federal State Budgetary Scientific Institution "GosNIIGenetika") according to the established methodology⁵. The method used is based on determining the growth rate of the test organism on an agar medium around wells inoculated with a specified volume of propionibacteria grown in a liquid nutrient medium. A standard solution of vitamin B₁₂ in varying concentrations serves as a control. The growth of the test organism (measured in millimeters of growth zones) depends on the amount of vitamin B₁₂ in a given volume of propionibacteria.

The active acidity of the samples was determined potentiometrically using a Testo 205 pH meter (Germany).

The content of *Lactobacillus* spp. in the finished samples of the biological product was determined by the method of limiting dilutions by deep seeding in Rogosa agar medium with incubation for 72 hours at 30 °C, the amount of *Propionibacterium* spp. - by the method of deep seeding in solid lactate medium according to Birger with incubation for 10 days at 30 °C.

RESULTS AND DISCUSSION

During the study, three experimental samples of probiotic for farm animals were developed.

The optimal nutrient medium for lactobacilli and propionic acid bacteria was a medium consisting of demineralized whey and bran broth in a 50:50 ratio. Yeast autolysate was also added to the nutrient medium as an additional growth factor, along with cobalt chloride (5 mg/1 dm³ of medium), necessary for the synthesis of vitamin B₁₂ by propionic acid bacteria. To ferment 1 liter of nutrient medium, 10 ml of probiotic organisms in liquid form were used.

Experimental sample No. 1 involved co-cultivation of microorganisms, while samples No. 2 and 3 involved separate cultivation. Cultivation was carried out in a TV-80-1 dry-air thermostat at 30°C in 2000 ml flasks.

At the stage of biomass growth, which was used for further preparation of experimental samples, microorganisms were cultivated separately in 250 ml flasks at 30 °C: three strains of propionic acid bacteria – 72 h, two strains of lactobacilli – 24 h. Demineralized whey was used as a nutrient medium for propionic acid bacteria, and bran broth for lactobacilli.

To create sample No. 1, 1.0% (10 ml) of the grown propionic acid bacteria biomass was added to 1000 ml of the nutrient medium. Then, cultivation was carried out for 48 hours at 30 °C. Next, the grown propionic acid bacteria biomass was deoxidized to pH = 6.5–6.8 for the subsequent addition of 1.0% (10 ml) of the grown lactobacilli biomass. Then, cultivation was carried out for 24 hours at 30 °C. In the finished version of sample #1, the content of *L. plantarum* was $(7.80 \pm 1.29) \cdot 10^8$ CFU/cm³, *P. Freudenreichii* spp. – $(7.23 \pm 2.58) \cdot 10^8$ CFU/cm³.

For sample No. 2, the microbial biomass was grown separately. *P. freudenreichii* spp. and *L. plantarum* were cultured at 30°C for 72 and 24 hours, respectively. The grown biomasses were then mixed in a 1:1 ratio (500:500 ml). The lactobacilli content in the finished sample was $(6.70 \pm 0.32) \cdot 10^8$ CFU/cm³, and propionic acid bacteria – $(6.31 \pm 1.59) \cdot 10^8$ CFU/cm³.

In the process of creating sample No. 3, separate cultivation of probiotic microorganisms was carried out at 30 °C. *P. freudenreichii* spp. was cultivated for 72 hours, *L. plantarum* – for 24 hours. Then, 10% (100 ml) of lactobacilli biomass was added to 1000 ml of the accumulated biomass of propionic acid bacteria. The number of lactobacilli in the finished sample was $(1.43 \pm 0.41) \cdot 10^8$ CFU/cm³, propionic acid bacteria - $(3.73 \pm 1.35) \cdot 10^8$ CFU/cm³.

⁵Microbiology Workshop: Textbook / edited by N.S. Egorov. Moscow: Moscow State University Publishing House, 1976, 308 p.

At each stage of probiotic sample preparation, active acidity was measured. At the final stage of production, sodium citrate was added to maintain buffering capacity. Data on the acid-forming activity of the samples are presented in Fig. 1.

According to Fig. 1, all experimental samples of the biopreparation have a fairly high active acidity, with the lowest pH value noted in sample No. 2 (4.39 ± 0.14).

Since propionic acid bacteria are producers of vitamin B₁₂, in order to include them in the probiotic, it was necessary to assess the level of this vitamin in all experimental samples (see Fig. 2).

The results confirmed the presence of vitamin B₁₂ in all samples tested. This indicates the biological activity of the biopharmaceutical being developed. Moreover, the vitamin B₁₂ level in sample No. 1 was 14.6% higher than in samples Nos. 2 and 3, reaching $0.82 \pm 0.03 \mu\text{g/ml}$.

CONCLUSION

In the course of the study, three experimental samples of a probiotic preparation for farm animals were prepared based on lactobacilli and propionic acid bacteria. The content of *L. plantarum* in the finished samples ranged from $(1.43 \pm 0.41) \cdot 10^8$ to $(7.80 \pm 1.29) \cdot 10^8$ CFU/cm³, *P. Freudenreichii* spp. – from $(3.73 \pm 1.35) \cdot 10^8$ to $(7.23 \pm 2.58) \cdot 10^8$ CFU/cm³. The highest number of probiotic microorganisms was noted

in experimental sample No. 1. Active acidity was measured at each stage. The pH level ranged from 4.39 to 4.83, which is considered the optimal acidity for the manifestation of the specific properties of the probiotic. All studied samples contained vitamin B₁₂, the amount of which varied from 0.70 ± 0.01 to $0.82 \pm 0.03 \mu\text{g/ml}$. Moreover, in sample No. 1, the content of this vitamin was $0.82 \pm 0.03 \mu\text{g/ml}$, which exceeds its amount in samples No. 2 and 3 by 14.6%. Thus, the most optimal version of the biological product in terms of technological effectiveness, manifestation of microbiological, physicochemical properties and quantitative content of vitamin B₁₂ is test sample No. 1.

СПИСОК ЛИТЕРАТУРЫ

1. Буйров В.С., Мальцева М.А., Алдобаева Н.А. Научно-практическое обоснование применения пробиотиков в молочном скотоводстве и мясном птицеводстве // Аграрный вестник Верхневолжья. 2018. Т. 2. № 23. С. 79–86.
2. Функ И.А. Эффективность использования пробиотического препарата Плантариум в кормлении сукозных коз // Вестник Новосибирского государственного аграрного университета. 2022. № 3 (64). С. 134–141. DOI: 10.31677/2072-6724-2022-64-3-134-141.
3. Платонов А.В., Смирнова Ю.М., Лантев Г.Ю., Хоштария Е.Е. Опыт применения кормовой добавки «Румит» в рационах лактирующих коров // Зоотехния. 2024. № 8. С. 13–17. DOI: 10.25708/ZT.2024.54.20.003.

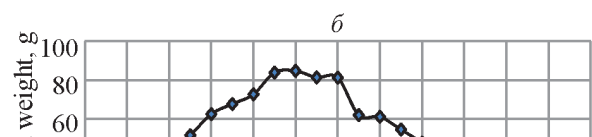
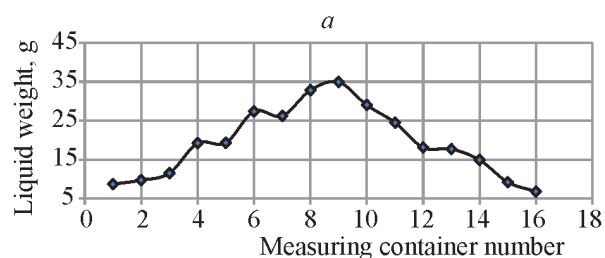


Рис. 1. Активная кислотность опытных образцов
Fig. 1. Active acidity of experimental samples

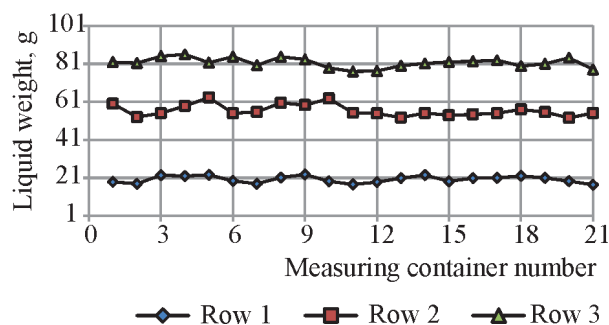


Рис. 2. Количество витамина B₁₂ в экспериментальных образцах

Fig. 2. The amount of vitamin B₁₂ in the experimental samples

4. Васильева О.А., Нуфер А.И., Шацких Е.В. Альтернативные пути замены кормовых антибиотиков // Эффективное животноводство. 2019. № 4 (152). С. 13–15.
5. Функ И.А., Отт Е.Ф., Орлова Т.Н., Дорофеев Р.В., Шевченко К.Е. Лактобациллы и их применение в биотехнологии // Молочная промышленность. 2020. № 6. С. 19–21. DOI: 10.31515/1019-8946-2020-06-19-21.
6. Орлова Т.Н., Отт Е.Ф. Изучение перспективных штаммов *Lactobacillus plantarum* для дальнейшего их использования в животноводстве и птицеводстве // Вестник Алтайского государственного аграрного университета. 2021. № 10. С. 85–88. DOI: 10.53083/1996-4277-2021-204-10-85-88.
7. Орлова Т.Н., Отт Е.Ф. Возможность использования пропионовокислых бактерий в рационах сельскохозяйственных животных и птиц в качестве источника витамина B₁₂ // Вестник Алтайского государственного аграрного университета. 2019. № 8. С. 135–138.
8. Логвинова Т.И. Использование пропионовокислых микроорганизмов: от теории к практике // Животноводство и кормопроизводство. 2023. Т. 106. № 4. С. 164–177. DOI: 10.33284/2658-3135-106-4-164.
9. Орлова Т.В. Изучение биологической активности пропионовокислых бактерий // The Scientific Heritage. 2021. № 79-2 (79). С. 31–33. DOI: 10.24412/9215-0365-2021-79-2-31-33.
10. Марченко М.В., Подволоцкая А.Б., Фищенко Е.С. Изучение возможности использования «диких» штаммов бактерий как возможных продуцентов витамина B₁₂ (кобаламина) // Достижения науки и техники АПК. 2020. Т. 34. № 7. С. 109–113. DOI: 10.24411/0235-2451-2020-10719.
11. Свиридов М.Л. Функции кобальта в организме сельскохозяйственных животных // Вестник науки. 2022. Т. 1. № 1 (46). С. 147–156.
121. (In Russian). DOI: 10.31677/2072-6724-2022-64-3-134-141.
3. Platonov A.V., Smirnova Yu.M., Laptev G.Yu., Hoshtariya E.E. The experience of using "Rumit" feed additive in the diets of lactating cows. *Zootekhnika = Zootechniya*, 2024, no. 8, pp. 13–17. (In Russian). DOI: 10.25708/ZT.2024.54.20.003.
4. Vasil'eva O.A., Nufer A.I., Shatskih E.V. Alternative ways to replace feed antibiotics. *Effektivnoe zhivotnovodstvo = Efficient animal husbandry*, 2019, no. 4 (152), pp. 13–15. (In Russian).
5. Funk I.A., Ott E.F., Orlova T.N., Dorofeev R.V., Shevchenko K.E. Lactobacilli and their use in biotechnology. *Molochnaya promyshlennost' = Dairy industry*, 2020, no. 6, pp. 19–21. (In Russian). DOI: 10.31515/1019-8946-2020-06-19-21.
6. Orlova T.N., Ott E.F. Study of promising strains of *Lactobacillus plantarum* for their further use in animal husbandry and poultry farming. *Vestnik Altayskogo gosudarstvennogo agrarnogo universiteta = Bulletin of Altai State Agricultural University*, 2021, no. 10, pp. 85–88. (In Russian). DOI: 10.53083/1996-4277-2021-204-10-85-88.
7. Orlova T.N., Ott E.F. The possibility of using propionic bacteria in farm animal and poultry diets as a source of vitamin B₁₂. *Vestnik Altayskogo gosudarstvennogo agrarnogo universiteta = Bulletin of Altai State Agricultural University*, 2019, no. 8, pp. 135–138. (In Russian).
8. Logvinova T.I. The use of propionic acid microorganisms: from theory to practice. *Zhivotnovodstvo i kormoproizvodstvo = Animal Husbandry and Fodder Production*, 2023, vol. 106, no. 4, pp. 164–177. (In Russian). DOI: 10.33284/2658-3135-106-4-164.
9. Orlova T.V. The study of biological activity of propionic acid bacteria. *The Scientific Heritage = The Scientific Heritage*, 2021, no. 79-2 (79), pp. 31–33. (In Russian). DOI: 10.24412/9215-0365-2021-79-2-31-33.
10. Marchenok M.V., Podvolotskaya A.B., Fishchenko E.S. Study of the possibility of using "wild" bacterial strains as possible producers of vitamin B₁₂ (cobalamin). *Dostizheniya nauki i tekhniki APK = Achievements of Science and Technology of AIC*, 2020, vol. 34, no. 7, pp. 109–113. (In Russian). DOI: 10.24411/0235-2451-2020-10719.
11. Sviridov M.L. Functions of cobalt in agricultural animals. *Vestnik nauki = Bulletin of Science*, 2022, vol. 1, no. 1 (46), pp. 147–156. (In Russian).

REFERENCES

1. Buyarov V.S., Maltseva M.A., Aldobaeva N.A. Scientific and practical rationale of probiotics application in dairy cattle and meat poultry breeding. *Agrarniy vestnik Verkhnevolzh'ya = Agrarian Journal of Upper Volga region*, 2018, vol. 2, no. 23, pp. 79–86. (In Russian).
2. Funk I.A. The efficiency of using the probiotic drug Plantarium in feeding gestation goats. *Vestnik Novosibirskogo gosudarstvennogo agrarnogo universiteta = Bulletin of Novosibirsk State Agrarian University*, 2022, no. 3 (64), pp. 134–

ИНФОРМАЦИЯ ОБ АВТОРАХ

✉ **Афанасьева Ю.Г.**, младший научный сотрудник; SPIN-код 7781-7933; **адрес для переписки:** Россия, 656910, Барнаул, п. Научный городок, 35; e-mail: yuliya.afanaseva.9718@mail.ru

Колодина Е.В., младший научный сотрудник; SPIN-код 8002-9935

Руппель И.А., старший научный сотрудник, кандидат сельскохозяйственных наук; SPIN-код 3055-0502

AUTHOR INFORMATION

✉ **Yuliya G. Afanaseva**, Junior Researcher; SPIN-code 7781-7933; **address:** 35, Nauchnyy Goro-dok, Barnaul, 656910, Russia; e-mail: yuliya.afanaseva.9718@mail.ru

Ekaterina V. Kolodina, Junior Researcher; SPIN-code 8002-9935

Irina A. Ruppel, Senior Researcher, Candidate of Science in Agriculture; SPIN-code 3055-0502

Дата поступления статьи / Received by the editors 02.10.2024
Дата принятия к публикации / Accepted for publication 19.12.2024
Дата публикации / Published 16.06.2025



Качество распределения жидких форм минеральных удобрений по обрабатываемой поверхности

✉ Назаров Н.Н., Некрасова И.В.

Сибирский федеральный научный центр агробиотехнологий

Российской академии наук

Новосибирская область, р.п. Краснообск, Россия

✉ e-mail: nazarovnn@sfsca.ru

В статье представлены результаты оценки качества распределения жидких минеральных удобрений по обрабатываемой площади при их поверхностном внесении с учетом установки распылителей на различном уровне относительно распределительной штанги. Установлено, что при использовании данного способа внесения неравномерность распределения рабочей жидкости, выраженная коэффициентом вариации, может достигать 20% и более, что снижает эффективность применяемых азотных удобрений до 45–50%, фосфорных – до 15–20%. Одна из главных причин возникновения указанной проблемы – установка распылителей на одном уровне в горизонтальной плоскости. Определено, что при использовании крупнокапельных распылителей дефлекторного типа, находящихся на одном уровне, встречающиеся факелы распыла создают на месте стыковки дополнительные объемы препарата, превышающие основной фон на 25–70%. В результате образуется высококонцентрированная по содержанию элементов питания полоса, не соответствующая основному агротехническому требованию, предполагающему равномерное распределение препарата по обрабатываемой площади. В ходе исследований обоснован шаг расстановки дефлекторных распылителей для внесения жидких минеральных удобрений – 0,5; 0,75 и 1,0 м при давлении в системе 0,1; 0,2 и 0,3 МПа. В этом случае формируется перекрытие взаимодействующих факелов распыла на уровне, превышающем 50% от их ширины захвата, а неравномерность внесения удобрений является минимальной (не более 7%) при разноуровневой установке распылителей относительно распределительной штанги. Выявлено, что качество распределения рабочей жидкости в значительной степени зависит от шага расстановки распылителей, в меньшей – от давления в системе и диаметра отверстия распылителей. Причем качество распределения будет возрастать, если давление в системе и диаметр отверстий распылителей находятся одновременно на верхнем или нижнем уровне своих значений.

Ключевые слова: жидкие минеральные удобрения, распределение, неравномерность, дефлекторные распределители, шаг расстановки, крупнокапельный распыл, факел распыла, ширина захвата, перекрытие, обрабатываемая площадь

Quality of distribution of liquid forms of mineral fertilizers over the working surface

✉ Nazarov N.N., Nekrasova I.V.

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

Krasnoobsk, Novosibirsk region, Russia

✉ e-mail: nazarovnn@sfsca.ru

The materials on the assessment of the quality of the distribution of liquid mineral fertilizers over the working area during their surface application, taking into account the installation of sprayers at various levels relative to the distribution rod, are presented. It has been found that the unevenness expressed by the coefficient of variation can reach 20% or more, which reduces the efficiency of nitrogen fertilizers to 45–50%, phosphorus fertilizers to 15–20%. One of the main reasons for its appearance is the

installation of sprayers at the same level in the horizontal plane. It has been determined that when using large-droplet sprayers of the deflector type, the spray flares that occur at the same level create additional volumes of the sprayed preparation at the place of their docking, exceeding the main background by 25–70%. As a result, a highly concentrated nitrogen-phosphorus content of the batteries strip that does not meet the basic agrotechnical requirement for uniformity of distribution of the sprayed preparation over the working surface is formed. The step of placement of the deflector sprayers for the introduction of the press is justified – 0.5; 0.75 and 1.0 m at a pressure of 0.1; 0.2 and 0.3 MPa in the system. In this case, an overlap of the interacting spray patterns at a level exceeding 50% of their capture width, and the uneven application of fertilizers is minimal (not higher than 7%) using a multi-level installation of sprayers relative to the distribution rod is formed. It has been found that the quality of the distribution of the working fluid largely depends on the step of the arrangement of the sprayers on the rod and to a lesser extent on the pressure in the system and the diameter of the sprayers. While, the quality of distribution will increase if the system pressure and the diameter of the holes of the sprayers are simultaneously at the upper or lower levels of their values.

Keywords: liquid mineral fertilizers, distribution, non-uniformity, deflector spreaders, spreading step, coarse-drop spray, spray pattern, working width, overlap, working surface

Для цитирования: Назаров Н.Н., Некрасова И.В. Качество распределения жидких форм минеральных удобрений по обрабатываемой поверхности // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 5. С. 106–114. <https://doi.org/10.26898/0370-8799-2025-5-10>

For citation: Nazarov N.N., Nekrasova I.V. Quality of distribution of liquid forms of mineral fertilizers over the working surface. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 5, pp. 106–114. <https://doi.org/10.26898/0370-8799-2025-5-10>

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

Благодарность

Работа выполнена в рамках финансируемой научно-исследовательской работы № 0533-2024-0004.

Acknowledgements

The work was carried out within the framework of the funded research work No. 0533-2024-0004.

INTRODUCTION

One of the keys to achieving consistently high grain yields is improving cultivation technology through adaptive intensification of the sowing process. The yield primarily depends on the availability of water, mineral nutrients, heat, light, and air to plants, of which water and mineral nutrients are, to a certain extent, controllable factors.

In this regard, the application of liquid nitrogen-phosphorus fertilizers and urea-ammonia solutions to the soil plays a crucial role. Despite the considerable development of this area, a number of unresolved issues remain, including

the dosing of small volumes of liquid fertilizers, their transportation to the application site, clogging of nozzle holes (tips) with soil, and rapid wear of the working fluid supply lines. Furthermore, the problem of reduced uniformity of liquid mineral fertilizer distribution during surface application has not been fully resolved. It has been established that when using this method, unevenness, expressed as the variation coefficient, can reach 20% or more, reducing the effectiveness of nitrogen fertilizers to 45–50% and phosphorus fertilizers to 15–20%^{1,2} [1–8].

One of the many reasons for the uneven distribution of liquid mineral fertilizers over the

¹Amelkin V.I., Dotsenko Yu.V. Ways to improve the uniformity of application of liquid mineral fertilizers // Results of research and development in the mechanization of production processes in plant growing: collection of scientific papers, Zernograd, 1991, pp. 111–115.

²Marchenko L.A., Romanov G.I., Kolesnikova V.A. Regulation of application rates of liquid mineral fertilizers // Tractors and agricultural machinery, 2004, No. 9, pp. 34–35.

treated area when applied superficially is the installation of sprayers at the same level in the horizontal plane³ [9–14]. When using large-droplet sprayers, the spray cones that meet at the same level create a highly concentrated strip of nutrients at the junction, which does not meet the basic agrotechnical requirement, which requires uniform distribution of the sprayed preparation over the treated area.

The purpose of the work is to evaluate the quality of distribution of the working fluid upon contact of meeting spray cone located at the same level.

The scientific task is to determine the influence of the main factors on the quality of distribution of the working fluid over the underlying surface.

MATERIAL AND METHODS

Experimental studies began with an examination of the distribution of the liquid sprayed by a single deflector-type sprayer within the work area, with system pressure varying from 0.1 to 0.3 MPa. The following parameters were determined: spray width (b , mm); and the distribution of the working fluid across the spray width. Based on the data obtained, a sprayer spacing was determined that ensures continuous coverage of the treatment area (the overlap of spray patterns from individual sprayers should be at least 40% of their total width).

In the second stage of the study, the quality of liquid mineral fertilizer distribution was assessed by installing a boom with sprayers at a specific height relative to the objects being treated (H), and spraying the product was carried out using alternately sprayers of the corresponding diameter located in the same plane. The pressure in the system varied from 0.1 to 0.3 MPa with a sprayer spacing of 500 to 1000 mm (250 mm interval). Liquid was collected from the corrugat-

ed collecting surface into measuring containers, and their contents were then weighed. Based on the results of the experiments, diagrams of liquid distribution over the collecting surface were constructed, assessing the quality of its distribution.

In the third stage, the spray bar was also installed at a specific height relative to the objects being treated. The product was sprayed alternately using spray bars of different diameters, positioned on the bars at different heights h (at different levels). The system pressure also varied from 0.1 to 0.3 MPa with spray bar spacing ranging from 500 to 1000 mm (250 mm interval). Liquid was collected from the corrugated collecting surface into measuring containers, and their contents were then weighed. Based on the results of the experiments, liquid distribution diagrams were constructed across the collecting surface, assessing the quality of its distribution.

In the fourth stage, the spray boom was also installed at a specific height relative to the objects being treated. However, unlike the previous stages, the quality of the working fluid distribution over the underlying surface was assessed based on key factors: the working fluid pressure in the system (P , MPa), the nozzle orifice diameter (D , mm), and the nozzle spacing (B , mm). All the nozzles were installed at an offset height relative to each other.

To assess the deposition quality of the sprayed preparation onto the underlying surface, a factorial experiment was conducted with the specified factors varied at three levels. A composite three-level symmetrical design #34⁴ was selected for the experiment. After implementing the experimental plan, the results were processed in accordance with the recommendations^{5, 6}.

³Application of liquid nitrogen fertilizers UAN and sulfur-containing fertilizers // AgroVestnik: Internet portal. URL: agrovesti.net/lib/tech/fertilizer-tech/primenenie-zhidkikh-azotnykh-udobrenij-kas-i-serosoderzhashchikh-udobrenij.html.

⁴*Brodsky V.Z., Brodsky L.I., Golikova T.I., Nikitina E.P., Panchenko L.A.* Tables of experimental plans for factor and polynomial models: reference ed. Moscow: Metallurgy, 1982, 752 p.

⁵*Melnikov S.V., Aleshkin V.R., Roshchin P.M.* Experimental planning in agricultural process research. 2nd ed., revised and enlarged. L.: Kolos, 1980, 168 p.

⁶*Mosteller F., Tukey D.W.* Data Analysis and Regression / translated from English by Yu.N. Blagoveshchensky; edited by Yu.P. Adler. Moscow: Finance and Statistics, 1982, 238 p.

The experiments were carried out on a specially created laboratory setup that allowed spraying and capturing the working fluid (see Fig. 1).

RESULTS AND DISCUSSION

In accordance with the selected methodological approaches, an assessment was made of the distribution of the product sprayed by a single deflector sprayer under varying hydraulic system pressure (0.1–0.3 MPa) and with the sprayer positioned at a height of 0.7 m above the underlying surface (see Table 1). The sprayer operated for 30 s. The collected working fluid was weighed on a VK-600 laboratory scale. Spray cone width graphs were plotted based on the weighing results of the liquid collected from the underlying surface (see Fig. 2).

The data presented indicate that an increase in the spray pattern width is observed both with increasing the nozzle orifice diameter and with increasing the system pressure. However, a stabilization of the spray pattern width is observed with increasing nozzle orifice diameter to 2.5–3.5 mm at a given system pressure. This means that nozzles can be spaced evenly on the boom.

As for the nature of the liquid distribution across the spray cone width, it fully complies with the law of normal distribution. Deviations in the lines in some places can be explained by imprecise manufacturing of the nozzles and microroughness of the collecting surface.



Рис. 1. Лабораторная установка для оценки качества распределения распыленной рабочей жидкости

Fig. 1. Laboratory setup for evaluating the quality of atomized working fluid distribution

Табл. 1. Ширина факела распыла жидкости в зависимости от давления в системе и диаметра отверстия распылителя, мм

Table 1. Width of fluid atomization plume depending on the system pressure and atomizer orifice diameter, mm

System pressure, MPa	Spray hole diameter, mm		
	1,5	2,5	3,5
0,1	1560	2200	2200
0,2	1880	2300	2300
0,3	2005	2400	2400

Further studies of the distribution of the liquid over the underlying surface with sprayers installed at different levels allow us to state a fairly high quality of its deposition: at $D = 1.5$ mm and $P = 0.1$ MPa, the unevenness expressed by the variation coefficient was 8.9%, at $D = 2.5$ mm and $P = 0.2$ MPa – 7.35%, at $D = 2.5$ mm and $P = 0.3$ MPa – 2.9% (see Fig. 3).

When spraying liquid with the nozzles installed at the same height, an increase in the volume of the collected liquid was observed at the points of contact of the meeting spray cones (at the center of the sprayer placement step).

In principle, the distribution of the liquid over the collecting surface is the same, so we will only show a few fragments (see Fig. 4).

At the final stage of the research, an assessment was made of the quality of distribution of the liquid medium over the underlying surface using deflector sprayers installed at different heights.

As noted earlier, a three-level symmetrical design No. 34 was implemented in the study (see footnote 4). After implementing the designated experimental plan and processing the results (see Table 2), the regression coefficients were calculated taking into account their significance, and a regression model of the liquid distribution process over the underlying surface was obtained

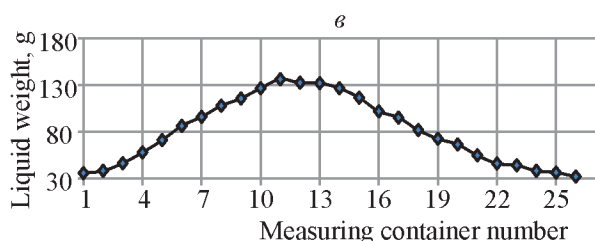
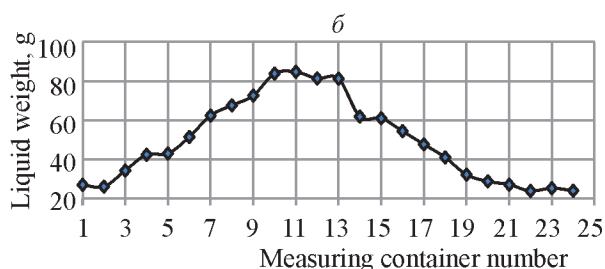
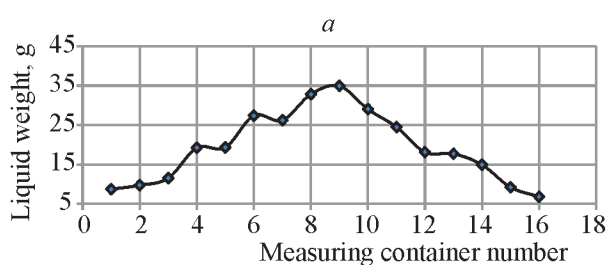


Рис. 2. Характер распределения жидкости в факеле распыла одиночного дефлекторного распылителя (фрагменты):

a – $D = 1,5$ мм, $P = 0,1$ МПа; *б* – $D = 2,5$ мм, $P = 0,2$ МПа; *в* – $D = 2,5$ мм, $P = 0,3$ МПа

Fig. 2. Character of liquid distribution in the atomizing plume of a single deflector atomizer (fragments):

a – $D = 1.5$ mm, $P = 0.1$ MPa; *б* – $D = 2.5$ mm, $P = 0.2$ MPa; *в* – $D = 2.5$ mm, $P = 0.3$ MPa

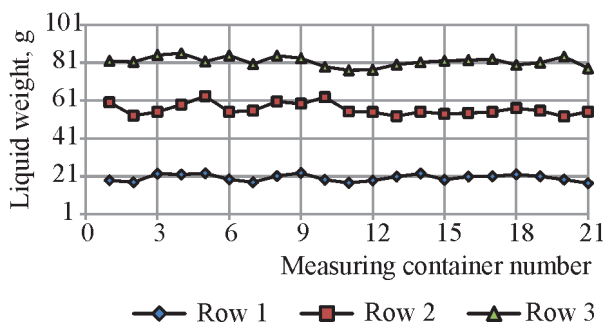


Рис. 3. Характер распределения жидкости по подстилающей поверхности при разноуровневой установке распылителей (фрагменты):

ряд 1 – $D = 1,5$ мм, $P = 0,1$ МПа; ряд 2 – $D = 2,5$ мм, $P = 0,2$ МПа; ряд 3 – $D = 2,5$ мм, $P = 0,3$ МПа

Fig. 3. Character of liquid distribution over the underlying surface at different levels of atomizer installation (fragments):

row 1 – $D = 1.5$ mm, $P = 0.1$ MPa; row 2 – $D = 2.5$ mm, $P = 0.2$ MPa; row 3 – $D = 2.5$ mm, $P = 0.3$ MPa

$$Y = 3,49 + 0,92 X_1^2 - 0,48 X_2^2 + 3,52 X_3^2 - 0,87 X_1 - 0,05 X_2 - 1,13 X_3 + 1,36 X_1 X_2 - 1,66 X_1 X_3 - 1,09 X_2 X_3.$$

As the analysis of the regression equation, the graphical interpretation of which is presented in Fig. 5, shows, the influence of each factor on the quality of distribution of the working fluid is ambiguous.

The quality of distribution depends to a greater extent on the spacing of the nozzles on the boom (factor X_3), and to a lesser extent on the pressure in the system (X_1) and the diameter of the nozzle opening (X_2).

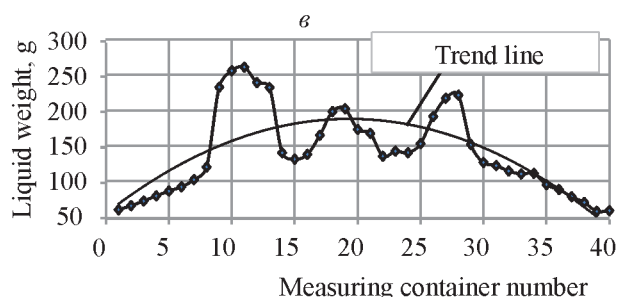
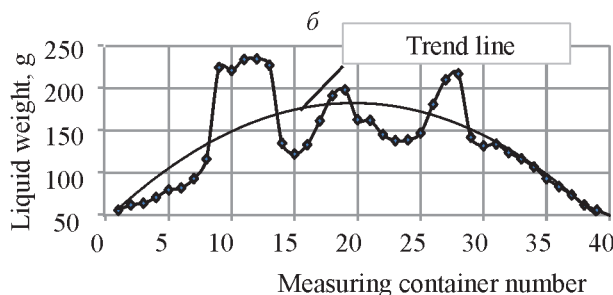
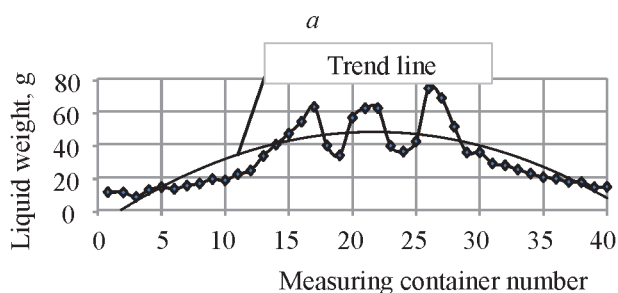


Рис. 4. Характер распределения жидкости при установке распылителей на одном уровне (фрагменты):

a – $D = 1,5$ мм, $P = 0,1$ МПа; *б* – $D = 2,5$ мм, $P = 0,2$ МПа; *в* – $D = 2,5$ мм, $P = 0,3$ МПа

Fig. 4. Character of liquid distribution when installing atomizers at the same level (fragments):

a – $D = 1.5$ mm, $P = 0.1$ MPa; *б* – $D = 2.5$ mm, $P = 0.2$ MPa; *в* – $D = 2.5$ mm, $P = 0.3$ MPa

Since $b_i > 0$, then an increase in X_i raises the unevenness of the distribution of the working fluid, the maximum effect is achieved when B_{min} .

The influence of the mixed product of factors is estimated by the significance and sign of the coefficient b_{ij} . Since at $X_1 X_2 b_{ij} > 0$, then the quality of distribution will increase, if X_1 and X_2 are simultaneously on the upper or lower level.

Taking into account that at $X_1 X_3 b_{ij} < 0$ the quality of distribution will increase if $X_1 X_3$ are located on opposite upper and lower levels. Given that at $X_2 X_3 b_{ij} < 0$ the quality of distribution will increase if X_2 and X_3 will also be on opposite levels.

At minimum values of the factors, their influence on the quality of distribution is practically equal, and this trend persists until the factors

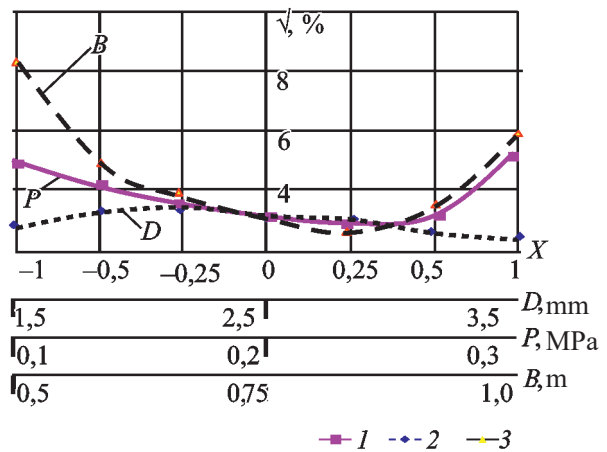


Рис. 5. Графическая интерпретация регрессионного уравнения:

$1 - \gamma = f(P); 2 - \gamma = f(D); 3 - \gamma = f(B)$

Fig. 5. Graphical interpretation of the regression equation:

$1 - \gamma = f(P); 2 - \gamma = f(D); 3 - \gamma = f(B)$

Табл. 2. Матрица планирования и результаты эксперимента

Table 2. Planning matrix and experimental results

Factor	Level of variation of factors			Unevenness (coefficient of variation) $\sqrt{\gamma}, \%$
	-1	0	+1	
System pressure, P , MPa (X_1)	0,1	0,2	0,3	
Spray hole diameter, D , mm (X_2)	1,5	2,5	3,5	
Step of placement of sprayers, B , mm (X_3)	500	750	1000	
	P	D	B	
Experiment number:				
1	-1	-1	-1	8,9
2	+1	-1	-1	8,2
3	-1	+1	-1	8,0
4	+1	+1	-1	12,5
5	-1	-1	+1	10,7
6	+1	-1	+1	3,1
7	-1	+1	+1	5,2
8	+1	+1	+1	3,3
9	-1	0	0	5,9
10	+1	0	0	2,9
11	0	1	0	2,3
12	0	1	0	3,7
13	0	0	-1	7,4
14	0	0	+1	6,6
Average				6,3

reach average values within the range of variation in the experiment. As the values increase further, the spacing of the nozzles exerts the greatest influence on the quality of distribution.

CONCLUSIONS

1. Using deflector sprayers, increased unevenness in the deposition of liquid mineral fertilizers onto the underlying surface has been revealed upon contact between spray cones located at the same level relative to the distribution rod (exceeding the base level by 1.8–2.4 times).

2. It has been established that due to the multi-level installation of deflector sprayers on the boom, minimal unevenness of the spraying of the working fluid is achieved (no more than 7%).

3. The spacing of the sprayers on the rod has the greatest impact on the quality of distribution of liquid mineral fertilizers during their surface application (91.8%); to a lesser extent, this indicator depends on the pressure in the system (5.7%) and the diameter of the sprayer opening (2.5%).

СПИСОК ЛИТЕРАТУРЫ

1. Назаров Н.Н., Некрасова И.В. Концептуальная модель процесса внесения в почву жидких форм минеральных удобрений // Сибирский вестник сельскохозяйственной науки. 2023. Т. 53. № 7. С. 88–98. DOI: 10.26898/0370-8799-2023-7-11.
2. Назаров Н.Н., Некрасова И.В. Распределение жидких минеральных удобрений по количеству рабочих органов // Вестник Алтайского государственного аграрного университета. 2023. № 5 (223). С. 106–113. DOI: 10.53083/1996-4277-2023-223-5-106-113.
3. Милюткин В.А., Иванов В.А., Попов А.В. Перспективные инновационные техника и технологии для внесения жидких азотных минеральных удобрений КАС // Известия Самарской государственной сельскохозяйственной академии. 2022. № 1. С. 38–47.
4. Прокопчук Р.Е. Эффективность применения гранулированных и жидких минеральных удобрений при возделывании яровой пшени-

- цы в Алтайском крае // Вестник молодежной науки Алтайского государственного аграрного университета. 2021. № 1. С. 110–113.
5. Васин А.В., Васин В.Г., Стрижаков А.О. Формирование продуктивности яровой мягкой пшеницы при системном применении жидких минеральных удобрений Мегамикс // Известия Самарского научного центра Российской академии наук. Сельскохозяйственные науки. 2022. Т. 1. № 4 (4). С. 28–35. DOI: 10.37313/2782-6562-2022-1-4-28-35.
6. Мамеев В.В., Нестеренко О.А., Дронов А.В., Ториков В.Е., Петрова С.Н. Эффективное применение минеральных удобрений компании «ФосАгро-Регион» в агроценозах кукурузы на серых лесных почвах Брянской области // Вестник Брянской государственной сельскохозяйственной академии. 2022. № 2 (90). С. 14–21. DOI: 10.52691/2500-2651-2022-90-2-14-21.
7. Милюткин В.А., Буксман В.Э. Повышение эффективности опрыскивателей для внесения жидких минеральных удобрений // Известия Оренбургского государственного аграрного университета. 2018. № 1 (69). С. 119–122.
8. Даниленко Ж.В., Шемякин А.В., Ерошкин А.Д., Андреев К.П., Костенко М.Ю., Терентьев В.В. Координатное внесение удобрений на основе полевого мониторинга // Вестник Рязанского государственного агротехнологического университета им. П.А. Костычева. 2018. № 4 (40). С. 167–172.
9. Милюткин В.А., Сысоев В.Н., Макушин А.Н., Длужевский Н.Г. Комплексное обеспечение инновационных технологий производства сельскохозяйственных культур с применением жидких азотных удобрений КАС // Вестник Иркутской государственной сельскохозяйственной академии. 2022. № 108. С. 19–31. DOI: 10.51215/1999-3765-2022-108-19-31.
10. Свиридов А.С., Катаев Ю.В., Загоруйко М.Г. Анализ типов распылителей сельскохозяйственных опрыскивателей // Аграрный научный журнал. 2021. № 6. С. 96–100. DOI: 10.28983/asj.y2021i6pp96-100.
11. Яковлев Д.А., Беляев В.И., Прокопчук Р.Е. Сравнительная энергооценка рабочих органов посевных машин для прямого посева в условиях различного увлажнения почв // Вестник Алтайского государственного аграрного университета. 2020. № 6 (188). С. 144–150.

12. Беляев В.И., Буксман В.Э., Прокопчук Р.Е. Мониторинг работы посевных комплексов Condor 15000 и Citan Z в Алтайском крае // Вестник Алтайского государственного аграрного университета. 2021. № 4 (198). С. 100–109.
13. Беляев В.И., Прокопчук Р.Е., Буторов Н.А. Влияние режимов работы посевных агрегатов на качество посева, водный режим почвы и урожай яровой пшеницы // Вестник Алтайского государственного аграрного университета. 2021. № 9 (203). С. 114–119. DOI: 10.53083/1996-4277-2021-203-09-114-119.
14. Прокопчук Р.Е., Беляев В.И. Энергооценка машинно-тракторных агрегатов для внутрипочвенного внесения жидких минеральных удобрений // Вестник АПК Верхневолжья. 2021. № 3 (55). С. 71–75. DOI: 10.35694/YARCX.2021.55.3.014.
1. Nazarov N.N., Nekrasova I.V. Conceptual model of the process of applying liquid forms of mineral fertilizers to the soil. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2023, vol. 53, no. 7, pp. 88–98. (In Russian). DOI: 10.26898/0370-8799-2023-7-11.
2. Nazarov N.N., Nekrasova I.V. Distribution of liquid mineral fertilizers by the number of working organs. *Vestnik Altayskogo gosudarstvennogo agrarnogo universiteta = Bulletin of Altai State Agricultural University*, 2023, no. 5 (223), pp. 106–113. (In Russian). DOI: 10.53083/1996-4277-2023-223-5-106-113.
3. Milyutkin V.A., Ivanov V.A., Popov A.V. Advanced engineering and technology for application of liquid nitrogen chemical fertilizer carbamide-ammonia mixture based. *Izvestiya Samarskoy gosudarstvennoy sel'skokhozyaistvennoy akademii = Bulletin Samara state agricultural academy*, 2022, no. 1, pp. 38–47. (In Russian).
4. Prokopchuk R.E. Efficiency of application of pelleted and liquid mineral fertilizers in cultivation of spring wheat in the Altai region. *Vestnik molodyozhnoy nauki Altayskogo gosudarstvennogo agrarnogo universiteta = Bulletin of Youth Science of Altai State Agricultural University*, 2021, no. 1, pp. 110–113. (In Russian).
5. Vasin A.V., Vasin V.G., Strizhakov A.O. Formation of productivity of spring soft wheat for systemic use of liquid mineral fertilizers Megamix. *Izvestiya Samarskogo nauchnogo tsentra Rossiyskoy akademii nauk = Izvestia of Samara Scientific Center of the Russian Academy of Sciences*, 2022, vol. 1, no. 4 (4), pp. 28–35. (In Russian). DOI: 10.37313/2782-6562-2022-1-4-28-35.
6. Mameev V.V., Nesterenko O.A., Dronov A.V., Torikov V.E., Petrova S.N. Effective application of mineral fertilizers of the company "Phos-Agro-Region" in agrocenoses of corn on gray forest soils of Bryansk region. *Vestnik Bryanskoy gosudarstvennoy sel'skokhozyaistvennoy akademii = Vestnik of the Bryansk state agricultural academy*, 2022, no. 2 (90), pp. 14–21. (In Russian). DOI: 10.52691/2500-2651-2022-90-2-14-21.
7. Milyutkin V.A., Buksman V.E. Increasing the effectiveness of sprayers for liquid mineral fertilizers application. *Izvestiya Orenburgskogo gosudarstvennogo agrarnogo universiteta = Izvestia Orenburg State Agrarian University*, 2018, no. 1 (69), pp. 119–122. (In Russian).
8. Danilenko Zh.V., Shemyakin A.V., Eroshkin A.D., Andreev K.P., Kostenko M.Yu., Terentyev V.V. Coordinate fertilizer approaches based on field monitoring. *Vestnik Ryazanskogo gosudarstvennogo agrotekhnologicheskogo universiteta imeni P.A. Kostycheva = Herald of Ryazan State Agrotechnological University Named after P.A. Kostychev*, 2018, no. 4 (40), pp. 167–172. (In Russian).
9. Milyutkin V.A., Sysoev V.N., Makushin A.N., Dluzhevskiy N.G. Integrated provision of innovative technologies for the production of agricultural crops using liquid nitrogen fertilizers CAM. *Vestnik Irkutskoy gosudarstvennoy sel'skokhozyaistvennoy akademii = Vestnik IrGSHA*, 2022, no. 108, pp. 19–31. (In Russian). DOI: 10.51215/1999-3765-2022-108-19-31.
10. Sviridov A.S., Kataev Yu.V., Zagoruyko M.G. Analysis of the types of agricultural sprayers' nozzles. *Agrarniy nauchnyy zhurnal = Agrarian Scientific Journal*, 2021, no. 6, pp. 96–100. (In Russian). DOI: 10.28983/asj.y2021i6pp96-100.
11. Yakovlev D.A., Belyaev V.I., Prokopchuk R.E. Comparative energy evaluation of the working tools of sowing machines for direct seeding under conditions of different soil moisture content. *Vestnik Altayskogo gosudarstvennogo agrarnogo universiteta = Bulletin of Altai State Agricultural University*, 2020, no. 6 (188), pp. 144–150. (In Russian).

12. Belyaev V.I., Buksman V.E., Prokopchuk R.E. Monitoring Condor 15000 and Citan Z seed drills in the Altai Territory. *Vestnik Altayskogo gosudarstvennogo agrarnogo universiteta = Bulletin of Altai State Agricultural University*, 2021, no. 4 (198), pp. 100–109. (In Russian).
13. Belyaev V.I., Prokopchuk R.E., Butorov N.A. Influence of operational modes of sowing units on sowing quality, soil water regime and spring wheat yield. *Vestnik Altayskogo gosudarstvennogo agrarnogo universiteta = Bulletin of Altai State Agricultural University*, 2021, no. 9 (203), pp. 114–119. (In Russian). DOI: 10.53083/1996-4277-2021-203-09-114-119.
14. Prokopchuk R.E., Belyaev V.I. Energy assessment of machine-tractor units for internal soil application of liquid mineral fertilizers. *Vestnik APK Verkhnevolzh'ya = Herald of Agroindustrial complex of Upper Volga region*, 2021, no. 3 (55), pp. 71–75. (In Russian). DOI: 10.35694/YARCX.2021.55.3.014.

ИНФОРМАЦИЯ ОБ АВТОРАХ

✉ **Назаров Н.Н.**, главный научный сотрудник, доктор технических наук; SPIN-код 4972-8597; **адрес для переписки:** Россия, 630501, Новосибирская область, р.п. Краснообск, а/я 463; e-mail: nazarovnn@sfscs.ru

Некрасова И.В., старший научный сотрудник; SPIN-код 4750-1114

AUTHOR INFORMATION

✉ **Nikolay N. Nazarov**, Head Researcher, Doctor of Science in Engineering; SPIN-code 4972-8597; **address:** PO Box 463, Krasnoobsk, Novosibirsk region, 630501, Russia; e-mail: nazarovnn@sfscs.ru

Irina V. Nekrasova, Senior Researcher; SPIN-code 4750-1114

Дата поступления статьи / Received by the editors 29.01.2025
Дата принятия к публикации / Accepted for publication 10.03.2025
Дата публикации / Published 16.06.2025

Подходы к численному моделированию работы биореакторов анаэробного сбраживания: обзор

Рубцов А.А.¹, (✉) Немущенко Д.А.²

¹Кемеровский государственный университет
Кемерово, Россия

²Новосибирский государственный технический университет
Новосибирск, Россия

(✉)e-mail: nemuschenko@corp.nstu.ru

С интенсивным развитием сельского хозяйства активно проявляются неблагоприятные экологические последствия. В частности, на решение проблем животноводческих комплексов в некоторых регионах Российской Федерации выделяются значительные финансовые ресурсы. В работе сделан обзор подходов к численному моделированию процессов, протекающих при анаэробном сбраживании и имеющих своей целью получение биогаза (метана) и органического удобрения. В последние годы наблюдается рост интереса среди зарубежных и российских ученых к проблеме моделирования технологического процесса биореакторов в связи с развитием вычислительных мощностей и возможностей учета в модели факторов, влияющих на эффективность сбраживания, – повышения выхода биогаза или качества удобрения. Выявлены тенденции и недостатки отдельных направлений, а также подходы, позволяющие учитывать биохимические процессы в объеме реактора и на поверхности частиц субстрата. Показана актуальность поиска способов оценки динамики численности и факторов, от которых зависит многообразие микробиологических консорциумов. Наиболее перспективными для практического применения при производстве биоудобрения следует считать модели, основанные на машинном обучении. Они позволяют прогнозировать развитие микробиологических сообществ, прошедшие верификацию на полупромышленных экспериментальных данных в условиях сбраживания конкретных субстратов, а также численные модели и программные средства, включающие расчет гидродинамических параметров, поля температур при перемешивании и подаче новой порции субстрата в реактор и некоторые наиболее важные биохимические процессы, приводящие к образованию лимитирующих продуктов стадий ацидогенеза и ацетогенеза. На основе полученного массива информации формулировались задачи численного моделирования условий перемешивания в реакторах действующего комплекса.

Ключевые слова: численное моделирование, анаэробное сбраживание, режим перемешивания, органическое удобрение, отходы животноводства, утилизация отходов, ферментер

Approaches to numerical modeling of anaerobic digestion bioreactor operation: a review

Rubcov A.A.¹, (✉) Nemuschenko D.A.²

¹Kemerovo State University
Kemerovo, Russia

²Novosibirsk State Technical University
Novosibirsk, Russia

(✉)e-mail: nemuschenko@corp.nstu.ru

With the intensive development of agriculture, unfavorable environmental effects are actively manifesting themselves. In particular, significant financial resources are allocated to solve the problems of livestock complexes in some regions of the Russian Federation. The paper provides an overview of the approaches to numerical modeling of processes occurring during anaerobic fermentation and aimed at obtaining biogas (methane) and organic fertilizer. In recent years, there has been an increase in the interest among foreign and Russian scientists in the problem of modeling the technological process of bioreactors due to the development of computing power and the ability to take into account in the model the factors affecting the efficiency of fermentation, increasing the yield of biogas or the quality of fertilizer. The trends and shortcomings of individual areas, as well as approaches that allow taking

into account biochemical processes in the reactor volume and on the surface of substrate particles, are identified. The relevance of searching for methods for assessing the dynamics of the number and the factors on which the diversity of microbiological consortia depends is shown. The most promising for practical application in the production of biofertilizers should be considered the models based on machine learning and allowing to predict the development of microbiological communities, verified on semi-industrial experimental data under the conditions of fermentation of specific substrates, as well as numerical models and software tools, including the calculation of hydrodynamic parameters, temperature fields during mixing and feeding a new portion of the substrate into the reactor and some of the most important biochemical processes leading to the formation of limiting products of the acidogenesis and acetogenesis stages. Based on the obtained array of information, the problems of numerical modeling of mixing conditions in the reactors of the operating complex were formulated.

Keywords: numerical modeling, anaerobic digestion, process of mixing, organic fertilizer, animal waste, waste disposal, digester

Для цитирования: Рубцов А.А., Немущенко Д.А. Подходы к численному моделированию работы биореакторов анаэробного сбраживания: обзор // Сибирский вестник сельскохозяйственной науки. 2025. Т. 55. № 5. С. 115–129. <https://doi.org/10.26898/0370-8799-2025-5-11>

For citation: Rubcov A.A., Nemuschenko D.A. Approaches to numerical modeling of anaerobic digestion bioreactor operation: a review. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2025, vol. 55, no. 5, pp. 115–129. <https://doi.org/10.26898/0370-8799-2025-5-11>

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

Благодарность

Работа выполнена в рамках субсидии Министерства науки и инновационной политики Новосибирской области, договор № Т-34 от 22.09.2023 г.

Acknowledgments

The work was carried out within the framework of a subsidy from the Ministry of Science and Innovation Policy of the Novosibirsk Region, agreement No. T-34 dated September 22, 2023.

Agricultural and farming facilities generate large quantities of livestock waste. Livestock waste is the substance left over from the vital processes of farm animals and poultry. In addition to the organic components of manure and litter, it also contains other components: process and flush water, feed residues, growth promoters and antibiotics, and gaseous substances.

Livestock farm waste contains approximately 100 types of pathogens that cause dangerous diseases. When stored outdoors, it releases volatile components that have a strong odor, known as "malodorants," which pose an environmental problem for communities located near livestock farms. Furthermore, decomposition results in air pollution with greenhouse gases and contamination of surface and groundwater with certain specific compounds.

Due to the intensive development of agriculture, soil degradation as a result of contamina-

tion by livestock waste is a pressing issue. It is important to promptly dispose of waste and convert it into cost-effective organic fertilizer, then incorporate it into organic farming systems as part of a technology for producing healthy crops. There is ample experience globally in operating biogas plants using organic feedstock, including agricultural waste.

Unfortunately, the practical importance of processing livestock waste into new bioorganic products, suitable for developing organic farming, which relies heavily on microbiota, is underestimated. Biofertilizer production can be achieved using processing facilities that utilize livestock waste in a manner that yields a safe bioorganic product based on humic substances, phytohormones, and beneficial microbiota. The resulting product can facilitate the conversion of soil minerals into a form more accessible to plants. Certain groups of anaerobic bacteria can

support and enhance the adaptive properties of plants.

Biogas plants and complexes of various designs implement the anaerobic digestion process. The intensity of the fermentation process and the production of an effective bioorganic fertilizer are determined by creating optimal conditions for the microbial colonies in the reactor. The following can be identified as the most important process parameters:

- temperature gradient in the bioreactor tank;
- acidity of the environment and the content of waste products;
- the speed of movement of biomass particles and flows in the reactor;
- characteristics of the nutrient medium.

Of no small importance are the composition and technology of raw material preparation, the technology of introduction into the reactor and other technological features.

The process of mixing the substrate in bioreactors directly affects the above indicators and solves the following problems¹⁻³:

- acceleration of fermentation of a fresh portion of raw materials due to contact with a biologically active liquid in the reactor, maintaining contact between enzymes and their substrates;
- uniform distribution of heat and nutrients throughout the reactor volume;
- preventing the formation of a crust at the boundary between liquid and gaseous media;
- intensification of biogas removal from the substrate.

Mixing can be accomplished by mechanical devices in the fermenter (stirrers), by pumping the feedstock from the upper to the lower zone using a pump, typically located outside the reactor⁴, or pneumatically by bubbling biogas

through the mass in the reactor. The advantages and disadvantages of these mixing methods have been described in detail⁵. For example, in Germany, up to 90% of biogas plants are equipped with stirrers of various designs (see footnote 1).

Optimizing mixing is crucial, as it is one of the most energy-intensive processes in anaerobic digestion reactor operation. The authors of the research paper set the following overall goal: modernizing an existing organic waste processing complex using anaerobic digestion. This modernization includes the implementation of an automated control system, increasing its energy efficiency, and improving the quality of the resulting organic fertilizer by improving mixing conditions. To achieve this goal, a review of existing, particularly international, experience in the field of biogas plant operation was conducted.

The publication review aims at identifying the directions and approaches to the numerical optimization of bioreactors, as well as indicators characterizing the mixing regime in the reactor for the production of biofertilizer, and identifying factors that can be neglected. Based on the obtained data, tasks for numerical modeling of the mixing conditions in reactors of the operating complex were formulated for specialized specialists.

In this review, we will focus on general trends in the field of numerical modeling of bioreactors, without going into detail about the mathematical algorithm and the program code.

Temperature conditions (absolute values and gradient) in the reactor have the greatest influence on the growth and activity of microorganisms, and, accordingly, the kinetics and stability of the anaerobic process [1]. Most often, temperature conditions are designed to maximize

¹Biogas Handbook. From Production to Use: A Draft // Agency for Renewable Resources (FNR), translated from German, 5th edition, revised. Germany, Gülzow, 2010, 213 p.

²Vedenev A.G., Maslov A.N. Construction of biogas plants: a brief guide. Bishkek: "Euro", 2006. 28 p.

³Shayakhmetov R.G., Isakov V.G., Efremov S.M. Experience of using the ANSYS WORKBENCH software package for modeling mixing processes in methane tanks // Bulletin of Kalashnikov ISTU, 2013, vol. 3, N 59, pp. 127–131.

⁴Rico C., Rico J.L., Munoz N., Gomez B., Tejero I. Effect of mixing on biogas production during mesophilic anaerobic digestion of screened dairy manure in a pilot plant // Engineering in Life Sciences, 2011, vol. 11, N 5, pp. 476–481. DOI: 10.1002/elsc.201100010.

⁵Suslov D.Yu. Mixing of biomass in a bioreactor for biogas production // Epoch of Science, 2015, N 4, pp. 444–447.

biogas yield and methane content⁶ [2].

The acidity of the environment (pH) has no small part. Different populations of microorganisms require certain optimal pH ranges in which they exhibit maximum activity [3]. For example, the pH range of 5.5–6.5 is most preferable for hydrolysis and acidogenesis, while for acetogenesis and methanogenesis, the most suitable pH value is in the range of 7.0–8.5.

Mathematical (numerical) modeling methods, implemented in the form of software packages from various developers, are increasingly used in the design of biogas plants and complexes. Calculations and visual aids obtained through modeling allow one to assess the impact of physicochemical and biological processes occurring in the reactor, mixing factors, and other process features on the efficiency of processing products without conducting costly full-scale experiments. Numerical modeling is used to optimize the shapes, designs, and operating modes of bioreactors to improve productivity and product quality.

The authors of the review [1] provide a classification of the methods for numerical modeling of anaerobic digestion processes that have found practical application:

1) models based on mathematical formulations of the basic laws reflecting the physicochemical and biological processes in the reactor: elementary models; models taking into account primarily mass transfer; models based on computational fluid dynamics;

2) kinetic models;

3) phenomenological models: regression models; models based on the support vector machine; models using neural networks and/or artificial intelligence, etc.

The first type of models is based on the laws of hydrodynamics, heat transfer, and the results of research into biochemical processes. Clearly, such models should have priority application, but they have significant drawbacks:

– the presence of a significant amount of unknown initial data that needs to be determined experimentally;

– limited computing resources due to the need to simultaneously take into account various physical and chemical processes in the model.

Elementary models are based on calculating the dynamics of individual components in the reactor—liquid, solid, and gaseous phases—the concentration of solid particles of biological and mineral substrate, the concentration of soluble components and microbial groups, and the concentration of biogas components. They primarily involve solving systems of differential equations to describe mass transfer processes or equilibrium conditions.

Models based on mass transfer calculations take into account primarily diffusion and convective transfer and are used, according to the authors⁷ [1], in the case of a concentrated substrate in the reactor (more than 15 wt.% solid phase). When the solid phase content is more than 15 wt.%, the term "solid-state anaerobic digestion" is used.

We consider the most promising direction in this area to be the one related to modeling (and generally studying the mechanisms) of transfer of products of biochemical processes between solid particles of raw materials (substrate) and cells of microorganisms, which the authors tried to model^{8–9}.

Computational fluid dynamics (CFD)-based models capture the most important processes

⁶Sihuang Xie, Faisal I. Hai, Xinmin Zhan, Wenshan Guo, Hao H. Ngo, William E. Price, Long D. Nghiem Anaerobic co-digestion: a critical review of mathematical modelling for performance optimization // *Bioresource Technology*, 2016, N 222, pp. 498–512. DOI: 10.1016/j.biortech.2016.10.015.

⁷Fuqing Xu, Yebo Li, Zhi-Wu Wang Mathematical modeling of solid-state anaerobic digestion // *Progress in Energy and Combustion Science*, 2015, N 51, pp. 49–66. DOI: 10.1016/j.pecs.2015.09.001.

⁸Kalyuzhnyi S.V., Veeken A., Hamelers H.V.M. Two-particle model of anaerobic solid-state fermentation // *Water Sci. Technol.*, 2000, vol. 41, N 3, pp. 43–50. DOI: 10.2166/wst.2000.0054.

⁹Fuqing Xu, Zhi-Wu Wang, Li Tang, Yebo Li. A mass diffusion-based interpretation of the effect of total solids content on solid-state anaerobic digestion of cellulosic biomass // *Bioresource Technology*, 2014, N 167, pp. 178–185. DOI: 10.1016/j.biortech.2014.05.114.

occurring during mixing. They are used to optimize reactor designs and mixing mechanisms, and to reduce energy consumption. The most widely used commercial software products are ANSYS Fluent [4–6], ANSYS CFX [7], and COMSOL Multiphysics [8]. Disadvantages of research using these products include the limited use of biochemical reactions in conjunction with fluid dynamics modeling.

So-called "kinetic models" are based on the use of adequate simplified equations that relate bioreactor performance to certain input data obtained from laboratory experiments or industrial reactor operation. These models are designed to simplify the modeling process by relying on two key assumptions that are bottlenecks in biogas synthesis technology [1]:

- the concentration of beneficial microorganisms is the only characteristic responsible for biogas/CH₄ production;
- the growth of microorganisms is limited only by the rate of hydrolysis and the availability of substrate particles for nutrition.

Phenomenological models utilize various machine learning technologies and are designed to address a limited number of target problems. The main advantage is that model construction does not require a deep understanding of the biochemical, chemical, and physicochemical processes occurring during anaerobic digestion [1].

Machine learning can be based on the results of field tests that relate the bioreactor's gas yield performance to the following process characteristics, such as [9]:

- the composition of the raw material and the ratio of substrate components (municipal wastewater and sludge, agricultural waste - straw, silage, husks, vegetable waste, carbohydrates, proteins, lipids, etc.), the chemical oxygen demand index;
- additives (various colonies of microorganisms, enzymes, microelements, defoamers, sorbents), dosage and particle size of the materials;

– conditions of the anaerobic digestion process (temperature, pH value, electrical conductivity, raw material pre-treatment technologies, proportion of the organic component).

The ANSYS CFX software package, with numerous simplifications, allows for the modeling of the velocity and temperature field within a reactor volume when formulating the problem of continuously feeding a cold substrate at a given flow rate [7]. To validate the model, co-fermentation of rice husks and pig manure was conducted in two types of bioreactors: one with a mixing system using substrate recirculation through the inlet and outlet pipes, and one without mixing.

For the hydrodynamic modeling, the bioreactor was assumed to operate at low flow rates in the recirculation stream ($Re < 2000$); turbulence models were not used. The reactor was analyzed in steady-state and transient conditions, taking into account heat transfer from the coil. Based on the heat flux estimates, the process can be considered isothermal [7].

The authors¹⁰ used a calculation method to study the temperature field in a biogas plant reactor.

The method is based on solving a continuous function that allows for modeling the heat conduction process. A horizontal reactor (tank) divided into sections by vertical partitions, without mixing devices, was chosen as the modeling object. The mathematical model is described in detail, and the results of a computational experiment are presented.

The authors [10] have systematized extensive experience in the application of computational fluid dynamics models for the study and optimization of anaerobic digestion processes. The review examines specific studies demonstrating the possibility of taking into account the combination of biochemical and hydrodynamic models, turbulence, heat transfer processes, reactors of various designs, and the multiphase nature of the environment.

¹⁰*Ilyin Yu.P., Belov A.V., Stabulit I.S., Kuzmina N.Yu., Rudnykh N.V.* Determination of the characteristics of a stationary random process in a biogas plant reactor based on one implementation // AIC of Russia, 2017, vol. 24, N 2, pp. 418–425.

According to the review, the following hydrodynamic parameters are used, which, in the authors' opinion, influence biochemical processes and/or improve the efficiency of biogas production: Reynolds number, velocity field homogeneity index, velocity gradient, shear stress, dead zone volume, vorticity, flow helicity, the angle between the vorticity vector and the velocity vector, circulation time, power consumed for mixing, and substrate flow rate. In particular, shear stress must be assessed, as it affects the vital activity of microorganisms.

Models have been developed that take into account the heterogeneity of the internal environment of the bioreactor – the presence of dispersed media: liquid – solid, liquid – gas, liquid – gas – solid¹¹ [10].

Yu L. et al. (see footnote 11) validated a complex multistage model using laboratory (1 l) and pilot (70 l) vertical tube reactors, with mixing achieved by substrate circulation. The solids concentration was no more than 5 wt%. The following assumptions were made in the modeling:

- liquid phase – Newtonian fluid – water at a temperature of 35 °C;
- gaseous phase – gas bubbles 0.1 mm in size, density 1.139 kg/m³, viscosity 1.9 · 10⁻⁵ kg/(m · s);
- solid phase – spherical particles of a certain diameter.

The system of differential equations was programmed on the Matlab/Simulink platform, and the hydrodynamics were programmed using the FLUENT package.

It is obvious that a developed turbulent regime is formed during the mixing process. However, according to the review [10], only 18% of the publications reviewed take this factor into account in the model. The methods for turbulence recording and the existing experience are discussed in detail.

Models that take heat distribution processes into account are also unfairly underutilized, perhaps due to the prevalence of publications by the authors from warmer climates. A study by Merlin G. et al.¹² examines the need to account for heat loss in reactors operating in continental climates. A steady-state heat transfer model is used, with a calculation uncertainty of ~10% compared to experimental measurements. It is crucial to use such models at the design stage of the facilities to reduce heat loss to the environment. Specifically, the authors¹³ were able to identify flows and reduce heat loss through the inlet system and the lid of a semi-buried reactor by 30%, and losses through biogas by 15%. The calculations took into account atmospheric conditions, including ambient temperature throughout the year, solar radiation, and rainfall intensity.

Thakur H. et al. [11] defined the following parameters as the criteria for comparing the efficiency of the mixing processes:

- 1) dead volume (volume of stagnant zones), determined by the proportion of the reactor volume with a flow velocity of less than 5% of the maximum (in this study – 0.64 m/s);
- 2) velocity gradient, determined by the formula

$$G = \sqrt{\left(\frac{\partial u_x}{\partial y} + \frac{\partial u_y}{\partial x}\right)^2 + \left(\frac{\partial u_x}{\partial z} + \frac{\partial u_z}{\partial x}\right)^2 + \left(\frac{\partial u_y}{\partial z} + \frac{\partial u_z}{\partial y}\right)^2}$$

where u_x , u_y and u_z – cell velocity in the directions x , y and z respectively;

$$3) \quad UI = \frac{\sum_i |v_i - \bar{v}| V_i}{2\bar{v} \sum_i V_i}, \quad \text{at} \quad \bar{v} = \frac{\sum_i v_i V_i}{\sum_i V_i}$$

where v_i and V_i – cell speed and volume, \bar{v} – volume-averaged velocity in a reactor. The UI value

¹¹Liang Yu, Jingwei Ma, Craig Frear, Quanbao Zhao, Robert Dillon, Xiujin Li, Shulin Chen Multiphase modeling of settling and suspension in anaerobic digester // Appl. Energy, 2013, N 111, pp. 28–39. DOI: <https://doi.org/10.1016/j.apenergy.2013.04.073>.

¹²Gerard Merlin, Francois Kohler, Maele Bouvier, Thierry Lissolo, Herve Boileau Importance of heat transfer in an anaerobic digestion plant in a continental climate context // Bioresource Technology, 2012, N 124, pp. 59–67. DOI: 10.1016/j.biortech.2012.08.018.

¹³Rainier Hreiz, Nouceiba Adouani, Yves Jannot, Marie-Noelle Pons. Modeling and simulation of heat transfer phenomena in a semi-buried anaerobic digester // Chem. Eng. Res. Des. 2017. N 119. P. 101–116. DOI: 10.1016/j.cherd.2017.01.007.

ranges from 0 (homogeneous mixing) to 1 (no homogeneity).

As research has shown, when simulating the mixing of low-concentration suspensions (less than 2.5% solids by weight), the substrate can be considered a Newtonian fluid. Biogas yield in this case depends little on the rotation speed of the mixer blades [11].

Thakur H. et al. [11] selected four cubic reactors and one cylindrical reactor with variable impeller sizes for their study. Simulations were conducted using the ANSYS Fluent package in steady-state and transient modes. A single-phase medium and a non-Newtonian fluid were adopted, as the study focused on a high solids content. For each reactor, velocity and temperature profiles were constructed, based on which the mixing process was optimized and conclusions were drawn about the correlation between energy consumption for mixing and process parameters – dead volume, velocity gradient and homogeneity index. In [12], the hydrodynamics and heat distribution during the co-fermentation of food waste, sewage sludge, and cow manure (inoculum) in various ratios in mesophilic reactors of 0.25 and 6.5 l volumes with continuous stirring were modeled. Additionally, the solid phase concentrations were varied in the range from 2.5 to 12.1 wt%.

The studies conducted [13, 14] focused on modeling high solid phase concentrations (up to 12 wt.%) and the rheological characteristics of this case during mixing. Numerical modeling in the ANSYS Fluent package is supported by validation with experimental data. The problem was posed based on the assumption of previous authors about a higher biogas yield with an increase in the concentration of the organic phase. The proportion of organic matter in the sludge is described by the concentration of solid particles in general [13]. The operation of laboratory reactors of cylindrical and egg-shaped shapes with two types of mixers is simulated: propeller (three propellers on a single shaft) and screw (spiral ribbon). In the laboratory experiment, rheology

is simulated using a mixture of glycerol and water, without any solid impurities. In [14], the solid phase and mineral content, pH, chemical oxygen demand, volatile fatty acid concentrations, temperature, and biogas yield were determined during the full-scale experiment. Good agreement between the numerical simulation and velocity field measurement results is demonstrated. As expected, for a viscous liquid, a screw mixer proved to be more effective in terms of velocity field uniformity [13].

Otieno E.O. et al. [15] used the so-called “Box Behnken Design” – a method of organizing an experiment and processing an array of data using mathematical statistics methods, which made it possible to identify which of the many experimental parameters have the most significant impact on the efficiency of fermentation – the yield of biogas. In a laboratory experiment, agricultural waste (pineapple processing waste) was fermented together with cattle waste using a 6 m³ Rehau domestic biogas system. The following parameters were selected for variation: reactor temperature, substrate pH, and the concentration of pineapple processing waste in the substrate. Design Expert software was used to generate graphs and response surfaces to optimize experimental conditions and reduce the required amount of experimental data. The response surfaces allow one to estimate biogas yield depending on the two variable parameters.

In [16], similar to the previous study, distillation plant wastewater was fermented together with livestock waste in a simplified laboratory experiment. Instead of the ratio of raw materials, the retention time of the substrate in the reactor was varied in the range of 17–22 days.

The results of the study by Kim M. and Cui F. [17] provide comprehensive information and are an example of the approach and use of models based on machine learning. Machine learning was based on experimental data collected during long-term operation of laboratory (operated for 350 days), pilot (150 days), and full-scale (750 days) anaerobic digestion reactors. Using

the example of the digestion of sewage sludge and food waste with varying reactor conditions and continuous mixing, biogas production and chemical oxygen demand (COD) were primarily monitored.

Calculations were performed using the MATLAB package for statistical data processing and regression modeling. The availability of experimental data allows for validation of calculation results at various levels and scalability of the study results to other installations. Response surfaces constructed from the modeling results, for example, for COD versus total nitrogen content and methane yield, correlate well with the experimental data [17].

The most important area of numerical modeling, in our view, is the need to develop the models that can predict biochemical processes and the vital activity of a microbial consortium, as well as the possibility of integrating them with hydrodynamic models. The ultimate goal of most research in this area is to determine the dependence of the rate of decomposition and conversion of organic matter and the increase in biogas production on biochemical and hydrodynamic parameters in a reactor [17]. Since the volume of necessary calculations increases exponentially, research is aimed at simplifying the models and identifying factors that can be neglected. Thus, the models of Wu B. et al.¹⁴ and Tobo Y.M. et al. [4] show a good approximation to experimental data and take into account the hydrolysis of carbohydrates, proteins and lipids to soluble sugar, amino acids and long-chain fatty acids, as well as changes in the mass of organic matter.

Vavilin V.A. et al.^{15, 16} also constructed a mathematical model based on the kinetics of anaerobic processes (raw material hydrolysis, acid formation, and methanogenesis), taking into account fatty acid concentrations and the pH of

the medium. It was shown that with high mixing intensity, the substrate is converted to a greater extent into fatty acids rather than into the target product, methane.

Dabiri S. et al. [18] integrated the processes of hydrolysis and substrate transformation by microorganisms (decomposition, formation of conglomerates) into a numerical hydrodynamic model. Mixing in the model reactor was carried out using the recirculation method. To simplify the calculation after comparing the hydrodynamic parameters of 2D and 3D modeling, the reactor was modeled in 2D.

A more complex model by Rezavand M. et al. [6] links some biochemical processes with hydrodynamics. The computational domain is divided into elements, each of which carries information about biologically active compounds and follows the flow of the substrate. Mass transfer between particles is reproduced by the diffusion equation. The model includes four processes: substrate hydrolysis, acidogenesis (the processing of soluble compounds by acidogenic bacteria), acetogenesis (the processing of volatile fatty acids and the formation of acetate by acetogenic bacteria that degrade propionate and butyrate), and methanogenesis (the consumption of acetate and the formation of methane by methanogenic bacteria). These biological reactions are modeled as a system of ordinary differential equations.

Few studies have been devoted to quantitative assessments of microbial communities. In particular, Yu S. et al. [19] used various machine learning models to determine the relationships between the microbial community, pH, and the content of volatile fatty acids in the substrate (acetic, propionic, butyric, isobutyric, valeric, isovaleric, and caproic acids were determined) during anaerobic digestion. The content of 7

¹⁴Binxin Wu, Eric L. Bibeau, Kifle G. Gebremedhin. Three-dimensional numerical simulation model of biogas production for anaerobic digesters // ASAE Annu. Meet. Am. Soc. Agric. Biol. Eng. 1. 2006. DOI: 10.13031/2013.20924.

¹⁵Vavilin V.A., Angelidaki I. Anaerobic degradation of solid material: importance of initiation centers for methanogenesis, mixing intensity, and 2D distributed model // Biotechnology and Bioengineering. 2005. V. 89. № 1. P. 113-122. DOI: <https://doi.org/10.1002/bit.20323>.

¹⁶Vavilin V.A., Lokshina L.Y., Flotats X., Angelidaki I. Anaerobic digestion of solid material: multidimensional modeling of continuous-flow reactor with nonuniform influent concentration distributions // Biotechnology and Bioengineering. 2007. V. 97. № 2. P. 354-366. DOI: <https://doi.org/10.1002/bit.21239>.

families of archaea and 30 types of bacteria in the substrate was assessed.

The initial data for the model was generated based on laboratory studies in mini-reactors (250 ml flasks). Whey was used as the fermentation substrate, and anaerobic sludge from wastewater treatment plants was used as the inoculum. The organic load of the reactors was varied, quantified by the COD value. To collect the required data volume, the experiment was run for a total of 281 days across 15 reactors. To test the effectiveness of the generalized machine learning model, the experimental data was divided into training, validation, and testing datasets [19].

From [19] we present some features of the selection of microbiological communities. Four bacterial groups were used as targets (*Bacteroidetes*, *Firmicutes*, *Proteobacteria* и *Spirochaetes*) and four archaeal families (Methanobacteriaceae, Methanoregulaceae, Methanomicrobiaceae and Methanomassiliicoccaceae). *Bacteroidetes*, *Firmicutes* and *Proteobacteria* are the main bacteria that indirectly influence hydrolytic fermentation in the reactors [19]. *Bacteroidetes* and *Firmicutes* are the most common bacteria involved in acidogenesis, secrete enzymes for the decomposition of organic matter and are capable of surviving in extreme conditions [20]. *Spirochaetes* have been proposed as a bacterial phylum that actively affects glucose and acetate¹⁷.

These bacterial communities were selected, in part, due to their abundance. Based on the study's results, optimal relative abundances of Methanoreg and Methanomicrob for stable bioreactor operation were proposed at 15–37% and 3–15%, respectively.

It should be noted that high mixing intensity and the resulting shear stresses have a negative

impact on the vital activity of microorganisms – their activity is suppressed and the flocculation structure is destroyed¹⁸ [21].

Some microorganisms may be vulnerable to mechanical damage due to their unique cell morphology—threadlike or other structures with significant linear dimensions. Some publications demonstrate the need to create "protective" stagnant zones in the reactor, which can serve as initiation sites for methanogens and protect them from acidification (see footnote 18).

Furthermore, it is reported (see footnote 18) that continuous agitator operation promotes rapid hydrolysis, resulting in the accumulation of acids that inhibit methanogenic bacteria. The paper analyzes the mechanism by which biogas yield decreases with intensive agitation. The authors also note the work of those who demonstrated, using experimental data, that even with the complete destruction of microbial conglomerates (flocs), the gross biogas yield does not decrease.

A review of numerical modeling experience revealed a lack of interest among researchers in improving the quality of the second most important product of anaerobic digestion technology—bioorganic fertilizer. In Russia, anaerobic digestion plants designed for biogas production are ineffective due to the country's own low-cost energy resources (natural gas, grid electricity), on the one hand, and harsh climatic conditions and prohibitively long payback periods for such plants, on the other. The key criteria for mixing efficiency should be linked to the quality of the resulting liquid substrate.

Most researchers have concluded that it is impossible to unambiguously determine the parameters of the mixing process based on laboratory experiments, modeling results, or calculations^{19,20} (see footnote 18).

¹⁷Sang-Hoon Lee, Jeong-Hoon Park, Sang-Hyoun Kim, Byung Jo Yu, Jeong-Jun Yoon, Hee-Deung Park. Evidence of syntrophic acetate oxidation by Spirochaetes during anaerobic methane production // *Bioresour. Technol.* 2015. N 190. P. 543–549. DOI: 10.1016/j.biortech.2015.02.066.

¹⁸Lindmark J., Thorin E., Fdhila R.B., Dahlquist E. Effects of mixing on the result of anaerobic digestion: Review // *Renewable and Sustainable Energy Reviews.* 2014. № 40. P. 1030–1047. DOI: 10.1016/j.rser.2014.07.182.

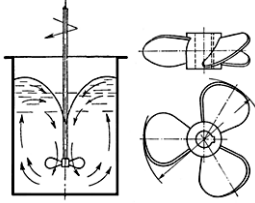
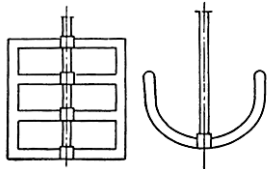
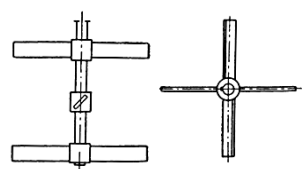
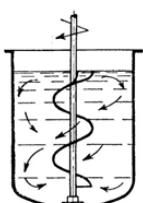
¹⁹Biogas Handbook. From Production to Use: A Draft // Agency for Renewable Resources (FNR), translated from German, 5th edition, revised. Germany, Gülzow, 2010, 213 p.

²⁰Karim K., Hoffmann R., Klasson T., Al-Dahhan M.H. Anaerobic digestion of animal waste: waste strength versus impact of mixing // *Bioresour. Technol.* 2005. Vol. 96. № 16. P. 1771–1781. DOI: 10.1016/j.biortech.2005.01.020.

Табл. 1. Примеры подходов к моделированию условий перемешивания и рассмотренные субстраты
Table 1. Examples of approaches to mixing conditions modeling and the substrates considered

№ п.п.	Substrate characteristics	Process performance indicators	Physicochemical processes incorporated into the model	Reactor shape	Source of information
1	Modeling mixture of glycerin and water	“Dead” volume share	Hydrodynamics, recording of turbulence	Laboratory cylindrical flask with a screw (auger) stirrer	[13]
2	Food waste, paper mill wastewater sludge	“Dead” volume share, velocity gradient, temperature field	Hydrodynamics, heat distribution, recording of turbulence	Laboratory cubic	[14]
3	Food waste, paper mill wastewater sludge, cattle manure	“Dead” volume share, velocity gradient, chemical oxygen demand (COD), organic acid content, solids concentration phase	Hydrodynamics, heat distribution	Laboratory reactors with a capacity of 0.25 and 6.5 liters	[12]
4	Agricultural waste (pineapple processing waste), cattle manure	Temperature field, substrate pH, solid phase concentration	Statistical processing, construction of response surfaces in the Design Expert software	Rehau biogas system with a capacity of 6 m ³	[15]
5	Wastewater from distilleries, cattle manure	Temperature field, substrate pH, substrate retention time in the reactor	Statistical processing, construction of response surfaces	Laboratory cylindrical flask with a volume of 600 ml	[16]
6	Sewage treatment plant sludge, food waste	Biogas yield, chemical oxygen demand	Machine learning	Laboratory (2 and 5 l), pilot (1.2 and 4.2 m ³) and full-scale (2320 m ³) cylindrical reactors	[17]
7	Sewage treatment plant sludge, cattle manure	Volume fraction and retention time of solids, yield and production rate of biogas	Hydrodynamics, accounting for a multiphase environment (liquid – gas – solid)	Laboratory (1 l) and pilot (70 l) cylindrical reactors	See footnote 11
8	Milk whey, sludge from sewage treatment plants	Microbial community, substrate pH, volatile fatty acid content, COD	Machine learning	Laboratory mini reactor (250 ml bottle)	[19]

Табл. 2. Рекомендованные типы механических мешалок для биогазовых реакторов и их применение
Table 2. Recommended types of mechanical stirrers for biogas reactors and their applications

Stirrer type	Stirrer characteristics	Source of information
<p>Propeller stirrer</p> 	<p>A high-speed stirrer, most effective for suspending low-viscosity substrates. Effective for intensifying biochemical processes. A three-blade design is recommended. It can be positioned not only coaxially but also obliquely, eccentrically, and laterally. A vortex may form during operation.</p>	<p>[14], [22], See footnote 21</p>
<p>Frame and a</p> 	<p>Low-speed stirrer. Used for homogenizing high-viscosity substrates (up to 100 Pa s). The stirrer's shape follows the profile of the reactor bottom. It breaks up the crust on the substrate surface and creates a predominantly circumferential circulation.</p>	<p>See footnote 22</p>
<p>Paddle stirrer</p> 	<p>A low-speed mixer used for homogenizing high-viscosity substrates (up to 100 Pa s). The number of blades and their angle can be varied. Easy to manufacture and install. Primarily circumferential circulation.</p>	<p>[11], see footnote 23, [22]</p>
<p>Auger (screw) mixer</p> 	<p>Low-speed stirrer. Used for homogenizing highly viscous substrates (up to 100 Pa s or more). Provides lower power consumption for viscous media.</p>	<p>[13]</p>

²¹Karim K., Hoffmann R., Klasson T., Al-Dahhan M.H. Anaerobic digestion of animal waste: waste strength versus impact of mixing // *Bioresource Technology*, 2005, vol. 96, N 16, pp. 1771–1781. DOI: 10.1016/j.biortech.2005.01.020.

²²Gaufullin I.Kh. Design development and justification of the parameters of a small-volume biogas plant: Abstract of a Ph.D. in Engineering Sciences, specialty 05.20.01 – Technology and means of agricultural mechanization. Kazan, 2022, 20 p.

²³Yampilov S.S., Kobyakova E.N., Druzyanova V.P. Justification of the use of a mixing device in a biogas plant for small livestock farms // *Vestnik of VSGUTU*, 2014, N 4, pp. 13–19.

Mixing modes (stirrer speed, mixing frequency) for real-world applications are typically determined during the bioreactor setup phase. Due to the diversity of industrially available mixing device designs, comparing modeling results from different authors is difficult. For clarity, Table 1 provides examples of the most comprehensively described research results, allowing one to evaluate the diversity of processes and approaches to modeling reactor conditions.

Taking into account the development of computing power, the most promising models for practical application in the production of biofertilizers, in our opinion, should be considered the following types:

– machine learning-based models that predict the development of microbiological communities and have been verified using semi-industrial experimental data under fermentation conditions of specific substrates;

– numerical models and software tools that allow combining hydrodynamic parameters, temperature field parameters during mixing and feeding a new portion of substrate into the reactor, and some of the most important biochemical processes leading to the formation of limiting products of the acidogenesis and acetogenesis stages.

Table 2 lists the types of mechanical stirrers used for substrate homogenization in bioreactors. The stirrer type is primarily determined by the substrate viscosity and the reactor shape.

СПИСОК ЛИТЕРАТУРЫ

1. *Tina Kegl, Eloisa Torres Jimenez, Breda Kegl, Anita Kovac Kralj, Marko Kegl.* Modeling and optimization of anaerobic digestion technology: Current status and future outlook // *Progress in Energy and Combustion Science.* 2025. N 106. DOI: 10.1016/j.pecs.2024.101199.
2. *Nurul Islam Siddique Md., Zularisam Ab. Wahid.* Achievements and perspectives of anaerobic co-digestion: a review // *Journal of Cleaner Production.* 2018. N 194. P. 359–371. DOI: 10.1016/j.jclepro.2018.05.155.
3. *Abdul-Aziz Issah, Telesphore Kabera, Francis Kemausuor.* Biogas optimisation processes and effluent quality: a review // *Biomass and Bioenergy.* 2020. N 133. DOI: 10.1016/j.biombioe.2019.105449.
4. *Yohannis Mitiku Tobo, Usman Rehman, Jan Bartacek, Ingmar Nopens.* Partial integration of ADM1 into CFD: understanding the impact of diffusion on anaerobic digestion mixing // *Water Sci. Technol.* 2020. Vol. 81. N 8. P. 1658–1667. DOI: 10.2166/wst.2020.076.
5. *Soroush Dabiri, Alireza Noorpoor, Maziar Arfaee, Prashant Kumar, Wolfgang Rauch.* CFD modeling of a stirred anaerobic digestion tank for evaluating energy consumption through mixing // *Water.* 2021. N 13. DOI: 10.3390/w13121629.
6. *Massoud Rezavand, Daniel Winkler, Johannes Sappl, Laurent Seiler, Michael Meister, Wolfgang Rauch.* A fully Lagrangian computational model for the integration of mixing and biochemical reactions in anaerobic digestion // *Computers and Fluids.* 2019. N 181. P. 224–235. DOI: 10.1016/j.compfluid.2019.01.024.
7. *Leite S.A.F., Leite B.S., Ferreira D.J.O., Baeta B.E.L., Dangelo J.V.H.* The effects of agitation in anaerobic biodigesters operating with substrates from swine manure and rice husk // *Chemical Engineering Journal.* 2023. N 451. DOI: 10.1016/j.cej.2022.138533.
8. *Leonzio G.* Study of mixing systems and geometric configurations for anaerobic digester using CFD analysis // *Renewable Energy.* 2018. N 123. P. 578–589. DOI: 10.1016/j.renene.2018.02.071.
9. *Rohit Gupta, Le Zhang, Jiayi Hou, Zhikai Zhang, Hongtao Liu, Siming You, Yong Sik Ok, Wangliang Li.* Review of explainable machine learning for anaerobic digestion // *Bioresource Technology.* 2023. N 369. DOI: 10.1016/j.biortech.2022.128468.
10. *Helene Caillet, Alain Bastide, Laetitia Adeland.* Advances in Computational Fluid Dynamics modeling of anaerobic digestion process for renewable energy production: A review // *Cleaner Waste Systems.* 2023. N 6. DOI: 10.1016/j.clwas.2023.100124.
11. *Hemant Thakur, Narendra Kumar Verma, Atul Dhar, Satvasheel Powar.* Investigation of con-

- tinuous stirred tank reactors for improving the mixing in anaerobic digestion: A numerical study // *Results in Engineering*. 2023. N 19. DOI: 10.1016/j.rineng.2023.101317.
12. Hemant Thakur, Rashmi Ira, Narendra Kumar Verma, Vikas Sharma, Shrawan Kumar, Atul Dhar, Tulika Prakash, Satvasheel Powar. Anaerobic co-digestion of food waste, bio-flocculated sewage sludge, and cow dung in CSTR using E(C2)Tx synthetic consortia // *Environmental Technology and Innovation*. 2023. N 32. DOI: 10.1016/j.eti.2023.103263.
 13. Thomas Neuner, Michael Meister, Martin Pillei, Wolfgang Rauch. Optimizing mixing efficiency of anaerobic digesters with high total solids concentrations using validated CFD simulations // *Biochemical Engineering Journal*. 2024. N 208. DOI: 10.1016/j.bej.2024.109320.
 14. Hemant Thakur, Narendra Kumar Verma, Atul Dhar, Satvasheel Powar. Anaerobic co-digestion of food waste and bio flocculated sewage sludge towards bio-methane production // *Energy Reports*. 2024. N 11. P. 2867–2876. DOI: 10.1016/j.egy.2024.02.040.
 15. Edwin Ochieng Otieno, Robert Kiplimo, Urbanus Mutwiwa. Optimization of anaerobic digestion parameters for biogas production from pineapple wastes co-digested with livestock wastes // *Heliyon*. 2023. N 9. DOI: 10.1016/j.heliyon.2023.e14041.
 16. Weldehans Mebrahtom Gebresemati. Optimization of distillery-sourced wastewater anaerobic digestion for biogas production // *Cleaner Waste Systems*. 2023. N 6. DOI: 10.1016/j.clwas.2023.100118.
 17. Kim Moonil, Cui Fenghao. Multiple-layer statistical methodology for developing data-driven models of anaerobic digestion process // *Journal of Environmental Management*. 2023. N 347. DOI: 10.1016/j.jenvman.2023.119153.
 18. Soroush Dabiri, Prashant Kumar, Wolfgang Rauch. Integrating biokinetics with computational fluid dynamics for energy performance analysis in anaerobic digestion // *Bioresource Technology*. 2023. N 373. DOI: 10.1016/j.biortech.2023.128728.
 19. Sung Il Yu, Heewon Jeong, Juhee Shin, Seung Gu Shin, Ather Abbas, Daeun Yun, Hyokwan Bae, Kyung Hwa Cho. Simulation models of microbial community, pH, and volatile fatty acids of anaerobic digestion developed by machine learning // *Journal of Water Process Engineering*. 2024. N 60. DOI: <http://doi.org/10.1016/j.jwpe.2024.105225>.
 20. Hasan Pasalari, Mitra Gholami, Abbas Rezaee, Ali Esrafil, Mahdi Farzadkia. Perspectives on microbial community in anaerobic digestion with emphasis on environmental parameters: A systematic review // *Chemosphere*. 2021. N 270. DOI: 10.1016/j.chemosphere.2020.128618.
 21. Conti F., Saidi A., Goldbrunner M. Numeric simulation-based analysis of the mixing process in anaerobic digesters of biogas plants // *Chemical Engineering & Technology*. 2020. Vol. 43. N 8. P. 1522–1529. DOI: 10.1002/ceat.201900650.
 22. Philipp Kress, Hans-Joachim Nagele, Andreas Lemmer, Bastian Kolb. Flow velocities and flow profiles in a thoroughly mixed biogas fermenter // *Landtechnik*. 2020. Vol. 75. N 2. P. 35–50. DOI: 10.15150/lt.2020.3230.

REFERENCES

1. Tina Kegl, Eloísa Torres Jimenez, Breda Kegl, Anita Kovac Kralj, Marko Kegl. Modeling and optimization of anaerobic digestion technology: Current status and future outlook. *Progress in Energy and Combustion Science*, 2025, no. 106. DOI: 10.1016/j.pecs.2024.101199.
2. Nurul Islam Siddique Md., Zularisam Ab. Wahid. Achievements and perspectives of anaerobic co-digestion: a review. *Journal of Cleaner Production*, 2018, no. 194. P. 359–371. DOI: 10.1016/j.jclepro.2018.05.155.
3. Abdul-Aziz Issah, Telesphore Kabera, Francis Kemausuor. Biogas optimisation processes and effluent quality: a review. *Biomass and Bioenergy*, 2020, no. 133. DOI: 10.1016/j.biombioe.2019.105449.
4. Yohannis Mitiku Tobo, Usman Rehman, Jan Bartacek, Ingmar Nopens. Partial integration of ADM1 into CFD: understanding the impact of diffusion on anaerobic digestion mixing. *Water Sci. Technol*, 2020, vol. 81, no. 8, p. 1658–1667. DOI: 10.2166/wst.2020.076.
5. Soroush Dabiri, Alireza Noorpoor, Maziar Arfaee, Prashant Kumar, Wolfgang Rauch. CFD modeling of a stirred anaerobic digestion tank for evaluating energy consumption through mixing. *Water*, 2021, no. 13. DOI: 10.3390/w13121629.

6. Massoud Rezavand, Daniel Winkler, Johannes Sappl, Laurent Seiler, Michael Meister, Wolfgang Rauch. A fully Lagrangian computational model for the integration of mixing and biochemical reactions in anaerobic digestion. *Computers and Fluids*, 2019, no. 181, pp. 224–235. DOI: 10.1016/j.compfluid.2019.01.024.
7. Leite S.A.F., Leite B.S., Ferreira D.J.O., Baeta B.E.L., Dangelo J.V.H. The effects of agitation in anaerobic biodigesters operating with substrates from swine manure and rice husk. *Chemical Engineering Journal*, 2023, no. 451. DOI: 10.1016/j.cej.2022.138533.
8. Leonzio G. Study of mixing systems and geometric configurations for anaerobic digester using CFD analysis. *Renewable Energy*, 2018, no. 123, pp. 578–589. DOI: 10.1016/j.renene.2018.02.071.
9. Rohit Gupta, Le Zhang, Jiayi Hou, Zhikai Zhang, Hongtao Liu, Siming You, Yong Sik Ok, Wangliang Li. Review of explainable machine learning for anaerobic digestion. *Bioresource Technology*, 2023, no. 369. DOI: 10.1016/j.biortech.2022.128468.
10. Helene Caillet, Alain Bastide, Laetitia Adelard. Advances in Computational Fluid Dynamics modeling of anaerobic digestion process for renewable energy production: A review. *Cleaner Waste Systems*, 2023, no. 6. DOI: 10.1016/j.cwas.2023.100124.
11. Hemant Thakur, Narendra Kumar Verma, Atul Dhar, Satvasheel Powar. Investigation of continuous stirred tank reactors for improving the mixing in anaerobic digestion: A numerical study. *Results in Engineering*, 2023, no. 19. DOI: 10.1016/j.rineng.2023.101317.
12. Hemant Thakur, Rashmi Ira, Narendra Kumar Verma, Vikas Sharma, Shrawan Kumar, Atul Dhar, Tulika Prakash, Satvasheel Powar. Anaerobic co-digestion of food waste, bio-flocculated sewage sludge, and cow dung in CSTR using E(C2)Tx synthetic consortia. *Environmental Technology and Innovation*, 2023, no. 32. DOI: 10.1016/j.eti.2023.103263.
13. Thomas Neuner, Michael Meister, Martin Pillei, Wolfgang Rauch. Optimizing mixing efficiency of anaerobic digesters with high total solids concentrations using validated CFD simulations. *Biochemical Engineering Journal*, 2024, no. 208. DOI: 10.1016/j.bej.2024.109320.
14. Hemant Thakur, Narendra Kumar Verma, Atul Dhar, Satvasheel Powar. Anaerobic co-digestion of food waste and bio flocculated sewage sludge towards bio-methane production. *Energy Reports*, 2024, no. 11, pp. 2867–2876. DOI: 10.1016/j.egy.2024.02.040.
15. Edwin Ochieng Otieno, Robert Kiplimo, Urbanus Mutwiwa. Optimization of anaerobic digestion parameters for biogas production from pineapple wastes co-digested with livestock wastes. *Heliyon*, 2023, no. 9. DOI: 10.1016/j.heliyon.2023.e14041.
16. Weldehans Mebrahtom Gebresemati. Optimization of distillery-sourced wastewater anaerobic digestion for biogas production. *Cleaner Waste Systems*, 2023, no. 6. DOI: 10.1016/j.cwas.2023.100118.
17. Kim Moonil, Cui Fenghao. Multiple-layer statistical methodology for developing data-driven models of anaerobic digestion process. *Journal of Environmental Management*, 2023, no. 347. DOI: 10.1016/j.jenvman.2023.119153.
18. Soroush Dabiri, Prashant Kumar, Wolfgang Rauch. Integrating biokinetics with computational fluid dynamics for energy performance analysis in anaerobic digestion. *Bioresource Technology*, 2023, no. 373. DOI: 10.1016/j.biortech.2023.128728.
19. Sung Il Yu, Heewon Jeong, Juhee Shin, Seung Gu Shin, Ather Abbas, Daeun Yun, Hyokwan Bae, Kyung Hwa Cho. Simulation models of microbial community, pH, and volatile fatty acids of anaerobic digestion developed by machine learning. *Journal of Water Process Engineering*, 2024, no. 60. DOI: <http://doi.org/10.1016/j.jwpe.2024.105225>.
20. Hasan Pasalari, Mitra Gholami, Abbas Rezaee, Ali Esrafil, Mahdi Farzadkia. Perspectives on microbial community in anaerobic digestion with emphasis on environmental parameters: A systematic review. *Chemosphere*, 2021, no. 270. DOI: 10.1016/j.chemosphere.2020.128618.
21. Conti F., Saidi A., Goldbrunner M. Numeric simulation-based analysis of the mixing process in anaerobic digesters of biogas plants. *Chemical Engineering & Technology*, 2020, vol. 43, no. 8, pp. 1522–1529. DOI: 10.1002/ceat.201900650.
22. Philipp Kress, Hans-Joachim Nagele, Andreas Lemmer, Bastian Kolb. Flow velocities and flow profiles in a thoroughly mixed biogas fermenter. *Landtechnik*, 2020, vol. 75, no. 2, pp. 35–50. DOI: 10.1515/lt.2020.3230.

ИНФОРМАЦИЯ ОБ АВТОРАХ

Рубцов А.А., аспирант, ORCID 0009-0008-5989-8165, SPIN-код 1559-6239

✉ **Немущенко Д.А.**, старший преподаватель, ORCID 0009-0000-8262-237X, SPIN-код 6213-1170; **адрес для переписки:** Россия, 630073, Новосибирск, проспект К. Маркса, 20; e-mail: nemuschenko@corp.nstu.ru

AUTHOR INFORMATION

Alexandr A. Rubcov, Post-graduate Student; ORCID 0009-0008-5989-8165, SPIN-code 1559-6239

✉ **Dmitriy A. Nemuschenko**, Senior Lecturer, ORCID 0009-0000-8262-237X, SPIN-code 6213-1170; **address:** 20, Prospekt K. Marksa, Novosibirsk, 630073, Russia; e-mail: nemuschenko@corp.nstu.ru

Дата поступления статьи / Received by the editors 24.02.2025
Дата принятия к публикации / Accepted for publication 30.04.2025
Дата публикации / Published 16.06.2025

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:

Quoted text₁,

1Klimova 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.

УВАЖАЕМЫЕ ПОДПИСЧИКИ!

Подписку на журнал «Сибирский вестник сельскохозяйственной науки»
(как на годовой комплект, так и на отдельные номера)
можно оформить одним из следующих способов:

- **В агентстве подписки ООО «Урал-Пресс»,
подписной индекс 014973**

Ссылка на издание <https://www.ural-press.ru/search/?q=014973>.

В разделе контакты зайти по ссылке
<http://ural-press.ru/contact/>, где можно выбрать филиал по месту жительства

- **В редакции журнала**

Тел.: +7 (383) 348-37-62, e-mail: sibvestnik@sfscs.ru

Полнотекстовая версия журнала
«Сибирский вестник сельскохозяйственной науки»
размещена на сайте Научной электронной библиотеки:
<http://www.elibrary.ru>

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. 5 (318)

DOI: 10.26898



2025
May

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.

Editor-in-Chief – Alexander S. Donchenko, Academician of the Russian Academy of Sciences, Doctor of Science in Veterinary Medicine, Head Researcher, Head of the Institute of Experimental Veterinary Science of Siberia and the Far East of the Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences, Novosibirsk, Russia

Deputy 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

Akhylybek 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

Editors *Evgeniya M. Isaevich, Elena V. Mosunova, 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

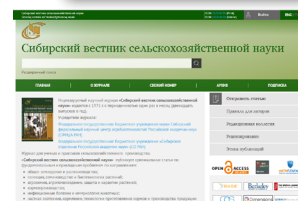
Published on 16.06.2025. Format 60 × 84¹/₈. Paper type. No. 1. Offset printing. Printer's sheet 16,75

Publisher's signature 17. 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



www.sibvest.elpub.ru