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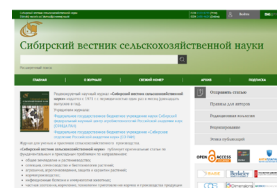
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Научные достижения в земледелии Сибири и их развитие

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Дан исторический обзор становления и развития научного земледелия в Сибири. Отмечены основные достижения ведущих научно-исследовательских институтов региона. Показан вклад сибирских ученых в развитие научного земледелия, в том числе его составных направлений. Представлено почти 100-летнее развитие исследований по земледелию – от Омского опытного хутора (XIX в.), сельскохозяйственных опытных станций – до современных федеральных научных центров. Продемонстрирована эволюция земледелия от отдельных приемов по возделыванию сельскохозяйственных культур до формирования зональных, а затем адаптивно-ландшафтных систем земледелия и современных агротехнологий. Приведены примеры законченных научных разработок по земледелию, готовых к внедрению в производство, количество которых исчисляется тысячами. Внедрение наукоемких агротехнологий гарантирует доведение объемов производства зерна в Сибири до 25–30 млн т, устойчивое развитие земледелия, стабильное обеспечение продовольствием и высокую окупаемость невозобновляемых ресурсов. Показана эволюция защиты растений от отдельных приемов против наиболее опасных вредных организмов до формирования интегрированных систем, учитывающих фитосанитарное состояние агроценозов и агроэкологические условия возделывания сельскохозяйственных культур. Наиболее важными приемами для оптимизации взаимоотношений между культурой и вредными организмами являются подбор устойчивых к их воздействию видов и сортов растений, оптимизация минерального питания растений и сроков сева. В настоящее время развитие научного земледелия связано с проектированием адаптивно-ландшафтных систем земледелия, выбором и поддержкой агротехнологий, рациональным использованием земельных ресурсов, совершенствованием подходов к сохранению и воспроизводству почвенного плодородия, систем обработки почвы, удобрений и интегрированной защиты растений, формированием адаптивных севооборотов, исследованием технологических и биологических процессов при возделывании сельскохозяйственных культур, использованием ГИС-технологий, дистанционного зондирования и искусственного интеллекта для организации рационального управления продуктивностью посевов сельскохозяйственных культур.

Ключевые слова: системы земледелия, севообороты, обработка почвы, удобрения, плодородие почв, агротехнологии, защита растений

Scientific achievements in Siberian agriculture and their development

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A historical review of the formation and development of scientific farming in Siberia is given. The main achievements of the leading research institutes of the region are highlighted. The contribution of Siberian scientists to the development of scientific farming, including its constituent directions, is

shown. It presents almost 100 years of development of research on agriculture - from the Omsk experimental farm (XIX century), agricultural experimental stations - to modern federal scientific centers. The evolution of farming from individual crop cultivation techniques to the formation of zonal and then adaptive-landscape farming systems and modern agro-technologies is demonstrated. Examples of completed scientific developments on farming, ready for implementation in production, the number of which runs into thousands, are given. Implementation of knowledge-intensive agro-technologies guarantees grain production in Siberia up to 25-30 million tons, sustainable development of farming, stable food supply and high return on non-renewable resources. The evolution of plant protection from individual methods against the most dangerous pests to the formation of integrated systems that take into account the phytosanitary state of agroecosystems and agro-ecological conditions of agricultural crops cultivation is shown. The most important techniques to optimize the relationship between the crop and pests are the selection of plant species and varieties resistant to their effects, optimization of mineral nutrition of plants and sowing dates. At present, the development of scientific farming is associated with the design of adaptive-landscape farming systems, selection and support of agro-technologies, rational use of land resources, improvement of approaches to the conservation and reproduction of soil fertility, soil treatment systems, fertilizers and integrated plant protection, formation of adaptive crop rotations, research of technological and biological processes in the cultivation of crops, use of GIS-technologies, remote sensing, and the use of remote sensing.

Keywords: farming systems, crop rotations, tillage, fertilizers, soil fertility, agro-technologies, plant protection

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The earliest center of arable farming in Siberia appeared in the Upper Ob River area in the middle of the 1st millennium A.D. (traces of farming in this area can be dated back to the Bronze Age). Single-bladed coulters were used as tools. By the end of the first millennium A.D., despite the arrival of Turkic-speaking tribes to the Upper Ob River area and the change of material culture, arable farming with land tillage remained the main one here throughout the second millennium A.D. Another center of arable farming was formed in the Tobolsk Irtysh River area only in the 12th–14th centuries and was associated with the arrival of significant groups of population from the western piedmont of the Ural Mountains, who brought with them a set of crops to be sown, traditional tools of cultivation and crop processing [1]. The development

of the southern taiga areas of Siberia by peasants-settlers from the European part of Russia with the use of centuries-old agricultural experience began in the late 16th century.

The development of new spaces caused the need to study the natural conditions and adapt old skills to them. This was carried out using peasant “experiments”, which included identification of suitable land for cultivation of crops, trial sowing, development of rules of plant cultivation, which the “Sibirsky prikaz” (Department of Siberian Affairs) passed on to the population. Rye and oats were the most widespread, barley and wheat were also cultivated in small areas.

By the beginning of the agricultural development of Siberia in the European part of the country, the fallow farming system prevailed

in the form of three-field farming with the preservation of shifting cultivation in some cases. European settlers sought in the southern taiga and forest-steppe zones to do without clearing the forest for arable land and developed lighted areas – glades. Wood clearing was used to expand the arable land that was introduced in three-field rotation system. Quickly occurring soil impoverishment forced to allocate fields for layland and fallow soil. Purely fallow and fallow-lealand farms prevailed until the twentieth century, although already in the late 17th–early 18th century some farms began to use manure fallow on “near-settlement” lands. However, in general, in Siberia fallow (two-field and three-field) and fallow-lealand systems were unmanured, and manure fallow was considered “not a tradition” for a Siberian farmer [2].

The agricultural development of Siberia, based on the transfer of empirical experience of peasants of different soil-climatic regions of European Russia and its adaptation to new conditions, lasted a century and a half, before the emergence of Russian scientific farming. At the origins of agricultural Siberian science, as in other regions of Russia, were the classics of agronomy A.T. Bolotov, I.M. Komov, S.M. Usov, A.V. Sovetov, I.A. Stebut, V.V. Dokuchaev, P.A. Kostychev, D.I. Mendeleev, A.S. Ermolov.

Scientific experimental work in Russia began in 1821 with the creation of Moscow Butyrsky khutor. The Omsk experimental khutor under the jurisdiction of the Siberian Linear Cossack Army was established in Siberia by the agronomists M.G. Pavlov, O. Obukhov, P. Scherbakov in 1828 by the order of the General I.A. Veliaminov, which served as the beginning of agricultural science in Siberia. 20 dessiatinas of land were allocated for the khutor and a school for 10 teenagers, children of Cossacks, was organized. The connection with European agricultural science was carried out by Moscow professor M.G. Pavlov. On the fields of the experimental khutor it was proposed to introduce two farming systems: fallow three-field and crop rotation six-field. They studied the methods of soil cultivation, other methods of agrotechnics

of cultivation of field crops, tested and mastered new machines and implements. During the same period, experimental khutors were created in Verkhneudinsk, Semipalatinsk and Kamchatka.

Omsk experimental khutor was reorganized into hetman khutor, and in 1853 into Omsk experimental field of local control. In 1923 it was united with the West Siberian breeding station named after N.L. Skalozubov (organized at the head of Petrograd professor V.V. Talanov) with the creation of the department of agriculture under the leadership of V.A. Fedorovsky. In 1931, the station was reformed into a zonal grain experimental station, transformed in 1933 into the Siberian Research Institute of Grain Farming (SibNIIZKh), which in 1956 became the Siberian Research Institute of Agriculture (SibNIISKh). In 1970, SibNIISKh became a part of the Siberian Branch of VASKHNIL. The Institute played the role of the leading center of Siberian scientific farming until 1980. The first director of the Institute was S.G. Alekseev. In subsequent years, the Institute was headed by I.I. Skorospeshkin, N.V. Tsitsin, P.G. Popov, I.L. Kozlov, A.I. Potashov, G.Y. Petrenko, G.P. Vysokos, A.T. Belozarov, I.V. Zezin, S.S. Sdobnikov, P.I. Khlebov, N.Z. Milashchenko, V.A. Domrachev, I.F. Khramtsov, V.S. Boyko. In 2018, the Institute was transformed into the Omsk Agrarian Scientific Center (Omsk ASC) by reorganization of the Siberian Research Institute of Agriculture in the form of a merger of the All-Russian Research Institute of Brucellosis and Tuberculosis of Animals and the Siberian Research Institute of Poultry Farming. Director – M.S. Chekusov.

Famous scientists who influenced the development of Siberian agriculture worked and are working in SibNIISKh: A.N. Kashtanov, N.Z. Milashchenko, G.P. Gamzikov, I.F. Khramtsov, A.E. Kochergin, N.V. Orlovsky, N.D. Gradoboev, A.I. Shevlyagin, V.A. Yuferov, O.T. Ermolaev, A.F. Neklyudov, S.S. Sdobnikov, O.V. Sdobnikova, V.M. Zerfus, O.I. Gamzikova, P.S. Denisov, V.G. Kholmov, P.F. Ionin, V.N. Slesarev, M.E. Cherepanov, Y.B. Moschenko, V.F. Gof, N.G. Ryzhkov, L.V. Berezin, A.N. Silantiev, V.I. Dmitriev,

V.A. Sinyavsky, L.V. Yushkevich, V.S. Boyko et al. Their research covered practically all the most important and priority areas of farming and agrochemistry and served as a basis for intensification of farming and development of modern resource-saving agro-technologies in the southern forest-steppe and steppe, improvement of soil-protective farming in dry-steppe areas, intensification of irrigated farming, justification of fertilizer systems for the planned yield in non-chernozem and chernozem zones.

In the field of agrochemistry a special place is occupied by the works of a prominent scientist-agrochemist A.E. Kochergin. During his work at the Institute, he developed diagnostic methods and scales of plant nitrogen nutrition to improve the efficiency of mineral fertilizers. This direction was further developed in the works of G.P. Gamzikov and his students, which investigated the qualitative and quantitative characteristics of the nitrogen fund of the main automorphous and semi-hydromorphous soils of different natural zones of the region, as well as the modes of mobile nitrogen compounds in them, and the effective use of nitrogen fertilizers [3, 4]. The developments of many other researchers were highly appreciated: I.F. Khramtsov – in scientific substantiation of fertilizer system and soil fertility reproduction in field crop rotations in the forest-steppe; V.G. Kholmov, Y.B. Moschenko, L.V. Yushkevich, V.L. Ershov, B.S. Koshelev – in solving the problems of intensification of farming on chernozems of steppe and forest-steppe; A.F. Neklyudov – in the scientific basis of field crop rotations; M.E. Cherepanov – in snow amelioration in soil-protective farming; P.F. Ionin – in substantiation of effective complex measures of weed control at intensification of farming; V.F. Gof and V.S. Boyko – in intensification of irrigated lands use.

V.A. Sinyavsky conducted research on the justification of fertilizer systems for the planned yield in the non-chernozem zone, L.V. Berezin – on the theoretical justification of chemical

amelioration of solonetz soils in the region [5, 6]. These and other studies on farming and related areas of agrarian science are summarized in the monograph [7].

The following scientists: V.S. Boyko, A.Y. Timokhin, E.V. Tukmacheva, E.N. Ledovsky, L.V. Yushkevich, N.F. Balabanova, N.N. Shuliko, E.V. Kubasova, N.A. Voronkova, V.V. Mikhailov and other scientists are conducting research on the development of new generation farming systems and agro-technologies for cereals, legumes and oilseeds, regulations for the integrated use of mineral fertilizers and biopreparations, systems of integrated crop protection from harmful objects, regional technologies of fodder production, formation of technological policy in agriculture of the region.

T.S. Maltsev made a significant contribution to the development of Siberian agriculture. His creative heritage is very extensive: from philosophical views on the “law of decreasing soil fertility” to specific agrotechnical methods of increasing the yield of the main “bread” crop of Siberia – spring wheat. Terenty Semenovich, in our opinion, anticipated the development of system approach in solving the problems of agronomy, which has developed significantly only in the last decade. “Maltsev farming system” included a number of fundamental assumptions, complex (in the system) implementation of which solved the problems of increasing crop yields and stabilization of soil fertility. These include the introduction of short-rotation crop rotations and the importance of clean fallows in increasing the yields and sustainability of farming, the role of annual crops in increasing the effective soil fertility, minimization of tillage for annual crops in the crop rotation, the ratio of spring wheat varieties with different vegetation period, sowing dates of cereal crops, etc. [8]. As noted by A.N. Kashtanov at the All-Russian scientific-practical conference dedicated to the 100th anniversary of Terenty Semenovitch's birth, “...more than one generation of Siberian agronomists and masters of high yields grew up on the ideas of T.S. Maltsev...”¹.

¹*Kashtanov A.N.* Significance of the works of T.S. Maltsev in modern farming // 100 years of T.S. Maltsev: scientific heritage of T.S. Maltsev and actual problems of modern agronomy: materials of the All-Russian scientific-practical conference, dedicated to the 100th anniversary of the birth of honorary academician Terenty Semenovich Maltsev. Novosibirsk, 1995, pp. 8–14.

The history of agricultural science in Altai began with an experimental field established near Barnaul in 1897, which received official status and relative stability only in 1921 in accordance with the decision of the Altai provincial land department to establish the Sukhologovsky experimental field and assign it a land plot of 1500 hectares. In 1926 it was transformed into Altai regional experimental field, in 1929 into Altai regional agricultural experimental station, in 1937 into Barnaul state breeding station. On its basis in 1950 the Altai Zonal Research Institute of Agriculture and Livestock was established, in 1956 it was transformed into the Altai Research Institute of Agriculture (ANIISKh). In 2006, the Kulunda Agricultural Experimental Station (AES) was incorporated into the Institute. The first director of the Institute was V.N. Fesik. In subsequent years, the Institute was headed by G.G. Vorkachev, G.A. Nalivaiko, A.N. Kashtanov, P.I. Khlebov, N.V. Yashutin, A.G. Ten, G.P. Gamzikov, V.V. Yakovlev, A.A. Garkusha. In 2016, the Federal Altai Scientific Center for Agrobiotechnology (FASCA) was formed by reorganizing the Altai Research Institute of Agriculture in the form of a merger with the M.A. Lisavenko Research Institute of Horticulture of Siberia, Siberian Research Institute of Cheesemaking, All-Russian Research Institute of Antler Reindeer Breeding, Altai Research Institute of Animal Husbandry and Veterinary Medicine and Gorno-Altaysk Research Institute of Agriculture. Director - A.A. Garkusha.

Famous scientists who influenced the development of Siberian agriculture worked and are working in the ANIISKh: G.A. Nalivaiko, A.N. Kashtanov, G.P. Gamzikov, A.G. Turbin, V.G. Tkachenko, N.V. Yashutin, V.V. Yakovlev, V.V. Volnov, V.P. Oleshko, G.Y. Stetsov, V.I. Usenko, P.R. Schott, P.G. Alinovsky, V.G. Antonov, V.I. Bespamyatny, A.A. Garkusha, A.Ya. Zhezher, L.V. Zhezher, V.M. Lashkin, I.M. Maltsev, M.I. Maltsev, V.Ya. Me-

telev, G.T. Rudenko, R.D. Rusinova, G.G. Sadvonnikov, V.I. Stolyarov, F.P. Shevchenko et al.

With the beginning of the development of virgin and fallow lands, the Institute staff members G.G. Vorkachev, F.S. Boyarintsev, M.M. Gorobchenko, Yu.A. Zakis, V.P. Zolotun, M.A. Kuzmina, A.P. Kurtesov and others, together with specialists from other institutions, were actively involved in the work on scientific support for the development of virgin and fallow lands. In the field of farming, they faced the tasks of increasing grain production, surveying the territory of the region for plowing, land management of virgin farms, selection of tillage and crop cultivation technologies, training of personnel, etc. By 1960 the scientists of the Institute developed the project of the System of farming by zones of the Altai Territory on the lessons of virgin lands^{2, 3}.

G.A. Nalivaiko, A.B. Mishin, V.R. Chuprakova, M.N. Shumilova and other scientists were the initiators and among the first in the country to develop the row crop farming system, the basis of which were crop rotations with their high saturation with corn and horse beans [9].

The Institute under the leadership of A.N. Kashtanov was one of the first in the USSR to develop the basics of contour reclamation farming and land management, allowing to fully protect the soil from erosion, to make fuller use of atmospheric precipitation, to introduce lands with high relief dissection into arable farming. The system is based on dissection of erodible lands at an angle to the relief horizontals by linear boundaries of the first and second order. Development of the elements of this system in the experimental production farm named after V.V. Dokuchaev and in other farms provided a 4-fold decrease in water erosion of soil, 1.5-2.0-fold increase in grain harvesting [10, 11].

An important stage in the scientific support of farming in the Altai Territory was the

²Garkusha A.A., Nikitina E.D. Altai Research Institute of Agriculture - 65 years: historical aspects, current status, development prospects // Actual issues of the agricultural sector of Siberia: results and prospects (to the 65th anniversary of the Altai Research Institute of Agriculture): a collection of scientific papers AltNIISKh. Barnaul: Concept, 2015, pp. 3–35.

³Sukhoverkova V.E., Merkulova S.I. History of ANIISKhoz: about those who worked on the virgin lands // Current state and prospects of development of agriculture and crop production (to the 60th anniversary of the virgin lands): a collection of scientific papers AltNIISKh. Barnaul: Azbuka, 2014, pp. 33–54.

zonal farming systems, in the development of which the ANIISKh and the Kulunda Agricultural Experimental Station staff A.N. Kashtanov, N.V. Yashutin, V.Ya. Metelev, L.A. Ageenko, P.G. Alinovsky, V.G. Antonov, M.I. Antonovich, V.I. Stolyarov and others took part. Improvement of the farming systems of the Altai Territory on the adaptive-landscape basis was reflected in the works of G.P. Gamzikov, V.V. Yakovlev, V. P. Oleshko, A. A. Garkusha, V.E. Sukhoverkova, V. M. Lashkin, V. V. Volnov, M. I. Maltsev, V.N. Mukhin, A.A. Kashtanov and others.

Differentiation of crop production, the emergence of new crops and modern varieties for the Altai Territory necessitated the development of agro-technologies for local conditions. Both agricultural scientists, agrochemists and plant protection specialists, as well as plant breeders and economists were involved in carrying out the studies (V.V. Yakovlev, A.A. Garkusha, V.A. Aparin, N.I. Vasyakin, A.A. Kashtanov, S.S. Kirillov, L.I. Kostrova, V.I. Kravchenko, B.I. Krivogornitsyn, P.A. Litvintsev, T.A. Litvintseva, N.I. Likhachev, A.M. Mitsurin, T.I. Moskvitina, V.A. Ovsyannikov, V.P. Oleshko, V.T. Polyakov, V.I. Ryabtsev, G.Ya. Stetsov, V.I. Stolyarov, V.I. Usenko, S.V. Usenko, N.I. Shakhov, P.R. Schott, V.I. Yanchenko, and others). [12].

To date, the Altai NIISKh (Barnaul) and the Kulunda AES (Klyuchi settlement) have preserved long-term multifactorial stationary field experiments, in which several generations of scientists (A.A. Garkusha, E.G. Deryanova, L.S. Dolmatova, V.I. Kravchenko, T.A. Litvintseva, S.A. Peshkov, D.V. Purgin, G.G. Sadovnikov, N.N. Sadovnikova, D.G. Salov, G.Ya. Stetsov, V.I. Usenko, L.A. Fedchenko, A.A. Shcherbakova, and others) continue studies of modern crop rotations, including those with different saturation of new crops, tillage systems, involving direct sowing of crops without tillage, traditional and promising types of fertilizers and growth regulators and methods of their application, as well as modern chemical and biological means of plant protection from pests.

The establishment of the Siberian Research Institute of Chemicalization of Agriculture (SibNIIHim) on the basis of the plant protection station of VIZR in 1969 became an important stage of further development of scientific research on agriculture and development of practical recommendations for production. In 1980, the Institute was renamed into the Siberian Research Institute of Agriculture and Chemicalization of Agriculture ("SibNIIZKhim"). In 2014 it was renamed into SibNIIZKh. In 2016, SibNIIZKh became a structural subdivision of the Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences (SFSCA RAS).

The institute was organized by Irakli Ivanovich Sinyagin, Vice-President of VASKHNIL and Chairman of the Siberian Branch of VASKHNIL. The first Director of SibNIIKhim was O.A. Ivanov, Director of the plant protection station of VIZR, on the basis of which the Institute was established. In subsequent years, the Institute was headed by E.L. Klimashevskii, V.V. Guliy, D.A. Altunin. For a long time SibNIIZKhim was headed by V.I. Kiryushin. From 1989 to 2016, its director was A.N. Vlasenko.

The beginning of research in the Institute on the problems of chemicalization of Siberian agriculture is associated with the name of I.I. Sinyagin. Experiments with fertilizers were laid, the results of which were summarized by I.I. Sinyagin in co-authorship with N.Ya. Kuznetsov and a monograph on the effective use of fertilizers in Siberia was published [13]. Since 1980 under the leadership of V.I. Kiryushin fundamental approaches to the formation of farming systems in Siberia have been developed. The results of these studies were summarized in zonal farming systems of the Novosibirsk region, which played a major role in clarifying the specialization of agricultural production, determining the structure of the cultivated areas and crop rotations, differentiating the systems of soil tillage and fertilizers for grain crops and plant protection in accordance with soil and climatic natural zones.

Significant contribution to the optimization of the structure of agricultural land use and crop rotations was made by V.I. Kiryushin, V.I. Ovsyanikov, V.K. Kalichkin, G.M. Zakharov, Yu.P. Filimonov, N.L. Romanova. Research on soil tillage was largely influenced by the works of T.S. Maltsev and A.I. Baraev and was aimed at optimizing agroecological properties of soils and the possibility of reducing energy inputs by minimizing tillage. The works of V.I. Kiryushin, A.N. Vlasenko, V.K. Kalichkin, V.E. Sineshchekov, L.N. Iodko, Y.P. Filimonov made a great contribution to solving these problems. It was shown that on the territory of the northern forest-steppe and subtaiga the main type of cultivation should be multi-depth plowing; in the southern forest-steppe and steppe on a significant part of the area - cultivation without bed turnover. For the forest-steppe zone as a whole, the ratio of plowing and no-tillage depends on the level of intensification of farming. On the intensive background the need for layer turnover decreases and plowing is obligatory only in case of technological necessity (grass layer cutting, fields clogged with perennial weeds, etc.). [14].

One of the important areas of research is the development of fertilizer systems and soil fertility reproduction, which were carried out under the guidance of I.M. Burdenkov, N.Y. Kuznetsov, A.A. Lamanov, L.N. Salmin, A.Y. Zhezher, L.P. Antipina, Y.I. Berkhin, A.I. Yuzhakov, M.I. Mostovoy, V.I. Usenko, and I.N. Sharkov. The methods of soil, tissue and leaf diagnostics of mineral nutrition of wheat with nitrogen were developed for Siberian conditions, gradations of soil phosphorus availability were specified and methods of optimization of mineral nutrition of plants were proposed [15]. Methodological and methodical bases for determining the doses of mineral fertilizers that provide the maximum yield and the highest income were developed by A.I. Yuzhakov.

N.V. Semendyaeva and N.I. Dobrotvorskaya summarized the results of long-term field studies on chemical amelioration of dark alkaline soils in the forest-steppe zone of Western Siberia. The optimal doses of chemical ameliorants on low-, medium- and high-sodium dark alka-

line soils are substantiated. The expediency of calculation of ameliorant doses according to the Gedroitz method and the possibility of doses reduction in fodder crop rotations are proved. The methods of ameliorants application are studied. Phosphogypsum, a waste product of superphosphate production, is characterized and ecological aspects of its application are considered [16].

V.K. Kalichkin, I.N. Minina, E.D. Kondratieva established that for more accurate diagnosis of liming of acid soils it is necessary to take into account the nature of acidity, aluminum and manganese content, as well as the degree of saturation of soils with bases. The meliorant doses are changed taking into account the granulometric composition of the soils, application of fertilizers and cultivated crops. Agrotechnical amelioration of acidic soils consists in application of deep no-tillage constantly or in alternation with shallow plowing against the background of chemical weeding of crops and application of fertilizers [17]. I.N. Sharkov developed a comprehensive approach to the reproduction of organic matter in the soils of agroecosystems, determined the extent of organic matter mineralization of the main zonal soils of Western Siberia [18]. V.I. Usenko, M.I. Mostov, V.I. Chukanov, V.K. Kalichkin studied the composition, properties and efficiency of the use of the main types of organic fertilizers (cattle manure, bedding and non-bedding, poultry manure, pig manure, peat, sapropel, composts and vermicomposts, sewage sludge, etc.) and developed the scientific basis for their rational use on chernozem soils of Western Siberia [19].

From 1986 to 1990, the country launched a campaign of intensification of grain production, and scientific institutions of the region developed the necessary recommendations. Thanks to the development of intensive technologies, the average yield in the region increased by 0.4–0.6 t/ha. The perception of possible productivity of grain crops has changed. A number of farms obtained wheat yields of more than 3.0 t/ha. In scientific and demonstration experiments of Y.P. Filimonov, V.N. Shoba, V.M. Novikov, K.G. Alimov, T.I. Bushmeleva, winter rye yields

reached 5.0 t/ha, spring wheat – 6.5, barley – 5.0 t/ha. The development of zonal farming systems has played a certain role in increasing the efficiency of farming in Siberia. In particular, grain crop yields in the Novosibirsk Region increased from 1.0 t/ha in 1983 to 1.52 t/ha in 1987. Under the leadership of N.G. Vlasenko the research on cultivation of grain crops by No-Till technology was carried out. The results were obtained, indicating that this technology is promising for use on the fields of Siberia [20].

Improvement of zonal farming systems was completed by the development of adaptive-landscape farming systems in the Novosibirsk region. They implement a system of land use of a certain agro-ecological group, focused on the production of products of economically and environmentally determined quantity and quality, in accordance with social needs, natural and production resources, ensuring the sustainability of the agro-landscape and the reproduction of soil fertility [21]. In 2002, this work was recognized by the Presidium of Rosselkhozakademy as the best completed development of the year. A great achievement in terms of development and implementation of new generation farming systems and agro-technologies was the methodological manual prepared under the editorship of V.I. Kiryushin and A.L. Ivanov, co-authors of this work were the scientists of the Institute A.N. Vlasenko, N.G. Vlasenko, V.K. Kalichkin, A.I. Yuzhakov [22].

In 2002–2005 a team of creative scientists: A.N. Vlasenko, V.K. Kalichkin, A.I. Yuzhakov, N.I. Dobrotvorskaya, L.N. Iodko, A.I. Pavlova (SibNIIZIKh); V.V. Alt, O.F. Savchenko, L.A. Kolpakova, T.N. Bobrova, S.K. Krasnousova (Siberia Physical and Engineering Institute of Agrarian Issues); A.S. Tarasov, T.M. Boyko, V.V. Vasin (North-Kulunda ES); V.A. Seredovich, V.A. Kalyuzhin, O.A. Michkova (Siberian State University of Geosystems and Technologies) developed a geoinformation system for designing and maintaining an adaptive-landscape farming system (ALFS). The ALFS computer model became the basis for the creation of an automated workstation (AWS) for a land surveyor-designer and an agrono-

mist-technologist [23, 24]. This product under the name “Automated workplace of an agronomist-land surveyor” in a form of a training program was distributed by the Siberia Physical and Engineering Institute of Agrarian Issues in the universities of Siberia.

Currently, a group of young scientists (V.S. Riksen, K.Y. Maksimovich, L.V. Garafutdinova, T.A. Kizimova, R.R. Galimov) in the SFSCA RAS is conducting research on the creation of a digital farming management system (DFMS) in the context of intelligent farming. The fundamental principles of the organization of DFMS are the following:

- monitoring of crops and the environment (*in situ*, remote sensing);
- formation of farming system archetypes on the basis of analyzing the results of long-term field experiments;
- spatial object modeling and land typification using GIS;
- planning and support of agro-technologies for adaptation to natural and economic conditions, etc. [25].

Scientists of the Krasnoyarsk Research Institute of Agriculture (Yu.F. Yedimeichev, A.M. Berzin, V.V. Lisunov, V.N. Romanov, P.I. Krupkin, A.A. Shpedt, Yu.N. Trubnikov, A.V. Bobrovsky, et al.) have proposed scientifically substantiated adaptive crop rotations providing high yields of grain and forage crops. Zonal resource-saving systems of basic tillage in crop rotations for the conditions of Eastern Siberia have been developed. Much work has been done to identify the effectiveness and rational use of fertilizers [26].

Scientists of the Research Institute of Agrarian Problems of Khakassia (E.Ya. Chebochakov, M.V. Fomin, T.I. Bushmeleva, O.A. Ivanov), the Irkutsk Research Institute of Agriculture (V.T. Maltsev, V.I. Solodun, N.N. Dmitriev, F.S. Sultanov, M.F. Bychko), the Kemerovo Research Institute of Agriculture (V.A. Kalugin, V.P. Burenok, L.Z. Kuznetsova, N.A. Lapshinov), the Buryat Research Institute of Agriculture (A.M. Emelyanov, T.P. Lapukhin, L.V. Budazhapov, A.K. Ulanov, A.A. Altaev, et al.), Research Institute of Agriculture of the North-

ern Trans-Urals (P.N. Polishchuk, V.V. Burlaka, N.F. Perfiliev, E.P. Renev, et al.), Siberian Research Institute of Agriculture and Peat (E.V. Titova, G.M. Chicherin), Tuvian Research Institute of Agriculture (S.S. Sonam, M.M. Dongak, R.B. Chysyma), Zabaikalsk Research Institute of Agriculture (G.G. Shashkova, O.G. Andreeva, D.I. Zavalishin) carried out extensive work in their regions to improve the scientific basis of conservation agriculture, resource-saving crop cultivation technologies, reclamation farming, fertilizer application systems, integrated plant protection against pests.

Establishment of plant protection in Siberia as a science took place in the early twentieth century and began with the establishment of the Siberian Entomological Bureau in Omsk at the end of 1918, and in the middle of 1919 provincial entomological bureaus in Tomsk and Barnaul. In 1922 the first Plant Protection Stations (PPS) were established on their basis. At the end of 1925 with the formation of the Siberian Territory as a single administrative entity, the Siberian Territorial Plant Protection Station was established in Novonikolaevsk. In 1929, the All-Union Research Institute of Plant Protection (VIZR) was organized as part of the VASKhNIL. Plant protection stations were re-formed, some of them were transferred to the subordination of the All-Union Research Institute of Plant Protection. Subsequently, the development of plant protection in Siberia was promoted by the establishment of scientific institutions on the basis of already existing experimental stations.

The results of works on plant protection can be judged by numerous publications in the collections of VIZR, Entomological Society and other organizations on locusts, meadow moth, hidden stem pests, plant diseases, prediction of pest spread, entomo-phytopathological assessment of soil treatment (G. Ya. Bey-Bienko, R.P. Berezhkova, A.N. Shvetsova, G.M. Vinokurova, A.P. Golubintseva, E.E. Golubintseva).

Further development of plant protection strategy and tactics in the country and abroad necessitated the transition from individual methods of reducing the number and harmfulness of pests to a system that integrates a va-

riety of methods into a single set of protective measures. The possibility of realization of this task in the Asian part of Russia was greatly facilitated by the organization of SibNIIKhim within the Siberian Branch of the VASKHNIL on the basis of the Novosibirsk station of VIZR, later transformed into SibNIIZKhim. Research on plant protection was also conducted in other research centers of Siberia (SibNIISKh, ANIISKh, NIISKh of the Northern Trans-Urals, Research Institute of Horticulture of Siberia named after M.A. Lisavenko, Kemerovo NIISKh, Krasnoyarsk NIISKh, etc.).

During this time extensive material has been collected, which allows to form crop protection systems taking into account phytosanitary condition of agroecosystems, agroecological conditions of crop cultivation and assortment of modern biological and chemical preparations. Justification of ways of ecologization and adaptive intensification of farming in the region and provision of technological solutions to this problem is given. All this served as a basis for the development of research on plant protection in new technological conditions. The works of scientists on various directions of plant protection are reflected in numerous methodical recommendations, monographs, books and brochures published annually and representing not only scientific but also practical interest [27].

Research work on plant protection problems in Siberia was carried out by the scientists of SibNIIKhim (O.A. Ivanov, V.A. Chulkina, V.V. Guliy, N.N. Gorbunov, O.A. Nesterova, M.V. Shternshis, T.V. Teplyakova, L.F. Ashmarina, V.A. Korobov, N.G. Vlasenko, A.A. Malyuga), SibNIISKh (N.Z. Milashchenko, P.F. Ionin, V.G. Doronin), ANIISKh (F.P. Shevchenko, P.G. Alinovsky, G.Y. Stetsov), NIISKh of Northern Trans-Urals (M.F. Sannikova, L.I. Garbar, Y.B. Shurovenkov), Research Institute of Horticulture of Siberia named after M.A. Lisavenko (M.A. Prokofiev, L.D. Shamanskaya) and other researchers of scientific organizations of the region. They defined the basic principles of developing agroecosystems optimized for phytosanitary characteristics. It was established

that the most important techniques to optimize the relationship between crops and pests are selection of plant species and varieties resistant to their impact, optimization of mineral nutrition of plants, sowing terms.

Under the leadership of N.G. Vlasenko and A.N. Vlasenko and with the participation of O.I. Teplyakova, O.V. Kulagin, P.I. Kudashkin and other scientists, zonal systems of spring wheat protection against weeds, diseases and pests in Western Siberia have been developed. They are based on a flexible approach to determining the feasibility, strategy and tactics of protective measures, which allows not only to increase grain production by 1.5–3.0 times, but also to reduce environmental risks associated with the unreasonable use of chemical plant protection products.

For the first time in Western Siberia A.A. Malyuga and N.S. Chulikova conducted original research on the distribution of Colorado potato beetle in the forest-steppe zone, phenotypic structure of the population and bioecology of the pest in the plantings of potato varieties of different ripeness groups, the harmfulness of the phytophage on each variety is presented. The possibility of optimizing the phytosanitary condition of potatoes through the use of biological features of the variety is shown. The system of crop protection from the phytophage taking into account varietal characteristics is proposed.

It is necessary to note the successful research work of the young generation of plant protection scientists - N.A. Korotkikh, A.A. Slobodchikov, N.S. Chulikova, V.N. Timofeev, G.G. Sadovnikov, N.N. Sadovnikova, L.S. Dolmatova and many others.

CONCLUSION

During the period of formation of scientific farming scientists have done a huge amount of work, which has been widely recognized not only in Siberia, but also beyond its borders and found practical application in agricultural production in the region. The number of completed scientific developments, ready for implementation in production and implemented, is counted in thousands. Summarizing the re-

sults of 40-year activity of the Siberian Branch of epy VASKpNIL, then the Siberian Branch of the Russian Academy of Agricultural Sciences, the Chairman of the Department Academician A.S. Donchenko at the general meeting gave the following information: 1023 scientific developments have been completed in the field of agriculture. The science-intensive agro-technologies developed by scientists guarantee grain production in Siberia up to 25–30 million tons, sustainable development of farming, stable food supply and high return on renewable and non-renewable resources. The realization of these technologies will require broad integration efforts in all aspects of the agriculture operation and related sectors of the economy.

At present, the main directions of scientific activity on farming in Siberia are as follows:

- improvement of approaches to the development of adaptive-landscape farming systems and new generation agro-technologies;
- development of the methods of rational utilization of land and agro-climatic resources;
- improvement of the approaches to the organization of rational soil fertility management;
- research to form highly efficient crop rotations;
- study of technological and biological processes in the cultivation of agricultural crops;
- improvement of soil tillage systems, fertilizer application and integrated plant protection systems;
- application of GIS-technologies and artificial intelligence for organization of rational crop productivity management.

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Развитие систем земледелия в Приенисейской Сибири

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Представлены результаты исследований, проводившихся с целью оценки развития систем земледелия в Приенисейской Сибири за длительный период времени как базиса для выявления факторов, определяющих продуктивность сельскохозяйственных культур, и в качестве информационной основы для прогноза урожайности к 2030 г. В работе приведены сведения, охватывающие более чем двухсотлетний период земледельческой практики в Приенисейской Сибири. Установлено, что во все периоды сельскохозяйственного производства, каждому из которых соответствует определенная система земледелия, тренд изменения урожайности был положительным. Каждый последующий период был короче предыдущего, при этом урожайность существенно увеличивалась. Период применения экстенсивных технологий в земледелии длился более 140 лет. В это время урожайность увеличивалась на 0,0018 т/га в год. Период использования ординарной (малоинтенсивной) системы земледелия продолжался примерно 50 лет. Тогда урожайность повышалась на 0,0204 т/га в год. В период интенсификации системы земледелия, который занял примерно 30 лет, урожайность увеличивалась на 0,0212 т/га в год и достигла к концу периода примерно 2,1 т/га. Период становления высокоинтенсивной системы земледелия самый короткий, характеризуется наиболее высокими показателями роста продуктивности – 0,0639 т/га в год. При сохранении данного тренда средняя многолетняя урожайность в объеме 3,0–3,5 т/га будет достигнута ориентировочно к 2030 г. Для каждой почвенно-климатической зоны целесообразно иметь свою оригинальную систему земледелия, разработанную с учетом почвенно-агрохимических свойств, ландшафтных и климатических особенностей, отличающуюся более углубленной дифференциацией индивидуального рабочего участка. В ней должны быть представлены цифровые технологии с использованием современных электронных средств информатизации, геоинформационных систем, дистанционных методов и средств управления технологическими процессами, аэро- и космических методов диагностики агроэкосистем.

Ключевые слова: система земледелия, урожайность, цифровизация, дистанционное зондирование, Приенисейская Сибирь

Development of farming systems in the Prienisey Siberia

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The paper presents the results of research conducted to assess the development of farming systems in the Prienisey Siberia over a long period of time as a basis for identifying factors determining crop productivity, and as an information basis for forecasting crop yields by 2030. The work provides information covering more than two hundred years of land practice in the Prienisey Siberia. It was found that in all the periods of agricultural production, each of which corresponds to a certain farming system, the trend of yield change was positive. Each successive period was shorter than the previous one, with yields increasing significantly. The period of extensive technologies application in farming lasted more than 140 years. At this time, yields increased by 0.0018 t/ha per year. The period of use of the ordinal (low-intensity) farming system lasted approximately 50 years. The yields then increased by 0.0204 t/ha per year. During the period of intensification of the farming system, which took about 30 years, the yields increased by 0.0212 t/ha per year and reached about 2.1 t/ha by the end of the period. The period of formation of high-intensity farming system is the shortest, characterized by the highest productivity growth rates – 0.0639 t/ha per year. If this trend is maintained, the long-term average yield of 3.0–3.5 t/ha will be reached approximately by 2030. For each soil-climatic zone it is advisable to have its own, original farming system, developed taking into account soil-agrochemical properties, landscape and climatic peculiarities, characterized by more in-depth differentiation of individual working area. It should present digital technologies using modern electronic means of informatization, geoinformation systems, remote methods and means of technological processes control, aerial and space methods of agro-ecosystems diagnostics.

Keywords: farming system, crop yields, digitalization, remote sensing, Prienisey Siberia

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Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Any farming system should be based on stable, highly profitable production of organic raw materials to obtain the necessary food products and fodder without environmental pollution, and to rationally utilize and preserve the natural fertility of the soil.

According to GOST 16265-89, a farming system is a set of interrelated organizational and economic, agrotechnical, ameliorative, soil protection measures aimed at the effective use of land, agroclimatic resources, biological potential of plants and increasing soil fertility in order to obtain high and sustainable crop yields¹.

Productivity of agricultural crops depends on natural conditions, as well as on the level of intensification of the farming system (see the table). And the influence of the sum of natural factors on productivity varies not very significantly by natural zones, as each of the factors complements the action of another, according to the law of the cumulative action of plant life factors. Influence of the level of intensification of a farming system on productivity is much more significant.

The results obtained in farming in Siberia show that the data given in the table generally reflect the trend of dependence of grain crop

¹GOST 16265-89. Land cultivation. Terms and definitions. Moscow: Publishing house of standards, 1990, pp. 2–3.

Возможные уровни продуктивности зерновых культур в Сибири в зависимости от природных условий и систем ведения земледелия, т/га [1]

Possible levels of productivity of grain crops in Siberia depending on natural conditions and farming systems, t/ha [1]

Natural factor			System of farming			
insolation, heat	moisturizing	soil fertility	extensive	ordinary	intensive	high-intensity
<i>Subtaiga</i> (the sum of active temperatures more than 10 °C – 1700...1800 °C, precipitation – 400–450 mm, vegetation period – 110–115 days)						
4,0–5,8	3,8–5,0	6,0–1,5	0,5–1,0	0,7–1,6	2,6–4,0	3,6–5,0
<i>Forest-steppe</i> (the sum of active temperatures more than 10 °C – 1800...2000 °C, precipitation – 300–400 mm, vegetation period – 120–130 days)						
5,0–7,2	1,7–4,5	1,2–2,4	0,8–1,5	1,0–2,4	2,2–3,5	3,5–4,0
<i>Steppe</i> (the sum of active temperatures more than 10 °C – 2000...2400 °C, precipitation – 200–280 mm, vegetation period – 125–135 days)						
4,0–8,6	0,8–2,5	1,0–1,6	0,4–1,3	0,8–1,6	1,5–2,2	2,0–2,7
Approximate number of farms, operating under the system, %			45–50	35–40	10–15	Fewer than 5

yields on natural-climatic and soil-agrochemical conditions, as well as on the geographical zonality and the applied farming system. This pattern is characteristic of agricultural zones with predominance of agro-chernozems (Western Siberia² [2, 3] and Prienisey Siberia³), as well as for agricultural lands with a high prevalence of agro-gray soils [4, 5].

In different subzones of Western Siberia, taking into account the agroecological typology of lands, the possibility of reducing clean fallows, transition to no-tillage crop rotation, development of mulching tillage and their minimization against the background of the use of mineral fertilizers and other agrochemical means has been substantiated [6, 7]. Modern agro-technological policy provides for the increasing use of the elements of biological farming [8, 9].

There is experience in the Prienisey Siberia in the application of high-intensive farming systems, providing for the application of mineral fertilizers in the doses of 150–180 kg a.i./ha, the use of modern plant protection products and other means of intensification. This makes it

possible for the AO "Iskra", AO "Solgonskoe" in the Uzhursky district, ZAO "Nazarovskoye" in the Nazarovsky district, OAO "Poultry Plant "Zarya" in the Emelyanovsky district and some other farms in the Krasnoyarsk region to consistently produce 4–5 t/ha of grain crops. In 2022, the grain crop yield in the AO "Solgonskoe" reached a record high for the entire agricultural history of the region – 7 tons/ha. High productivity of crop production in these farms is due not only to natural factors and highly intensive farming, but also to highly competent production management. The experience of Krasnoyarsk farmers shows that the level of crop production productivity of a particular year is determined mainly by three factors: weather, intensification of agro-technologies and management.

According to generalized data of scientists, in Siberian agriculture the share of the weather conditions influence on crop productivity is 50–60% of the sum of all factors, the share of agrotechnics – 20–25%, the importance of crop and variety – on average 15–20% [10]. It should be noted that such a ratio of factors is more like-

²Adaptive-landscape farming systems of the Novosibirsk region / edited by V.I. Kiryushin, A.N. Vlasenko. Novosibirsk, 2002, 387 p.

³Farming system of the Krasnoyarsk region on the landscape basis: scientific and practical recommendations / edited by S.V. Brylev. Krasnoyarsk, 2015, 224 p.

ly to be true for extensive farming system. When intensification increases, the influence of the weather conditions decreases, and the anthropogenic conditions, on the contrary, increases.

The relevance of our research is conditioned by the need to realize the modern paradigm of the system of precision (digital, addressable) farming taking into account the peculiar natural-resource potential of the Priensiey Siberia.

The purpose of the research is to assess the dynamic development of the farming systems in the Priensiey Siberia over a long period of time as a basis for identifying the factors determining the productivity of agricultural crops and forecasting the yields by 2030.

MATERIAL AND METHODS

Various bibliographic sources and data from the Krasnoyarskstat archive served as the information basis of the research⁴⁻⁸.

The following methods were used in the work: statistical, comparative-analytical, analysis and synthesis, modeling, formalization. Microsoft Excel was used to graphically display the results of the study. Mathematical processing of the results was carried out using the methods of linear trend analysis of the time-series data.

RESULTS AND DISCUSSION

Traditionally, in the territory of the Priensiey Siberia a fallow-layland farming system was formed. Crops were cultivated on the freshly-raised virgin soil for 6–10 years, after which the arable land was left fallow (for 25–30 years) or layland (for 10–20 years). Mainly spring wheat, winter and spring rye, and oats were cultivated. The first governor of the Yenisey province A.P. Stepanov described the system of field cultivation that existed at that time: "The

land is plowed not before 7, 10, 12 years, but with the help of fallow it is good for up to 18 years. The left plowed land, having rested for 20 years, again goes into arable land"⁹. The system, under which the restoration of the soil fertility occurred naturally, prevailed until the middle of the XXth century. Under these conditions, no more than 25% of land was under crops, which makes it possible to consider such a system as unproductive.

Depending on the zonality of farming, there were differences in the frequency and time of plowing for sowing and fallow fields. Thus, the field intended for fallow was left untilled in winter after harvesting. The first plowing in the central part of the Yenisey Province (Krasnoyarsk District) was carried out from May 24 to June 22, in the western part (Achinsk District) from May 26 to June 25, in the southern part from June 1 to June 20 (Minusinsk District) and from June 2 to June 15 (Kansk District). The second plowing was conducted in the Krasnoyarsk District from June 20 to July 13, in the Achinsk District from June 29 to July 16, in the Minusinsk District from June 20 to July 20, and in the Kansk District from July 1 to July 17. Wealthy peasants, if necessary (in case the field was overgrown with weeds), carried out the third plowing in the middle of August. The depth of tillage depended on the timing of its implementation. The first plowing was carried out at a depth of 9–11 cm, the second 13–16 cm, the third 15–18 cm. There was also a difference in the timing of sowing. Sowing of spring crops in the southern regions was started on April 23, in the northern regions on May 6–9. The first to sow were spring rye and wheat, then oats, and lastly barley. Harrowing as a means of drought and weed control was

⁴*Sabashnikov V.V.* Agriculture in the Priensiey region. Krasnoyarsk: Publication of the Central Siberian State Geographical Society, 1929. Ch. 1: Farming, horticulture, fruit growing. 33 p.

⁵The system of farming in collective and state farms of the Krasnoyarsk region / edited by A.T. Belozarov (editor-in-chief) et al. Krasnoyarsk, 1960, 458 p.

⁶The system of farming of the East Siberian zone. Krasnoyarsk, 1967, 531 p.

⁷Farming system of the Krasnoyarsk region. Novosibirsk, 1982, 631 p.

⁸Krasnoyarsk regional statistical yearbook: stat. coll. / Krasnoyarskstat. Krasnoyarsk, 2000–2021. URL: <https://krasstat.gks.ru/folder/30015>.

⁹*Stepanov A.P.* Yenisey Province. Krasnoyarsk: Gornitsa, 1997, Ch. 1–2, 226 p.

of great importance in the general cycle of agricultural work in Siberia. Peasants paid special attention to the quality of seeds. In the Yenisey province, in order to prevent degeneration of seeds, the largest grain was selected for sowing, moreover, from the drying shed that gave the highest threshing rate¹⁰.

In the late 1930s, V.R. Williams¹¹ developed a grassland agriculture system aimed at restoring soil fertility through the cultivation of perennial cereals, leguminous grasses and their mixtures. Here is what the researcher of agricultural production of Siberia V.V. Sabashnikov wrote in 1929 about grassland agriculture in the Prienisey region: “The survey of a number of advanced peasant farms in the Krasnoyarsk, Achinsk and Kansk districts, made in 1927 by the Prienisey Regional Agricultural Experimental Station, showed that along with the farms of the old type with the predominant grain direction, there are farms with the predominance of cultural cattle breeding, with crops on the fields of fodder grasses and tuber crops, proper crop rotations, etc., in a word, farms transitioning to the highest form of field farming – the fallow-grassland agriculture system” (see footnote 4).

Grassland agriculture existed for a short time and did not manage to spread widely. The Great Patriotic War interfered, and after the Great Patriotic War other priorities and problems related to the restoration of the destroyed national economy became sharply defined. First of all, it was necessary to get food grain. Agrarian policy in the post-war period was aimed at increasing the area of agricultural land, mainly arable land. At first, a program on large-scale development of virgin and fallow lands was implemented, later on the land reclamation. Irrigation systems were built in the southern regions of the Prienisey Siberia, and drainage systems in the central and northern regions. Cultivation works were carried out on the forested areas, accompanied by reclamation. All these objects of land use had, in fact, their own farming systems.

In 1956 on the basis of the Kamalinskaya State Breeding Station the Krasnoyarsk Research Institute of Agriculture (KrasNIISKh) was established. According to the system of farming in collective and state farms of the Krasnoyarsk region, developed by the KrasNIISKh, “in relation to the conditions of each collective and state farm, a significant place should be taken by detailed agro-soil surveys. <...> Each kolkhoz and sovkhoz should have a detailed (scale 1: 10000, 1: 25000) soil map with agro-productive assessment of the soils and an appendix of cartograms on application of fertilizers, improvement of acid and alkaline soils, anti-erosion and land reclamation measures” (see footnote 5). This system also scientifically justified the use of zonal field crop rotations, which have retained their relevance until today. According to the system, “the placement of crops and specialization of agriculture should correspond to the soil and climatic conditions and peculiarities of this or that zone”. This approach predetermined the transition to the zonal system of farming. In the system of farming of the Eastern Siberia zone developed by the KrasNIISKh 7 years later, the zonal approach was expressed even more clearly (see footnote 6).

The farming system of the Krasnoyarsk Territory, proposed by the staff of the Krasnoyarsk Research Institute of Agriculture, Krasnoyarsk Agricultural Institute and the Territory Production Department of Agriculture in 1982 (see footnote 7), was also zonal. GOST 16265-89 defines a zonal farming system as “a system, all links of which fully take into account and realize soil-climatic, material-technical and labor resources of a particular natural zone”. All links of the mentioned system (crop rotations, soil treatment, fertilization, weed, disease and pest control, etc.) should be matched to specific soil-climatic zones. The authors of the system note that the existing distribution of the crops in the region mainly corresponds to its natural conditions. However, the set of varieties well adapted

¹⁰*Meshalkin P.N.* Yenisey province at the world exhibitions (late XIX - early XX century) // XX century. Historical experience of agrarian development of Siberia: materials of the national scientific conference Krasnoyarsk, 1993, pp. 80–85.

¹¹*Williams V. R.* Collected Works: in 12 vol. Moscow: Selkhozgiz, 1949, vol. 4: Meadow farming, 504 p.

to local natural conditions, taking into account the great diversity of these conditions for many crops was insufficient. Despite the positive results achieved, zonal farming systems did not fully ensure the preservation and improvement of soil fertility. The pursuit of maximum productivity was not always economically justified and did not meet the requirements of the market. The very concept of “zonal” was not sufficiently elaborated. It was not taken into account that the farmer works not only in the natural-climatic zone, but, first of all, on a particular field, which is confined to a particular landscape.

In 1988, scientists of the Krasnoyarsk Research Institute of Agriculture, Krasnoyarsk Agricultural Institute and the employees of the Regional Production Department of Agriculture developed a system of farming in the Krasnoyarsk region¹². The published recommendations define the idea of intensification of production: “At the present stage of agricultural development, intensification of farming and increasing crop yields on this basis is the main way to increase agricultural production. Reserves for the development of new lands are practically exhausted. Their plowing on a large scale in the established areas of agriculture can increase soil erosion. The development of new lands for arable farming in the northern regions will require large capital investments, which in the foreseeable future, apparently, would be more appropriate to be directed to the settled areas”. As we can see, at that time there was a clear understanding of the current situation and outlined ways of solving agrarian problems.

A new agronomic paradigm has been formed in agriculture at the beginning of the XXIst century, taking into account the experience of the zonal farming systems development. For all their importance, zonal farming systems have ceased to meet the requirements of ecological management, i.e. to meet the requirements of natural factors. Modern approaches to the development of farming are based on detailed knowledge of soil properties, soil cover, and, consequently,

rational (ecologically and economically) placement of major crops. The concepts of adaptive, adaptive-landscape, landscape-ecological farming are being formulated, allowing to obtain profitable production [6]. It is believed that at the current level of information support a more progressive and rational approach to the land use can be formed.

The need to develop new approaches is also conditioned by the social situation in the agrosphere, the reduction of arable land due to its transfer into private ownership, the ruin of a huge number of agricultural enterprises and land abandonment. Arable land, meadows and forests were abandoned, perennial fallow lands overgrown with weeds, bushes and forests were formed by themselves. Soil-protection measures were not carried out. The situation was aggravated by a sharp outflow of human resources from the rural areas, and there was a widespread shortage of workers and specialists. The main agricultural products were produced by a few large enterprises, which operate thanks to the government subsidies.

Undoubtedly, the former farming system of the Krasnoyarsk region, developed in 1982, required improvement. This is due to the changes in the forms of ownership of land and management facilities, agricultural techniques, variety of chemical plant protection products and fertilizers, varietal composition of crops, etc. Gradually, taking into account the accumulation of new knowledge, zoning of new varieties, application of modern technology and agricultural implements, the former system was improved. This is how the landscape-based farming system of the Krasnoyarsk Territory emerged. Its main theses in the form of scientific and practical recommendations are presented in the book published in 2015 (see footnote 3). The new farming system is built taking into account natural and climatic resources, soil conditions, economic situation, market conditions, etc. The recommended technological operations take into account the species and variety composition of the crops, differ-

¹²The system of farming in the Krasnoyarsk region: recommendations. Novosibirsk, 1988, 238 p.

entiation of fertilizer and plant protection agent application systems depending on the agroecological conditions of the agrocenosis, modern energy equipment facilities.

In the 2015 system the geomorphological (natural) district is taken as a basis for zoning. There are five of them: Kansky, Krasnoyarsksky, Achinsko-Bogotolsky, Chulymo-Yeniseisky, and Yuzhno-Minusinsky. Within the districts, the natural zones (relief, climate, soils, vegetation) are characterized in detail, and detailed information on the agrolandscapes is provided for each natural zone. In some landscapes the areas are highlighted. Within the framework of this system "landscape approach" was widely declared. However, science-based farming on a landscape basis requires more knowledge, in-depth scientific research in the conditions of stationary field experiments covering the prevailing agrolandscapes. It is necessary to form ecologically balanced agrolandscapes and adapt technological processes to them more deeply for sustainable farming and reproduction of agro-resources (moisture, nutrition elements, organic matter, soil physical properties, etc.). Such research was limited, mainly during three long-term stationary field experiments: at the Mininsky (open forest-steppe), Solyansky (typical forest-steppe) and Zarechensky (subtaiga) stations, included in the register of long-term stationary field experiments of the state scientific institutions¹³. The research results obtained at these stations are representative only for the corresponding soil-agrochemical and agroclimatic conditions. In this regard, the task of adapting technologies to specific selected landscapes was not fully accomplished. The 2015 farming system largely retained the zonal approach to farming.

At the current level of agricultural production, new strategies and new requirements for the quality of work performed are necessary. This requires revision of the whole paradigm of agro-technological modeling. It is based not only

on the narrowing of the ecological address of the farming system, but also on the differentiation of the main elements. Experiments conducted in the Altai Territory showed that the effectiveness of fertilizers on leached chernozem increases with the increase in the level of pesticide saturation, providing on a protected background an increase in wheat yield after fallow by 0.47 t/ha (23%), after oats by 0.52 t/ha (37%). The efficiency of pesticides increased on the background of fertilizers: the increase in wheat yield after fallow from the use of pesticides on unfertilized and fertilized ($N_{40}P_{25}$) backgrounds was 0.57 and 0.76 t/ha, respectively [11]. Thus, the ecological address of the farming system becomes not only a natural zone or province, but also an agro-ecological group of lands of a particular province with optimal agro-technological parameters. It can be concluded that for each soil-climatic zone it is advisable to have its own original farming system, allowing to make adjustments in case of violation of any of its links due to natural or anthropogenic reasons with minimal damage. More in-depth differentiation concerns an individual working plot with a certain geospatial orientation. Each system should begin with the assessment of natural-resource potential of the territory.

In recent years, with different intellectual and instrumental intensity, a digital (precise, representative) farming system has been developing, the purpose of which, in generalized form, is to balance the main target blocks of farming: crop yields, financial benefits, and environmental impact. The basis of the scientific concept of precision farming is the concept of soil fertility diversity within one field. Assessment of soil heterogeneity requires the development of modern technologies adapted to specific soil and climatic conditions, based on geoinformation systems of global positioning with special sensors, aerial photo and space images, special programs for agro-management. These resources are used to plan precise

¹³Register of long-term stationary field experiments of the state scientific institutions of the Siberian Branch of Rosselkhozakademy / compiled by L.F. Ashmarina, A.I. Ermokhina, T.A. Galaktionova: L.F. Ashmarina, A.I. Ermokhina, T.A. Galaktionova; under general ed. by N.I. Kashevarov. Novosibirsk, 2009, 285 p.

seeding, calculate fertilizer and crop protection rates, predict yields more likely, and plan financially. Elements of digital farming include: digitization of fields, soil sampling for analysis in a coordinate system, digital agrochemical cartograms, satellite monitoring of vehicles, parallel driving, differentiated tillage based on soil maps, differentiated seeding, monitoring of agrocenosis condition using remote sensing, differentiated application of fertilizers and plant protection products, preparation of digital maps for yield forecasting, etc.

Scientific and technical resources of the Krasnoyarsk Scientific Center of the Siberian Branch of the Russian Academy of Sciences (FRC KSC SB RAS) allow for the assessment of agrolandscapes on the basis of ground monitoring and remote sensing. Without this information it is impossible to implement precision agriculture.

Introduction of precision farming technologies in the work of agricultural enterprises should be carried out under a number of preconditions. Before starting to implement precision farming, it is necessary to:

- 1) fully utilize the technological resources and principles of the adaptive-landscape system;
- 2) develop legislative measures aimed at economic support of the farms implementing precision farming technologies;
- 3) prepare scientific support for the development and implementation of precision farming principles based on digital technologies;
- 4) conduct training seminars on precision technologies with agronomists and farm managers;
- 5) provide for the study of technological processes in accordance with the requirements of precision agriculture in the curricula of agrarian universities and agricultural colleges, in the training of agronomists, agrochemists, land reclamation specialists and land surveyors.

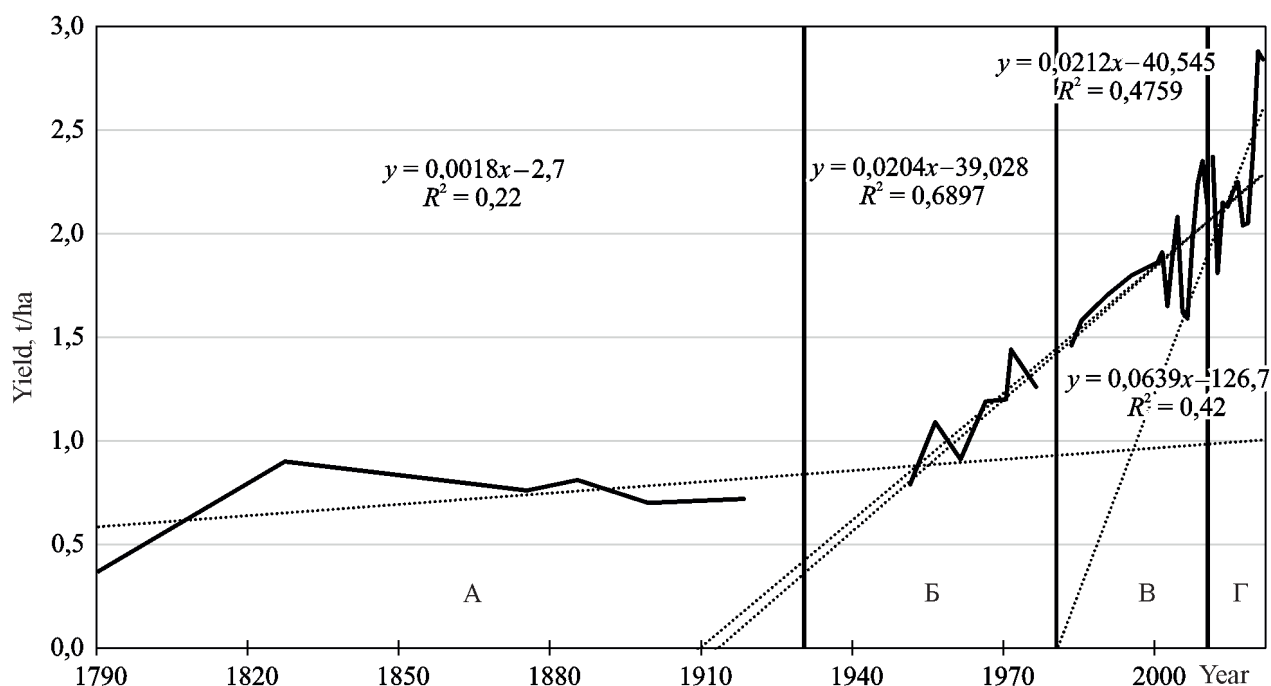
To understand the role of farming systems in shaping the productive capacity of agrocenoses, we calculated the trend of grain crop yields over a long period. The graph of changes in grain yields in the Yenisey Province and the Krasnoyarsk Territory covers the period from 1790 to 2021 (see the figure). Primary information on

crop yields was collected from various sources and the Krasnoyarskstat archive.

It should be noted that the authors do not have data for each calendar year, so the flat lines of the graph reflect averaged data by years, and broken lines show more complete, annual data. According to the graph, in all periods, when using this or that farming system, the trend of yield change remained positive. Each subsequent period was significantly shorter than the previous one, and the yields increased significantly. The period of extensive agriculture lasted more than 140 years. During this time, according to the trend equation, the yields increased by 0.0018 t/ha per year, from 0.37 to 0.72 t/ha. Ordinary farming system was used for about 50 years. During this period, the yields increased at a rate of 0.0204 t/ha/year and reached 1.4 t/ha by 1980. The period when intensification of the farming system took place with a break for radical agrarian reforms can be defined as about 30 years. It was characterized by the growth of the yields by 0.0212 t/ha per year and achievement of the yields of about 2.1 t/ha by the end of the period. The period of origin of the high-intensity farming system is the shortest, with the highest productivity growth (increase of 0.0639 t/ha per year). If this trend is maintained, the average yield of 3.0–3.5 t/ha will be achieved in the Krasnoyarsk Territory by 2030.

CONCLUSION

In all the periods accompanied by the application of one or another farming system, the trend of yield change remained positive. The conditional time period of existence of each subsequent system was significantly shorter than the previous one, and the corresponding yield was significantly higher. Under the extensive farming system, the yields increased by 0.0018 t/ha per year (from 0.37 to 0.72 t/ha). Under the ordinal farming system, the yields increased by 0.0204 t/ha per year, reaching 1.4 t/ha by 1980. During the period of intensification of the farming system there was an increase in the yields by 0.0212 t/ha per year, due to which by the end of the period this indicator amounted to about



Урожайность зерновых культур в Енисейской губернии и Красноярском крае с 1790 по 2021 г.

Система земледелия: А – экстенсивная (1790–1930 гг.); Б – ординарная (1930–1980 гг.); В – интенсивная (1980–2010 гг.); Г – высокоинтенсивная (2010–2021 гг.)

Grain yields in the Yenisey province and the Krasnoyarsk Territory from 1790 to 2021

The farming system: А – extensive (1790–1930); Б – ordinary (1930–1980); В – intensive (1980–2010); Г – highly intensive (2010–2021)

2.1 t/ha. The period of origin of high-intensive technologies is the shortest, characterized by the highest productivity growth of 0.0639 t/ha per year. If the above trend is maintained, the yield of 3.0–3.5 t/ha will be achieved in the Krasnoyarsk Territory by 2030.

For each soil-climatic zone it is advisable to have its own original (zonal) farming system with more in-depth differentiation of individual working area, which will present digital technologies using modern electronic means of informatization, geoinformation systems, remote control means of technological processes, aerial and space methods of agro-ecosystem diagnostics.

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Совершенствование элементов технологии возделывания картофеля в производственных условиях

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Представлены результаты совершенствования технологии возделывания картофеля за счет повышения эффективности системы защиты растений в условиях производственного опыта. Исследование проводили в 2021–2023 гг. на землях ООО «Дружба-2» (Брянская область, Жирятинский район). Объектом исследования являлись два сорта картофеля первой репродукции – Ред Скарлетт (Нидерланды) и Гала (Германия). Схема опыта включала два варианта: 1) традиционная система защиты картофеля, принятая в хозяйстве (контроль); 2) усовершенствованная система защиты. Обе системы защиты направлены на профилактику вредителей (колорадский жук, личинка жука-щелкуна), сорняков (подмаренник цепкий, паслен черный, яснотка пурпурная, марь белая, трехреберник непахучий, мятлик однолетний, метлица обыкновенная) и болезней (альтернариоз, фитофтороз, серебристая парша, ризоктониоз, различные виды гнилей, питиум). Почвы участков дерново-подзолистые. Предшественник – озимый рапс. Общая площадь производственного опыта составила 120 га (по 60 га под каждым сортом). Картофель выращивали по интенсивной технологии с традиционной системой обработки почвы по схеме 75 × 28 см. Норма посадки – 50 тыс. клубней на 1 га. Технология рассчитана на получение урожайности клубней 40–60 т/га. Опытным путем установлено, что применение усовершенствованной технологии с использованием новой для хозяйства системы защиты растений способствует увеличению густоты стояния растений и их сохранности на момент уборки на 2,5–3,0%, повышению числа клубней с одного растения на 7,5–10,0%, средней массы одного клубня – на 7–11%, массы клубней с одного растения – на 14,5–23,0%, урожайности – на 17–26%, товарности – на 12,5–14,5%, товарной урожайности – на 32–45%, условного чистого дохода – на 16,2–24,5%.

Ключевые слова: картофель, технология возделывания, система защиты, урожайность, эффективность

Improvement of potato cultivation technology elements in production conditions

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The results of improving potato cultivation technology by increasing the efficiency of plant protection system in the conditions of production experience are presented. The study was conducted in 2021–2023 on the lands of the ООО "Druzhba-2" (Bryansk region, Zhiryatinsky district). Two potato varieties of the first reproduction, Red Scarlett (Netherlands) and Gala (Germany), were the object of the study. The experiment scheme included two variants: 1) traditional potato protection system adopted in the farm (control); 2) improved protection system. Both protection systems are aimed at the prevention of pests (Colorado potato beetle, snap beetle larvae), weeds (cleavers, black nightshade, purple deadnettle, lamb's quarters, wild camomile, annual bluegrass, wind bent grass) and diseases (early blight, late blight, silver scurf, rhizoctoniosis, various types of rots, pythium). Soils of the sites are sod-podzolic. The forecrop is winter rapeseed. The total area of the production experiment was 120 ha (60 ha under each variety). Potatoes were grown under intensive technology with conventional tillage system on a 75 × 28 cm pattern. Planting rate is 50 thousand tubers per 1 ha. The technology is designed to obtain tuber yields of 40–60 t/ha. Experimentally it has been established that the application of the improved technology with the use of a new plant protection system for the farm contributes

to an increase in plant stand density and their safety at the time of harvesting by 2.5–3.0%, increase in the number of tubers from one plant by 7.5–10.0%, average weight of one tuber – by 7–11%, weight of tubers from one plant – by 14.5–23.0%, yield – by 17–26%, marketability – by 12.5–14.5%, marketable yield – by 32–45%, conditional net income – by 16.2–24.5%.

Keywords: potatoes, cultivation technology, protection system, yield, efficiency

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Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the main agricultural crops cultivated on more than 19 million hectares of agricultural land [1]. The annual gross tuber yield in the world reaches 400 million tons with an average yield of about 18 t/ha, and these figures are constantly increasing. The world's largest potato producers are China, India and Russia [2]. According to FAO (Food and Agriculture Organization of the United Nations) estimates, worldwide per capita consumption of potatoes and potato products is about 35 kg per year, with an average of 85 kg in Europe and 90 kg in Russia [3].

Potato tubers contain carbohydrates, proteins, vitamins, essential amino acids, mineral salts and organic acids. In the world, it ranks fifth among the sources of energy in the human diet after wheat, corn, rice and barley, because of which it is often called the second bread¹. In addition, since potatoes are a good forecrop for most cultivated crops, they are considered to be an agronomically important crop [4].

In 2021 in Russia, the area under potatoes in the farms of all categories amounted to 1,146.3 thousand hectares, including 154.4 thousand hectares in agricultural associations, 125.5 thousand hectares in peasant households and individual entrepreneurs and 866.5 thousand hectares in household farms. Gross potato harvest in

the farms of all categories reached 18.2 million tons, including 6.56 million tons in agricultural associations and peasant households. Over 50% of the production of the total consumption is directed to the preparation of a variety of potato dishes, primarily in the home as well as in the catering industry [5, 6]. According to the Ministry of Agriculture of the Russian Federation, in 2022, despite difficult weather conditions during harvesting in some regions, 7.2 million tons of potatoes were harvested in the commercial sector against 6.6 million tons in 2021. The Bryansk Region, as before, was the region with the largest area under commercial potato production in Russia in 2022. The region's area amounted to 29.8 thousand hectares (9.9% of the total industrial potato area in Russia). Over the year, the area increased by 5.9% (by 1.7 thousand ha).

Potato is a high-yielding crop, which gives good yields of high-quality tubers if the production technology is correct. Violation of cultivation technologies leads to a decrease in the size and quality of yield, increase in labor and money costs per unit of production [7]. Specialists note that the potential yield of potato varieties in Russia is not realized by as many as half and the average tuber yield has barely reached the average world level (18 t/ha) [8]. According to this indicator, as well as the quality of potato products, our country ranks among the last in the world [9].

¹Belous N.M., Torikov V.E., Kotikov M.V., Bogomaz O.A., Bogomaz A.V. Potatoes: biology and cultivation technologies. Bryansk: Bryansk State Agrarian University Publishing House, 2010, 110 p.

There are a number of reasons for the low yields and instability of the crop in our country. First of all, at present, the potato industry, as well as agricultural production in general, is seriously affected by the changing climate – the instability of temperature and precipitation has increased, the nature and area of distribution of harmful objects have changed [10, 11]. Other reasons for the decrease in potato yields are non-compliance with agrotechnical methods of cultivation of the crop and untimeliness of their implementation [12].

However, one of the most serious reasons for reducing the efficiency of potato production in Russia has become a massive development of diseases, pests and weeds, various rots (in storage), caused by the lack of varieties with group resistance, the reduction of protective activities [13].

About 30 common harmful diseases (early blight, wet rot of tubers caused by bacterial or fungal pathogens, potato scab and silver scurf, rhizoctoniosis, late blight, viral diseases, etc.) and a number of common pests (Colorado potato beetle, wireworms and false wireworms, caterpillars of moths and aphids) are registered annually on potato plants and tubers, total yield losses from which may exceed 50% [9]. Moreover, at the International Plant Protection Congress (IPPC 2015), data was presented that in potato cultivation, even with the use of chemical defenses, losses due to various diseases amount to 25–30% [14].

Control of pests on potatoes is complicated by the fact that about 85% of their areas are in the private sector, and 15% belong to agricultural holdings, cultivating land with the use of modern technologies and the use of a wide range of protection products [9, 15]. At the same time, in most potato farms the representation of foreign varieties reaches 100%. Active expansion of foreign varieties and non-compliance with regulations on their agrotechnics led to a deplorable result: new pathogens have spread on the territory of the Russian Federation [14].

In the Bryansk region, potato production is one of the most dynamically developing branches of agriculture. The average potato yield in the region for two decades increased from 13.5

to 30.2 t/ha, i.e. 2.2 times (or by 223.7%), and gross production for the same period increased by 655.7 thousand tons (220.6%), despite the decrease in the area planted with potatoes in the regional structure of agricultural crops [16, 17]. In the advanced farms of the region, in which the Western European technology is applied in potato cultivation, the tuber yield reaches 40–50 tons/ha, for some varieties – 60–70 tons/ha and higher [18, 19].

However, even in advanced farms the problem of controlling the number of pests that cause millions of rubles of damage annually is acute. Therefore, it is necessary to implement a set of protective measures at all stages in the fight against pests in potato plantings: during soil and seed preparation for planting, in pre-harvest and harvesting periods, during post-harvest processing of tubers and directly during storage. This complex includes various measures, but the central place is occupied by the chemical method of protection, the improvement of which will make it possible to obtain consistently high yields with full and healthy tubers [20]. At the same time, experts note that when using a chemical system of protection, the productivity of the crop is 1.5 times higher than when using a biological system [21].

The purpose of the research is to improve the technology of potato cultivation in the OOO “Druzhba-2” in the Zhiryatinsky district of the Bryansk region by increasing the efficiency of the protection system.

MATERIAL AND METHODS

The research was conducted in the conditions of a production experiment on the lands of the OOO “Druzhba-2” in 2021–2023. The soils are sod-podzolic. The object of research were two potato varieties of the first reproduction (RS 1): Red Scarlett (Netherlands) and Gala (Germany). The area of their planting in the farm reaches 1500 hectares. The choice of these varieties for cultivation in the OOO “Druzhba-2” on large areas is justified by the fact that the consumer in modern conditions has high requirements for the commercial appearance of tubers, the color of the skin and flesh, taste, starch content, stora-

bility. More and more preference is given to the varieties with a beautiful shape of tubers, preferably pink or red, yellow flesh color with high taste qualities [22, 23]. The varieties Red Scarlett and Gala fully meet all market requirements and were included in the State Register in 2000 and 2008, respectively².

The experiment scheme included two variants:

a) option 1 – traditional potato protection system adopted by households (control);

б) option 2 – advanced protection system (see Fig. 1).

Characteristics of both protection systems are presented in Table 1.

Both protection systems are aimed at pest prevention (Colorado potato beetle, snap beetle larvae), weeds (cleavers, black nightshade, purple deadnettle, lamb's quarters, wild camomile, annual bluegrass, wind bent grass), and diseases (early blight, late blight, silver scurf, rhizoctonia, various types of rots, pythium).

The total area of the production experiment

amounted to 120 ha (60 ha under each variety). The potatoes were grown according to the intensive technology with traditional tillage system (see footnote 1) on the scheme 75×28 cm. Planting rate – 50 thousand tubers per 1 ha. The forecrop – winter rapeseed. The technology is designed to obtain the yield of 40–60 tons/ha.

Potato varieties were recorded for diseases and pests, as well as for the assessment of yield structure, yield and tuber marketability according to the methodology of the state variety testing of agricultural crops³. Weediness of plantings was determined by the glasometer method. Statistical processing of research results was carried out by dispersion method⁴. Economic efficiency was calculated according to the recommendations⁵.

RESULTS AND DISCUSSION

Studies conducted in 2021–2023 showed that the average standing density of potato plants at the time of harvesting ranged from 47.2 to 49.0 thousand pieces/ha, tuber weight per plant from



Рис. 1. Картофельные поля, выращиваемые с применением традиционной (а) и усовершенствованной (б) систем защиты

Fig. 1. Potato fields grown using traditional (a) and advanced (б) protection systems

²The State Register of Breeding Achievements Approved for Use. vol. 1: Plant Varieties. URL: <https://gossortrf.ru/> (date of reference: 21.12.2023).

³Methodology of state varietal testing of agricultural crops. Moscow, 2015, Issue 4: Potato, vegetable and melon crops, 14 p.

⁴Dospekhov B.A. Methods of field experiment (with the basics of statistical processing of research results): textbook for university students, 6th ed. Moscow: Alliance, 2011, 350 p.

⁵Chenkin A.F., Glebov M.A., Lapshin L.V. Economics and organization of plant protection. Moscow, 1978, 256 p.

Табл. 1. Система защиты картофеля по вариантам производственного опыта
Table 1. Potato protection system by variants of production experience

Phase of development	Name of preparation	Preparation dosage	Method and time of treatment, specifics of application
Option 1			
1. Planting	Prestizh, SC	1,0 l/t	Treatment of tubers
	Albit, PA	0,1 l/t	
2. Before sprouting	Zenkor Ultra, SC	1,2 l/ha	Soil spraying
3. Active growth	Ridomil Gold MC, WDG	2,5 kg/ha	1st plant treatment
	Infinito, SC	1,6 l/ha	14 days later
	Izabion, AS	2,0 l/ha	
4. Complete development	Infinito, SC	1,6 l/ha	14 days later
	Acrobat MC, WDG	2,0 kg/ha	10 days later
	Izabion, AS	2,0 l/ha	
5. Tuber growth	Acrobat MC, WDG	2,0 kg/ha	7 days later
6. Wilting of the haulm	Infinito, SC	1,6 l/ha	Before harvesting
	Reglon Forte, AS	1,0 l/ha	
Option 2			
1. Planting	Kvadrис, SC	3,0 l/ha	Soil spraying
	Cruiser 350, SC	0,22 l/t	Treatment of tubers
2. Before sprouting	Gezagard, SC	3,0 l/ha	Soil spraying
	Boxer, EC	3,0 l/ha	
3. Active growth	Ridomil Gold MC, WDG	2,5 kg/ha	1st plant treatment
	Ridomil Gold MC, WDG	2,5 kg/ha	14 days later
	Izabion, AS	2,0 l/ha	
4. Complete development	Revus Top, SC	0,6 l/ha	14 days later
	Revus Top, SC	0,6 l/ha	10 days later
	Skor, EC	0,4 l/ha	
	Izabion, AS	2,0 l/ha	
5. Tuber growth	Bravo, SC	2,5 l/ha	7 days later
6. Wilting of the haulm	Shirlan, SC	0,3 l/ha	Before harvesting
	Reglon Forte, AS	1,0 l/ha	

764.8 to 1187.8 g, number of tubers per plant from 9.2 to 10.3 pieces, average tuber weight from 83.4 to 115.7 g. The yield depending on the variety and the variant of the experiment was from 36.1 to 58.2 t/ha (see Table 2).

Of the studied varieties, the lowest yield structure and yield indices were observed in the variety Red Scarlett. Thus, the average number of plants at the time of harvesting in this variety was at the level of 47.2–48.6 thousand pieces/ha, tuber weight per plant was 764.8–938.3 g, average tuber weight 83.4–92.6 g, average number of tubers per bush 9.2–10.1 pieces, yield 36.1–45.6 tons/ha. In the variety Gala, the listed productivity indicators were as follows: 47.9–49.0 thousand pieces/ha; 1037.6–1187.8 g; 108.2–

Табл. 2. Продуктивность сортов картофеля (среднее за 2021–2023 гг.)**Table 2.** Productivity of potato varieties (average for 2021–2023)

Experiment variant	Number of plants at the time of harvesting, thousand pieces/ha	Tuber weight per plant, g	Number of tubers per plant, pcs.	Average tuber weight, g	Yield, t/ha
<i>Red Scarlet</i>					
1	47,20	764,8	9,20	83,40	36,10
2	48,60	938,3	10,10	92,60	45,60
LSD ₀₅	1,04	29,8	0,72	6,21	6,15
<i>Gala</i>					
1	47,90	1037,6	9,60	108,20	49,70
2	49,00	1187,8	10,30	115,70	58,20
LSD ₀₅	0,96	22,5	0,54	3,18	5,46

115.7 g; 9.6–10.3 pieces and 49.7–58.2 t/ha, respectively.

It is important to note that both the traditional protection system used in the farm (option 1) and the improved system (option 2) showed high efficiency. At the planting rate of 50 thousand tubers per 1 ha at the time of harvesting there were from 47.2 to 49.0 thousand plants. Thus, the safety of plants in the two variants of the experiment amounted from 94.4 to 98.0%. However, the efficiency of the improved system was higher than the traditional one. Thus, the safety of plants at the time of harvesting on the studied varieties under the traditional system of protection (control) was at the level of 94.4–95.8%, when using the improved system, it was 97.2–98.0%.

Improvement of potato varieties cultivation technology also contributed to a significant increase in other indicators of the yield structure. Thus, the average tuber weight in the control in the variety Red Scarlett was 83.4 g, in the variety Gala it was 108.2 g. In the variant 2 this indicator corresponded to the values of 92.6 and 115.7 g, the gain to the control reached 9.2 and 7.5 g. The average number of tubers per plant in option 1 varied in the range from 9.2 to 9.6 pieces, in option 2 from 10.1–10.3 pieces, which is on average 0.7–0.9 tubers more than control.

Increase in the values of these two indicators due to the changes in the plant protection system contributed to an increase in the productivity of one plant. Thus, the average tuber weight per plant in the Red Scarlett variety in the control

variant amounted to 764.8 g, in variant 2 to 938.3 g (+ 173.5 g relative to the control), and in the Gala variety to 1037.6 and 1187.8 g (+ 150.2 g), respectively.

A greater number of plants at the time of harvesting and a greater weight of the tubers per plant in the application of improved technology contributed to a significant increase in the yield. Since the yield of Red Scarlett variety in the control variant was 36.1 t/ha, that of the Gala variety was 49.7 t/ha, and in variant 2 it was 45.6 and 58.2 t/ha, respectively; the yield increase of these varieties reached 9.5 and 8.5 t/ha at LSD₀₅ equal to 6.15 and 5.46 t/ha.

Improvement of the potato cultivation technology elements, in addition to the crop yield, contributed to an increase in the marketability and, consequently, to an increase in the marketable yield (see Table 3).

In the Red Scarlett variety, the tuber marketability averaged 76.8% for three years of research when using the traditional protection system (variant 1) and 88% when using the improved technology (see Table 3, Fig. 2). In the Gala variety, the tuber marketability was higher: in the control it was 82.9%, in variant 2 it was 93.3% (see Table 3, Fig. 3). Thus, the marketable yield of potato tubers in variant 1 was 27.7 and 41.2 t/ha, in variant 2 it was 40.1 and 54.3 t/ha depending on the variety.

With marketable yield of the Red Scarlett variety at the level of 27.7 t/ha and the Gala variety at 41.2 t/ha (in the variant with the use of traditional technology) and the selling price of the marketable tubers of 10 000 rubles/t, the cost of

Табл. 3. Урожайность и товарность сортов картофеля (среднее за 2021–2023 гг.)
Table 3. Yield and marketability of potato varieties (average for 2021–2023)

Experiment variant	Yield, t/ha	Marketability, %	Marketable yield, t/ha
<i>Red Scarlett</i>			
1	36,10	76,80	27,70
2	45,60	88,00	40,10
LSD ₀₅	6,15	5,56	7,68
<i>Gala</i>			
1	49,70	82,90	41,20
2	58,20	93,30	54,30
LSD ₀₅	5,46	5,12	7,83

marketable products amounted to 277 000 and 412 000 rubles/ha, respectively (see Table 4).

Since the production costs to obtain marketable products in these varieties correspond to the values of 144,647 and 178,837 rubles / ha, the value-added income amounted to 132,353 and 233,163 rubles / ha, and the profitability was 91.5 and 130.4%. The total value-added income from the sale of marketable products obtained on the two varieties amounted to 365,516 rubles /ha.

In variant 2, where the improved technology was applied, the yield of the marketable products on the variety Red Scarlett was 40.1 t / ha, on the variety Gala it was 54.3 t / ha, the cost of marketable products amounted to 401 000 and 543 000 rubles / ha, the production costs to 236 208 and 272 171 rubles / ha, the value-added income was 164 792 and 270 829 rubles / ha, and the profitability 69.8 and 99.5%, respectively. The total value-added income from the sale of marketable products obtained on the two varieties reached 435,621 rubles/ha.

Thus, the use of a new technology of potato cultivation for the farm instead of the traditionally used, despite the decrease in profitability of commercial production by 21.7 (Red Scarlett) and 30.9% (Gala) and an increase in production costs by 91,561 and 93,334 rubles / ha, respectively (primarily due to an increase in the cost



Рис. 2. Общий вид клубней сорта Ред Скарлетт:
a – вариант 1; *б* – вариант 2
Fig. 2. General view of the Red Scarlett variety tubers:
a – option 1; *б* – option 2

of protective measures for 47,743 rubles / ha), contributes to an increase in the value of conditional net income by 32,439 and 37,666 rubles / ha due to an increase in marketable yield. In this case, the total value-added income from the sale of marketable products obtained on two varieties in variant 2, compared with the control variant increased by 70,105 rubles / ha (by 19.2%).

CONCLUSION

Three-year production experience with potato varieties Red Scarlett and Gala, conducted on the land use of the OOO "Druzhba-2", Zhiryatinsky district, Bryansk region, showed that the traditional protection system used on this farm and the improved system have high efficiency (on average 94.4–98.0%). At the same time, the

Табл. 4. Экономическая эффективность применения изучаемых систем защиты картофеля

Table 4. Economic efficiency of the studied potato protection systems application

Indicator	Option 1		Option 2	
	Red Scarlet	Gala	Red Scarlet	Gala
Marketable yield, t/ha	27,7	41,2	40,1	54,3
Cost of marketable products, rubles/ha	277 000	412 000	401 000	543 000
Production costs, rubles/ha	144 647	178 837	236 208	272 171
Cost of protection products, rubles/ha	54 740		102 483	
Value added profit, rubles/ha	132 353	233 163	164 792	270 829
Profitability, %	91,5	130,4	69,8	99,5



Рис. 3. Общий вид клубней сорта Гала:

a – вариант 1; *б* – вариант 2

Fig. 3. General view of the Gala variety tubers:

a – option 1; *б* – option 2

efficiency of the improved system was higher than that of the traditional system and amounted to 97.2–98.0% against 94.4–95.8% depending on the variety.

Improvement of the cultivation technology of potato varieties also contributed to the growth of crop productivity. The number of tubers from one plant increased by 7.5–10.0%, average tuber weight by 7–11%, tuber weight from one plant by 14.5–23.0%.

The greater number of plants at the time of harvesting and greater tuber weight per plant when applying the improved technology contributed to a significant increase in the yield from 36.1–49.7 to 45.6–58.2 t/ha (by 17–26%).

In addition, the improvement of potato cultivation technology elements contributed to an increase in marketability by 12.5–14.5%, and, consequently, to an increase in marketable yield from 27.7–41.2 to 40.1–54.3 t/ha (by 32–45%) depending on the variety.

At this level of marketable yield and sale price of marketable tubers of 10 000 rubles / t, the use of new potato cultivation technology for a farm instead of the traditionally used one, despite the decrease in profitability of marketable production by 21.7–30.9% (primarily due to an increase in the cost of protective measures), contributed to an increase in the value-added income by 16.2–24.5%.

Based on the results of the experience we recommend the improved system of protection to be used as one of the elements of technology in industrial cultivation of potatoes in the Bryansk region.

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Аспекты совместного культивирования *Bacillus amyloliquefaciens* и *Bacillus aryabhatai* для интенсификации синтеза ростостимулирующих веществ

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Изучены ростостимулирующие свойства штаммов *Bacillus amyloliquefaciens* B-11265 и *Bacillus aryabhatai* B-13192, а также дана оценка возможности их совместного культивирования для интенсификации активности. Установлено, что исследуемые штаммы способны синтезировать индолил-3-уксусную и гиббереллиновую кислоты, сидерофоры: *B. amyloliquefaciens* B-11265 в количестве 5,23 мкг/мл, 1,05 мг/мл, 46,15%; *B. aryabhatai* B-13192 – 3,07 мкг/мл, 0,84 мг/мл, 35,50% соответственно. Результаты исследования показали, что штаммы являются биосовместимыми и не ингибируют развитие друг друга, что позволяет включить их в состав одного консорциума. Совместное культивирование штаммов показало, что соотношение микроорганизмов в питательном субстрате оказывает значительное влияние на выход целевых веществ. При соотношении *B. amyloliquefaciens* и *B. aryabhatai* 1 : 1 отмечено угнетение синтеза индолил-3-уксусной кислоты, соотношения 2 : 3 и 3 : 2 приводили к снижению продуцирования гиббереллиновой кислоты. Установлено, что оптимальным соотношением, позволяющим добиться повышения выхода целевых веществ по сравнению со средними значениями, характерными для отдельных штаммов, являлось три (*B. amyloliquefaciens*) к одному (*B. aryabhatai*). В данном варианте синтез ростостимулирующих веществ консорциумом составил: индолил-3-уксусная кислота – 5,31 мкг/мл, гиббереллиновая кислота – 1,23 мг/мл, сидерофоры – 51,27%. Полученные результаты свидетельствуют о высоком потенциале сконструированного консорциума для применения в сельском хозяйстве. Однако для разработки ростостимулирующего препарата на его основе необходимо провести ряд дополнительных исследований, направленных на изучение влияния штамма на сельскохозяйственные культуры в условиях лабораторных и полевых экспериментов.

Ключевые слова: биологизация, *Bacillus*, ростостимулирующие свойства, фитогормоны, сидерофоры, микробный консорциум

Aspects of the joint cultivation of *Bacillus amyloliquefaciens* and *Bacillus aryabhatai* for the intensification of growth-stimulating substances synthesis

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Growth-stimulating properties of *Bacillus amyloliquefaciens* B-11265 and *Bacillus aryabhatai* B-13192 strains were studied, and the possibility of their co-cultivation for activity intensification was evaluated. The strains under study were found to be able to synthesize indolyl-3-acetic and gibberellic acids, siderophores: *B. amyloliquefaciens* B-11265 in the amount of 5.23 µg/ml, 1.05 mg/ml, 46.15%; *B. aryabhatai* B-13192 – 3.07 µg/ml, 0.84 mg/ml, 35.50%, respectively. The research results showed

that the strains were biocompatible and did not inhibit each other's development, allowing them to be included in the same consortium. Joint cultivation of the strains showed that the ratio of microorganisms in the nutrient substrate has a significant effect on the yield of the target substances. At the ratio of *B. amyloliquefacien* and *B. aryabhatai* 1 : 1, inhibition of indolyl-3-acetic acid synthesis was observed; ratios of 2 : 3 and 3 : 2 led to a decrease in gibberellic acid production. It was found that three (*B. amyloliquefacien*) to one (*B. aryabhatai*) was the optimal ratio to increase the yield of the target substances compared to the average values characteristic of individual strains. In this variant, the synthesis of growth-stimulating substances by the consortium was: indolyl-3-acetic acid – 5.31 µg/ml, gibberellic acid – 1.23 mg/ml, siderophores – 51.27%. The results obtained indicate the high potential of the engineered consortium for agricultural applications. However, in order to develop a growth-stimulating preparation based on it, it is necessary to conduct a number of additional studies aimed at investigating the effect of the strain on agricultural crops in laboratory and field experiments.

Keywords: biologization, *Bacillus*, growth-stimulating properties, phytohormones, siderophores, microbial consortium

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INTRODUCTION

The growing demand for organic products and stricter legislative requirements for pesticides and mineral fertilizers necessitate the search for environmentally safe methods of increasing plant resistance to biotic stresses and achieving high productivity [1, 2]. In this regard, the most relevant is the biotechnological approach based on the use of the potential of growth-stimulating microorganisms. Promising representatives of such microorganisms are facultative mutualists of the genus *Bacillus*. They have a number of growth-stimulating properties and are also non-symbiotic (do not form specific anatomical structures within plants), which allows using them to increase the productivity of a variety of crops [3, 4]. Currently, the use of *Bacillus* in agriculture is limited to preparations

based on *B. subtilis*. In this regard, the introduction of new representatives of this genus with high growth-stimulating activity into practice is an actual direction, opening prospects for the development of innovative biopreparations and improving the efficiency of crop production. In addition, interest in the use of symbiotic consortia of microorganisms as an alternative to single strains is increasing [5, 6]. This is due to the fact that in natural conditions plants interact not with individual microorganisms, but with a complex microbial community [7].

The purpose of the study was to investigate the growth-stimulating properties of domestic strains of *B. amyloliquefaciens* B-11265 and *B. aryabhatai* B-13192, as well as to evaluate the possibility of their joint cultivation to intensify their activity.

MATERIAL AND METHODS

The research was conducted in 2024 on the basis of the laboratory of phytoremediation of technogenically disturbed ecosystems of the Kemerovo State University. Bacterial strains obtained from the National Bioresource Center of the All-Russian Collection of Industrial Microorganisms of the SRC “Kurchatov Institute” were used: *B. amyloliquefaciens* B-11265 (the strain was isolated from soil and is an antagonist of phytopathogenic bacteria) and *B. aryabhatai* B-13192.

Preparation of bacterial suspension

From the daily culture grown on an agarized nutrient medium, a suspension was prepared using peptone water to a McFarland turbidity coefficient of 0.8–1.0 using a Densichek plus densitometer (BioMerieux, France). Then 1 ml of the obtained suspension was added to 10 ml of the Luria-Bertani liquid nutrient medium modified by Miller (“Biolight”, Russia). The culture was carried out in a shaker-incubator LSI-3016R (“Daihan Labtech”, South Korea) at a temperature of 28 ± 2 °C and a rotation speed of 110 rpm for 24 hours. The culture liquid was separated from the cells by centrifugation for 10 min at 7500 rpm. The obtained supernatant was used for the further analysis.

To analyze the production of the indolyl-3-acetic acid, 1 ml of the Salkovsky reagent was added to 1 ml of the supernatant. The obtained solution was incubated for 30 min at 22 ± 2 °C and the optical density of the obtained solution was determined spectrophotometrically at a wavelength of 535 nm. At the same time, a control experiment was carried out under the same conditions; nutrient medium was used as a control. The optical density of the sample was determined by the formula

$$OD = OD_e - OD_c, (1)$$

where OD – estimated optical density of the sample; OD_e – experimental optical density of the sample; OD_c – optical density of the control.

The amount of the synthesized indolyl-3-acetic acid was determined from a 0.2 to 10 µg/ml

standard solution of the acid by a graduation plot [8].

To analyze gibberellic acid production, 280 ml of 1 M solution of zinc acetic acid 2-water (“ProfSnab”, Russia) and 10.6% solution of potassium ferrocyanide III (“LenReactiv”, Russia) were added to 2 ml of the supernatant, stirred rapidly and centrifuged at 4500 rpm for 10 min. Then 1 ml of 30% hydrochloric acid (“LenReactiv”, Russia) was added to 1 ml of supernatant. The solution was kept for 75 min at a temperature of 22 ± 2 °C. The optical density of the samples was determined with respect to 5% hydrochloric acid using a UV 1800 spectrophotometer (“Shimadzu”, Japan) at a wavelength of 254 nm. Quantitative determination of synthesized gibberellic acid was carried out using calibration graph of standard acid solution (“Diaem”, Russia) in the range from 100 to 700 µg/ml [9].

To analyze the production of siderophores, 1 ml of freshly prepared Chorme Azurol S reagent was added to 2 ml of the supernatant, incubated for 20 min at 22 ± 2 °C. Optical density was determined spectrophotometrically at a wavelength of 630 nm. Simultaneously, a control experiment was carried out under the same conditions; nutrient medium was used as a control. The concentration of siderophores was determined by the formula [10]

$$C_{sid} = \frac{OD_{sam} - OD_c}{OD_c} \times 100 \%, (2)$$

where C_{sid} – concentration of siderophores, %; OD_{sam} – optical density of the sample; OD_c – optical density of the control sample.

Biocompatibility of the studied cultures was determined by the perforation method. For this purpose, bacterial suspensions were prepared according to the previously described method. The test culture was applied to the surface of a Petri dish with agarized Luria-Bertani medium in Miller's modification by the lawn method using a Drigalsky spatula. Then, a hole with a diameter of 5 mm was made and cell-free culture fluid of the tested bacterial strain was introduced into it. The cultures were cultured for 24 h at a

temperature of 28 ± 2 °C. Cultures were considered biocompatible if there was no zone of growth inhibition of the test culture around the hole¹.

Construction of symbiotic bacterial consortia

For this purpose, bacterial suspensions were prepared according to the previously presented method. Bacterial suspensions were added to sterile liquid Luria-Bertani medium in Miller's modification in the ratio according to Table 1.

Cultivation was carried out under the conditions described earlier. The production of indolyl-3-acetic and gibberellic acids and siderophores by consortia was analyzed according to the methods described above.

RESULTS AND DISCUSSION

The results of the study of the ability of *B. amyloliquefaciens* B-11265 and *B. aryabhattai* B-13192 to synthesize phytohormones and siderophores are shown in Table 2.

It was found that the strains are able to synthesize indolyl-3-acetic and gibberellic acids, as

well as siderophores. The results of the study are confirmed by the data obtained by other scientists. Thus, Hui-juan Zhou et al. [11] noted the presence of YsnE metabolic pathways responsible for the synthesis of indolyl-3-acetic acid in *B. amyloliquefaciens* strain HZ-12. Jiahui Shao et al. found the synthesis of indolyl-3-acetic acid in *B. amyloliquefaciens* SQR9². *B. amyloliquefaciens* YL-25 strain studied in the work of Jun Yuan et al. had complex growth-stimulating activity, in particular, synthesized gibberellin A3, indole-3-acetic acid³. *B. amyloliquefaciens* MB-1600 produced catecholate-siderophore bacillibactin under iron deficiency conditions [12].

B. aryabhattai GR42 exhibited the ability to synthesize siderophores and ACC deaminase [13]. *B. aryabhattai*, studied in the research by Sol Lee et al. showed the ability to synthesize indolyl-3-acetic acid, gibberellins, and other growth-stimulating substances⁴.

In order to determine the possibility of joint cultivation of the studied strains of microorganisms, their biocompatibility was analyzed. The results of the analysis indicate the absence of inhibitory effect of the cultures on each other,

Табл. 1. Соотношение штаммов в бактериальных консорциумах

Table 1. Ratio of strains in bacterial consortia

Consortium number	Ratio	
	<i>B. amyloliquefaciens</i> B-11265	<i>B. aryabhattai</i> B-13192
C. 1	1	1
C. 2	1	2
C. 3	2	1
C. 4	1	3
C. 5	3	1
C. 6	2	3
C. 7	3	2

Табл. 2. Результаты исследования ростостимулирующих свойств штаммов

Table 2. The results of the study of the growth-stimulating properties of strains

Indicator	Strain	
	<i>B. amyloliquefaciens</i> B-11265	<i>B. aryabhattai</i> B-13192
IAC, µg/ml	$5,23 \pm 0,07$	$3,07 \pm 0,04$
GA, mg/ml	$1,05 \pm 0,01$	$0,84 \pm 0,01$
Siderophores, %	$46,15 \pm 0,31$	$35,50 \pm 0,38$

¹Irkitova A.N., Kagan J.R., Sokolova G.G. Comparative analysis of the methods for determining the antagonistic activity of lactic acid bacteria // Izvestiya of Altai State University, 2012, N 3, pp. 41–44.

²Shao J., Xu Z., Zhang N., Shen Q., Zhang R. Contribution of indole-3-acetic acid in the plant growth promotion by the rhizospheric strain *Bacillus amyloliquefaciens* SQR9 // Biology and Fertility of Soils, 2015, vol. 51, pp. 321–330. DOI: 10.1007/s00374-014-0978-8.

³Shao J., Xu Z., Zhang N., Shen Q., Zhang R. Contribution of indole-3-acetic acid in the plant growth promotion by the rhizospheric strain *Bacillus amyloliquefaciens* SQR9 // Biology and Fertility of Soils, 2015, vol. 51, pp. 321–330. DOI: 10.1007/s00374-014-0978-8.

⁴Lee S., Ka J.O., Song H.G. Growth promotion of *Xanthium italicum* by application of rhizobacterial isolates of *Bacillus aryabhattai* in microcosm soil // Journal of Microbiology, 2012, vol. 50, pp. 45–49. DOI: 10.1007/s12275-012-1415-z

which confirms the possibility of their joint use as part of a microbial consortium.

At the next stage of the study, bacterial consortia were designed, the ratio of the studied strains in which is shown in Table 1. In order to determine which ratio allows to achieve the maximum synergistic effect, the ability of consortia to synthesize target growth-stimulating substances was studied. The results are presented in Fig. 1–3.

It was found that the synthesis of indolyl-3-acetic acid by consortia ranged from 2.86 to 5.31 µg/ml of the nutrient medium, gibberellic acid from 0.80 to 1.23 mg/ml, and siderophores from 35.86 to 51.27%. The lowest ability to synthesize growth-stimulating substances was possessed by K.4 consortium. A number of other variants of consortia showed a decrease in the synthesis of one of the target growth-stimulating substances in comparison with separately taken bacterial strains. Thus, the K. 2 consortium produced 3.56 µg/ml of indolyl-3-acetic acid, whereas the average synthesis of this phytohormone by individual strains was 3.79 µg/ml. Consortia K. 6 and K. 7 produced less gibberellic acid (0.91 and 0.85 mg/ml, respectively)

compared to the average of individual strains (0.92 and 0.97 mg/ml, respectively). A decrease in synthesis of siderophores was observed in K. 4 consortium. The highest ability to synthesize growth-stimulating substances was possessed by consortium K. 5: indolyl-3-acetic acid 5.31 µg/ml, gibberellic acid 1.23 mg/ml, siderophores 51.27%. Thus, a ratio of 3 : 1 should be used to maximize the synergistic effect when *B. amyloliquefaciens* B-11265 and *B. aryabhattai* B-13192 are used together, respectively.

CONCLUSION

The studied strains *B. amyloliquefaciens* B-11265 and *B. aryabhattai* B-13192 have complex growth-stimulating properties, including synthesis of phytohormones (indolyl-3-acetic and gibberellic acids) and siderophores. The strains are biocompatible and do not inhibit each other's growth and development. When *B. amyloliquefaciens* B-11265 and *B. aryabhattai* B-13192 were co-cultured in a 3 : 1 ratio, a synergistic effect was observed, i.e. an increase in the synthesis of growth-stimulating substances compared to the average value of individual strains. When cultivated in this ratio, the consor-

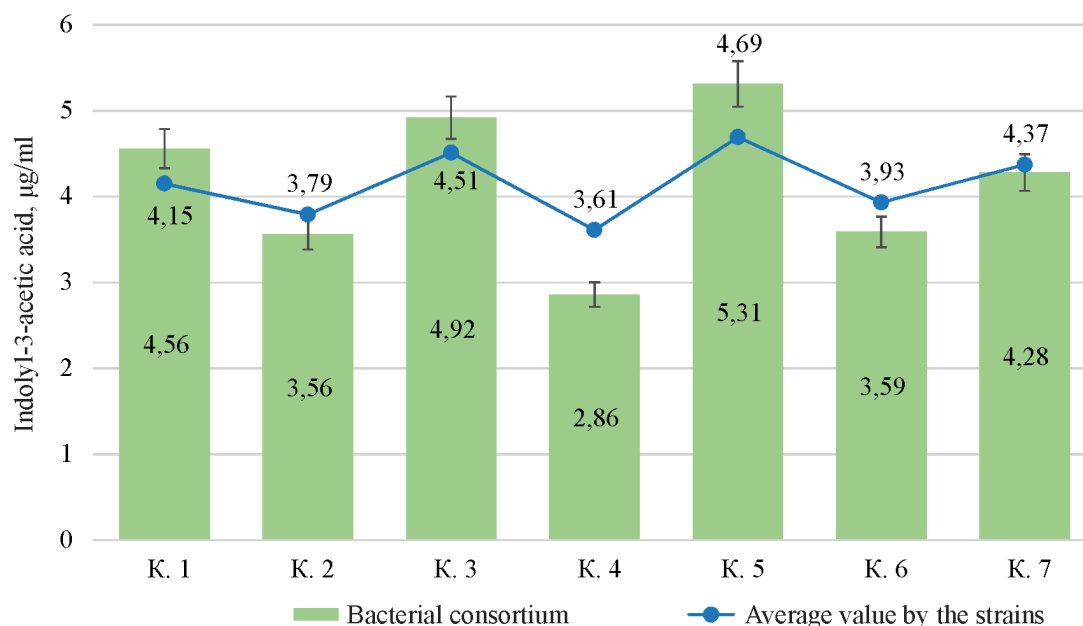


Рис. 1. Исследование количества синтезируемой индолил-3-уксусной кислоты консорциумами

Fig. 1. Investigation of the amount of indolyl-3-acetic acid synthesized by consortia

⁴Lee S., Ka J.O., Song H.G. Growth promotion of *Xanthium italicum* by application of rhizobacterial isolates of *Bacillus aryabhattai* in microcosm soil // *Journal of Microbiology*. 2012. Vol. 50. P. 45–49. DOI: 10.1007/s12275-012-1415-z.

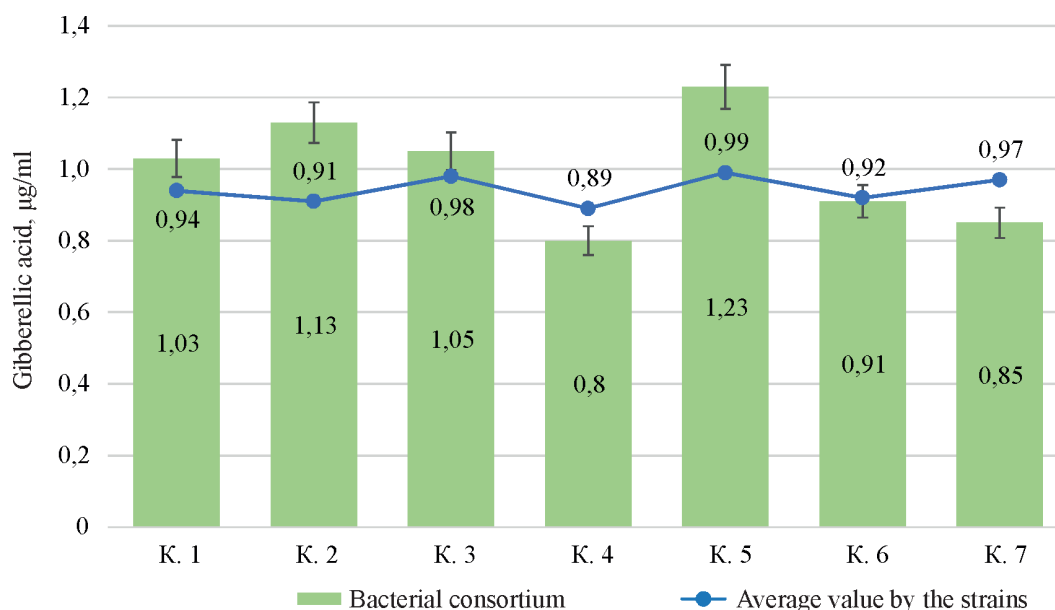


Рис. 2. Исследование количества синтезируемой гиббереллиновой кислоты консорциумами

Fig. 2. Investigation of the amount of gibberellic acid synthesized by consortia

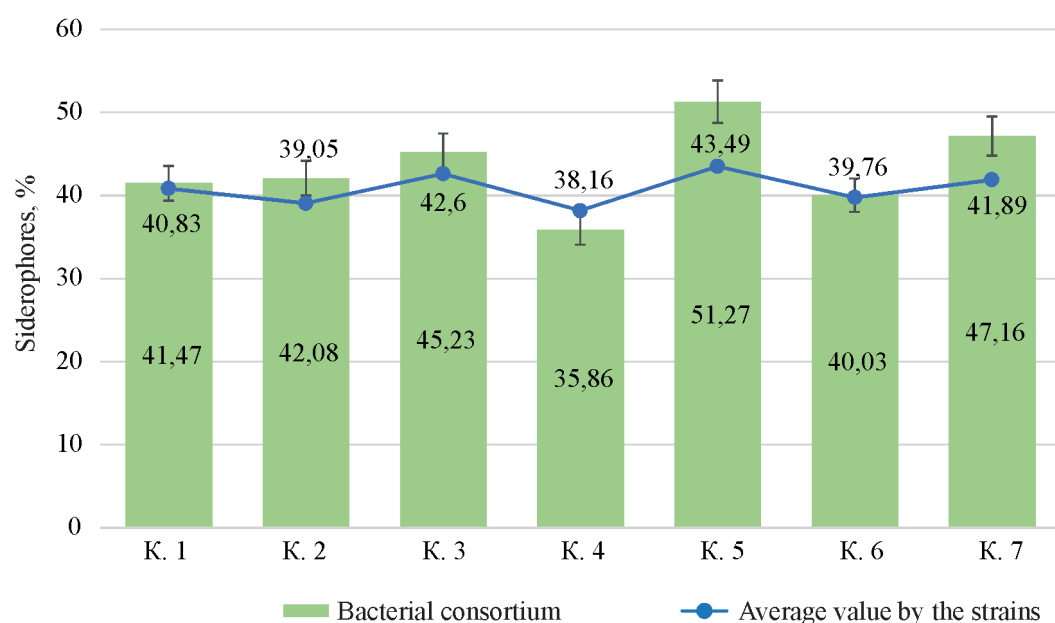


Рис. 3. Исследование количества синтезируемых сидерофоров консорциумами

Fig. 3. Investigation of the number of siderophores synthesized by consortia

tium of microorganisms produced indolyl-3-acetic acid in the amount of 5.31 µg/ml, HA of 1.23 mg/ml, and siderophores of 51.27%. The results obtained indicate the high potential of the constructed consortium for agricultural applications. However, in order to develop a growth-stimulating preparation based on it, it is necessary to conduct a number of additional studies aimed at investigating the effect of the strain on agricul-

tural crops in laboratory and field experiments.

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Влияние физиологически активных веществ на рост, развитие и урожайность сои

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Представлены результаты исследований влияния физиологически активных веществ на рост, развитие и урожайность сои в условиях Средневолжского региона. Изучение препаратов проводили на районированном сорте сои Южанка. Препараты Мивал Агро, Витанолл NP (N 10%, P 30%), Витанолл NP (N 30%, P 10%) и НаноКремний применяли в дозировках, рекомендуемых производителями. Схема опыта включала четыре варианта обработок препаратами и контроль (вода). Препараты применяли для предпосевной обработки семян и опрыскивания вегетирующих растений. Регулятор роста Мивал Агро (обработка семян и растений) обеспечил повышение урожайности на 23,1%. Обработка препаратом Витанолл NP (N 10%, P 30%) дала прибавку урожайности на 18,3% в сравнении с контролем. Наибольшая урожайность получена на варианте с обработкой препаратом Витанолл NP (N 30%, P 10%), которая превысила контрольный вариант на 68,8%. Прибавка урожайности при обработке препаратом НаноКремний превысила контрольный вариант на 29,4%. Применение всех физиологически активных веществ положительно сказалось на росте, развитии и продуктивности растений сои. Применение препарата Витанолл NP (N 10%, P 30%) оказало положительное влияние на такие показатели структуры урожая, как высота растения (527 см) и высота прикрепления нижнего боба (15,8 см). Препараты Витанолл NP (N 30%, P 10%) и НаноКремний способствовали увеличению числа бобов (18,1–18,2 шт.). Также изучаемые препараты оказали положительное влияние на массу 1000 семян, высоту растений и высоту прикрепления нижнего боба в сравнении с контролем.

Ключевые слова: соя, урожайность, обработки, Мивал Агро, Витанолл NP (N 10%, P 30%), Витанолл NP (N 30%, P 10%), НаноКремний

Effect of physiologically active substances on the growth, development and yield of soybeans

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The results of research on the influence of physiologically active substances on the growth, development and yield of soybean in the conditions of the Middle Volga region are presented. The study of preparations was carried out on the released soybean variety Yuzhanka. The preparations Mival Agro, Vitanol NP (N 10%, P 30%), Vitanol NP (N 30%, P 10%) and NanoSilica were applied at the dosages recommended by the manufacturers. The experiment scheme included four variants of treatments with preparations and control (water). The preparations were applied for pre-sowing seed treatment and spraying of vegetative plants. The growth regulator Mival Agro (seed and plant treatment) provided a 23.1% increase in yield. Treatment with Vitanol NP (N 10%, P 30%) gave an 18.3% yield increase compared to the control. The highest yield was obtained in the variant with Vitanol NP treatment (N 30%, P 10%), which exceeded the control variant by 68.8%. The yield increase when treated with NanoSilicon exceeded the control variant by 29.4%. Application of all physiologically active substances had a positive effect on the growth, development and productivity of soybean plants. Application of Vitanol NP (N 10%, P 30%) had a positive effect on the yield structure parameters such as plant height (527 cm) and lower bean attachment height (15.8 cm). Vitanol NP (N 30%, P 10%) and NanoSilica preparations contributed to the increase in the number of beans (18.1–18.2 pcs). Also, the studied preparations had a positive effect on 1000 seed weight, plant height and height of the lower bean attachment, compared to the control.

Keywords: soybean, productivity, processing, Mival Agro, Vitanol NP (N 10%, P 30%), Vitanol NP (N 30%, P 10%), NanoSilicon

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Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Increasing the production of goods that provide high-protein food, feed and technical raw materials is currently one of the most important tasks of intensive technologies in crop production [1]. Legumes are valuable crops that contain a large amount of protein, oil, essential acids, and are rich in various microelements. Due to symbiotic nitrogen fixation, they can enrich the soil with available forms of nitrogen from the air, transforming it into the ammonium form available to plants. One of the promising crops of this family is soybean, which has great economic, ecological and social importance in the agricultural sector [2-4]. For a long time, it was used as a crop exclusively for oil production. Soybean then gained the role of an excellent high-protein crop with a wide range of applications, evolving from the production of meal for livestock feed to a highly processed protein isolate and lecithin. Due to its rich chemical composition, soybeans have gained popularity among both industrial production and the general public as a food containing all essential amino acids and beneficial phospholipids [5].

The necessary amount of soybean yield can be obtained without expanding the area under crops. Long-term exploitation of agricultural lands without replenishment of microelement nutrition leads to their significant depletion and, as a consequence, to a sharp decrease in yield [1]. The possibilities of increasing crop yields include the introduction of new progressive resource-saving technologies, the use of bioprepa-

rations that increase plant resistance to abiotic and biotic stressors. Introduction of new elements into the technological process is necessary, but first it is necessary to determine their adaptability to the given technology and the efficiency of their application by experience [6].

Currently, there is a huge number of applied or tested chemical preparations (growth stimulators, mineral and organic fertilizer complexes, etc.) in the field of agriculture, allowing to obtain additional sources of mineral nutrition of plants [7]. Preference is given to the preparations capable of influencing the efficiency of symbiosis, causing visible changes in plant growth and development and improving the use of other nutrient elements¹.

The key point in creating favorable conditions for plant growth and development is the use of high-quality physiologically active preparations. The strategy of modern adaptive crop production involves increasing the efficiency of production processes by incorporating developments in the integrated use of new-generation fertilizers and the use of preparations containing physiologically active substances (PAS). Efficiency of PAS application depends largely on the object of influence: species, age of plant, part of plant organism and other features. The use of new-generation PASs in the treatment of seed material before sowing and foliar feeding of plants allows to increase stress resistance of plants to abiotic factors, to influence the quality and productivity of the crop (see footnote 1).

The purpose of the research was to study the effect of physiologically active substances

¹Belchenko S.A., Belous I.N., Kovalev V.V. Material and technical support and innovative development of the agro-industrial complex of the Bryansk region // Actual issues of economics and agribusiness: a collection of scientific papers, 2021, vol. 1, N 1, pp. 388-400.

on the growth, development and productivity of soybean variety Yuzhanka depending on the growing conditions.

MATERIAL AND METHODS

The research was conducted in 2020-2022 on the experimental field of breeding crop rotation of the laboratory of introduction, breeding of forage and oilseed crops of the Volga Research Institute of Breeding and Seed Production – branch of the Samara Federal Research Center of the Russian Academy of Sciences.

The soil of the experimental plot, on which the research was conducted, is typical chernozem, low-humus light loamy by granulometric composition with a granulated-clumpy structure, pH of the salt extract is 5.3. [8]. The climate of the study area is moderately continental. This zone is characterized by pronounced seasons, sharp temperature contrasts between cold and warm seasons, moisture deficit, evaporation intensity and richness of sunshine.

Soil preparation was carried out according to the agrotechnics adopted for the conditions of the study area: early spring harrowing with a tooth harrow BZSS-10, following the accumulation of moisture in the soil, cultivation was carried out to a depth of 6-8 cm. Sowing was carried out in May on a flat surface with a seed drill SN-10Ts in a wide-row method with a row spacing of 45 cm. The total area of the experimental plot was 25 m², the repetition was fourfold, the placement of variants was randomized. Yuzhanka soybean variety included in the State Register for the Middle Volga (7) region was used in the research. The plant is of the indeterminant type of development. The pubescence of the main stem is gray. The flower is white. Seeds are yellow with a yellow leaf scar. Flowering starts early. The vegetation period is 95–102 days. The weight of 1000 seeds is 110-122 g. The content of protein in the seeds amounts to 29.2%, fat to 25.3%. The variety is suitable for cultivation without irrigation. The average seed yield in the Middle Volga region is 1.51 t/ha.

Seed material was treated with the studied preparations.

The following preparations were used in the experiments:

– Mival Agro – a complex preparation, which in addition to biologically active organosilicon compound from the silatran group includes an analog of phytohormones from the auxin group [9]. Active substance: 760 g/kg orthocresoxyacetic acid triethanolammonium salt + 190 g/kg chloromethylsilatran. The preparation protects against adverse environmental effects, reduces stress load on the plant, as well as improves the transport of the nutrients and accelerates metabolic processes inside the cell [10];

– Vitanol NP (N 10%, P 30%) – a vitaminized fertilizer based on the content of a complex of macro- and microelements (nitrogen – 9–12%, phosphorous – 28–30%, Mg, Mn, S, Zn, B, M); Vitanol NP (N 30%, P 10%) contains 30% nitrogen, 10% phosphorus [10]. The drug has stimulating antioxidant properties due to the presence of a complex of biologically active acids in its composition [11];

– NanoSilica – a mineral fertilizer based on biologically active crystalline silicon particles [12]. It is a new type of a modern fertilizer that helps crops better absorb micronutrients and be more resistant to diseases and parasites.

The experiment scheme included four variants of treatments with preparations and the control:

- control (water);
- Mival Agro (pre-sowing seed treatment (5 g/t) + single vegetation treatment (10 g/ha));
- Vitanol NP (N 10%, P 30%) (pre-sowing seed treatment (0,5 l/t) + single treatment during vegetation with the preparation (0,3 l/ha));
- Vitanol NP (N 30%, P 10%) (pre-sowing seed treatment (0,5 l/t) + single treatment during vegetation with the preparation (0,3 l/ha));
- NanoSilica 100 л/га (pre-sowing seed treatment (200 g/t) + double treatment during vegetation with the preparation (100 g/ha)).

All treatments were carried out once in the period of budding – beginning of flowering, except for NanoSilica. This preparation was applied twice according to the manufacturer's recommendations. The first treatment was carried out in the initial period of plant growth, the second in the period of budding – beginning of flowering.

During the vegetation of soybean plants, manual weeding of experimental plots was carried out. All records and observations in field studies, including statistical data processing, were carried out in accordance with the generally accepted methodological recommendations².

RESULTS AND DISCUSSION

The existing hydrothermal conditions in the years of research were different both in terms of the temperature indices and the amount of precipitation during the growing season of soybeans.

Samara region is characterized by a variety of natural and climatic conditions. Depending on the level of precipitation and temperature conditions, it can be conditionally divided into southern, central and northern zones.

Soybean is a crop of monsoon climate, which has high requirements for moisture and heat. Climatic conditions of the Samara region are generally favorable for cultivation of this crop.

In 2020, the average daily air temperature during the sowing – sprouting period was close to the optimal values and amounted to 19.2 °C (see Table 1). The amount of precipitation was 0.10 mm, the hydrothermal coefficient (HTC) was 0.01, which characterizes the conditions of this period as acutely arid. The average daily air temperature during the interphase period sprouting - flowering was 16.6 °C, the amount of precipitation ranged within 3 mm, HTC – 0.84.

Sufficient precipitation during this period of vegetation had a positive effect on soybean yield, because the greatest need for moisture in soybean plants falls on the flowering phase. The temperature regime during the flowering – ripening period was at 20.5 °C, precipitation was 3.0 mm, HTC – 0.47.

During the whole vegetation period 2021, increased air temperature and uneven precipitation were observed. The average daily air temperature during the sowing – sprouting period was

22.7°C, no precipitation was observed during this vegetation period.

During the period of sprouting – flowering, the average daily air temperature was within 20.9 °C. This period with precipitation of 5.8 mm (HTC 1.15) was favorable for growth and development of soybean plants, which allowed to obtain a high yield of seeds. In the phase of flowering – ripening there were arid conditions, the average daily air temperature was at 24.7 °C, the amount of precipitation – 4.2 mm, HTC – 0.14.

The meteorological conditions during the sowing – sprouting period in 2022 were characterized by low average daily temperature (10.4 °C) and excessive moisture (HTC – 1.52),

Табл. 1. Характеристика метеорологических условий и ГТК в периоды вегетации сои

Table 1. Characteristics of meteorological conditions and the HTC during soybean vegetation periods

Period	2020	2021	2022	Average over the years
<i>Average daily air temperature, °C</i>				
Sowing - sprouting	19,2	22,7	10,4	17,1
Sprouting - flowering	16,6	20,9	18,5	18,7
Flowering - ripening	20,5	24,7	19,8	20,7
Sprouting - ripening	20,1	24,6	21,8	22,2
<i>Precipitation, mm</i>				
Sowing - sprouting	0,1	0,0	2,1	1,1
Sprouting - flowering	3,0	5,8	5,0	4,6
Flowering - ripening	3,0	4,2	3,9	3,5
Sprouting - ripening	1,8	4,2	4,0	3,3
<i>HTC</i>				
Sowing - sprouting	0,01	0,00	1,32	0,44
Sprouting - flowering	0,84	1,15	0,57	0,85
Flowering - ripening	0,47	0,14	0,31	0,30
Sprouting - ripening	0,55	0,48	0,43	0,49

²Dospekhov B.A. Methodology of field experiment (with the basics of statistical processing of research results); 5th edition, supplemented and revised, Moscow: Agropromizdat, 1985, 351 p.

which had a negative impact on the intensity of germination of soybean seeds and led to an increase in this interphase period up to 8 days. Reduced moisture availability (3.0–3.9 mm) in the interphase periods sprouting – flowering and flowering – ripening negatively affected the overall level of soybean yield. The vegetation period 2022 was characterized by low average daily temperature and precipitation deficit. The hydrothermal coefficient was 0.43 and it was the lowest for the years of research.

The conducted research allowed to establish that the most favorable weather conditions for soybean cultivation were formed in 2021.

On average for 2020–2023 sowing was carried out in the first ten-day period of May, by this time the soil temperature was 10–12 °C. On average for 3 years of research it was found that the duration of the sowing – sprouting period was 6–8 days and depended on the hydrothermal conditions.

Among all the studied preparations, the variant with NanoSilica treatment contributed to the increase in the duration of the periods sprouting – flowering (by 2–3 days) and flowering – ripening (by 2–4 days).

In our studies, no significant difference in the onset of phenological phases of growth and development in the variety Yuzhanka was observed during treatment with the other studied preparations. The vegetation period averaged 100 days in all the experiments during the years of research.

Pre-sowing treatment of the seeds one day before the sowing with Mival Agro, Vitanol NP (N 10%, P 30%), Vitanol NP (N 30%, P 10%) and NanoSilica promoted better penetration of the preparations into the seeds, improving germination energy and emergence of friendly sprouts, which is especially important for soybeans at the initial stages of plant development.

Treatment of the plants with preparations during vegetation increased the safety of the plants by the time of harvesting (see Table 3). Plants survived and vegetated quite well, higher indicators were obtained during treatment with

the studied preparations. The response of the Yuzhanka soybean to the preparations was different, safety to the time of harvesting by the treatment variants was from 86.9 to 92.8%. Maximum safety was formed in the variants with the application of Vitanol NP (N 10%, P 30%) and NanoSilica, amounting to 90.5 and 92.8%, respectively, and in the variants with the application of Mival Agro and Vitanol NP (N 30%, P 10%) the safety was closer to the control variant (86.6%) and amounted to 86.9–88.2%.

Табл. 2. Продолжительность вегетации и межфазных периодов сои в днях

Table 2. Duration of soybean vegetation and interphase periods in days

Option	Sowing - sprout- ing	Interphase vegetation period		
		sprout- ing - flower- ing	flower- ing - rip- ening	sprout- ing - rip- ening
2020				
Control (water)	7	40	67	107
Mival Agro	7	40	67	107
Vitanol NP (N 10%, P 30%)	7	42	68	108
Vitanol NP (N 30%, P 10%)	7	42	68	108
NanoSilicon	7	43	69	109
2021				
Control (water)	6	35	61	96
Mival Agro	6	35	61	96
Vitanol NP (N 10%, P 30%)	6	37	63	96
Vitanol NP (N 30%, P 10%)	6	37	63	96
NanoSilicon	6	38	65	98
2022				
Control (water)	8	51	46	97
Mival Agro	8	51	46	97
Vitanol NP (N 10%, P 30%)	8	53	47	97
Vitanol NP (N 30%, P 10%)	8	53	47	97
NanoSilicon	8	53	48	98

Табл. 3. Влияние физиологически активных препаратов на урожайность сои**Table 3.** Effect of physiologically active substances on soybean yield

Option	Plant viability, %	Weight of 1000 seeds, g	Seed yield, g/m ²			
			2020	2021	2022	Average
Control (water)	86,6	109,86	110,26	183,29	66,96	120,18
Mival Agro	86,9	111,85	121,97	244,59	77,22	147,93
Vitanol NP (N 10%, P 30%)	92,8	109,89	119,73	217,85	85,50	142,19
Vitanol NP (N 30%, P 10%)	88,2	109,64	122,88	254,51	78,94	202,81
NanoSilicon	90,5	111,12	124,92	250,17	91,59	155,56
LSD ₀₅			1,69	2,95	1,64	—

Weight of 1000 seeds is one of the important indicators affecting the yield of the variety. In the studies, this indicator was at the level of 109.86–111.85 g. The most fulfilled seeds were in the variants with treatments with the preparation Mival Agro – 111.85 g and NanoSilica – 111.12 g, exceeding the control (water) by 1.8–1.1%. This indicator in the variants with the use of the preparation Vitanol NP (N 10%, P 30%) and Vitanol NP (N 30%, P 10%) was at the level of control, amounting to 109.89 and 109.64 g.

Soybean yield averaged from 120.18 to 202.81 g/m² in 2020–2022. A significant increase to the control was observed in all the variants with the use of physiologically active preparations. On average for 3 years of research, the highest soybean yield was obtained in the variant with treatment with Vitanol NP (N 30%, P 10%) – 202.81 g/m², which is 68.8% higher than the values of the variant without treatment. Double treatment of soybean during the growing season with NanoSilica provided a 29.4% increase in the yield compared to the control, amounting to 155.56 g/m². Yield increase in the treatments with Mival Agro (147.93 g/m²) and Vitanol NP (N 10%, P 30%) (142.19 g/m²) amounted to 18.3 and 23.1%, respectively, depending on the control variant.

The obtained data showed that the greatest impact on soybean yield was made by the variant with the treatment with the preparation Vita-

nol NP (N 30%, P 10%), the increase of which in relation to the control amounted to 82.63 g/m². In the variant with the treatment with NanoSilica preparation the yield increase was equal to 35.38 g/m², exceeding the control variant by 29.4%. Other variants with treatments also gave an increase in yield, but to a lesser extent.

On average for 3 years of research, the height of the above-ground part of soybean plants with the application of physiologically active preparations varied from 49.1 to 52.7 cm, which exceeded by 1.2–4.8 cm the height of plants in the control variant by 47.9 cm (see Table 4). The increase in plant height was observed in the variants with treatments with Vitanol NP (N 10%, P 30%) and NanoSilica, amounting to 52.1–52.7 cm. In the treatment variants with Mival Agro and Vitanol NP (N 30%, P 10%), the plants were higher than the control variant, amounting to 49.1–49.7 cm.

The height of the lower bean attachment is closely related to the plant height. According to our data, the correlation between the traits is $r = 0.41–0.76$. This indicator is very important, because it is responsible for the suitability of the variety for mechanical harvesting. In the Yuzhanka soybean plants, variants with treatments had a significant effect on this morphological trait. In all the variants with treatments, the height of the lower bean attachment was formed 0.3–0.9 cm higher than in the variant without treatment, amounting to 15.2–15.8 cm.

Табл. 4. Влияние физиологически активных препаратов на элементы структуры урожайности сои (2020–2022 гг.)

Table 4. Effect of physiologically active preparations on the elements of soybean yield structure (2020–2022)

Option	Height, cm	Height of the lower bean attachment, cm	Number of		
			side branches	beans on a plant	seeds in a bean
Control (water)	47,9	14,9	1,9	13,9	2,1
Mival Agro	49,7	15,2	2,0	17,5	2,1
Vitanol NP (N 10%, P 30%)	52,7	15,8	1,8	17,1	2,0
Vitanol NP (N 30%, P 10%)	49,1	15,8	1,9	18,1	2,2
NanoSilicon	52,1	15,3	1,9	18,2	2,1
LSD ₀₅ based on factor A (year)	0,78	0,46	0,10	1,15	0,10
LSD ₀₅ based on factor B (preparation)	1,00	0,60	0,13	1,48	0,12
LSD ₀₅ (AB)	1,74	1,03	0,23	2,57	0,21

On average, the application of physiologically active substances had no statistically significant effect on the trait “number of lateral branches” during the years of study. Almost all the variants with treatments were at the level with the control (1.9 pieces), except for the variants with application of Mival Agro preparations – 2.0 pieces and Vitanol NP (N 10%, P 30%) – 1.8 pieces.

The variants treated with Vitanol NP (N 30%, P 10%) and NanoSilica had the most effective impact on the number of productive beans per plant on average for 3 years. These variants produced 30% more beans – 18.1–18.2 pieces, while in the control – 13.9 pieces. Preparations Mival Agro and Vitanol NP (N 10%, P 30%) also exceeded the control variant by 23–25%, amounting from 17.1 to 17.5 pieces.

During the period of research between the variants with treatments with physiologically active substances and the control variant the number of seeds in the bean did not differ significantly and was within the range of 2.0–2.1 pcs.

CONCLUSIONS

1. The results of research showed that all applied preparations had a positive effect on the growth, development and yield of soybeans.
2. The highest seed yield was provided by Vitanol NP (N 30%, P 10%) and NanoSilica

preparations, exceeding the control variant by 29,4–68,8%.

3. Vitanol NP (N 10%, P 30%) (92.8%) had the maximum effect on plant safety, increasing the safety by 7.2% relative to the control.

4. High indicators of 1000 seeds weight were obtained by treatment with Mival Agro and NanoSilica preparations, exceeding the control by 1.26–1.99 g.

5. Treatment with Vitanol NP (N 10%, P 30%) had a positive effect on the yield structure parameters such as plant height (52.7 cm) and lower bean attachment height (15.8 cm).

6. Treatment with Vitanol NP (N 30%, P 10%) and NanoSilica increased the number of beans (18.1–18.2 pieces).

Also, these preparations had a positive effect on plant height and height of lower bean attachment compared to the control.

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ИНФОРМАЦИЯ ОБ АВТОРАХ

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Селекционные сорта клевера лугового с высокими продуктивными качествами для условий Волго-Вятского региона

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Представлены результаты оценки пяти селекционных сортов клевера лугового (*Trifolium pratense* L.) по показателям кормовой и семенной продуктивности. Исследованы селекционные сортопопуляции П-15, ГПФ-49-3, ГПФ-86-3 СГПФ-159-3, СГПФ-159-3 + СГП-117 двуукосного типа в сравнении со стандартом Дымковский за 3 года (2020–2022) хозяйственного использования травостоев в конкурсном сортоиспытании посева 2019 г. Исследования проведены на сильноокислых ($\text{pH}_{\text{KCl}} = 4,47$) дерново-подзолистых почвах с высоким содержанием обменных форм фосфора и калия (192,5 и 217,9 мг/кг), низким – гумуса (2,2%). Погодные условия в годы исследований характеризовались как умеренно теплые. Среднемесячная температура воздуха за апрель – август составила 13,0–15,6 °C с разным обеспечением осадками: в 2020 г. – избыточным, в 2021 г. – с легким дефицитом, в 2022 г. – близким к нормальному. За годы исследований установлена высокая зимостойкость всех изучаемых сортов (более 80%). Определена продолжительность периодов развития растений у сортов при укосном и семенном использовании травостоев. Дана хозяйственно-биологическая характеристика сортов с описанием характера изменений высоты и облиственности растений, кормовой и семенной продуктивности в сравнении со стандартом Дымковский. По результатам проведенных исследований выделены два селекционных сорта ГПФ-49-3 и П-15. Зимостойкость данных сортов составила 92,6 и 96,9%, суммарный сбор сухого вещества за 2 года – 21,90 и 21,56 т/га (+12,7 и 11,0% к стандарту) и урожайность семян в среднем за 2 года – 1,72 и 2,14 ц/га (+8,9 и +35,4% к стандарту). В условиях Волго-Вятского региона эти сорта перспективны для передачи на государственное сортоиспытание.

Ключевые слова: клевер луговой, селекционные сорта, кормовая продуктивность, урожайность семян

Selection varieties of meadow clover with high productive qualities for the conditions of the Volgo-Vyatka region

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The results of evaluation of five breeding varieties of meadow clover (*Trifolium pratense* L.) in terms of fodder and seed productivity are presented. Breeding varietal populations of P-15, GPF-49-3, GPF-86-3 SGPF-159-3, SGPF-159-3 + SGP-117 of the double-cut type were investigated in comparison with the standard Dymkovsky for 3 years of economic use of grass stands (2020–2022) in a competitive varietal trial of 2019 sowing. The studies were conducted on strongly acidic ($\text{pH}_{\text{KCl}} = 4,47$) sod-podzolic soils with high content of exchangeable forms of phosphorus and potassium (192.5 and 217.9 mg/kg), low – humus (2.2%). The weather conditions in the years of research were characterized as moderately warm. The average monthly air temperature for April–August amounted to 13.0–15.6 °C with different precipitation supply: in 2020 – excessive, in 2021 – with a

slight deficit, in 2022 – close to normal. During the years of research, high winter hardiness of all the studied varieties (more than 80%) was established. The duration of plant development periods in the varieties at mowed and seed use of grass stands was determined. The economic and biological characteristics of the varieties were given, describing the nature of the changes in plant height and foliage, fodder and seed productivity in comparison with the standard Dymkovsky. Two breeding varieties GPF-49-3 and P-15 have been identified based on the results of this research. The winter hardiness of these varieties was 92.6 and 96.9 %, total dry matter yield for 2 years – 21.90 and 21.56 t/ha (+12.7 and 11.0 % to the standard) and the seed yield on average for 2 years – 1.72 and 2.14 kg/ha (+8.9 and +35.4 % to the standard). These varieties are promising for testing in the Volga-Vyatka region and are suitable for state variety trials.

Keywords: meadow clover, selection varieties, grazing capacity, seed yield

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Conflict of interest

The authors declare no conflict of interest.

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INTRODUCTION

Among perennial grasses cultivated in the system of field fodder production in the north-east of the non-Chernozem zone, the traditional legume crop meadow clover (*Trifolium pratense* L.) plays a leading role for the preparation of high-grade nutritious fodder. Its wide distribution is due to its good adaptability to extreme soil and climatic conditions of the zone (bioclimatic potential of the zone is 12% lower than the national average¹), high fodder qualities, diversity of fodder mass utilization, high nitrogen-fixing capacity and positive impact on soil fertility, energy and economic efficiency [1–4]. Scientists working in different regions of our country note that in increasing the productive and biological

potential of the crop an important role belongs to breeding [5], the priority task of which is the creation and introduction of advanced varieties capable of providing sustainably high yields of fodder mass and seeds under difficult climatic conditions [6–8]. According to many researchers, the creation of varieties should be carried out taking into account the natural-climatic zone. Each region should have the varieties that are able to realize the biological potential under their conditions [9–13].

Increasing the range of varieties, as well as replacement of old varieties with new, more productive ones, allows to increase crop productivity by 15–20% without additional costs². Currently, the State Register of Breeding Achievements of the Russian Federation contains 13 varieties

¹Sysuev V.A., Mukhamadyarov F.F., Ashikhmina T.Y., Kuznetsov V.M., Lisitsyn E.M., Golovko T.K., Mishurov V.P., Sirotenko O.D. Biological resources of the north-east of the European part of Russia and their rational use in the food complex // Health - nutrition - biological resources, vol. 1. Breeding, seed production, farming: materials of the International scientific and practical conference devoted to the 125th anniversary of the birth of Academician N.V. Rudnitsky. Kirov: NIISKh of the North-East, 2002, pp. 38–52.

²Sharipkulova Z.M. The role of a cultivar in intensification of production // Achievements of science and technology of AIC, 2007, N 2, pp. 24–25.

of meadow clover of the Vyatka selection of different maturity dates, ploidy, possessing a complex of economically useful traits³. Despite the successes achieved, scientists continue breeding work, searching for solutions to a number of the problems associated with the possibility of combining a complex of traits in one variety [14].

The purpose of the research is to evaluate the breeding varieties of meadow clover in the competitive variety trial (CVT) on the indicators of fodder and seed productivity, to select the promising ones for transfer to the state variety trial (SVT).

MATERIAL AND METHODS

The research was conducted in 2019-2022 at the breeding plot of the laboratory of breeding and primary seed production of perennial grasses of the experimental field of the Federal Agrarian Scientific Center of the North-East named after N.V. Rudnitsky.

In the nursery of competitive varietal testing (2019 sowing) five varietal populations of the double-crop meadow clover type from the perennial grass department of the FASC of the North-East created by different methods were studied:

- *in vitro* selection of the acid tolerant genotypes from selection number M 266 (the work was carried out at the Federal Williams Research Center of Forage Production & Agroecology) with further formation of a population based on the best regenerants (P-15);

- selection of the genotypes resistant to fusarium disease on artificial infectious fusarium background from hybrid and complex-hybrid populations from artificial crossing (GPF-49-3, GPF-86-2, SGPF-159 and SGPF-159-3 + SGP-117).

Evaluation of productivity indicators was carried out in comparison with the zoned stan-

dard variety Dymkovsky. The sowing was carried out in summer in rows without cover. The area of plots in testing for fodder purposes was 10 m², placement randomized in four-fold repetition, for seed purposes – 30 m² with a systematic placement in a single repetition.

In the conditions of the Volgo-Vyatsky region, the economic use of meadow clover is limited to two years, so the main research was conducted in the first and second years of use, and in the third year of use the economic longevity of the breeding varieties was evaluated.

The soil of the experimental plot was sod medium podzolic semi-loam strongly acidic (pH_{Cl} = 4.47) with high content of exchangeable forms of phosphorus (P₂O₅) and potassium (K₂O) – 192.5 and 217.9 mg/kg (according to Kirsanov), low humus content – 2.2% (according to Tyurin).

Recordings, observations, and evaluations were carried out in accordance with the generally accepted methods⁴⁻⁷. Statistical processing of the experimental results was carried out by the method of dispersion and correlation-regression analysis using the package of breeding-oriented programs AGROS v. 2.07 and Microsoft Office Excel 2011 program.

The conditions of the three autumn and winter periods (2019/20, 2020/21, 2021/22) during the breeding trial were satisfactory for meadow clover overwintering.

Meteorological conditions of the vegetation periods differed in heat and moisture availability, which allowed to reveal individual reaction of the varieties to growing conditions and give them an objective assessment.

The weather conditions of the first half of the summer season 2020 and 2022 (May-June) were similar in terms of temperature regime and precipitation availability. They were characterized by low average daily air temperature – 13.7 and 12.3 °C (0.8 and 1.6 °C below the norm) and ex-

³Federal State Budgetary Institution “State Commission of the Russian Federation for Testing and Protection of Breeding Achievements” (FSBI “Gossortkomissiya”). Plant varieties included in the State Register of Breeding Achievements admitted to use. Varieties of the crop “Meadow clover”: <http://reestr.gossort.com/reestr/culture/45>.

⁴A broad unified classifier of the genus *Trifolium* L. Leningrad: VIR, 1983, 32 p.

⁵Methodology of the State variety testing of agricultural crops. Moscow, 1985, 269 p.

⁶Methodological guidelines for breeding and primary seed production of clover. Moscow: VNIIC, 2002, 72 p.

⁷Dospekhov B.A. Methodology of field experiment. Moscow: Agropromizdat, 1985, 351 p.

cess precipitation – 129 and 170 mm (111.0 and 124.5% of the norm). In 2021 in this period, the average daily air temperature was warmer, the average daily air temperature was 17.5°C (3.6°C above the multiyear average), and a slight precipitation deficit was recorded (120 mm or 92.5% of the multiyear average).

In the second half of the summer (July – August), the weather was moderately warm with the average daily air temperature of 17.8 °C (0.55 °C above the multiyear average) and accumulation of 792.9 °C of effective temperatures. Precipitation was within the norm – 161.0 mm (104.5% of the norm). In 2021 and 2022 during the same period, the weather was hot, sometimes very hot, with average daily air temperatures of 19.0 and 20.0 °C (1.75 and 2.55 °C above the norm) and accumulation of 867.5 and 926.7 °C of effective temperature, precipitation totaled 130.9 and 75.0 mm (85 and 48% of the norm).

RESULTS AND DISCUSSION

Winter hardiness as the ability to resist the complex of negative environmental influences during winter and early spring periods is an important characteristic of the variety. It allows us to assess the possibility of its preservation under cultivation in extreme soil and climatic conditions of the north-eastern European part of Russia, which includes the Volgo-Vyatka region.

In the years of research, all varieties showed high and very high winter hardiness: on average

it amounted to 81.2–92.9% in the first year of use and 100% in the second and third years of use.

The beginning of spring regrowth of plants was observed in close calendar dates in all years of the trials – April 20–21.

The period from the beginning of regrowth to flowering in the varieties depended on the meteorological conditions of the first half of the summer season: in cool with excessive moisture in 2020 (the first year of use) and 2022 (the third year of use) it was longer and was 72–76 and 75–78 days, while in warm with normal moisture supply in 2021 (the second year of use) it was short – 57–64 days (see Table 1).

According to the results of phenological observations, all breeding varieties entered the flowering phase on average 1–5 days earlier than the standard Dymkovsky.

Plant height is an element of variety characterization and one of the factors of agronomic control over the process of yield formation. As records showed, depending on the weather conditions of the research year, grass stands differing from each other in plant height were formed.

Under conditions of excessively wet growing season 2020 (290 mm of precipitation, or 107.8% of the norm), the average plant height was 93.0 cm in the first cutting (medium-growing grass) and 55.1 cm in the second cutting (low-growing). Under conditions of weak moisture deficit in 2021 and 2022 (88.8 and 86.3% of

Табл. 1. Показатели фенологических наблюдений за травостоями селекционных сортов клевера лугового (КСИ, посев 2019 г.)

Table 1. Indicators of phenological observations of the grass stands of meadow clover selection varieties (CVT, sowing 2019)

Variety	Flowering start date			Period from spring growth to flowering, days				
	2020	2021	2022	2020	2021	2022	Average	± to the standard
GPF-49-3	02.07	19.06	05.07	72	57	75	68	–5
P-15	03.07	22.06	05.07	73	63	75	70	–3
SGPF-159-3 + SGP-117	03.07	21.06	05.07	73	62	75	70	–3
SGPF -159-3	03.07	22.06	06.07	73	63	76	71	–2
GPF -86-3	06.07	22.06	07.07	76	63	77	72	–1
Dymkovsky (standard)	06.07	23.06	08.07	76	64	78	73	–

the norm), plants were low-growing – 60.6; 61.6 and 43.3 cm in the first and second harvests of 2022, respectively. In the third-year grass stands (2022), the second ear was not formed due to hot and dry weather in the second half of the growing season.

Interpopulation differences in plant height were revealed: in GPF-49-3 this index reached maximum values in all harvests with a reliable excess of the standard by 1.5 cm ($LSD_{05} = 0.5$ cm) in the first harvest and by 7.5 cm ($LSD_{05} = 2.1$ cm) in the second harvest (see Table 2).

Population P-15 in the first cutting formed a grass stand equal in height to the standard Dymkovsky, in the second cutting it was reliably higher by 5.0 cm.

In the varieties SGPF-159-3 and SGPF-159-3 + SGP-117 plants of the first cutting were significantly lower than the standard Dymkovsky by 5.1 and 3.7 cm, respectively. The height of the second cutting plants in the population SGP-159-3 significantly exceeded the standard by 5.5 cm, in SGPF-159-3 + SGP-117 it was at its level.

The GPF-86-3 population was characterized by high-growing plants of the first cutting, significantly exceeding the Dymkovsky variety by 0.9 cm, and low-growing and equal to it in the second one.

One of the characteristics of the fodder value of the variety is the foliage. Clover leaves are

richer in organic and mineral content than the stems.

Leaf content in the grass stands of the first cutting amounted to 42.5% and corresponded to the gradation “average”. According to this indicator, all breeding varieties surpassed the Dymkovsky variety (41.5%) by 0.2–2.4%. The share of the leaves on the plants of the second cutting was 14.1% higher than the first one and averaged 56.6% in the nursery. On the background of high plant foliage, all studied populations were inferior to the standard Dymkovsky (63.5%) by 4.0–10.8%.

According to the paired correlation-regression analysis, a strong negative relationship ($r = -0.81$) was found between the indicators of the plant height and foliage, from which it can be concluded that the taller the plants, the less foliated they are.

For a more objective evaluation of the varieties, the leaf dry matter yield (t/ha) was determined based on the plant foliage (%).

According to this indicator, in the first cutting, the breeding varieties SGPF-159-3, P-15, SGPF-159-3 + SGP-117 and GPF-86-3 showed a significant increase (0.34–0.76 t/ha, $LSD_{05} = 0.30$ t/ha); GPF-49-3 showed an insignificant increase (0.30 t/ha). In the second cutting, populations GPF-86-3 and GPF-159-3 + GPF-117 significantly exceeded the standard by 0.14 and 0.18 t/ha ($LSD_{05} = 0.17$ t/ha), while the other populations were at its level (see the figure).

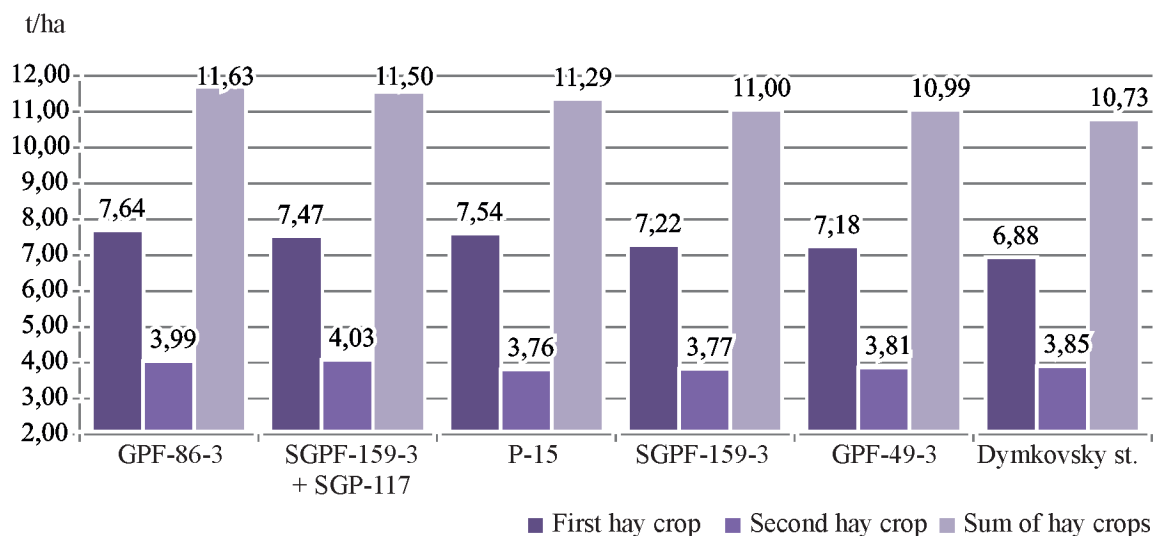
The total (per two harvests) leaf yield under two-year regime of use in all the breeding varieties was higher than the variety Dymkovsky (10.73 t/ha) by 0.26–0.90 t/ha. Significant excess over the standard was obtained in the populations P-15, SGPF-159-3 + SGPF-117, GPF-86-3 - 0.56; 0.77 and 0.90 t/ha ($LSD_{05} = 0.29$ t/ha).

The studies showed that all breeding varieties had the most productive herbage of the first year of use (2020): the average dry matter collection in the nursery was 13.31 t/ha. In the second year of use there was a decrease in the productivity of grass stands to the level of the first year by 42.4% (2021), the total collection of fodder mass amounted to 7.67 t/ha. Age grass stands of the third year of use formed only the first harvest

Табл. 2. Характеристика селекционных сортов клевера лугового по высоте растений, см (КСИ, посев 2019 г., среднее за второго года пользования)

Table 2. Characteristics of the meadow clover selection varieties by plant height, cm (CVT, sowing 2019, average for 2 years of use)

Variety	Hay crop	
	first	second
GPF -49-3	79,4	53,5
GPF -86-3	78,8	46,9
P-15	78,0	51,0
SGPF -159-3 +SGP-117	74,2	46,4
SGPF -159-3	72,8	51,5
Dymkovsky (standard)	77,9	46,0
Average for the nursery	76,9	49,2
LSD_{05}	0,5	2,1



Характеристика селекционных сортов клевера лугового по сбору сухой массы листьев (КСИ, посев 2019 г., среднее за 2 года пользования)

Characteristics of the meadow clover selection varieties in terms of leaf dry mass collection (CVT, sowing 2019, average for 2 years of use)

with the average value of 3.49 t/ha of dry matter (see Table 3).

Fodder productivity of all the breeding varieties exceeded the variety Dymkovsky in the first year of use by 0.22–0.71 t/ha, in the second year by 0.96–1.76 t/ha. Varieties SGPF-159-3 + SGP-117, GPF-86-3, P-15 and GPF-49-3 with additions of 0.61–0.71 and 0.98–1.76 t/ha by years, respectively ($LSD_{05} = 0.46$ and 0.78 t/ha) showed a reliable advantage over the standard Dymkovsky (12.83 and 6.60 t/ha) in both years of use.

At a low level of fodder productivity of third-year grass stands, all the breeding varieties exceeded the Dymkovsky variety (3.10 t/ha) by 0.33–0.69 t/ha. The highest yield of fodder mass was obtained in the variety GPF-86-3 at 3.79 t/ha with a reliable gain to the standard of 0.69 t/ha ($LSD_{05} = 0.63$ t/ha).

Under the two-year regime of herbage use, the total dry matter yield of all the breeding varieties significantly exceeded the Dymkovsky variety (19.43 t/ha) by 1.18–2.47 t/ha ($LSD_{05} = 1.03$ t/ha).

Obtaining fodder mass in the third year of use indicates that in the conditions of the Kirov region in case of high preservation of plants after overwintering and favorable heat and moisture availability during vegetation periods all

the studied varieties have productive longevity (3 years).

Under the three-year regime of herbage use, four varieties (GPF-49-3, GPF-86-3, P-15 and SGPF-159-3 + SGP-117) provided a reliable increase in fodder mass collection (3.84; 2.64; 2.60 2.06 t/ha, respectively) in comparison with the standard Dymkovsky (22.53 t/ha).

According to our data, the most productive breeding varieties - GPF-49-3, P-15, GPF-86-3 and SGPF-159-3 + SGP-117, which provided a reliable increase in fodder mass collection both at two-year and three-year regimes of herbage utilization, were identified.

According to the results of the previously conducted studies, the dynamics of fodder mass intake by cutting varied on average for the evaluated varieties from 50.2 to 73.6% in the first year of use, from 51.0 to 76.3% in the second year. It was noted that the share of the second cutting of the total productivity decreases with the age of the grass stand, which is due to the aging of the plants and weakening of their regenerative capacity [14].

According to the character of fodder mass distribution in all the years of research, the breeding varieties and the standard were more productive in the first harvests.

In our studies, the contribution of the first cutting to the total dry matter yield averaged 67.0%

Табл. 3. Сбор сухого вещества у селекционных сортов клевера лугового по годам пользования, т/га (КСИ, посев 2019 г.)

Table 3. Collection of dry matter from the meadow clover selection varieties by years of use, t/ha (CVT, sowing 2019)

Variety	Year of study (use)			Total dry matter yield under the grass utilization regime	
	2020 (first)	2021 (second)	2022 (third)	two-year	three-year
GPF -49-3	13,54*	8,36*	3,47	21,90*	25,37*
P-15	13,49*	8,08*	3,56	21,56*	25,13*
GPF -86-3	13,53*	7,85*	3,79*	21,39*	25,17*
SGPF -159-3 + SGP-117	13,44*	7,58*	3,57	21,02*	24,59*
SGPF -159-3	13,05	7,56*	3,43	20,61*	24,04
Dymkovsky (standard)	12,83	6,60	3,10	19,43	22,53
Average for the nursery	13,31	7,67	3,49	20,99	24,47
LSD ₀₅	0,46	0,78	0,63	1,03	1,55

* $p \geq 0,95$.

in the first year of use and 67.9% in the second year, while the contribution of the second cutting was 33.0 and 32.1%. The stability of the ratio of the first and second cuttings during the first two years of use indicates that the regenerative capacity of plants in these years is preserved (see Table 4).

In the first year of use, the share of the first cutting in the breeding varieties ranged from 65.0 to 67.5%, in the second year it varied from 65.1 to 70.3%; in the standard Dymkovsky it amounted to 69.2 and 69.7%.

By the second year of use, the minimum decrease in the proportion of the second cutting in

comparison with the first year was observed in the population of SGPF-159-3 (by 0.1%), in the standard Dymkovsky by 0.5%, the maximum decrease in GPF-86-3 (by 1.4%), SGPF-159-3 + SGP-117 (by 3.0%), P-15 (by 3.3%). The variety GPF-49-3 showed an increase in the share of the second cutting by 2.4%.

Seed yield was evaluated along with the study of the breeding varieties' fodder productivity indices.

In both years of use winter hardiness of the plants in seed grass stands was at the level of very high indicators (more than 87%). The variety GPF-49-3 was characterized by the highest winter hardiness – 97.8% (see Table 5).

Табл. 4. Сбор сухого вещества по укосам, % (КСИ, посев 2019 г.)

Table 4. Collection of dry matter by hay crops, % (CVT, sowing 2019)

Variety	Year of study (use)					
	2020 (first)		2021 (second)		Average	
	Hay crop					
	first	second	first	second	first	second
GPF -49-3	67,5	32,5	65,1	34,9	66,3	33,7
P-15	67,0	33,0	70,3	29,7	68,6	31,4
SGPF -159-3	65,0	35,0	65,1	34,9	65,0	35,0
SGPF -159-3+SGP-117	66,1	33,9	69,1	30,9	67,6	32,4
GPF -86-3	67,5	32,5	68,9	31,1	68,2	31,8
Dymkovsky (standard)	69,2	30,8	69,7	30,3	69,5	30,5
Average for the nursery	67,1	33,0	68,0	32,0	67,5	32,5

The period from the beginning of regrowth to harvesting maturity of seed grass stands was the shortest in the varieties GPF-49-3 and P-15. The populations of SGPF-159-3 and SGPF-159-3 + SGP-117 lagged behind them on average by one day, and GPF-86-3 by two days. All the breeding varieties ripened earlier than the Dymkovsky variety by 2–5 days.

In 2020 (the first year of use) seed grasses with plant height of 96.9 cm were formed, in 2021 (the second year) it was 61.1 cm. During the years of research, the tallest plants in the grass stands were obtained from the varieties P-15, GPF-49-3 and the variety Dymkovsky, their average heights were 81.8; 80.4 and 80.1 cm. Other populations did not exceed 80 cm.

The level of seed productivity was significantly influenced by the meteorological conditions of the study year. Thus, under low air temperatures and excessive moisture in 2020 (the first year of use), the average variety yield was 1.04 c/ha, while in warmer and slightly deficient precipitation conditions in 2021 (the second year) it increased by 125% and amounted to 2.34 c/ha. The contribution of the first year of use to the total seed yield was 31.2%, the second year 68.9% (see Table 6).

When comparing the seed productivity with the standard Dymkovsky in the first year of use, the variety SGPF-159-3 with 0.88 kg of seeds/ ha

showed a low (below 70% of the standard) level of seed productivity, populations GPF-86-3, SGPF-159-3 + SGP-117, GPF-49-3 and P-15 (0.96–1.13 kg/ha) demonstrated the average level (70–110% of the standard).

In the second year of use, variety P-15 with seed yield of 3.14 c/ha provided a very high (150% and more to the standard) level of seed productivity, SGPF-159-3 + SGPF-117, SGPF-159-3, GPF-49-3 (2.14–3.14 c/ha) showed a high (110–149% to the standard) level, GPF-86-3 (1.99 c/ha) a medium level.

According to the results of two years of tests, the population P-15 with an excess over the standard Dymkovsky (1.58 c/ha) by 0.56 c/ha (135.4% to the standard) was the highest yielding in the nursery. Varieties GPF-49-3 and SGPF-159-3 with a gain of 0.14 and 0.11 c/ha (108.9 and 107.0% to the standard) provided an average level of seed productivity.

CONCLUSION

The results of evaluation of the economically useful traits of meadow clover varietal populations confirm the effectiveness of the breeding work on the creation of new generation varieties. In our research, the selected varieties GPF-49-3 and P-15 were identified as winter-hardy (> 90%), highly productive in terms of fodder

Табл. 5. Хозяйственно-биологическая характеристика селекционных сортов клевера лугового при возделывании на семена (КСИ, посев 2019 г.)

Table 5. Economic and biological characteristics of the meadow clover selection varieties when cultivated for seeds (CVT, sowing 2019)

Variety	Winter hardiness, %			Period from aftergrowth to technical maturity of the grass stand, days			Plant height at maturity phase, cm		
	Year of use								
	first	second	average	first	second	average	first	second	average
GPF -49-3	98,9	96,7	97,8	111	90	101	99,5	61,2	80,4
P-15	96,8	91,8	94,3	111	91	101	99,7	63,8	81,8
SGPF -159-3	96,8	88,2	92,5	112	91	102	96,5	61,8	79,2
SGPF -159-3+SGP-117	87,5	95,7	91,6	112	91	102	93,7	59,4	76,6
GPF -86-3	88,2	93,8	91,0	114	94	104	94,5	57,6	76,1
Dymkovsky (standard)	87,5	92,9	90,2	116	95	106	97,4	62,8	80,1
Average for the nursery	92,6	93,2	92,9	112,7	92,0	102,7	96,9	61,1	79,0

Табл. 6. Семенная продуктивность селекционных сортов клевера лугового, ц/га (КСИ, посев 2019 г.)
Table 6. Seed productivity of the meadow clover selection varieties, c/ha (CVT, sowing 2019)

Variety	Year of use			± to the standard		Contribution of the year of use to the total seed yield, %	
	first	second	average	c/ha	%	first	second
P-15	1,13	3,14	2,14	+0,56	135,4	26,5	73,5
GPF -49-3	0,97	2,47	1,72	+0,14	108,9	28,2	71,8
SGPF -159-3	0,88	2,49	1,69	+0,11	107,0	26,1	73,9
SGPF -159-3+SGP-117	0,97	2,14	1,56	-0,02	98,7	31,2	68,8
GPF -86-3	0,96	1,99	1,48	-0,10	93,7	32,5	67,5
Dymkovsky (standard)	1,34	1,82	1,58	—	—	42,4	57,6
Average for the nursery	1,04	2,34	1,70	—	—	31,2	68,9

mass (total dry matter yield for 2 years 21.90 and 21.56 t/ha (+12.7 and 11.0% to the standard) and seed yield (average for 2 years 1.72 and 2.14 kg/ha (+8.9 and +35.4% to the standard)). In the conditions of the Volga-Vyatka region they are promising for transfer to the State variety trial.

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Эффективность предпосевной обработки семян люпина белого комплексными составами на основе фунгицида Тебу 60

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Представлены результаты лабораторного и полевого изучения эффективности протравителя Тебу 60, МЭ (микроэмульсия) в чистом виде и в баковых смесях с препаратами Гумат+7 и Фитактив Вита против семенной инфекции антракноза и других болезней люпина. Исследования проведены в 2020–2022 гг. в Брянской области. Объект изучения – семена, проростки и посевы люпина белого сорта Мичуринский. В лабораторных условиях биологическую оценку эффективности протравителя Тебу 60 в чистом виде (норма расхода – 0,5 л/т) и баковых смесей Тебу 60 + Гумат+7 (0,5 + 0,5 л/т) и Тебу 60 + Фитактив Вита (0,5 + 0,05 л/т) против семенной инфекции антракноза проводили по числу пораженных проростков, выращенных в бумажно-полиэтиленовых рулонах, в сравнении с контролем (без протравливания). Высокую биологическую эффективность против антракноза показала баковая смесь Тебу 60 + Фитактив Вита (100%). При этом данная смесь достоверно ($HCp_{05} = 0,66$) оказывала наименьшее воздействие на снижение длины гипокотили проростков (8,8%). Полевой опыт закладывали в четырехкратном повторении. Площадь делянки составила 34 м². Норма высева – 1,0 млн всхожих семян/га. Почва участка серая лесная, содержание гумуса – 2,6%. Предшественник – яровые зерновые культуры. Протравливание семян Тебу 60 (0,5 л/т) и баковыми смесями Тебу 60 + Гумат+7 (0,5 + 0,5 л/т) и Тебу 60 + Фитактив Вита (0,5 + 0,05 л/т) проводили за месяц до посева. Эффективность протравливания оценивали в сравнении с контролем. В среднем наибольшую биологическую эффективность против семенной инфекции антракноза показала баковая смесь Тебу 60 + Фитактив Вита (98,1%). К фазе блестящего боба число пораженных бобов составило 20,5% при 78,4% в контроле. Биологическая эффективность против фузариоза и ризоктонии составила 65,9 и 74,4% соответственно. Распространение на бобах серой и белой гнили сократилось в 8 и 11 раз соответственно. Всхожесть семян достоверно ($HCp_{05} = 0,74$) увеличилась на 16,2%, сохранность продуктивных растений к уборке – на 56,5%. Достоверная прибавка урожая семян составила 2,52 т/га, окупаемость затрат – 64,88 р.

Ключевые слова: люпин белый, болезни, протравитель, регуляторы роста, эффективность, урожайность

Efficiency of pre-sowing treatment of white lupine seeds with complex compositions based on Tebu 60 fungicide

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The results of laboratory and field tests of effectiveness of the Tebu 60 protectant, ME (micro-emulsion) in its pure form and in tank mixtures with Humate+7 and Fitaktiv Vita against anthracnose

seed infection and other diseases of lupine are presented. The research was conducted in 2020–2022 in the Bryansk region. The object of the study were the seeds, seedlings and crops of the Michurinsky white lupine variety. In laboratory conditions, biological evaluation of the effectiveness of the Tebu 60 protectant in pure form (rate of consumption – 0.5 l/t) and tank mixtures Tebu 60 + Humate+7 (0.5 + 0.5 l/t) and Tebu 60 + Fitaktiv Vita (0.5 + 0.05 l/t) against anthracnose seed infection was carried out by the number of affected seedlings grown in paper-polyethylene rolls in comparison with the control (without treatment). The tank mixture Tebu 60 + Fitaktiv Vita (100%) showed high biological efficacy against anthracnose. Moreover, this mixture significantly ($LSD_{05} = 0.66$) had the least effect on reducing the hypocotyl length of the seedlings (8.8%). The field experiment was laid down in a fourfold repetition. The plot area was 34 m². The seeding rate was 1.0 million germinated seeds/ha. The soil of the site was gray forest soil, humus content – 2.6%. The forecrop was spring cereal crops. Seed dressing with Tebu 60 (0.5 l/t) and tank mixtures Tebu 60 + Humate+7 (0.5 + 0.5 l/t) and Tebu 60 + Fitaktiv Vita (0.5 + 0.05 l/t) were conducted one month before the sowing. The effectiveness of the treatment was evaluated in comparison with the control. On average, the highest biological efficacy against anthracnose seed infection was shown by the tank mixture Tebu 60 + Fitaktiv Vita (98.1%). By the shiny pod phase, the number of affected beans was 20.5% compared to 78.4% in the control. The biological efficacy against fusarium disease and rhizoctonia was 65.9 and 74.4%, respectively. The prevalence of gray rot and white rot on beans was reduced 8 and 11 times, respectively. Seed germination increased significantly ($LSD_{05} = 0.74$) by 16.2%, safety of productive plants to harvesting – by 56.5%. Reliable increase in the seed yield was 2.52 t/ha, cost recovery – 64.88 rubles.

Keywords: white lupine, diseases, dresser, growth regulators, efficiency, yield

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Conflict of interest

The authors declare no conflict of interest.

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INTRODUCTION

White lupine (*Lupinus albus* L.) is a high-protein legume crop and has the highest productivity potential among the cultivated lupine species. Seed yield of the modern varieties of white lupine ranges from 3 to 5 tons/ha, the yield of green mass – from 70 to 100 tons/ha. Lupine seeds contain 37–42% of protein, 8–12% of fat and 9.5–10.5% of fiber¹ [1]. Unlike soybean,

they contain almost no trypsin inhibitors, which allows to use them for animal feed without heat treatment². The introduction of new varieties developed by the All-Russian Research Institute of Lupine (VNII of Lupine) made it possible to increase the area under the crop grown for grain to 122.5 thousand ha (for comparison: in 2011, the area under crops was 14.5 thousand ha). The largest part of the sown areas (97.4 thousand ha)

¹Podobedov A.V. Lupine – the way to salvation // Compound feeds, 2013, N 3, pp. 63–65.

²Kuptsov N.S., Pashkevich A.P., Shor V.Ch., Kritsky M.N., Lapytko A.V. White lupine – a valuable oil-protein crop: appendix to the journal of the Russian Academy of Sciences // Agriculture and plant protection, 2020, N 1, pp. 23–27.

is located in the Central Federal District of the Russian Federation (Orel, Kursk, Tula, Bryansk and Lipetsk regions) [2]. Among the factors limiting the expansion of the sowing areas and productivity of white lupine in the Russian Federation are plant diseases, the most dangerous of which is anthracnose, the causative agent of which is the imperfect fungus *Colletotrichum lupini* var. *lupini*³ [1, 3]. Yield losses from this disease can range from 30 to 90%.

In lupine, seeds are the main source of primary infection of anthracnose and many other diseases (fusarium disease, gray and white rot)⁴ [4, 5]. For this reason, it is obligatory to disinfect them in order to suppress the disease at the beginning of its development and avoid significant yield losses (see footnote 4) [5, 6]. In Russia, a limited number of dressing agents are allowed for disinfection of sown lupine seeds. Unfortunately, they do not have high activity against anthracnose and many other pathogens [1, 5, 6]. Lupine plants, especially in the sprouting phase, show high sensitivity to the action of fungicides from the chemical group of triazoles. At the same time, the attractiveness of preparations of this group is due to their low price and a wide range of antifungal activity⁵ [7]. One of the active substances of the preparations of this chemical group is tebuconazole, which is included in many fungicides (see footnote 5) [8, 9].

The physiological effect of tebuconazole action consists in suppression of gibberellin synthesis, increase of abscisic acid content, content of polyunsaturated fatty acids in cells membranes, which leads to growth inhibition, increase of plant resistance to unfavorable environmental factors and increase of their productivity [7, 10].

It is possible to reduce the negative effect of triazoles on the growth of grain and legume crops by including growth regulators in the cultivation technology⁶ [11, 12]. In recent years, complex growth regulators have been developed that contain not only humic compounds, but also amino acids and trace elements that play an important role in plant life⁷ [13–15].

The active ingredient of fungicide Tebu 60, ME (microemulsion) is tebuconazole (60 g/l). This protectant is recommended for disinfection of the seeds of many crops from the whole complex of diseases (the recommended rate of consumption – 0.4–0.5 l/t)⁸. Tebu 60 has not been used in pure form and in tank mixtures with growth regulators to disinfect lupine seeds. For this reason, it is necessary to study the activity of this preparation separately and in a mixture with growth regulators against seed infection, including anthracnose, in order to protect white lupine crops.

The purpose of the research was to study biological and production efficiency of Tebu 60 dressing agent application in pure form and in a tank mixture with Fitaktiv Vita and Humate+7 against fungal pathogens of white lupine under conditions of the Bryansk region.

MATERIAL AND METHODS

Initial study of the activity of Tebu 60 protectant in pure form and in a tank mixture with Fitaktiv Vita formulations (2-ethyl-indole-3-n-propylene – 3.61 mg/l; 2-fullerene – 50 mg/l; 4-indolyl-3-butyric acid – 10 mg/l; N – 70.8 g/l; P – 3.5 g/l; Mg – 3.2 g/l; Fe – 45 g/l; Zn – 16 g/l; Cu – 5 mg/l; Mn – 65 mg/l; Mo – 5 mg/l; B – 85 mg/l; Co – 5 mg/l) and Humate+7 (humates + N, K, Cu, Mn, Zn, Bg and Fe) in relation to anthracnose seed infection were con-

³Adhikari K.N., Thomas G., Diepeveen D., Trethowan R. Overcoming the barriers of combining early flowering and anthracnose resistance in white lupin (*Lupinus albus* L.) for the Northern Agricultural Region of Western Australia // Crop and Pasture Science, 2013, vol. 64, N 9, pp. 914–921.

⁴Talhinhas R., Barancelli P., Floch G.L. Anthracnose of lupins caused by *Colletotrichum lupini*: a recent disease and a successful worldwide pathogen // Journal of Plant Pathology, 2016, vol. 98, N 1, pp. 5–14.

⁵Zinchenko V.K. Chemical plant protection: means, technology and environmental safety. Moscow: Kolos, 2007, 232 p.

⁶Melnikov N.N., Novozhilov K.V., Belan S.R. Pesticides and plant growth regulators. Moscow: Khimiya, 1995, 575 p.

⁷Knyazeva T.V. Plant growth regulators in the Krasnodar Territory. Krasnodar, 2013, 128 p.

⁸Product catalog “Shchelkovo Agrokhim”. URL: <https://betaren.ru/catalog/sredstva-zashchity-rasteniy>.

ducted in laboratory conditions on the seed material of white lupine of the Michurinsky variety. Consumption rate of the preparations: Tebu 60–0.5 l/t, Fitaktiv Vita – 0.05 l/t, Humate+7 – 0.5 l/t. To increase the sensitivity of the experiments, the seeds artificially infected with anthracnose were used. Biological efficiency was determined by the percentage of the affected seedlings from their total number. The seeds were grown in paper-polyethylene rolls at the optimal temperature of 22–24 °C for pathogen development for 7 days^{9, 10}. The sample volume for each variant was 240 seeds (6 rolls of 40 seeds each). The effect of the protectant and its tank mixtures on lupine plants was determined by the number of germinated seeds with strong and weak seedlings, as well as by hypocotyl and root length¹¹.

The field tests of Tebu 60 dressing agent in pure form and in a tank mixture with Fitaktiv Vita and Humate+7 were conducted on the experimental field of the All-Russian Research Institute of Lupine. The soil of the experimental field was gray forest, light loamy in mechanical composition, humus content – 2.6%. To exclude the transfer of anthracnose infection from plot to plot at the beginning of vegetation, a 10 m wide separating strip sown with spring crop (wheat, barley) was made between them. The experiments were laid in fourfold repetition on the plots with the area of 34 m². The sowing was mechanized, seeding rate – 1 million germinated seeds/ha.

Anthracnose infection of the sown seeds was 7–10% depending on the year of the study. Seed dressing was conducted one month before

sowing, phyto-examination of the sown seeds – one week before sowing (see footnotes 9–11). Disease damage of lupine and the effectiveness of the dressing agent in pure form and in tank mixtures were determined in comparison with the control (without dressing) starting from the phase of full sprouts and ending with the shiny bean phase^{12, 13}. Wet chambers and light microscope¹⁴ were used for identification of the pathogens by morphological signs of sporulation. The effect of the dressing agent and tank mixtures on lupine was evaluated by the number of germinated seeds and plant height. The number of beans on the plant was determined using a trial sheaf of 20 plants. Before harvesting the number of plants with beans per 1 m² was counted. Seed yield was determined from each plot by continuous threshing of beans by combine harvester “Sampo 500”. The method of dispersion analysis with determination of the smallest significant difference was used for statistical processing of the obtained data¹⁵.

RESULTS AND DISCUSSION

Laboratory tests of Tebu 60 dressing agent in pure form and in a tank mixture with Fitaktiv Vita and Humate+7 revealed its high activity against anthracnose pathogen – from 98.9 to 100% (see Table 1). The highest efficiency (100%) against anthracnose seed infection in white lupine was shown by the tank mixture consisting of 0.5 l/t of the fungicide Tebu 60 and 0.05 l/t of the fertilizer Fitaktiv Vita.

In the control variant, 68% of the 7-day-old seedlings were affected by anthracnose. Anthracnose appeared on the affected seedlings

⁹GOST 12044-93. Seeds of agricultural crops. Methods for determining disease infestation. Moscow: Standards Publishing House, 2011, 55 p.

¹⁰Gadzhieva G.I., Gutkovskaya N.S. Methodological guidelines for determining the infestation of lupine seeds with anthracnose. Minsk, 2013, 20 p.

¹¹Likhachev B.S., Skanchenko S.A., Yagovenko L.P., Kornev A.P., Kosorotikova A.V. On the assessment of sowing qualities of lupine seeds // Breeding and Seed Production, 1991, N 4, pp. 42–45.

¹²Methodological guidelines for state tests of fungicides, antibiotics and seed protectors for agricultural crops. Moscow: Publishing house of the All-Russian Research Institute of Plant Protection, 1985, 130 p.

¹³Böttecher I., Wetzel T., Dreves F.W., Kegler H., Naumann K., Freyer B., Frauenstein K., Fuchs E. Methods of determination of diseases and pests of agricultural plants. Moscow: Agropromizdat, 1987, 226. p.

¹⁴Kungurtseva O.V. Methods of lupine anthracnose monitoring. SPb.: Publishing house of the All-Russian Research Institute of Plant Protection, 2002, 11 p.

¹⁵Dospekhov B.A. Methodology of field experiment. Moscow: Agropromizdat, 1985, 351 p.

Табл. 1. Токсичность и эффективность против семенной инфекции антракноза протравителя Тебу 60 в чистом виде и в смеси с препаратами Фитактив Вита и Гумат+7 в лабораторных условиях

Table 1. Toxicity and efficacy against anthracnose seed infection of Tebu 60 protectant in pure form and in mixture with Fitaktiv Vita and Humate+7 under laboratory conditions

Variant	Consumption rate, l/t	Hypocotyl/root length, mm	Efficiency against anthracnose, %	Laboratory germination rate, %		
				total seedlings	strong	weak
Control (without treatment)	–	20,5/55,8	–	95,9	88,3	7,6
Tebu 60, ME	0,5	17,0/70,4	98,2	97,3	94,1	3,2
Tebu 60, ME + Humate+7	0,5 + 0,5	17,6/67,2	98,8	99,6	97,6	2,0
Tebu 60, ME + Fitaktiv Vita	0,5 + 0,05	18,7/66,8	100,0	99,6	98,0	1,6
LSD ₀₅		0,66/0,76	–	0,42	–	–

as brown spots on hypocotyl and cotyledons. In the variants with seed treatment, the disease was observed only on the seedlings, the incidence was from 0.8 to 1.2%.

When grown in paper rolls, the studied dressing in pure form and in a mixture with growth regulators had a positive effect on seed germination. The total laboratory germination of the seeds in these variants significantly ($LSD_{05} = 0.42$) exceeded the control by 1.4–3.7%. The highest total germination (99.6%) was observed in the mixed variants. The highest number of seeds with strong seedlings (98%) was recorded in the variant that provided for the use of Tebu 60 together with Fitaktiv Vita. The seed dressing in pure form and in a mixture had a positive effect on the linear root growth. Depending on the variant, the length of the roots increased significantly ($LSD_{05} = 0.76$) by 19.7–26.2%. The greatest increase in the root length (by 26.2%) was recorded in the variant with Tebu 60 in pure form. The studied dressing in pure form and in mixed variants had an inhibitory effect on hypocotyl growth of the seedlings. Hypocotyl length significantly ($LSD_{05} = 0.66$) decreased by 8.8–17.1%. The smallest decrease in the hypocotyl length (by 8.8%) was observed in the variant Tebu 60 + Fitaktiv Vita.

Laboratory tests of Tebu 60 dressing agent in pure form and in a mixture with Humate+7 and Fitaktiv Vita revealed its high activity against

anthracnose seed infection. The studied tank mixtures had a positive effect on seed germination and seedling growth. Field trials were conducted to confirm these data.

The weather conditions during the field trials (2020–2022) were favorable for the development and spread of anthracnose and many other diseases of white lupine. This allowed to fully evaluate the activity of the dressing and its tank mixtures against diseases (including anthracnose), and the effect of the preparations on plant growth and yield of seeds.

The growing season in 2020 was warm and excessively wet ($HTC = 2.2$). May was cool and excessively wet ($HTC = 4.1$). The period of lupine sprouting was long. The development of anthracnose seed infection was delayed. Favorable conditions for the development and spread of the disease were formed in June ($HTC = 2.31$) and July ($HTC = 1.42$). In these months, with sufficient heat (20.3 and 18.8 °C, respectively) and precipitation (104.7 and 75.9 mm), the anthracnose pathogen developed intensively on the plants and young beans.

The weather conditions of the growing season 2021 were warm and humid ($HTC = 1.97$). May was characterized by lack of heat (13.3 °C) and excessive precipitation (143.3 mm), which prevented intensive development of anthracnose. Favorable conditions for the spread of the disease occurred in June. Optimal air tem-

perature (19.9 °C) and excessive precipitation (153.7 mm) favored mass spread of the pathogen in lupine crops. July was dry. The air temperature in this month was 4.4 °C above the mean annual temperature and amounted to 22.1 °C. August was warm and moderately humid (HTC = 0.99).

The growing season 2022 was characterized as warm and humid (HTC = 1.43). May was cold and excessively wet (HTC = 2.35). Air temperature was 2.1°C below the average multiyear values, and precipitation was 30.5 mm above the norm. June was characterized by hot and humid weather conditions. Average daily air temperature exceeded the mean annual values by 2.8 °C, precipitation exceeded the average annual values by 10.8 mm (89.8 mm). HTC amounted to 1.57 units. The first signs of the disease appeared on the plants in the first ten days of June. The disease was massively observed on leaf petioles and leaf plates (see Fig. 1).

The fungus formed orange-colored spots on leaf petioles. The petioles were bent and broken in the places of lesions. Different shapes of light pink spots with brown border with sporulation of the fungus were observed on the affected leaf plates. Over time, the spots occupied the entire leaf plate, which shriveled and fell off.

The growing conditions in July were also warm and humid (HTC = 1.52, air temperature was 1.0 °C above the average annual temperature). During this period, the phase of lupine bean formation took place. Intensive development and spread of anthracnose occurred on young beans. Affected beans in the places of fungus penetration were deformed and acquired different shapes. The pathogen intensively developed, occupying more and more bean surface, forming pink depressed spots with sporulation (see Fig. 2).

Seeds in the affected beans became puny and had brown spots. Strongly infected seeds were covered with grayish-white mycelium of the fungus. In the shiny bean phase, the number of infected beans in the control was 98.3%, 60.0% more than in 2021. In August, the weather conditions were warm and dry (HTC = 0.26). The average daily air temperature exceeded the long-term average by 4.2 °C, amounting to 20.8 °C. Under these conditions, the number of beans affected by white and gray rot was insignificant and amounted to 2.7 and 0.7%, respectively.

In the period of sprouting – budding, lupine plants were affected by root rot caused by the fungus *Fusarium avenaceum* and root rot caused by *Rhizoctonia solani*. In the flowering phase (blue bean), lupine crops were affected by



Рис. 1. Поражение антракнозом растений люпина белого в фазу стеблевания

Fig. 1. The anthracnose infection of white lupin plants at the stem formation stage



Рис. 2. Пятна антракноза на бобах люпина белого в фазу блестящего боба

Fig. 2. The anthracnose lesions on the pods of the white lupin at the shiny pod stage

the fungus *F. oxysporum* spp. causing tracheomycosis wilting of the plants (blockage of stem vessels by fungus).

The analysis of meteorological parameters showed that the most favorable conditions for the development and spread of anthracnose in lupine crops were formed in the first half of the growing season.

On average over the years of the study, the bean anthracnose lesion observed in the control crop was 31.9% higher than in the plants with treated seeds.

According to the results of the phyto expertise, the content of infected seeds in the sowing material of the control variant was as follows: anthracnose – 5.6–9.2%, fusarium – 1.2–2.0%, alternaria – 4.2–6.2%, gray and white rot – 3.0–1.2%. Seed treatment with Tebu 60 seed dressing pure and mixed with Humate+7 and Fitaktiv Vita significantly reduced infection of the sown seeds by pathogenic microflora.

On average, the biological efficiency of Tebu 60 dressing against anthracnose amounted to 96.4% during the years of study. In relation to the control, the number of the plants affected by this disease in the shooting phase decreased by 44.8%. The biological efficacy of tank mixtures of the dressing with Humate+7 and Fitaktiv Vita against anthracnose was higher and amounted to 97.6 and 98.1%, respectively.

In the shiny bean phase, the number of beans affected by anthracnose in the control amounted to 78.4%, in the variants with the dressing agent in pure form and in a mixture with Humate+7 and Fitaktiv Vita it decreased by 53.9; 57.7 and 57.9%, respectively. Biological efficiency against fusarium and rhizoctonia in these variants amounted to 51.0; 60.0; 64.8 and 65.9; 67.1; 74.4%, respectively. The spread of gray and white rot on the beans reduced from 1.6 to 0.2 and from 2.2 to 0.2%, respectively.

Tebu 60 dressing agent at the rate of 0.5 l/t had no negative effect on the field germination of white lupine seeds, which averaged 96.1% over three years. The introduction of the preparations Humate+7 and Fitaktiv Vita significantly ($LSD_{05} = 0.74$) increased the field germination by 2.3 and 3.0% (see Table 2).

The best variant of tank mixtures in terms of the effect on field germination of seeds was the mixture of Tebu 60 + Fitaktiv Vita (99.1%).

Tebu 60 dressing agent in pure form and in tank mixtures had an inhibitory effect on plant growth only at the beginning of vegetation. On average, during the years of study, the height of the plants in the shooting phase was significantly ($LSD_{05} = 0.75$) lower in these variants than in the control, respectively, by 5.2; 5.0 and 4.6 cm. At the same time, these plants differed from the control by darker coloring of the cotyledonary and true leaves. At the phase of full ripeness, the height of the plants in the mixed variants significantly ($LSD_{05} = 0.68$) exceeded the control by 3.8 and 4.2 cm.

Reduction in the number of diseased plants in the variants with dressing of the sown seeds contributed to an increase in their safety and productivity by the phase of full ripeness. The greatest influence on plant viability was exerted by the tank mixture Tebu 60 + Fitaktiv Vita. In this variant, the number of preserved plants with beans amounted to 64.2 pcs/m² with 41.0 pcs/m² in the control. The ratio of the number of beans was as follows: 4.8 and 3.1 pieces per plant (see Fig. 3).

Increase in the yield of white lupine seeds as a result of application of Tebu 60 dressing

Табл. 2. Действие протравителя в чистом виде и в баковых смесях с регуляторами роста на всхожесть и урожайность люпина белого сорта Мичуринский (полевой опыт 2020–2022 гг.)

Table 2. The effect of the protectant in a pure form and in tank mixtures with growth regulators on germination and yield of the Michurinsky white lupine variety (field experiment of 2020–2022)

Variant	Consumption rate, l/t	Germination rate, %	Plant height, cm		Number of productive plants for harvesting, pcs./m ²	Number of beans per plant, pcs.	Seed yield, t/ha	Seed yield increase, t/ha	Cost recovery, rubles
			shooting phase	full ripeness phase					
Control	–	82,9	15,3	54,3	41,0	3,1	0,60	–	–
Tebu 60, ME	0,5	96,1	10,1	54,4	57,5	4,1	2,22	1,62	47,81
Tebu 60 + Humate+7	0,5 + 0,5	98,4	10,3	58,1	61,0	4,5	2,95	2,35	56,37
Tebu 60 + Fitaktiv Vita	0,5 + 0,05	99,1	10,7	58,5	64,2	4,8	3,12	2,52	64,88
LSD ₀₅	–	0,74	0,75	0,68	–	–	0,081	–	–

a



б



Рис. 3. Делянки люпина белого в фазу блестящего боба:

a – контроль (без обработки); *б* – смешанный вариант Тебу 60 + Фитактив Вита

Fig. 3. The white lupine plots at the shiny pod stage:

a – control (no treatment); *б* – the mixture variant of the Tebu 60 protectant + Fitaktiv Vita

agent in pure form and in a tank mixture with the preparations Humate+7 and Fitaktiv Vita provided an increase in the number of surviving plants by harvesting and reduction of their damage by anthracnose, fusarium and other diseases. At the same time, the use of a mordant tank mixture, which has high efficacy against a complex of pathogens, including anthracnose, allows reducing the number of treatments of crops during the growing season, which significantly reduces the cost of protection of field crops [6, 11, 14].

Lupine seed yield in the variant with Tebu 60 mordant amounted to 2.22 t/ha, which is

1.62 t/ha more than in the control. Addition of the preparations Humate+7 and Fitaktiv Vita to Tebu 60 dressing agent contributed to a reliable (LSD₀₅ = 0.081) increase in yield by 0.73 and 0.90 t/ha. The difference in cost recovery between the variants “mordant in pure form” and “tank mixtures” amounted to 8.56 and 17.07 rubles, respectively, with an increase in favor of the variants with growth regulators.

CONCLUSION

Pre-sowing treatment with tank mixtures, including along with fungicidal mordant Tebu 60 the preparation Humate+7 and the growth

stimulant Fitaktiv Vita, had a more pronounced positive effect on the yield formation of white lupine of the Michurinsky variety than single application of the mordant Tebu 60.

Increase in productivity of white lupine plants after application of tank mixtures (Tebu 60 + Humate+7 and Tebu 60 + Fitaktiv Vita) was provided by higher biological efficacy against anthracnose seed infection (97.6 and 98.1%). This reduces the infectious load of the pathogen on plants during the growing season and improves the phytosanitary situation in crops. In mixed variants, the spread of anthracnose on the plants in comparison with the variant, assuming the use of only Tebu 60, decreased by 0.6 and 0.8%, and the lesion of beans by the same pathogen in the shiny bean phase decreased by 3.8 and 4.0%, respectively. Fusarium damage of the plants decreased by 1.9 and 2.9%. Addition of Humate+7 and Fitaktiv Vita preparations to the dressing agent reduced the spread of gray rot on the beans by 1.6 and 2.5 times, white rot – by 2.5 times. Field germination of the seeds significantly ($LSD_{05} = 0.74$) increased by 2.3 and 3.0%, respectively.

The highest yield of white lupine seeds of the Michurinsky variety (3.12 t/ha) was obtained by treatment of the sown seeds with the tank mixture Tebu 60 + Fitaktiv Vita (0.5 + 0.05 l/t). The increase in lupine seed yield as a result of using this tank mixture provided not only an increase in the number of productive plants by harvesting (1.6 times relative to the control), but also an increase in the number of beans per plant (1.5 times relative to the control). The use of the tank mixture Tebu 60 + Humate+7 increased the yield by 0.73 t/ha compared to the use of Tebu 60, compared to the tank mixture Tebu 60 + Fitaktiv Vita by 0.90 t/ha. The obtained reliable ($LSD_{05} = 0.081$) seed yield gains increased cost recovery by 8.56 and 17.07 rubles.

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Влияние аутбридинга и инбридинга на молочную продуктивность коров костромской породы

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Представлен материал о современной генеалогической структуре костромской породы крупного рогатого скота, племенной базе и родственными связями коров в племенных хозяйствах Костромской области. Отечественная костромская порода крупного рогатого скота, обладающая ценными хозяйственно полезными качествами, составляет в регионе 33,5%. Исследования проведены в трех племенных хозяйствах и двух племенных репродукторах в 2023 г. В качестве материала исследований использованы данные племенного и зоотехнического учета. Методы исследований – зоотехнические, популяционно-генетические и аналитические с использованием компьютерных программ. Проанализирована молочная продуктивность коров при аутбридинге (неродственном разведении) и при разных степенях родства при инбридинге отдельно по всем племенным заводам и племенным репродукторам в Костромской области. Из 1736 исследуемых коров костромской породы аутбридингом получено 918 (52,9%), с использованием инбридинга – 818 (47,1%), в том числе отдаленным – 461 (26,5%), умеренным – 310 (17,8%), близким – 41 (2,4%) и кровосмешением – 6 (0,4%). В племенных хозяйствах в основном использовали аутбридинг, а также отдаленный и умеренный инбридинг. Уровень стихийного инбридинга составил 2,8%. Более высокие удои коров присущи аутбредным коровам из всех племенных хозяйств Костромской области, содержание жира и белка в молоке – аутбредным и животным при разных степенях инбридинга в условиях конкретных хозяйств. Результаты исследований свидетельствуют о более высокой молочной продуктивности коров при аутбридинге. Полученные данные использованы при составлении планов селекционно-племенной работы с костромской породой крупного рогатого скота в племенных хозяйствах.

Ключевые слова: крупный рогатый скот, костромская порода, племенные хозяйства, подбор, инбридинг, аутбридинг, молочная продуктивность

Influence of outbreeding and inbreeding on milk productivity of the Kostroma breed cows

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The material about modern genealogical structure of the Kostroma breed of cattle, breeding base and kinship relations of cows in the breeding farms of the Kostroma region is presented. Domestic Kostroma breed of cattle, possessing valuable economically useful qualities, accounts for 33.5% in the region. The studies were conducted in three breeding farms and two pedigree breeding units in 2023. Breeding and zootechnical records data were used as the research material. The research methods are zootechnical, population-genetic and analytical with the use of computer programs. Milk productivity of cows at outbreeding (unrelated breeding) and at different degrees of kinship at inbreeding was analyzed separately for all breeding plants and pedigree breeding units in the Kostroma region. Out of

1736 cows of the Kostroma breed studied, 918 (52.9%) were obtained by outbreeding, 818 (47.1%) by inbreeding, including distant – 461 (26.5%), moderate – 310 (17.8%), close – 41 (2.4%) and consanguinity – 6 (0.4%). Outbreeding and distant and moderate inbreeding were mostly used in breeding farms. The level of spontaneous inbreeding was 2.8%. Higher milk yields are inherent to outbred cows from all breeding farms of the Kostroma region, fat and protein content in milk - to outbred cows and the animals with different degrees of inbreeding in the conditions of specific farms. The results of the research indicate higher milk productivity of the cows under outbreeding. The obtained data were used for making plans of selection and breeding work with the Kostroma breed of cattle in breeding farms.

Keywords: cattle, Kostroma breed, breeding farms, cows, selection, inbreeding, outbreeding, milk productivity

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Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

In the Russian Federation at the beginning of 2023 the number of cattle amounted to 17 million 488.6 thousand heads. Despite the reduction in the number of livestock, farms of all categories saw a 2% increase in raw milk production compared to 2021, with production reaching 32.98 million tons in 2022.

The main livestock and most of the milk produced are concentrated in large agricultural organizations, where milk yield per cow averaged 7,440 kg, which practically corresponds to the level of countries with highly developed dairy cattle breeding¹.

In recent years there has been a significant change in the relative number of cattle of different breeds. Such changes occurred in the Kostroma region, which is the main supplier of pedigree animals of the Kostroma breed [1–3].

Domestic Kostroma breed of cattle, possessing valuable economically useful qualities, makes up 33,5% in the region [4–9].

Systematic selection and purposeful choice of outstanding animals, evaluation of stud bulls on the quality of offspring and subsequent maximum

use of bulls-improvers played a great role in breeding the Kostroma breed.

Brown Swiss breed bulls of different selection have been used in herds since the 70s of the XX century in order to increase genetic diversity of the breed. As a result, milk productivity of the cows increased, morpho functional properties of udder improved, the share of cows with dairy type of physique increased, genealogical structure of the herds changed. There was an accumulation of the breeding stock with different share of blood on the improving breed. Blood relationship of the Brown Swiss breed stud bulls used in breeding farms is up to 87.5% [2].

Modern dairy management includes the use of optimized indices based on the knowledge of genetics, economics, and the possibilities of modern technologies for safe breeding of animals. Selection of related animals contributes to the improvement of productive and pedigree qualities of cattle of modern intensive breeds. However, there are positive and negative aspects here. Changing the combination of gene forms of the previous selection creates new interrelationships that cause the manifestation of

¹Yearbook on breeding work in dairy cattle breeding in the farms of the Russian Federation (2022) / G.F. Safina, V.V. Chernov, I.M. Dunin, S.E. Tyapugin, et al. Moscow: Publishing house of the FSBSI VNIIPlem, 2023, 255 p.

desirable economically useful qualities. At the same time, lack of control over related mating can negatively affect the level of reproductive performance in herds^{2,3} [11, 12].

The purpose of research is to analyze milk productivity of the Kostroma breed of cows at outbreeding and different degree of inbreeding.

MATERIAL AND METHODS

The research was conducted in three breeding plants (AO "Plemzavod 'Karavaevo', APC 'Kolkhoz 'Rodina' and APC "Gridino") and two pedigree breeding units (OOO "Agrofirma "Planeta" and OOO "Minskoe") of the Kostroma region in 2023. The object of research is cattle of the Kostroma breed. Zootechnical, population-genetic and analytical methods of research were used with the help of computer programs IAS SELEX Multifarm and BON-MilkRegion. The stud bulls degree of inbreeding was determined by the generally accepted method of Pusha-Shaporuzha and the inbreeding coefficient by the formula of Kislovskii

$$Fx = \sum (1/2)^{n+n_1-1} \times (1 + fa) \times 100,$$

where Fx – the coefficient of inbreeding; $1/2$ – the proportion of heredity received by the proband (the individual from whom the pedigree begins) from each ancestor, depending on which row of the pedigree it is in; n – ancestry series in which a common ancestor occurs in the female part of the pedigree; n_1 – ancestry series in which a common ancestor occurs in the male part of the pedigree; fa – the coefficient of inbreeding of the common ancestor, if inbred.

Statistical processing of the materials was performed using Microsoft Excel computer program with calculation of the Student's criterion of reliability. A total of 1736 animals were included in the study.

RESULTS AND DISCUSSION

Traditionally, the Kostroma breed was improved in the dairy direction of productivity first on the basis of purebred breeding, later by crossing with producers of the related Brown Swiss breed of the imported selection. The breeding base of the Kostroma breed of cattle in the Kostroma region includes three breeding farms and two pedigree breeding units. The modern genealogical structure of the breed is represented by factory lines of the stud bulls Ladka 2537, Kurs 3722, Salat 1216, Karo 1494, Barkhat 2336 and related groups obtained on the basis of the use of the Swiss bulls of imported selection Master 106902, Meridian 90827, Hill 76059, Concentrate 106157, Laird 71151, Butler 107206, Oregon 086356 and Laddi 125640.

As a result, the herds have accumulated livestock with different bloodlines of the Brown Swiss breed. The number of the breeding stock of the stud line animals according to the 2022 appraisal amounted to 32.4%, the number of the related groups breeding stock – 67.6%. In the future it is planned to increase the breeding stock of animals of the stud lines.

When working with lines, related groups, as a rule, it is necessary to solve the question of using inbreeding. The biological essence and practical significance of inbreeding are reduced to fixing desirable heredity, increasing homogeneity and hereditary stability (prepotency) of the inbred offspring. However, achieving this goal through inbreeding is often associated with the risk of reducing the viability of the offspring during selection, i.e. with the phenomenon of inbred depression (see footnote 2) [12].

According to I.M. Donnik et al. inbreeding affects milk productivity, milk quality and reproductive ability of cows (see footnote 3).

The figure shows the structure of cows depending on kinship in the breeding farms of the Kostroma region.

²Klimova S.P., Shendakov A.I., Shendakova T.A. Influence of the inbreeding degrees on milk productivity of Black-and-White Holstein cattle. <https://cyberleninka.ru/article/n/vliyanie-stepeney-inbridinga-na-molochnuyu-produktivnostchyorno-pyostrogogolshtinizirovannogo-skota>.

³Donnik I.M., Mymrin V.S., Loretz O.G., Likhodeevskaya O.E., Barashkin M.I. Effect of inbreeding on milk productivity, milk quality and reproductive ability of cows: <https://cyberleninka.ru/article/n/vliyanie-inbridinga-namolochnuyu-produktivnost-kachestvo-moloka-i-sposobnost-nuyu-sposobnost-korov>.

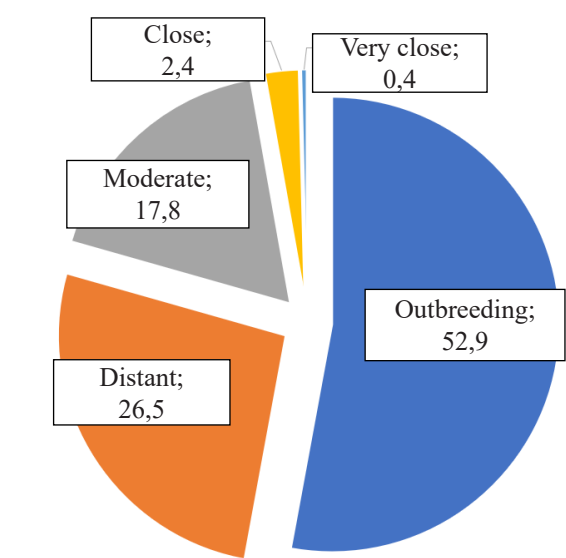
The structure of cow distribution according to the degree of relatedness shows that out of 1736 cows, outbreeding produced 918 cows (52.9%), whereas inbreeding produced 818 cows (47.1%).

The data on the influence of the inbreeding degree on the productivity of the same animals (first-calf cows and cows) on average for the first - third lactation at the stud plants and pedigree breeding units of the Kostroma region are presented in the Tables 1–5.

Information on the level of inbreeding in the herd of the “Karavaevo” stud farm is given in Table 1.

Most of the stock in the herd of the “Karavaevo” stud farm (267 cows (61.8%) out of 462 animals) was obtained by outbreeding, which confirms the fact that the farm carries out a competent selection of bulls for breeding stock. Distant and moderate inbreeding is found in 153 animals (35,4%), close inbreeding and consanguinity – in 12 cows (2,8%).

In the first lactation there are no significant differences between the milk yield of cows depending on the degree of inbreeding. In terms of milk fat content, first-calf heifers with moderate inbreeding showed reliable superiority over the



Структура коров костромской породы по степени инбридинга в племенных хозяйствах Костромской области, %

Structure of the Kostroma breed cows according to the degree of inbreeding in breeding farms of the Kostroma region, %

cows with outbreeding. The fat content in milk of the animals amounted to 4.27%, which is higher by 0.06% ($p \leq 0.05\%$) compared to the cows obtained by outbreeding. The highest pro-

Табл. 1. Уровень инбридинга в стаде племзавода «Караваетово» и влияние на продуктивность коров ($n = 432$)

Table 1. The level of inbreeding in the herd of the "Karavaevo" breeding farm and its influence on cow productivity ($n = 432$)

Degree of inbreeding	Inbreeding coefficient	Number of cows	Productivity for 305 days of lactation			Live weight, kg
			Milk yield, kg	Fat, %	Protein, %	
First lactation						
Outbreeding	0	267	7601 ± 130	4,21 ± 0,01	3,45 ± 0,01	523 ± 1*
Distant	0,1–0,39	85	7312 ± 208	4,24 ± 0,02	3,50 ± 0,02*	518 ± 3
Moderate	0,78–3,125	68	7344 ± 228	4,27 ± 0,03*	3,46 ± 0,02	517 ± 2
Close	6,25–12,5	11	6944 ± 654	4,22 ± 0,03	3,43 ± 0,10	520 ± 3
Consanguinity	25	1	7810	4,33	3,40	508
First - third lactation (on average)						
Outbreeding	0	267	8754 ± 93***	4,21 ± 0,01	3,49 ± 0,01	534 ± 1
Distant	0,1–0,39	85	8008 ± 168	4,23 ± 0,02	3,53 ± 0,02***	531 ± 2
Moderate	0,78–3,125	68	8057 ± 190	4,25 ± 0,02	3,50 ± 0,01	533 ± 2
Close	6,25–12,5	11	8259 ± 372	4,21 ± 0,04	3,45 ± 0,01	531 ± 4
Consanguinity	25	1	7887	4,43	3,43	538

Here and in Tables 2–5:
* $p \leq 0,05$.
** $p \leq 0,01$.
*** $p \leq 0,001$.

tein content in milk was observed in first-calf heifers with distant inbreeding – 3,50%. Compared to first-calf cows obtained by outbreeding, the difference was 0.05% ($p \leq 0.05\%$). At outbreeding the live weight of first-calf cows is the highest. It is 523 kg, or 6 kg more than the same indicator for the first-calf heifers with moderate inbreeding ($p \leq 0,05\%$).

Over a series of lactations, outbred cows had higher milk yields than those with distant inbreeding, by 746 kg ($p \leq 0.001$), and by 697 kg ($p \leq 0.001$) with moderate inbreeding. In terms of fat content in cow milk and live weight, there was no significant difference between the groups; in terms of protein, cows with distant inbreeding had an advantage of 3.53%, which was 0.08% higher than cows with close inbreeding ($p \leq 0,001$).

The milk productivity of cows in the first lactation and on average for a number of lactations in the APC "Rodina" depending on the degree of inbreeding is shown in Table 2.

In this farm, 46.6% of cows were obtained by outbreeding. Outbred cows in the first lactation exceeded the animals obtained by distant inbreeding in milk yield by 337 kg ($p \leq 0.001$), and by 264 kg ($p \leq 0.05$) by moderate inbreeding. First-calf cows with moderate inbreeding

outperformed their counterparts with distant inbreeding in fat content by 0.03% ($p \leq 0.05$), in live weight by 6 kg ($p \leq 0.05$) ($p \leq 0,05$).

In the first to third lactation, outbred cows outperformed their distantly inbred counterparts in average milk yield by 212 kg ($p \leq 0.01$) and protein content by 0.03% ($p \geq 0.05$). Moderately inbred cows outperformed distantly inbred peers in milk fat content by 0.03% ($p \leq 0.01$). Cows with moderate inbreeding on average live weight for a number of lactations exceeded their outbred peers by 8 kg ($p \leq 0.01$), peers with close inbreeding - by 24 kg ($p \leq 0.05$). Due to insufficient sample size, no significant positive or negative effect of close inbreeding and consanguinity on cow performance was found.

The data on the influence of the inbreeding degree on cow productivity in the herd "Gridino" are presented in Table 3.

Out of 381 cows in the stud farm "Gridino", 183 (48.0%) were obtained by mating unrelated individuals, i.e. by outbreeding (see Table 3). Distant inbreeding was detected in 121 cows (31.8%), moderate inbreeding in 64 cows (16.8%), and close inbreeding in 13 cows (3.4%).

When comparing the milk yield of the outbred heifers and those with different degrees of inbreeding, no significant differences were

Табл. 2. Влияние степени инбридинга на продуктивность коров в стаде СПК «Колхоз "Родина"» ($n = 446$)

Table 2. The influence of the degree of inbreeding on the productivity of cows in the herd of the agricultural production complex «Collective farm "Rodina"» ($n = 446$)

Degree of inbreeding	Inbreeding coefficient	Number of cows	Productivity for 305 days of lactation			Live weight, kg
			Milk yield, kg	Fat, %	Protein, %	
First lactation						
Outbreeding	0	208	5528 ± 63***	3,97 ± 0,01	3,22 ± 0,01	500 ± 1
Distant	0,1–0,39	145	5191 ± 57	3,95 ± 0,01	3,20 ± 0,01	497 ± 1
Moderate	0,78–3,125	83	5264 ± 87	3,98 ± 0,01*	3,22 ± 0,01	503 ± 2*
Close	6,25–12,5	5	6129 ± 605	3,96 ± 0,04	3,18 ± 0,05	493 ± 5
Consanguinity	25	5	5396 ± 282	3,97 ± 0,03	3,21 ± 0,03	509 ± 12
First - third lactation (on average)						
Outbreeding	0	208	6025 ± 58**	3,97 ± 0,004	3,23 ± 0,004***	538 ± 2
Distant	0,1–0,39	145	5813 ± 57	3,95 ± 0,005	3,20 ± 0,004	540 ± 2
Moderate	0,78–3,125	83	5914 ± 92	3,98 ± 0,01**	3,22 ± 0,01	546 ± 2**
Close	6,25–12,5	5	6216 ± 372	3,94 ± 0,02	3,19 ± 0,05	522 ± 10
Consanguinity	25	5	5693 ± 454	3,97 ± 0,02	3,20 ± 0,03	532 ± 13

observed. Outbred first-calf cows were significantly superior to peers obtained with moderate inbreeding in terms of fat content by 0.07% ($p \leq 0.01$), protein - by 0.04% ($p \leq 0.01$). In comparison with first calf heifers with other degrees of inbreeding, no significant differences in fat and protein were found.

In terms of average milk yield over a series of lactations, outbred cows outperformed their counterparts with distant inbreeding by 319 kg of milk ($p \leq 0.001$). In terms of the average fat content, outbred cows outperformed distantly inbred cows by 0.06% ($p \leq 0.001$), closely inbred cows by 0.1% ($p \leq 0.001$), and moderately inbred cows by 0.08% ($p \leq 0.001$). Outbred cows were 0.06% ($p \leq 0.001$) higher in milk protein content than closely inbred cows and 0.03% higher than moderately inbred cows ($p \leq 0.05$). The average live weight of outbred cows over a series of lactations was 33 kg ($p \leq 0.001$) higher than that of closely inbred cows, 17 kg ($p \leq 0.001$) higher than that of moderately inbred cows, and 13 kg ($p \leq 0.01$) higher than that of distantly inbred cows.

Milk productivity of cows in the first lactation and on average for a number of lactations in the pedigree breeding unit "Agrofirma 'Planeta'" is shown in Table 4 depending on the degree of inbreeding.

In the pedigree breeding unit "Agrofirma 'Planeta'" the majority of cows (202 (52.2%)) were obtained by unrelated breeding. Distant inbreeding was detected in 99 cows (25.6%), moderate inbreeding in 79 (20.4%), and close inbreeding in 7 animals (1.8%).

Outbred cows showed a milk yield of 6142 kg, fat content of 4.12%, and protein content of 3.31% with a live weight of 527 kg in the first lactation. They were superior to the cows with distant inbreeding by 413 kg of milk ($p \leq 0.001$), moderate inbreeding – by 375 kg ($p \leq 0.01$). There was no significant difference in milk yield between the outbred cows and first calf heifers obtained by close inbreeding. At the same time, productivity at close inbreeding was high: milk yield amounted to 6554 kg of milk, milk fat content – 4.26%, protein – 3.41%. First-calf heifers with close inbreeding exceeded their outbred counterparts in milk fat content by 0.14% ($p \leq 0.05$), and with distant inbreeding by 0.15% ($p \leq 0.05$). There was no significant difference in protein content between outbred first-calf heifers and the animals with different degrees of inbreeding. In terms of live weight, first-calf heifers obtained with moderate inbreeding had higher values of 538 kg ($p \leq 0.05$).

On average for three lactations cows with close inbreeding had higher productivity than

Табл. 3. Влияние степени инбридинга на продуктивность коров в стаде СПК «Гридино» ($n = 381$)
Table 3. The influence of the degree of inbreeding on the productivity of cows in the herd of the "Gridino" agricultural production complex ($n = 381$)

Degree of inbreeding	Inbreeding coefficient	Number of cows	Productivity for 305 days of lactation			Live weight, kg
			Milk yield, kg	Fat, %	Protein, %	
First lactation						
Outbreeding	0	183	5807 ± 68	4,58 ± 0,01**	3,35 ± 0,01**	494 ± 2
Distant	0,1–0,39	121	5798 ± 59	4,54 ± 0,02	3,33 ± 0,02	492 ± 2
Moderate	0,78–3,125	64	5922 ± 123	4,51 ± 0,03	3,31 ± 0,01	490 ± 2
Close	6,25–12,5	13	5848 ± 260	4,55 ± 0,04	3,33 ± 0,03	485 ± 6
First - third lactation (on average)						
Outbreeding	0	183	6241 ± 53***	4,57 ± 0,01***	3,32 ± 0,01***	550 ± 2***
Distant	0,1–0,39	121	5922 ± 48	4,51 ± 0,02	3,31 ± 0,01	537 ± 4
Moderate	0,78–3,125	64	6135 ± 98	4,49 ± 0,02	3,29 ± 0,01	533 ± 4
Close	6,25–12,5	13	5958 ± 181	4,47 ± 0,02	3,26 ± 0,01	517 ± 12

Табл. 4. Влияние степени инбридинга на продуктивность коров в стаде племенного репродуктора «Агрофирма "Планета"» ($n = 387$)**Table 4.** The influence of the degree of inbreeding on the productivity of cows in the breeding herd of the pedigree breeding unit «Agrofirma "Planeta"» ($n = 387$)

Degree of inbreeding	Inbreeding coefficient	Number of cows	Productivity for 305 days of lactation			Live weight, kg
			Milk yield, kg	Fat, %	Protein, %	
First lactation						
Outbreeding	0	202	6142 ± 66***	4,12 ± 0,02	3,31 ± 0,01	527 ± 3
Distant	0,1–0,39	99	5729 ± 102	4,11 ± 0,03	3,29 ± 0,01	536 ± 3
Moderate	0,78–3,125	79	5767 ± 106	4,15 ± 0,03	3,32 ± 0,02	538 ± 4*
Close	6,25–12,5	7	6554 ± 631	4,26 ± 0,06*	3,41 ± 0,14	530 ± 10
First - third lactation (on average)						
Outbreeding	0	202	6403 ± 63**	4,08 ± 0,02	3,33 ± 0,01	586 ± 4
Distant	0,1–0,39	99	6076 ± 93	4,10 ± 0,02	3,32 ± 0,01	590 ± 4
Moderate	0,78–3,125	79	6056 ± 102	4,13 ± 0,03	3,34 ± 0,01	594 ± 3
Close	6,25–12,5	7	7276 ± 335***	4,21 ± 0,01***	3,45 ± 0,12	580 ± 28

outbred cows by 873 kg ($p \leq 0.05$), with distant inbreeding - by 1200 kg ($p \leq 0.001$), moderate inbreeding - by 1220 kg ($p \leq 0.001$). Outbred cows in the first to third lactation outperformed cows with remote inbreeding by 327 kg of milk ($p \leq 0.01$), moderate inbreeding by 347 kg ($p \leq 0.01$). Cows with close inbreeding had the highest fat content (4.21%) and outperformed the outbred cows by 0.13% ($p \leq 0.001$), distant cows by 0.11% ($p \leq 0.001$), and moderate cows by 0.08% ($p \leq 0.05$). There was no significant difference in live weight between cows with outbreeding and cows with different degrees of inbreeding.

In the pedigree breeding unit “Minskoe”, depending on the degree of inbreeding, milk productivity of cows in the first lactation and on average for a number of lactations is shown in Table 5.

In the herd of pedigree breeding unit “Minskoe” 64.4% of cows were obtained by outbreeding. Outbred cows in the first lactation exceeded the cows with distant inbreeding by 945 kg ($p \leq 0.05$). The cows with distant inbreeding outperformed their closely inbred counterparts in milk fat content by 0.32% ($p \leq 0.05$). The cows with distant inbreeding outperformed outbred peers in milk protein content by 0.1% and close inbreeding by 0.18% ($p \leq 0.05$).

In terms of average productivity over a number of lactations, no reliable difference between the indicators was revealed.

CONCLUSION

Out of 1736 studied cows of the Kostroma breed, 918 (52,9%) were obtained by outbreeding, 818 (47,1%) by inbreeding, including distant inbreeding – 461 (26,5%), moderate inbreeding – 310 (17,8%), close inbreeding – 41 (2,4%) and consanguinity – 6 (0,4%). Outbreeding and distant and moderate inbreeding were mainly used in the stud farms. The level of spontaneous inbreeding amounted to 2.8%. Higher cow milk yields are inherent to outbred cows from all the breeding farms of the Kostroma region, fat and protein content in milk – to outbred cows and animals with different degrees of inbreeding in the conditions of specific farms.

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Табл. 5. Влияние степени инбридинга на продуктивность коров в стаде племярепродуктора ООО «Минское» (*n* = 90)

Table 5. The influence of the degree of inbreeding on the productivity of cows in the breeding herd of the pedigree breeding unit ООО "Minskoye" (*n* = 90)

Degree of inbreeding	Inbreeding coef- ficient	Number of cows	Productivity for 305 days of lactation			Live weight, kg
			Milk yield, kg	Fat, %	Protein, %	
First lactation						
Outbreeding	0	58	7015 ± 154*	4,17 ± 0,04	3,35 ± 0,03	526 ± 3
Distant	0,1–0,39	11	6070 ± 393	4,35 ± 0,09*	3,45 ± 0,04*	535 ± 3
Moderate	0,78–3,125	16	6439 ± 383	4,12 ± 0,07	3,36 ± 0,03	537 ± 4*
Close	6,25–12,5	5	5592 ± 902	4,02 ± 0,07	3,27 ± 0,06	529 ± 10
First - third lactation (on average)						
Outbreeding	0	58	7362 ± 113	4,23 ± 0,05	3,36 ± 0,03	586 ± 4
Distant	0,1–0,39	11	7344 ± 304	4,33 ± 0,08	3,38 ± 0,03	591 ± 4
Moderate	0,78–3,125	16	7331 ± 287	4,16 ± 0,05	3,33 ± 0,03	594 ± 3
Close	6,25–12,5	5	6993 ± 214	4,22 ± 0,14	3,38 ± 0,07	581 ± 28

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Сравнительный филогенетический анализ сибирских изолятов пестивирусов крупного рогатого скота

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Приведены результаты сравнительного филогенетического анализа 52 изолятов пестивирусов крупного рогатого скота трех видов, циркулирующих среди высокопродуктивного молочного скота в Сибири, а также присутствующих в образцах коммерческой эмбриональной сыворотки, перевиваемых линиях культур клеток и живых вакцинах по четырем генам: Npro, Erns, E1 и E2. Полученные данные сравнивали с данными сиквенса по гену 5'UTR, полученными ранее. Результаты подтвердили циркуляцию на территории Сибири 11 субтипов BVDV-1 (a, b, c, d, f, g, i, j, k, p, r), трех субтипов BVDV-2 (a, b, c) и одного BVDV-3 (a). Генетические профили изолятов по генам 5'UTR, Npro, Erns и E1 совпали полностью. Исключение составили три изолята BVDV-1a (R/FBS/96, N/MDBK/08 и SA/FBS/08), выявленные в инфицированных культурах клеток, которые сгруппировались в кладу, сформированную референтными последовательностями BVDV-1j. Остальные изоляты, ранее показавшие 100%-ю идентичность последовательностей 5'UTR, имели сходство нуклеотидных последовательностей генов Npro, Erns, E1 и E2 в пределах 96–99%, что также подразумевает их близкое родство. Результаты сиквенса изолятов BVDV-2 показали полное соответствие последовательностей геномов, выявленных в предыдущих исследованиях. Сравнительный сиквенс также подтвердил циркуляцию изолятов пестивируса Н итапо-бразильской группы (BVBD-3a) в Сибири, однако все изоляты разделились на две субклады. К первой отнесли изоляты, выделенные из эмбриональных сывороток и культур клеток, ко второй – выделенные из вакцин и внутренних органов больных животных при вспышках болезни в хозяйствах. Обсуждается вопрос о генетическом многообразии пестивирусов крупного рогатого скота, их происхождении и изменчивости.

Ключевые слова: пестивирусы, виды, субтипы, филогенетический анализ, гены, крупный рогатый скот

Comparative phylogenetic analysis of Siberian isolates of bovine pestiviruses

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The results of comparative phylogenetic analysis of 52 isolates of bovine pestiviruses of three species circulating among highly productive dairy cattle in Siberia, as well as those present in the samples of commercial fetal serum, transfected cell culture lines and live vaccines on four genes: Npro, Erns, E1 and E2 are presented. The obtained data were compared with the results of the 5'UTR gene sequencing obtained earlier. The results confirmed the circulation in Siberia of eleven subtypes of BVDV-1 (a, b, c, d, f, g, i, j, k, p, r), three subtypes of BVDV-2 (a, b, c) and one BVDV-3 (a). The genetic profiles of the isolates for the 5'UTR, Npro, Erns and E1 genes matched completely. The exceptions were three BVDV-1a isolates (R/FBS/96, N/MDBK/08 and SA/FBS/08) detected in infected cell cultures that clustered in a clade formed by BVDV-1j reference sequences. The remaining isolates previously shown to have 100% sequence identity of the 5'UTR had nucleotide sequence similarities of the Npro, Erns, E1, and E2 genes ranging from 96–99%, which also implies that they are closely related. The results of the BVDV-2 isolates sequencing showed a complete correspondence with the genome sequences identified in the previous studies. Comparative sequencing also confirmed the circulation of

H Italian-Brazilian pestivirus isolates (BVBD-3a) in Siberia, but all the isolates were divided into two subclades. The first included the isolates isolated from fetal sera and cell cultures, while the second included those isolated from the vaccines and internal organs of diseased animals during outbreaks in farms. The genetic diversity of bovine pestiviruses, their origin and variability are discussed.

Keywords: pestiviruses, species, subtypes, phylogenetic analysis, genes, cattle

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Conflict of interest

The authors declare no conflict of interest.

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INTRODUCTION

Bovine pestiviruses cause significant economic losses in the dairy cattle industry. Diseases caused by them are widespread all over the world with different prevalence associated with regional peculiarities of cattle breeding strategy¹⁻³. According to the current classification, bovine pestiviruses (*Pestiviruses*) include the prototypic species *Pestivirus A* (bovine viral diarrhea virus type 1; BVDV-1), *Pestivirus B* (bovine viral diarrhea virus type 2; BVDV-2), and *Pestivirus H* (Hobi-like pestivirus; HoBiPeV; bovine viral diarrhea virus type 3; BVDV-3)⁴.

All three viruses are represented by cytopathogenic (Cp) and non-cytopathogenic (NCp) biotypes. Unlike Cp, NCp does not cause visible morphologic destruction of the cell cultures and

represents more than 90% of the virus population⁵. The agents are the causative agents of viral diarrhea – mucous membrane disease (VD-MMD), a widespread and economically damaging infection of cattle⁶ [1].

The number of the known subtypes of BVDV-1 is 22 (a...v), BVDV-2 – 4 (a...d) and BVDV-3 – 4 (a...d) [2, 3]. Their role in the infectious pathology of cattle is not completely clear. The existence of such polymorphism complicates the diagnosis of the diseases caused by pestiviruses and reduces the effectiveness of vaccination and control programs [4].

All pestiviruses have a similar virion structure. Their genome is represented by a 12.3 kbp single-stranded RNA of positive polarity. It has one open reading frame (ORF) ~4,000 codons long, encoding 12 structural and non-structural

¹Chernykh O.Y., Shevchenko A.A., Dzhalidi G.A., Mishchenko V.A., Mishchenko A.V., Shevkopyas V.N. Problems of viral diarrhea of cattle // Proceedings of the Kuban State Agrarian University, 2016, N 58, pp. 194–198.

²Shilova E.N., Ryaposova M.V., Shkuratova I.A., Vyalykh E.V. Viral diarrhea – disease of mucous membranes of cattle in the Ural region // Veterinary medicine, 2014, N 5, pp. 19–21.

³Ridpath J.F. Bovine viral diarrhea virus: global status. *Vet. Clin. North Am // Food Anim.Pract.*, 2010, vol. 26, pp. 105–111.

⁴ICTV. International Committee on Taxonomy of Viruses. Genus: Pestivirus; 2019. Available at: https://talk.ictvonline.org/ictv-reports/ictv_online_report/positive-sense-rna-viruses/w/flaviviridae/361/genus_pestivirus.

⁵Bovine Viral Diarrhea Virus. Diagnosis, Management and Control / edited by S.M. Goyal and J.F. Ridpath. 2005, Blackwell Publishing Ltd., p. 261.

⁶Verkhovskaya A.E., Sergeev V.A., Aliper T.I., Ivanov E.V. Features of diagnosis and prevention of viral diarrhea of cattle // Veterinary medicine, 2009, N (8), pp. 3–7.

tural proteins (Npro-C-Erns-E1- E2-p7-NS2-NS3-NS4A-NS4B-NS5A-NS5B). This site is flanked at the 5'- and 3'-ends by untranslated regions (5'UTR and 3'-UTR). Of all the regions of the viral genome, the 5'UTR is widely used for differentiation and phylogenetic analysis. It is highly conserved and is more often used for virus species identification. For more precise identification of the isolates at the subtype level, it is necessary to use several genes, in particular Npro, Erns, E1 and E2, which play a role in virus replication, its evasion of the immune response of the animal organism and may influence its variability (see footnotes 4, 5).

Data on the distribution and phylogenetic analysis of pestiviruses in Russia are fragmentary.

The purpose of this work is to present a comparative phylogenetic analysis of three pestivirus species circulating among highly productive dairy cattle in Siberia and present in commercial fetal serum samples, transfected cell culture lines and live vaccines for four genes: Npro, Erns, E1 and E2.

MATERIAL AND METHODS

52 isolates of three species of pestiviruses previously characterized by the 5'-UTR gene were used. RNA of the isolates was isolated using a commercial kit “RIBO-prep”, and the reverse transcription was performed using the “REVERTA-L” kit produced by the Central Research Institute of Epidemiology of the Rospotrebnadzor.

For amplification of the Npro, Erns, E1 and E2 gene fragments, the primers presented in the table were used.

The sequencing reaction on both DNA strands was performed using BigDye 3.1 kit (Applied-Biosystems, USA) according to the manufacturer's instructions in a GeneAmp PCR-system 6700 programmable thermostat. The obtained nucleotide sequences were analyzed using the BioEdit 7.0.0 and Laser-gene 7.1.0 software packages. Phylogenetic dendrogram was constructed using the nearest neighbor method in MEGA 11.0 program. The topology of dendrogram branches was confirmed by bootstrap analysis (1000 replication steps). The nucleotide sequences of the synthesized fragments were analyzed by alignment with sequences of other virus strains published in GenBank using the ClustalW⁷ program.

Последовательности праймеров для секвенирования изолятов вируса ВД-БС КРС по генам Npro, Erns, E1, E2
Primer sequences for sequencing bovine BVDV isolates for the Npro, Erns, E1, E2 genes

Gene	Primer	Amplicon size, bp.	Source (see the footnotes)
Npro	TCTCTGCTGTACATGGCACATGCCATCTATRCACACTAAATGTGGT	428	8
Erns	GAGAACATAACACAATGGAATTTG TGCATGAGC-CCCGAACC	681	9
E1	ACAAACATGGTTGGTGCAACTGGT CTTACACAGACATATTTGCC TAGGTTCCA	826	10
E2	GACCTCAGTTGTAAGCCTGAGCCCCCTAGCTCCTTGTTCAGT	1119	11

⁷Thompson J.D., Higgins G.D., Gibson T.J. Clustal W: improving the sensitivity of progressive multiple sequence alignment through sequence weighting, position specific gap penalties and weight matrix choice // Nucleic Acids Res., 1994, vol. 22, pp. 4673–4680.

⁸Vilcek S., Paton D.J., Durkovic B., Strojny L., Ibata G., Moussa A., Loitsch A., Rossmannith W., Vega S., Scicluna M.T., Paifi V. Bovine viral diarrhoea virus genotype 1 can be separated into at least eleven genetic groups // Archives of Virology, 2001, vol. 146 (1), pp. 99–115.

⁹Vijayaraghavan B., Xia H., Harimoorthy R., Liu L., Belák S. Evaluation of envelope glycoprotein E(rns) of an atypical bovine pestivirus as antigen in a microsphere immunoassay for the detection of antibodies against bovine viral diarrhea virus 1 and atypical bovine Pestivirus // J. Virol Methods, 2012, vol. 185 (2), pp. 193–198. DOI: 10.1016/j.jviromet.2012.06.017.

¹⁰Sullivan D.G., Akkina R.K. A nested polymerase chain reaction assay to differentiate Pestiviruses // Virus Res., 1995, vol. 38, pp. 231–239.

¹¹Liu L., Xia H., Wahlberg N., Belák S., Baule C. Phylogeny, classification and evolutionary insights into Pestiviruses // Virology, 2009, vol. 385 (2), pp. 351–357. DOI: 10.1016/j.virol.2008.12.004.

Evolutionary trees were constructed using the minimum evolution method with a bootstrap analysis (1000 repeats)¹². Evolutionary distances were calculated using the Tamura-Nei method¹³ and expressed in units of the number of base substitutions per site. The differences in composition bias among the sequences were accounted for in evolutionary comparisons using the Close-Neighbor-Interchange (CNI) algorithm at search level 1. The evolutionary analysis was performed in the MEGA11 program [5].

RESULTS AND DISCUSSION

In this study, we characterized 52 isolates of bovine pestiviruses using comparative phylogenetic analysis on four genes. The results of previous studies showed that 11 subtypes of BVDV-1 circulate in Siberia among native and imported animals, %: 1a (5), 1b (35), 1c (5), 1d (10), 1f (20), 1g, 1i (2.5 each), 1j, 1k, 1p and 1r (5% each), three BVDV-2 subtypes, %: 2a (25), 2b (10) and 2c (5). Pestivirus H (BVDV-3) is represented by a subtype of the Italian-Brazilian group (3a) [6–9].

BVDV-1. Comparative phylogenetic analysis on Npro, Erns, E1, and E2 genes showed that isolates of this subtype mostly grouped into single clades, except for three BVDV1a isolates (R/FBS/96, N/MDBK/08, and SA/FBS/08) that we identified in infected cell cultures, which grouped into a clade formed by BVDV-1j reference sequences.

Sequence similarity analysis of four genes showed 100% identity of the isolates of the corresponding sub-genotypes: BVDV-1a (N/KCT/06 and N/Vero/10), BVDV-1j (R/FBS/96, N/MDBK/08 and SA/FBS/08), BVDV-1b (T07/09 and K14/08), BVDV-1f (T11/15, K12/15 and O10/15), indicating a high degree of homology. The remaining isolates, which had previously shown 100% sequence identity of the 5'UTR, had nucleotide sequence similarities of the Npro, Erns, E1 and E2 genes ranging

from 96 to 99%, which also implies that they are closely related to each other.

BVDV-2. The results of the sequencing of BVDV-2 isolates showed a complete correspondence with the genome sequences identified in the previous studies.

BVDV-3. According to the E2 gene, BVDV-3a isolates were grouped into two subclades, each of which showed 100% identity in all four genes. The first subclade included the isolates extracted from fetal sera and cell cultures (E15-02, E10-01, A15-101, A15-101-1551, A11-101, A15-102, A15-101-0130) and the second subclade included the isolates extracted from vaccines and animal organs from farm outbreaks (V23/00ZUD, V23/01, V23/02, V23/03). The level of variation between the subclades was within 97%. Sequencing confirmed that virus isolates from both subclades belonged to the BVDV-3a subtype of the Italian-Brazilian group.

The results are presented in Fig. 1–4.

The obtained data confirmed the initial results of genotyping of the virus isolates available at our disposal according to the 5'UTR gene. Thus, 11 subtypes of BVDV-1, three subtypes of BVDV-2, and one subtype of BVDV-3 are circulating in Siberia. Some differences in subtype affiliation were detected during sequencing by the E2 gene, but they were insignificant in percentage terms and concerned only pestivirus A (BVDV-1). It is assumed that this species is the most ancient, genetically divergent, and more often involved in recombination events, as it is classified into several subclades and 22 subtypes. The origin of the virus and the time of introduction to Siberia is currently difficult to establish. Our data are in agreement with the results of the Chinese researchers [10]. With respect to BVDV-2, the results of comparative sequencing coincided for all the genes.

Bovine pestiviruses are rapidly and dynamically evolving agents. It is known that E2 protein

¹²Rzhetsky A., Nei M. A simple method for estimating and testing minimum evolution trees // Molecular Biology and Evolution, 1992, vol. 9, pp. 945–967. DOI: 10.1093/oxfordjournals.molbev.a040771.

¹³Tamura K., Kumar S. Evolutionary distance estimation under heterogeneous substitution pattern among lineages // Molecular Biology and Evolution, 2002, vol. 19, pp. 1727–1736. DOI: 10.1093/oxfordjournals.molbev.a003995.

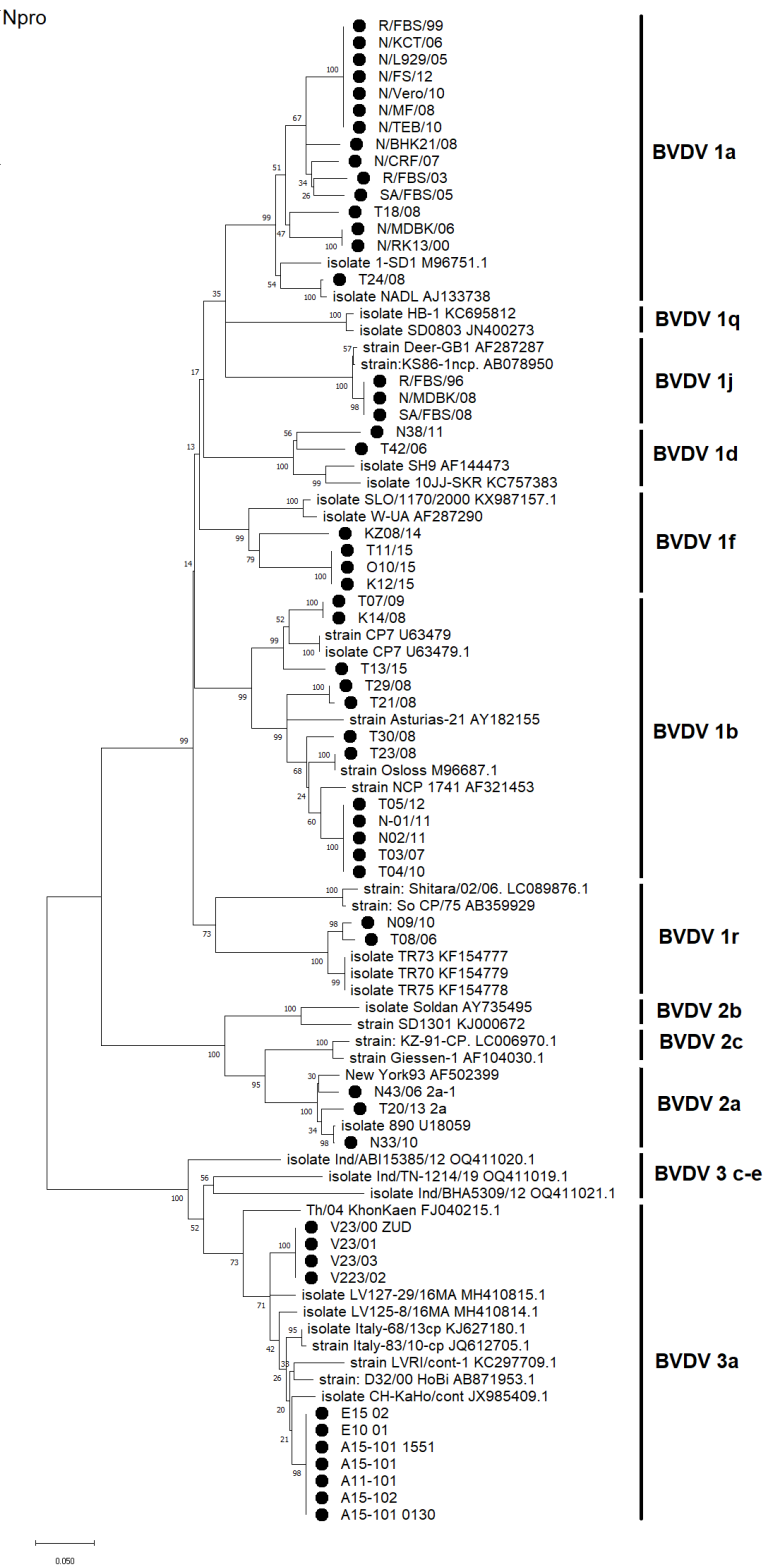


Рис. 1. Филогенетическая дендрограмма, построенная на основе нуклеотидной последовательности области генома Npro пестивирусов крупного рогатого скота; матрица генетических расстояний рассчитана методом максимальной эволюции; указаны индексы статистической поддержки узлов, бутстреп-анализ рассчитан для 1000 реплик

Fig.1. Phylogenetic dendrogram on the basis of the nucleotide sequence of the Npro of bovine pestiviruses genome region; the genetic distance matrix was calculated by the maximum evolution method; indexes of statistical node support are indicated, bootstrap test is calculated for 1000 replicas

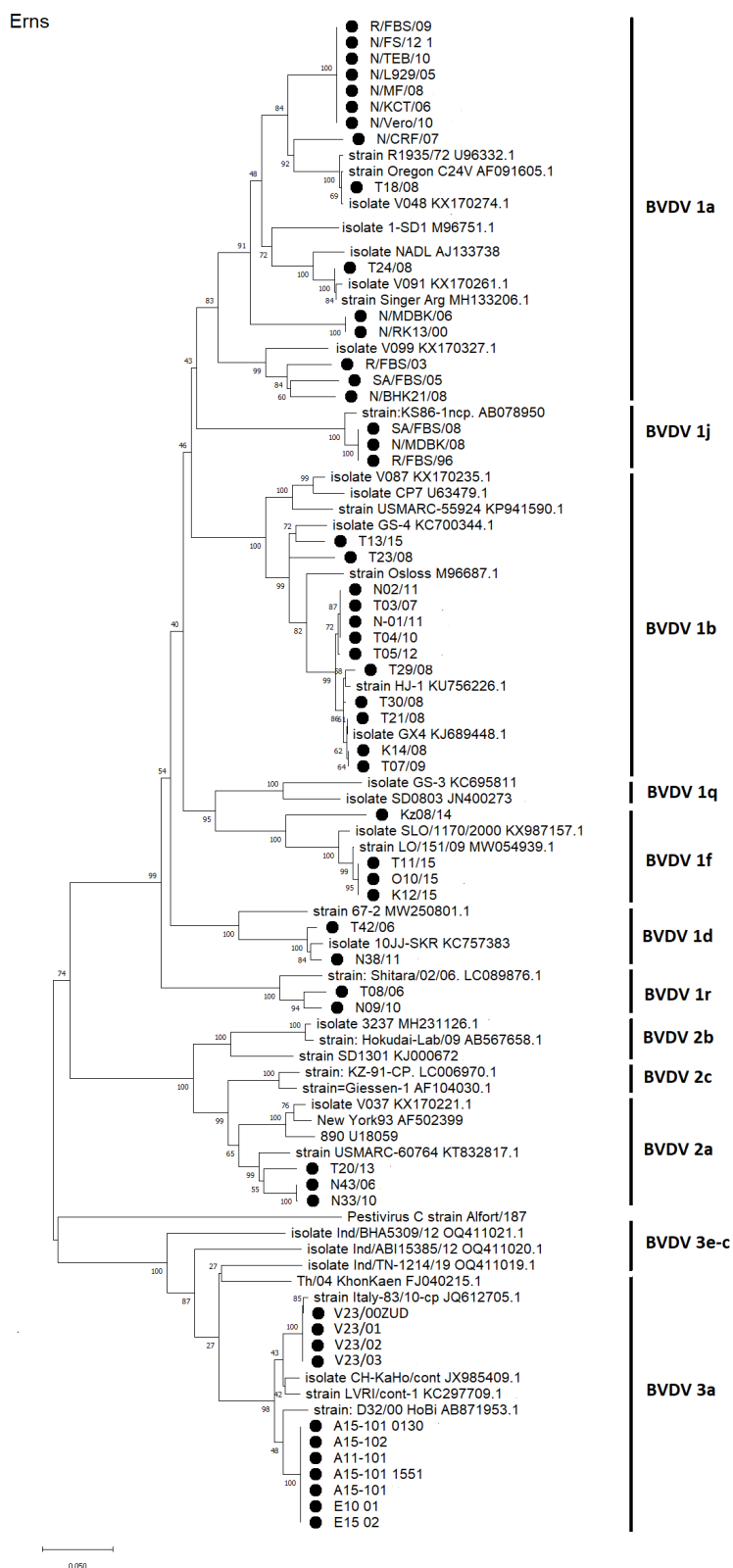


Рис. 2. Филогенетическая дендрограмма, построенная на основе нуклеотидной последовательности области генома Erns пестивирусов крупного рогатого скота; матрица генетических расстояний рассчитана методом максимальной эволюции; указаны индексы статистической поддержки узлов, бутстреп-анализ рассчитан для 1000 реплик

Fig. 2. Phylogenetic dendrogram on the basis of the nucleotide sequence of the Erns of bovine pestiviruses genome region; the genetic distance matrix was calculated by the maximum evolution method; indexes of statistical node support are indicated, bootstrap test is calculated for 1000 replicas

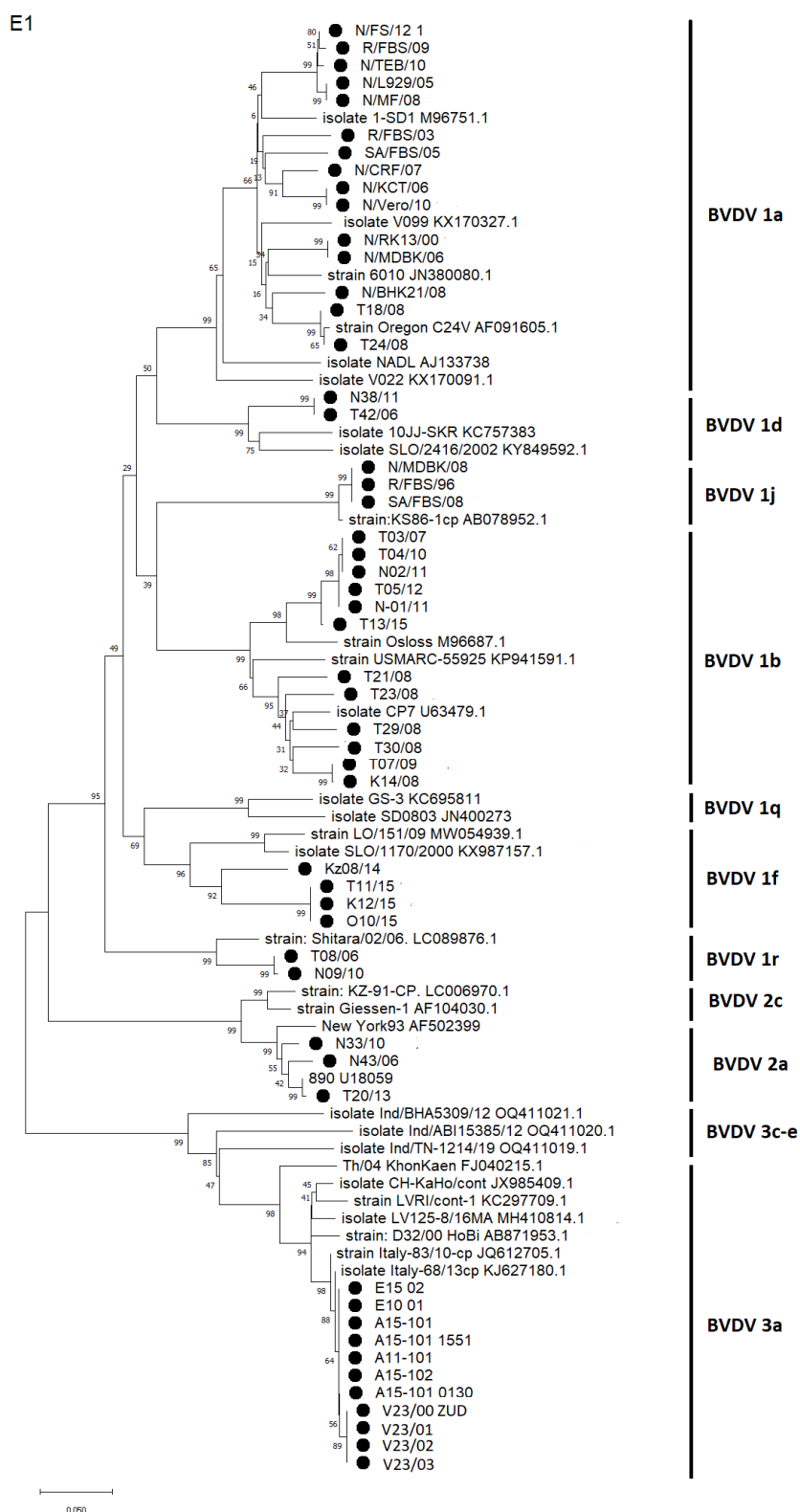


Рис. 3. Филогенетическая дендрограмма, построенная на основе нуклеотидной последовательности области генома E1 пестивирусов крупного рогатого скота; матрица генетических расстояний рассчитана методом максимальной эволюции; указаны индексы статистической поддержки узлов, бутстреп анализ рассчитан для 1000 реплик

Fig.3. Phylogenetic dendrogram on the basis of the nucleotide sequence of the E1 of bovine pestiviruses genome region; the genetic distance matrix was calculated by the maximum evolution method; indexes of statistical node support are indicated, bootstrap test is calculated for 1000 replicas

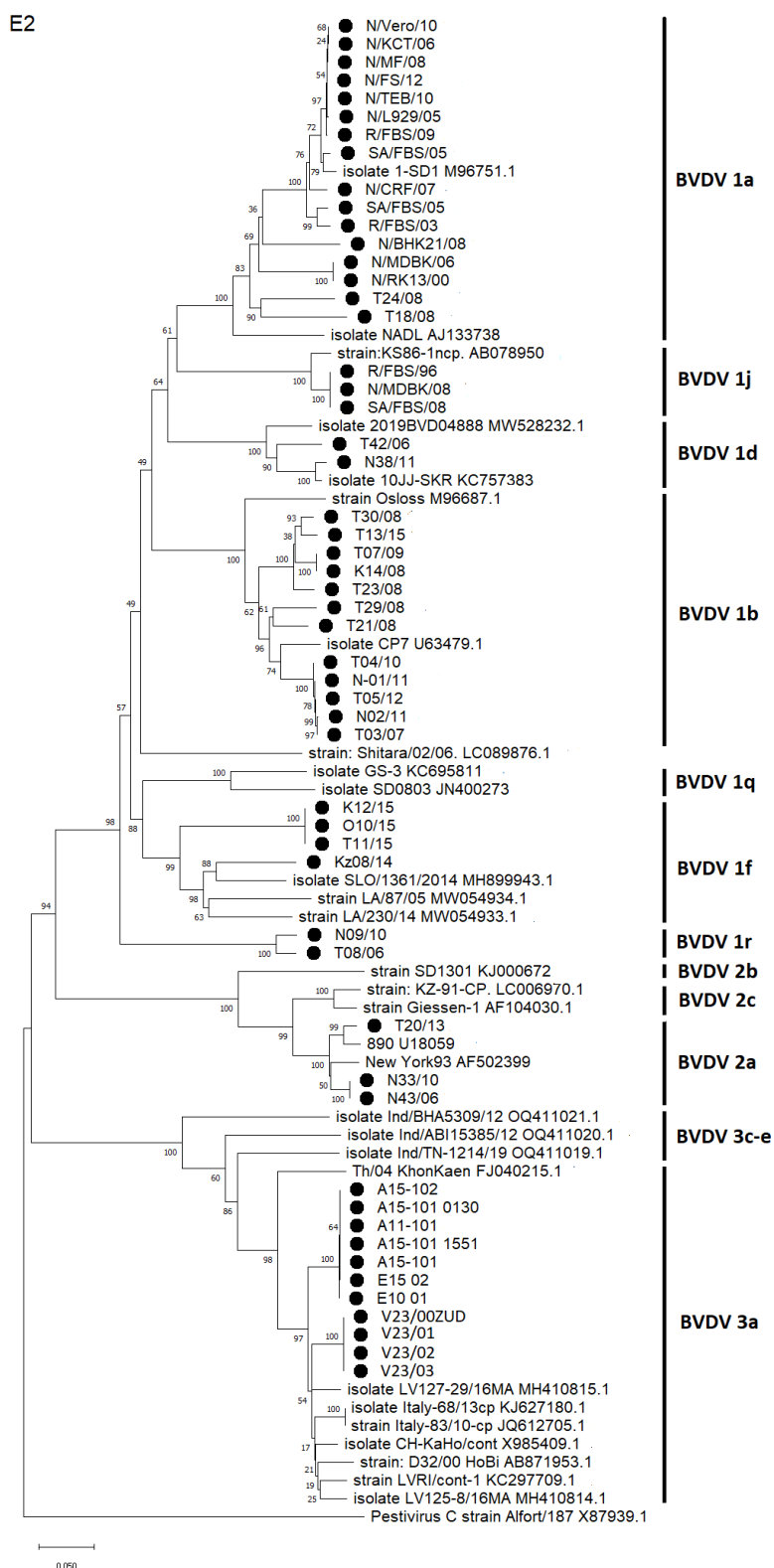


Рис. 4. Филогенетическая дендрограмма, построенная на основе нуклеотидной последовательности области генома E2 пестивирусов крупного рогатого скота; матрица генетических расстояний рассчитана методом максимальной эволюции; указаны индексы статистической поддержки узлов, бутстреп-тест рассчитан для 1000 реплик

Fig. 4. Phylogenetic dendrogram on the basis of the nucleotide sequence of the E2 of bovine pestiviruses genome region; the genetic distance matrix was calculated by the maximum evolution method; indexes of statistical node support are indicated, bootstrap test is calculated for 1000 replicas

is an immunodominant structural protein and contains neutralizing epitopes. The pronounced antigenic variability of this protein accounts for the poor efficacy of vaccines. The mutation rate of the E2 gene of BVDV-1 is higher than that of E2 BVDV-2. Since E2 is the main target for neutralizing antibodies, it probably evolves at a higher rate than the rest of the virus genome [11–13].

BVDV-1a, -1c, and -1i subtypes are thought to share a common ancestor, and BVDV-2a gave rise to -2c. BVDV-1a, -1b, and -1e are considered the oldest and most geographically widespread BVDV-1 subtypes, while -1h, -1k, and -1m are new and less widespread [14, 15].

Changes in the genome of pestiviruses are the result of three processes leading to the formation of divergent but closely related mutants (subtypes): accumulation of point mutations as a result of RNA-dependent RNA polymerase errors, non-homologous RNA recombination, and recombination of homologous RNA.

The frequency of mutations is similar to that of other RNA-containing viruses; one point mutation is thought to be introduced into the pestivirus genome per replication cycle (see footnote 7). The average evolutionary rate of Italian strains for the 5'-UTR region is assumed to be 9.3×10^{-3} substitutions/site/year with a confidence interval between 4.8 and 14.7 substitutions/103 nucleotides [16]. The substitution rate of the E1–E2 region is about 10 times higher than that of the 5'UTR.

Western Canadian isolates of BVDV-1a are assumed to have originated in the early 20th century, isolates of BVDV-2 in the 1990s of the 20th century. The average substitution rate of 1.4×10^{-3} substitutions/site/year was similar for BVDV-1 and for BVDV-2. The rate of evolution in the E2 gene was slightly higher than in other regions of the virus genome. Therefore, continuous monitoring of the emerging variants of bovine pestiviruses is necessary [17].

Comparative sequencing also confirmed the circulation of pestivirus isolates of the Italian-Brazilian group (BVBD-3a), but all isolates were divided into two subclades. The first one

included the isolates extracted from fetal sera and cell cultures, and the second one – isolated from vaccines and internal organs of infected animals during outbreaks on farms. Research in this direction should be continued. It is possible that this virus species is also subject to significant mutations based on the E2 protein and other proteins.

The origin and evolution of HoBiPeV have not been fully elucidated. Indian researchers hypothesize the existence and independent evolution of four clades of the virus worldwide with genetic divergence ranging from 13.0 to 18.2%. The authors suggest that the virus originated in India around 1938. Its evolutionary rate is estimated to be 2.133×10^{-3} subsites/year at the level of the complete genome, but varies greatly among the individual genes. The largest number of mutations was detected in the gene of the E2 protein [18].

CONCLUSION

Bovine pestiviruses are rapidly and dynamically evolving agents. Their genetic polymorphism complicates disease diagnosis, reduces the effectiveness of vaccination and control programs. There are also no data on the level of cross-protection between the virus subtypes. Phylogenetic studies are of great practical importance to identify epizootologic, immunologic and evolutionary processes affecting the genetic variability of the viruses. In the future, studies on the phylodynamics of pestiviruses may be of great importance in the study of genetic diversity and variability.

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Виды стрессов и методы снижения стрессовой нагрузки у крупного рогатого скота

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В последнее время значительной проблемой современного животноводства стал стресс животных. По мере индустриализации сельского хозяйства эта проблема все больше обостряется, в результате которой животноводческие предприятия и фермы несут ощутимые экономические потери. На протяжении всей жизни животное подвергается многочисленным стрессорам, имеющим совершенно разную природу возникновения, но неизменно ведущей к одним и тем же изменениям в организме. Животное заметно теряет в массе, слабеет, у него понижается сопротивляемость к заболеваниям. Дан обзор научных источников по некоторым видам стрессовой нагрузки на крупный рогатый скот: тепловому стрессу, стрессу при транспортировке, предубойному. По данным многих исследований, стрессовое состояние животного на 70–80% зависит от кормления и содержания и лишь на 20–30% – от генетики. На организм сельскохозяйственных животных постоянно воздействуют разнообразные факторы внешней среды. К их числу относятся технология производства, способ содержания, плотность размещения, величина групп, микроклимат помещений, тип и уровень кормления, биологическая полноценность рационов, способы подготовки и раздачи кормов, качество питьевой воды, ветеринарно-профилактические и зоотехнические мероприятия (вакцинация, санитарная обработка животных, взвешивание, кастрация и др.). При изменении указанных факторов в организме животных происходят определенные реакции. Природа стресса может быть различной: механической, физической, химической, биологической и психической. Знание причин стресса, закономерностей его течения и последствий, изложенных в указанных научных источниках, позволит рационально использовать предлагаемые способы уменьшения неблагоприятного влияния различных стресс-факторов на животных для сохранения их здоровья и высокой продуктивности.

Ключевые слова: крупный рогатый скот, стресс, стресс-факторы, тепловой стресс, предубойный стресс

Types of stress and methods of stress reduction in cattle

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Recently, stress has become the most urgent problem of modern animal husbandry. With the industrialization of agriculture, this problem is becoming more and more acute, as a result, livestock enterprises and farms suffer significant economic losses. Throughout its life, the animal is exposed to numerous stressors that have a completely different nature of occurrence, but invariably lead to the same changes in the body. The animal noticeably loses weight, weakens, its resistance to diseases decreases. A review of scientific sources on some types of stress loading on cattle: heat stress, transportation stress, pre-slaughter stress is given. According to many studies, the stress state of an animal depends on feeding and maintenance by 70-80% and only 20-30% on genetics. The body of farm animals is constantly affected by various environmental factors. These include production technology, method of maintenance, density of accommodation, size of groups, microclimate of premises, type and level of feeding, biological full-value of diets, methods of preparation and distribution of feed, quality of drinking water, veterinary and preventive and zootechnical measures (vaccination, sanitary treatment of animals, weighing, castration, etc.). When the above factors change, certain reactions occur in the

animal body. The nature of stress can be different: mechanical, physical, chemical, biological, mental. Knowledge of the causes of stress, the patterns of its course, its consequences, outlined in the mentioned scientific sources, will allow rational use of the proposed ways to reduce the adverse effects of various stress factors on animals to preserve their health and high productivity.

Keywords: cattle, stress, stress factors, heat stress, pre-slaughter stress

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The most important problem in animal breeding with the introduction of technological elements that limit the possibility of taking into account the individual characteristics of animals is the problem of adaptation of an organism to new conditions.

The nature and physiological properties of an animal, formed over many centuries, are not able to change with the same speed as environmental conditions and technology of animal husbandry. In this regard, there is a discrepancy between the biological nature of an organism, its physiological capabilities and the environment, i.e. the state of stress. For the first time this concept was introduced by the Canadian scientist Hans Selye in 1936. Under stress he understood the state in which the organism was under the influence of various environmental stimuli. He called the environmental factors capable of causing homogeneous response reactions of the organism the stressors [1].

Recently, stress has been more often defined as a set of general stereotypical responses of the

organism to the action of strong stimuli of different nature, and its clinical manifestation in the organism as a general adaptation syndrome. Consequently, stress by its nature is a specific syndrome, and by its origin it is nonspecific. Nonspecificity of stress formation is determined by the fact that it occurs under the influence of various stimuli on the organism – mechanical, chemical, biological and mental stimuli [2].

Stress reactions of an animal organism can cause both negative and positive consequences. Everything is determined by the nature, species, purpose of the animal and physiological state of an animal [3].

Stress is the natural reaction of an organism to the impact of any sharp environmental stimulus.

The purpose of the study is to investigate the main types of stress during cattle breeding and their influence on the current processes in the body for their further correction.

Heat stress. This stress is associated with a significant economic burden for livestock pro-

ducers worldwide [4]. If modeling projections are accurate, climate change is likely to have a significant impact on the stability and sustainability of livestock production enterprises worldwide. One of the projected impacts of climate change is an increase in the prevalence and intensity of heat stress periods [5]. Climate trends change each year, and prediction models suggest that there will continue to be significant variability in the climatic behavior of heat stresses in the future¹.

Heat stress occurs when an animal cannot maintain a balance between heat accumulation and dissipation [6]. Climatic factors affecting heat accumulation in dairy cattle include ambient temperature, relative humidity, solar radiation and wind velocity². The impact of heat stress on dairy cattle is also influenced by the genotype, health and immune status of an individual animal [7]. It is well known that heat stress reduces dry matter intake of cattle, which has a negative effect on nutrient absorption in general, affecting the immune system and inflammatory response of the body [8]. The results of heat stress exposure vary from animal discomfort to lethality in some cases [9].

During periods of heat stress, the hypothalamic-pituitary-adrenal system is activated to maintain homeostasis in response to stress stimuli [10]. Cortisol production during the periods of acute stress acts as a stimulus to the immune system, but during chronic stress, cortisol secretion is associated with immune suppression [11]. Consequently, suppression of the immune system results in an animal becoming more susceptible to disease and immune problems. Of the two immune responses (innate and adaptive), the adaptive response is more complex and requires prolonged immunologic exposure to become functionally active.

Although the innate and adaptive immune response are distinct, they interact to protect the body from pathogens and/or foreign substances. The adaptive immune system can be divided into cell-mediated and humoral immunity. T-lymphocytes are actively involved in cell-mediated immunity, whereas B-lymphocytes play a vital role in humoral immunity. Both types of immunity maintain a balance, ensuring that immune function remains effective. This balance can be suppressed during exposure to stressors³.

Lactating dairy cows have increased sensitivity to heat stress compared to dry cows due to increased metabolic milk production [12]. Moreover, due to the positive relationship between the amount of milk produced and heat production, higher yielding cows are more susceptible to heat stress than low yielding animals [13].

When an animal experiences heat stress, the immediate coping mechanism is a decrease in dry matter intake, which leads to a decrease in the availability of the nutrients used for milk synthesis [14]. Simultaneously, there is an increase in basal metabolism due to activation of the thermoregulatory system. Heat stress can increase the need for metabolic maintenance by 7–25% [15], which further aggravates both the existing metabolic stress and the decrease in the amount of milk produced.

Decreased milk yield has been used in some studies as an indicator of decreased welfare in the animals that are already suffering from various diseases such as mastitis [16]. It has also been demonstrated that milk yields instantly decrease when animals are stressed [17]. As a result, it is often assumed that milk production can be interpreted as a direct indicator of animal welfare because it gives producers the opportunity to monitor their individual response to a particular event (e.g., an increase in ambient

¹Hansen P.J. Physiological and cellular adaptations of zebu cattle to thermal stress // *Anim Reprod Sci.*, 2004, vol. 82, 83, pp. 349–60. DOI: 10.1016/j.anireprosci.2004.04.011.

²Li Q.L., Ju Z.H., Huang J.M., Li J.B., Li R.L., Hou M.H., Wang C.F., Zhong J.F. Two novel SNPs in HSF1 gene are associated with thermal tolerance traits in Chinese Holstein cattle. *DNA Cell Biol.* vol. 30 (4), pp. 247–54. DOI: 10.1089/dna.2010.1133.

³Roman-Ponce H., Thatcher W.W., Wilcox C.J. Hormonal interrelationships and physiological responses of lactating dairy cows to a shade management system in a subtropical environment // *Theriogenology*, 1981, vol. 16 (2), pp. 139–154. DOI: 10.1016/0093-691x(81)90097-2.

temperature or a change in nutrition). However, other researchers have questioned the use of milk production as an acceptable indicator of animal welfare [18], especially for heat stressed cows, because of the interfering effects of decreased dry matter intake and the delayed decline in the amount of milk produced due to increased ambient temperature.

After periods of high ambient temperatures, a delay is usually observed before milk production decreases. A delay of 24 to 48 h has been reported between an increase in ambient temperature and a decrease in milk production [19]. Further evidence has shown that milk production only begins to decline when the temperature and humidity index has been consistently above 74 for the previous four days [20]. Obviously, if changes in milk production are only detected within a few days of heat stress, this indicator is limited in that it only indicates that the animal was under heat stress and may have been in poor health, but given the elapsed time this is at best an indirect result [21].

Despite documented problems with using milk production as an indicator of lactating dairy cow welfare, recent evidence suggests that changes in milk composition may be more useful for assessing cows under immediate heat stress [22]. Follow-up studies are needed to determine whether on-farm cow tests that monitor significant changes in milk composition in response to heat stress can be practically implemented on cows.

The addition of organic selenium to cattle rations can protect animals from oxidative stress and increase milk yields, especially when cattle are exposed to heat stress. This conclusion was reached by scientists from the USA, China and Spain in a joint study [23]. The researchers found that organic selenium supplementation increased selenium content in serum and milk, and increased markers of antioxidant activity and performance. At the same time, selenium supplementation decreased the percentage of milk fat in milk.

Many researchers have studied heat reduction strategies over the past 40 years. Most of

them have focused on cooling cows under confinement conditions. Cattle kept on pasture often cannot protect themselves from climatic conditions such as heat, rain, wind or snow [24]. Various management practices focus on reducing the negative effects of heat stress on lactating dairy cows, including genetic selection for more heat-tolerant animals, nutritional management, and environmental modification or cow cooling strategies [25]. Changing external factors is generally a simpler and faster way to improve animal condition, performance and reproduction than improving genetic selection for heat tolerance [26].

Implementing an appropriate cow cooling strategy is an important management decision for dairy producers and can reduce economic losses associated with heat stress. Cow cooling strategies used in confinement settings include fans, shade, natural ventilation and water-cooling systems (sprayers, sprinklers) [27]. For cattle in pasture, natural shade from trees, permanent or portable shade structures, or spray nozzle lines with spray nozzles that produce fog can be created and used as cooling [28]. The application and economic impact of cow cooling strategies on pasture-based dairy farms needs to be investigated to better understand the importance of implementing temperature reduction for grazing cattle.

Transportation stress. Transporting animals can lead to increased disease and animal deterioration. Transported animals may suffer tissue damage and body malfunctions. In addition, pathological effects may occur that would not have resulted from pathogens already present, disease from pathogens transmitted from one transported animal to another, and disease in non-transported animals due to transmission of the pathogens from the transported animals.

Increased susceptibility to infection and disease as a result of transportation has been the subject of numerous studies [29]. Transported cattle, especially those transported over long distances, have significant body condition problems. As a consequence, there are economic losses caused by “road fever”. This term is used

to describe a number of diseases caused by *Pasteurella* species, bovine respiratory syncytial virus, infectious rhinotracheitis virus and para-influenza-3 virus. Stress can cause reactivation of viruses that are present in animals after a previous infection.

Many infectious diseases can be spread by the transportation of animals, such as outbreaks of classical swine fever. Foot-and-mouth disease can be exacerbated by the fact that animals in some cases transmit the disease at collection points or places of trade [30]. Large disease outbreaks cause economic problems. If stress is minimized, as is the mixing of animals and their products, diseases can be prevented or made less likely to occur.

The way the vehicle is driven can have a major impact on the welfare of the animals being transported. The driver needs to drive carefully, as animals are much less able to cope with disturbances such as those caused by turning or sudden braking. Cattle, sheep and horses always try to stand in the vehicle in such a way as to minimize the likelihood of being thrown around and avoid contact with other animals. In a study of cattle transported on winding or straight roads, plasma cortisol concentrations were found to be significantly higher on winding roads than on straight roads [31].

Animals may be injured during transport and appropriate measures should be taken to eliminate or minimize such injuries. On all but the shortest journeys, it is important that there is adequate opportunity for intermediate inspection of animals [32].

Actual physical conditions, such as temperature and humidity, may change during transportation and require action by the person responsible for the animals. Prolonged transportation involves a much higher risk of animal deterioration and can lead to significant problems. Consequently, the condition of the animals should be carefully monitored at appropriate intervals [33].

Pre-slaughter stress. Animal welfare monitoring in a slaughterhouse is somewhat different from the situation on the farm. Throughput in

slaughterhouses can be very high. There is no way to know the individual history, background or habits of each animal. Animals are unfamiliar to the staff and vice versa. Moreover, most animals are unknown to each other, even if they are delivered in groups or batches, so it is not uncommon to see mixing. The environment in slaughterhouses is also completely unfamiliar to the animals, as large areas are not always designed to minimize noise or visual distraction to the animals. Mistreatment of animals can be seen in many slaughterhouses where animals are roughly coerced using sticks, physical force and shouting, forcing them to move quickly in a desired direction. It is important to be aware of these factors, as they can cause animals to become overexcited, causing them to become restless, agitated and stressed.

Handling of livestock in slaughterhouses should be as short, well thought out and structured as possible to allow animals to move freely in the right direction according to their behavioral characteristics and not to be distracted. In addition, any elements of disturbance such as flashing lights, changing lighting conditions, moving objects (e.g. fan blades) should be eliminated. The slaughterhouse floor should be arranged and maintained to minimize the risk of animals slipping, falling, or injuring limbs. If these criteria are not met, the slaughter line may be slowed down. All of this may also cause inappropriate attitudes among the personnel responsible for handling animals. In such situations, operators will routinely use animal stimulation tools (electric cattle prod or sticks). The heart rate of the cattle will increase with each subsequent application of physical stimulation to them [34]. Carcass injuries (bruises, petechial hemorrhages, etc.) may occur on carcasses due to excessive use of electric cattle prods, as well as due to frequent falls, slips and injuries on corridor partitions, especially if the animal does not have enough room to move. Refusal to move in cattle could also be due to inadequate training of staff or poor supervision [35]. Incorrect behavior of the staff and their lack of knowledge of ethology leads to poor human-animal interactions. Employees'

knowledge of the ethology allows the animal to move physiologically without physical force on them, which is a strong stressor [36].

Minimizing pre-slaughter stress is to introduce cattle into the stunning box only when the operator is ready to perform it. Proper lighting of the box is essential. Visibility of already slaughtered animals should be avoided: the use of partitions between the stunning box and the paddock helps in this case. The possibility of animals escaping from the stunning box must be avoided by adapting the height of the box walls to the size of the animal. [37].

CONCLUSION

The most important stress-factor affecting the organism of animals is the impact of the external environment. Throughout its life, an animal is subjected to numerous stressors that have completely different nature of occurrence, but invariably lead to the same changes in the body. An animal exposed to negative stress noticeably loses weight, weakens, and loses resistance to disease. As a consequence, livestock enterprises and farms suffer significant economic losses.

With increasing industrialization of production, animals begin to be subjected to stressors, previously unknown and unstudied. In this regard, livestock breeders of all countries are constantly facing the tasks of improving the feed, raw materials, climatic base, as well as reducing the stress load negatively affecting the animal organism [38].

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Посуточный мониторинг биопотенциала проростков пшеницы как средство повышения качества оценки стрессоустойчивости растений

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Представлены результаты изучения процесса изменения биопотенциала проростков пшеницы сорта Новосибирская 41 при воздействии на них повышенной (43 °C) и пониженной (8 °C) температуры. Эксперименты проходили в 2020 и 2022 гг. При проведении исследований использована автоматизированная система «АвтоЭкспИ». Получены данные о динамике биопотенциала растений, возникающего в результате идентичных температурных изменений окружающей среды при изменении возраста проростков. Полученные в 2020 и 2022 гг. среднестатистические абсолютные максимальные центрированные значения ($U_{\max \text{ ц}}$) биопотенциала проростков в возрасте от 10 до 19 сут при действии на них повышенной и пониженной температуры были подвергнуты статистическому анализу с использованием ПО «Статистика 6» (Statistica 6). Регрессионные зависимости, определенные в ходе регрессионного анализа показателей биопотенциала при действии повышенной температуры, описываются относительно возраста проростков полиномами второго порядка с коэффициентом корреляции $R = 0,997$ при $p = 0,072$ для результатов экспериментальных исследований 2020 г. и $R = 0,986$ при $p = 0,028$ для данных за 2022 г. При действии пониженной температуры также получены квадратичные регрессионные зависимости с коэффициентом корреляции $R = 0,995$ при $p = 0,1023$ для результатов экспериментальных исследований 2020 г. и $R = 0,9998$ при $p = 0,00023$ для данных за 2022 г. Отмечена близость графического отображения аналогичных регрессионных зависимостей, на основании чего определен алгоритм и получены выражения для коррекции экспериментальных данных, полученных в процессе продолжительных экспериментальных исследований.

Ключевые слова: биопотенциал, пшеница, стрессоры, температура, мониторинг, возраст растений

Daily monitoring of the biopotential of wheat seedlings as a means of increasing the assessment of plant stress resistance

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The results of studying the process of changing the biopotential of wheat seedlings of the Novosibirskaya 41 variety when exposed to elevated (43 °C) and reduced (8 °C) temperatures are presented. The experiments took place in 2020 and 2022. The automated system "AutoExpI" was used in the

research. The data on the dynamics of plant biopotential resulting from identical temperature changes in the environment when the age of seedlings changes were obtained. The mean absolute maximum centered values ($U_{\max c}$) of the biopotential of seedlings aged 10 to 19 days when exposed to elevated and reduced temperatures in 2020 and 2022 were statistically analyzed using Statistica 6 software (Statistica 6). The regression relationships determined during the regression analysis of the biopotential indices under the action of elevated temperature are described with respect to the age of seedlings by second-order polynomials with correlation coefficient $R = 0.997$ at $p = 0.072$ for the results of the experimental studies in 2020 and $R = 0.986$ at $p = 0.028$ for the data for 2022. For the effect of reduced temperature, quadratic regression relationships were also obtained with a correlation coefficient of $R = 0.995$ at $p = 0.1023$ for the 2020 experimental results and $R = 0.9998$ at $p = 0.00023$ for the 2022 data. The closeness of the graphical representation of similar regression dependencies was noted, on the basis of which the algorithm was determined and expressions for correction of experimental data obtained in the process of prolonged experimental studies were obtained.

Keywords: biopotential, wheat, stressors, temperature, monitoring, plant age

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Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Numerous scientific studies have proved that bioelectrical signals are an integral part of living biological tissue of animal and plant origin^{1, 2}. These signals are manifested in the process of metabolism during the whole vegetation period, arise in different parts of plants at one or another change of the environment [1].

The history of discovery and subsequent studies of electrical signals arising in plants under biotic and adiabatic stresses (environmental changes) are described in detail in the works [2–4]. It was found that these signals arise under the changes in temperature, humidity, illumination, and other environmental parameters, the level of which exceeds the threshold of plant sensitivity [5, 6]. Thus, biopotential is generated in

flower pistils during pollination when stigmas move or are touched by insects (bees)³.

Naturally, the biopotential included in the process of plant metabolism should correspond to the age of the plant, starting from its seedling [7, 8]. In this regard, the biopotential arising from exposure of the seedlings of different ages will be formed under the conditions of the functional changes in plant life activity and will differ⁴ [3, 9, 10]. Consequently, it can be assumed that during the experiment with seedlings, the value of biopotential of one and the same seedling measured on different days will differ [11]. As a result, when conducting statistical analysis of experimental data on the biopotential of seedlings from the same batch, but of different ages, there will be a priori an additional error,

¹Burdon-Sanderson L. Note on the electrical phenomena which accompany irritation of the leaf of *Dionaea muscipula* // Proceeding of the Royal Society of London, 1875, vol. 21, pp. 495–496.

²Opritov V.A., Pyatygin S.S., Retivin V.G. Bioelectrogenesis in higher plants. Moscow: Nauka, 1991, 216 p.

³Sinyukhin A.M., Britikov E.A. Generation of action potentials in pistils of *Incarvillea* and lily in connection with stigma movement and pollination // Russian Journal of Plant Physiology, 1967, N 14, pp. 463–475.

⁴Surova L.M. Influence of variation potential on the stability of photosynthetic apparatus of pea (*Pisum sativum* L.): Candidate's thesis in Biology. N. Novgorod, 2017, 111 p.

which can seriously affect the result of cluster analysis when assessing varietal differences.

In this regard, when conducting experimental studies, there is a need to assess the influence of plant age (in particular, wheat seedlings) on the level of measured biopotential, as well as to identify the possibilities of harmonizing the obtained results to a unified measurement system.

MATERIAL AND METHODS

Assessment of the effect of the age of seedlings on their biopotential under the influence of temperature was carried out on wheat seedlings of the Novosibirskaya 41 variety at the age of 10–19 days twice – in 2020 and 2022. In the course of the experiment an automated system “AutoExpl”⁵ developed for the study of biological structures in the Siberian Institute of Physics and Technology of Agrarian Problems and additionally equipped with a device for the formation of temperature profile (DFTP)⁶ was used. The DFTP was based on a Peltier element and allowed to form different temperature profiles affecting plants in laboratory conditions.

The studies were conducted on ten wheat seedlings, which were grown and kept in the climatocamera “Biotron 8” in laboratory conditions. Starting from 10 days of age each plant was exposed to elevated (43 °C) and reduced (8 °C) temperature 5 times during 10 days.

The experiment was carried out in the following order. The plant was placed on a laboratory DFTP thermostat so that its roots were in a cuvette with tap water and the shoot was on the surface of the stage (see Fig. 1). Part of the stage is a copper plate covered with thermally conductive insulating material, in the zone where the plant is exposed to temperature (see footnote 5). Formation of the temperature profile acting on the plant under the study was

realized by a Peltier element connected to this plate by the DFTP control system included in the “AutoExpl”. The laboratory table with the experimental plant was placed in a climatic chamber, the air temperature in which was set within 20 ± 1 °C. The same temperature (background temperature) was set in the zone of the temperature influence of the laboratory table. The plant on the laboratory table was covered with a special shield for thermal insulation of the place of the temperature influence. The unipolar method of the AP withdrawal was used according to the nature of the electrode arrangement, in which nonpolarizing electrodes were placed as follows: one (measuring electrode) – on the surface of the seedling shoot, the second (reference electrode) – in the root area. The place of contact between the electrode and the plant was smeared with conductive gel or wetted with tap water to improve the contact.

After preparing the plant for the experiment, the automated system “AutoExpl” was switched

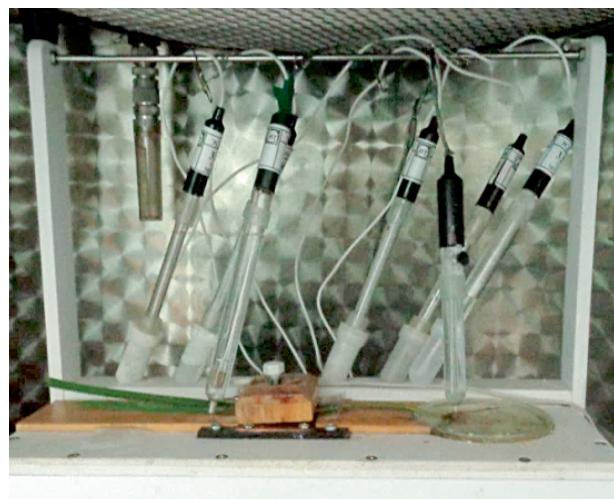


Рис. 1. Размещение проростка на лабораторном термостатике

Fig. 1. Placing the seedling on the laboratory thermal table

⁵Seroklinov G.V., Gunko A.V. Information technologies in the study of plant biopotentials under stressors // Computational Technologies, 2016, vol. 21, N S1, pp. 94-103.

⁶Pat. RU 2775642. Device for temperature profile formation / G.V. Seroklinov, V.A. Grinkevich, V.A. Zolotarev, V.M. Furzikov. Published 05.07.2022.

on. The PC keyboard of the system was used to start the cycle of biopotential measurement in accordance with the algorithm laid down in the computer program, according to which the formation of a given temperature profile affecting the plant began 6 s after the start. The signals obtained as a result of the seedling biopotential measurement were recorded into the PC database created on the basis of the FireBird relational DBMS during the entire measurement time. The measurement algorithm included 10 kHz imaging and recording of the changing signals of biopotential (plant response to the stimulus) and effective temperature for 160 s. The temperature effects were formed in the form of a trapezoidal profile with a steady-state increased temperature of 43 °C and decreased temperature of 8 °C for a total duration of 60 s. For each plant the specified cycle of biopotential measurement was carried out 2 times.

The obtained realizations of the seedling biopotential signals ($U(t)$) and temperature parameters were exported to the Matlab environment and processed with the application of the algorithms using vectorized calculations. As a result of preliminary processing, 24 parameters of different absolute values of each biopotential signal realization were selected for further analysis, including the most significant one – the maximum value of the filtered centered signal ($U_{\max c}$) [12]. The data array of the absolute values of biopotential signals for each of ten seedlings studied in each age group was subjected to statistical analysis, as a result of which the following were determined: the mean value of the absolute value of the biopotential signal, its

mean deviation and dispersion for a given age of seedlings.

RESULTS AND DISCUSSION

As a result of preliminary statistical processing, data arrays were formed to estimate the change in the average absolute values of biopotential ($\hat{U}_{\max c}$) of the wheat seedlings for the given age groups. Absolute values of the wheat seedlings biopotential when exposed to elevated temperature are given in Tables 1 and 2, and when exposed to reduced temperature – in Tables 3 and 4.

The obtained data were exported to the environment of the program “Statistica 6”, where as a result of the regression analysis nonlinear regression dependences of daily changes in absolute statistical values of biopotential of wheat seedlings of the variety Novosibirskaya 41 under the influence of increased and decreased temperature were obtained.

In the process of the experimental data regression analysis for 2020 (exposure to elevated temperature), a nonlinear (quadratic) regression dependence of the following kind was constructed:

$$\hat{U}_{\max c.t} = 0,0246 - 0,0023 \cdot t + 0,000062 \cdot t^2$$

at $R = 0,997$ and $p = 0,072$,

(1)

where $\hat{U}_{\max c.t}$ – absolute statistical mean value of the seedling biopotential when exposed to elevated temperature; t – seedling age; R – correlation coefficient; p – significance factor. As a result of the same analysis, a nonlinear (quadratic) regression dependence was also ob-

Табл. 1. Статистические показатели посуточного изменения биопотенциала проростков пшеницы при воздействии повышенной температуры (2020 г.)

Table 1. Statistical indices of daily variation in biopotential of wheat seedlings under exposure to elevated temperature (2020)

Indicator	Age of seedlings, days				
	10	12	14	17	19
Average value	0,0082728	0,00622922	–	0,004214	0,0039072
Average deviation	0,003108	0,00121642	–	0,0012226	0,0004734
Dispersion	0,000013	0,00000273	–	0,0000027	0,0000005

Табл. 2. Статистические показатели посуточного изменения биопотенциала проростков пшеницы при воздействии повышенной температуры (2022 г.)

Table 2. Statistical indices of daily variation in biopotential of wheat seedlings under exposure to elevated temperature (2022)

Indicator	Age of seedlings, days				
	10	12	14	16	18
Average value	0,02571	0,022164	0,015623	0,0140419	0,013049
Average deviation	0,014687	0,01864	0,011345	0,0083163	0,0052524
Dispersion	0,0004	0,000652	0,000288	0,0001215	0,0000488

Табл. 3. Статистические показатели посуточного изменения биопотенциала проростков пшеницы при воздействии пониженной температуры (2020 г.)

Table 3. Statistical indices of daily changes in biopotential of wheat seedlings under the influence of reduced temperature (2020)

Indicator	Age of seedlings, days				
	10	12	14	17	19
Average value	0,0096349	0,0084775	–	0,0073594	0,0060401
Average deviation	0,0044647	0,0030185	–	0,0035047	0,0021921
Dispersion	0,000029	0,0000132	–	0,0000176	0,00000753

Табл. 4. Статистические показатели посуточного изменения биопотенциала проростков пшеницы при воздействии пониженной температуры (2022 г.)

Table 4. Statistical indices of daily changes in biopotential of wheat seedlings under the influence of reduced temperature (2022)

Indicator	Age of seedlings, days				
	10	12	14	16	18
Average value	0,0271424	0,0198	0,014951	0,01215	0,012224
Average deviation	0,0139285	0,010995	0,007223	0,007542	0,0048056
Dispersion	0,000303	0,000342	0,000157	0,0000881	0,0000664

tained for the experimental data obtained during analogous studies in 2022, which has the following form

$$\hat{U}_{\max \text{ c.x}} = 0,0753 - 0,0067 \cdot t + 0,0002 \cdot t^2$$

at $R = 0,986$ and $p = 0,028$. (2)

The combined plot of the obtained regression dependences of the biopotential under the action of increased temperature is shown in Fig. 2, a.

Regression analysis of biopotential indices of wheat seedlings of Novosibirskaya 41 variety under the influence of reduced temperature

allowed to obtain the following regression dependencies:

a) for the experimental data of 2020:

$$\hat{U}_{\max \text{ c.x}} = 0,018 - 0,0011 \cdot t + 0,0000298 \cdot t^2$$

at $R = 0,995$ and $p = 0,1023$; (3)

б) for the experimental data of 2022:

$$\hat{U}_{\max \text{ c.x}} = 0,1002 - 0,0103 \cdot t + 0,0003 \cdot t^2$$

at $R = 0,9998$ and $p = 0,00023$. (4)

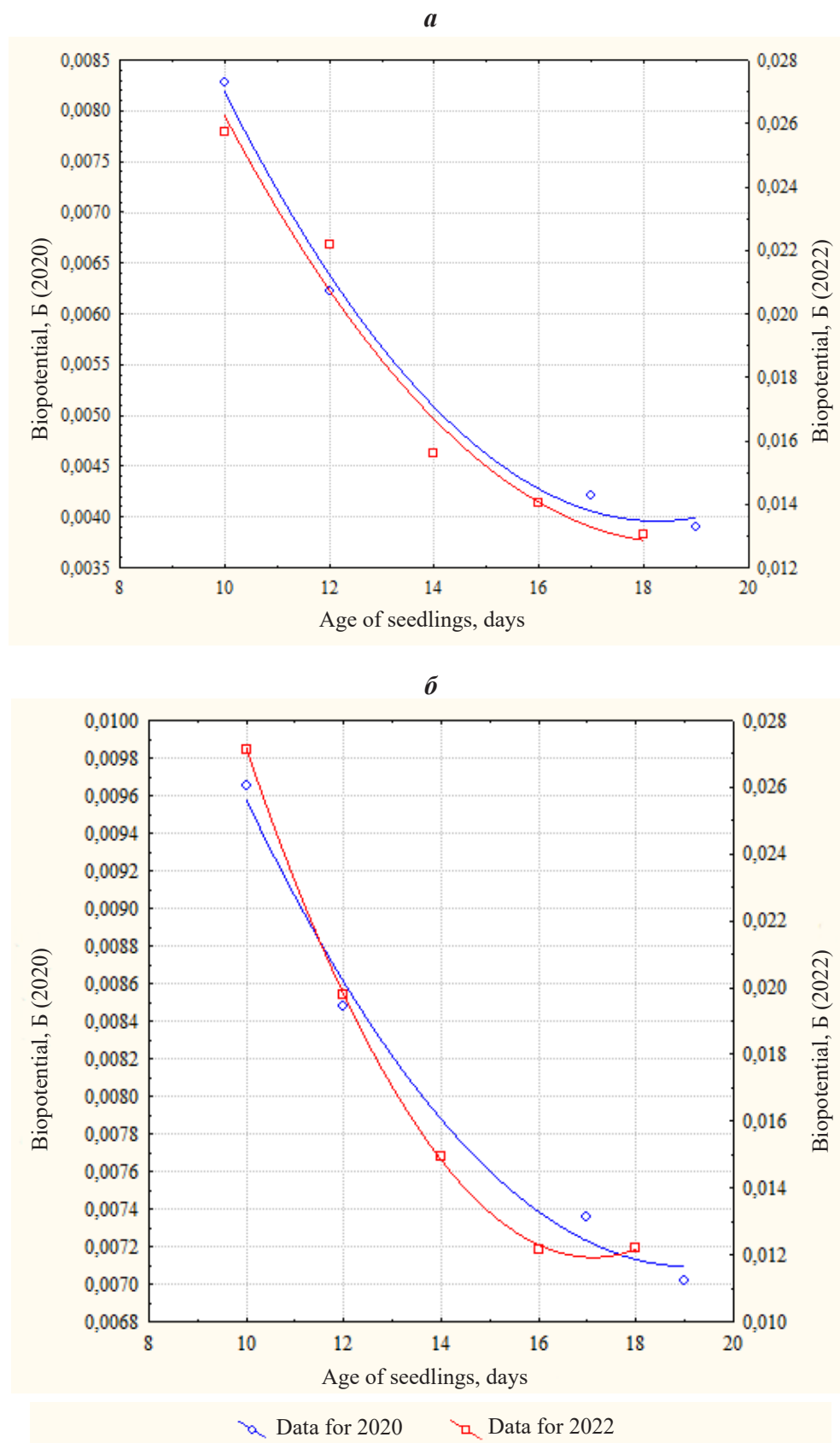


Рис. 2. График посуточного изменения биопотенциала проростков пшеницы сорта Новосибирская 41 при воздействии повышенной (а) и пониженной (б) температуры

Fig. 2. The graph of daily changes in biopotential of wheat seedlings of the Novosibirskaya 41 variety under the influence of elevated (a) and reduced (б) temperatures

The combined plot of the obtained regression dependencies is shown in Fig. 2, *б*.

The graphs show that, despite the difference in the absolute values of biopotential in the experiments conducted at different times, there is an identical nature of the changes under the influence of both increased and decreased temperature. Based on these observations, it is reasonable to consider the possibility of bringing the data obtained in the process of multi-day experiments to a homogeneous state, excluding the age effect on the biopotential of the research object.

To do this, let us bring the obtained regression equations into a single coordinate system, normalizing them with respect to the free term. As a result of normalization, the following expressions are obtained for equations (1) and (2):

$$\begin{aligned} U'_{\max \text{ c.x}} &= \frac{a_0}{a_0} - \frac{a_1}{a_0}t + \frac{a_2}{a_0}t^2 = \\ &= 1 - 0,0935t + 0,0025t^2; \\ U'_{\max \text{ c.x}} &= \frac{b_0}{b_0} - \frac{b_1}{b_0}t + \frac{b_2}{b_0}t^2 = \\ &= 1 - 0,089t + 0,00265t^2, \end{aligned} \quad (5)$$

where a_i – corresponding coefficients of the regression dependence obtained from the results of the studies of 2020; b_i – similar coefficients of the regression dependence obtained from the results of the studies of 2022. Given that these expressions describe identical processes, they can be regarded as a system of equations, which, moreover, have coefficients at variable t that are close in value. By averaging the value of the coefficients of the system of equations, we obtain an averaged normalized regression equation of the following form at the corresponding variables:

$$\begin{aligned} U'_{\max \text{ c.t.}} &= \left(\frac{a_0}{a_0} - \frac{b_0}{b_0} \right) / 2 - \left(\left(\frac{a_1}{a_0} + \frac{b_1}{b_0} \right) / 2 \right) t + \\ &+ \left(\left(\frac{a_2}{a_0} + \frac{b_2}{b_0} \right) / 2 \right) t^2 = 1 - 0,0913t + 0,00258t^2. \end{aligned} \quad (6)$$

Differentiating this expression, we obtain the equation of the rate of biopotential change:

$$\Delta_t = -0,0913 + 0,0516 \cdot t. \quad (7)$$

Carrying out similar transformation and calculations for the regression dependencies (3) and (4), estimating changes in wheat seedling biopotential depending on the age under the action of reduced temperature, we obtain an expression for correction of the average value of biopotential taking into account the age of the seedling:

$$\Delta_x = -0,08195 + 0,00466 \cdot t. \quad (8)$$

The obtained expressions (7) and (8) allow us to numerically estimate the change in the absolute values of the biopotential arising under the influence of increased and decreased temperature, in case of increasing the duration of the experiments and as a consequence of changing (increasing) the age of seedlings.

CONCLUSION

As a result of the experimental studies of changes in the biopotential of wheat seedlings of the Novosibirskaya 41 variety under the influence of increased (43 °C) and decreased (8 °C) temperature on the plants, conducted in 2020 and 2022, it was found that the average absolute value of the biopotential decreases when the age of plants changes (increases).

Statistical studies of the obtained data allowed us to obtain regression dependences of absolute mean values of seedling biopotential on their age under the action of increased and decreased temperature, which are described by a second-order polynomial.

It was also found that despite the numerical difference in the coefficients of the obtained regression expressions for the data for 2020 and 2022, the equations have an identical character under the action of both increased and decreased temperatures.

Taking into account the proximity of normalized equations of statistical regressions, built on the results of the experiments of 2020 and 2022, statistical values of the averaged estimates of deviations of absolute values of the biopotential

of wheat seedlings of Novosibirskaya 41 variety, caused by changes in their age, were determined. The obtained results will allow obtaining more accurate data when measuring the biopotential of the seedlings of this variety during long-term studies on comparative study of drought and cold tolerance of different wheat varieties. For this purpose, it seems advisable to carry out further experimental studies on the preparation of the values of biopotential given in the paper with the application of expressions (7) and (8) to one age of seedling samples and their subsequent analysis by clustering methods. The result of this analysis will allow to confirm or refute the hypothesis put forward in this article.

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ИНФОРМАЦИЯ ОБ АВТОРАХ

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К 95-летию со дня рождения Алексея Федоровича Абрамова



Алексей Федорович родился 5 июля 1929 г. в местности Арыылаах 3-Едюгейского наслега Верхневилуйского улуса. В 1957 г. с отличием окончил Омский государственный ветеринарный институт по специальности «Ветеринария», после чего был назначен зоотехником колхоза им. Ленина Верхневилуйского улуса. В 1958–1959 гг. работал ассистентом кафедры физиологии животных Якутского государственного университета, в 1959–1960 гг. – заместителем председателя колхоза им. Ленина Верхневилуйского района. В это же время он участвовал в создании крупной звероводческой фермы, которая стала базой для проведения научных опытов в период его учебы в аспирантуре во Всесоюзном институте экспериментальной ветеринарии. В 1964 г. Алексей Федорович защитил диссертацию на соискание ученой степени кандидата биологических наук по теме «Изучение физиологических основ и методов профилактики бесплодия серебристо-черных лисиц на звероводческих фермах Якутской АССР». В этом же году был принят на работу старшим научным сотрудником в Якутский научно-исследовательский институт сельского хозяйства, где впоследствии заведовал лабораториями по борьбе с бесплодием сельскохозяйственных животных (1965–1970 гг.), биохимии, массового анализа и переработки сельскохозяйственной продукции (1971–2014 гг.). В 2014–2016 гг. работал научным консультантом.

С 1965 г. А.Ф. Абрамов начал исследования по изучению влияния неблагоприятных условий внешней среды на процессы размножения, питания, воспроизводства якутской лошади. В 1992 г. в Институте эволюционной морфологии и экологии животных им. А.Н. Северцова АН СССР защитил докторскую диссертацию по теме «Якутская лошадь (экология, размножение, питание, оптимизация воспроизводства)» по специальностям «Охрана окружающей среды и рациональное использование природных ресурсов» и «Экология».

Алексеем Федоровичем впервые в практике табунного коневодства Якутии разработаны рекомендации по профилактике абортных кобыл, улучшению зимнего кормления якутских лошадей, прогнозированию условий тебеневки лошадей в республике, которые послужили научной основой совершенствования технологии кормления и содержания якутских лошадей.

Им внесен большой вклад в науку по развитию кормовой базы животноводства республики, разработаны нормативы расхода зеленой массы на приготовление различных видов кормов, эколого-биохимическим основам рационального использования тебеневочных пастбищ, технологии производства комбикормов, полнорационных кормосмесей и рационы кормления якутских лошадей.

А.Ф. Абрамовым также проведены исследования по технологии сберегающего земледелия и повышения плодородия земель с использованием сидеральных удобрений при выращивании овощей, картофеля и ягодных кустарников, по предупреждению накопления нитратов в кормах и сельскохозяйственных продуктах в условиях Якутии.

Многочисленные исследования Алексея Федоровича – использование естественного холода при замораживании и хранении продуктов, разработка параметров инфракрасной сушки овощей и ягод, технологий производства молочных, мясных и рыбных продуктов питания из местного сырья – посвящены проблемам питания населения. Совместно с сотрудниками Медицинского института СВФУ им. М.К. Аммосова он проводил исследования по проблемам профилактики и лечения раковых заболеваний.

А.Ф. Абрамов долгие годы был членом ученого совета ЯНИИСХ, методических советов по растениеводству, животноводству, председателем методического совета по животноводству, неоднократно избран секретарем партийной организации, был председателем профкома ЯНИИСХ, членом научно-технического совета Министерства сельского хозяйства Республики Саха (Якутия) по переработке, принимал непосредственное участие в подготовке программ по кормопроизводству, системе ведения сельского хозяйства. Он является одним из разработчиков закона «О производстве кумыса в Республике Саха (Якутия)» (2002 г.).

Алексеем Федоровичем опубликовано 500 научных трудов, в том числе 40 монографий, 49 брошюр, 11 рекомендаций, 253 статьи в ведущих журналах, 148 статей на страницах республиканских газет и журналов. Со своими учениками им разработано 29 технических условий на новые виды продуктов питания, получено 30 патентов Российской Федерации на изобретения.

Алексей Федорович внес большой вклад в подготовку научных кадров и специалистов высшей квалификации в республике. Он был руководителем аспирантуры по специальности «Экология», в 1995–2012 гг. – заместителем председателя, членом диссертационных советов по защите диссертаций по специальностям «Охрана окружающей среды и рациональное использование природных ресурсов», «Частная зоотехния и технология производства продуктов животноводства», «Экология», членом объединенного ученого совета АН РС (Я) по биологическим, медицинским и сельскохозяйственным наукам. Алексеем Федоровичем подготовлены 11 кандидатов, один доктор наук. Он был оппонентом 5 кандидатских диссертаций и рецензентом 26 диссертационных работ, в том числе 8 докторских.

Алексей Федорович в течение многих лет заведовал кафедрой физиологии животных и экологии Якутской государственной сельскохозяйственной академии, был руководителем более 20 дипломных работ студентов в ЯГУ, ЯГСХА, председателем и членом ГАК Якутского государственного университета им. М.К. Аммосова, Якутской государственной сельскохозяйственной академии. В 1995 г. ему присвоено ученое звание профессора кафедры физиологии животных и экологии, в 2013 г. – профессора по специальности «Частная зоотехния, технология производства продуктов животноводства». В 1996 г. Алексей Федорович был избран академиком Академии аграрного образования Российской Федерации, в 1998 г. – академиком Российской экологической академии, в 2000 г. – академиком Международной академии аграрного образования.

За большой вклад в развитие сельскохозяйственной науки и сельского хозяйства А.Ф. Абрамов награжден государственными наградами СССР, Российской Федерации, ЯАССР и РС (Я). Среди них орден «Знак Почета», почетная грамота Президиума Верховного Совета ЯАССР,

грамота Президента Республики Саха (Якутия), грамоты Правительства, Государственного собрания Ил Тумэн РС (Я), грамоты СО РАСХН и РАСХН. Награжден медалями Н.В. Черского и И.И. Синягина, знаком отличия «Гражданская доблесть». Алексей Федорович является заслуженным деятелем науки Республики Саха (Якутия), лауреатом Государственной премии республики по науке и технике, заслуженным ветераном СО РАСХН, почетным гражданином Верхневилуйского района, ветераном тыла и труда.

Алексей Федорович скончался в 2023 г., но в памяти людей, знавших его и работавших вместе с ним, он навсегда останется Ученым с большой буквы. Его преданность науке, умение руководить коллективом, поступки и дела, человеческая доброта и порядочность служат примером, а его научные труды еще долго будут востребованы учеными и практиками.

Доктор биологических наук М.М. Черосов,
доктор ветеринарных наук, профессор М.П. Неустроев,
академик РАН А.С. Донченко,
академик РАН Н.И. Кашеваров,
доктор сельскохозяйственных наук В.К. Каличкин,
кандидат медицинских наук У.М. Лебедева,
научный сотрудник Т.В. Слепцова,
кандидат биологических наук В.Т. Васильева

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 4.1.1. General agriculture and crop production
Fodder 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
Zootechnics and veterinary medicine	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	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
Scientific relations	4.2.3. Infectious diseases and animal immunology
From the history of agricultural science	4.2.4. Private zootechnics, feeding, technology of feed preparation and production of livestock products
Brief reports	4.2.5. Breeding, selection, genetics, and animal biotechnology
From dissertations	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@sfsc.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:

1. 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 15. 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.

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, placed page by page through 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-bis/>) = 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, 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 text.

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, TABLES, SCREENSHOTS AND PHOTOGRAPHS

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 num-

bered 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 and other non-drawn illustrations must be uploaded separately as *.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.

Attention should be paid to the spelling of formulas in the article. 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 cancelled from the register.

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

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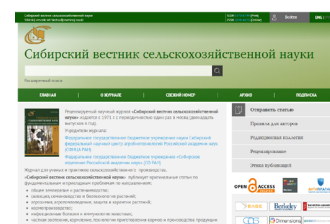
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