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СОДЕРЖАНИЕ

CONTENTS

СОДЕРЖАНИЕ

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ШТРИХИ К ИСТОРИИ АГРАРНОЙ НАУКИ В СИБИРИ

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Дан обзор зарождения, развития, современного состояния и научных достижений аграрной науки в Сибири. Приведены исторические сведения о развитии сельского хозяйства в период переселения миллионов крестьян из Европейской части Российской империи. Описано начало первых системных научных исследований в Сибири. Представлена история создания Сибирского отделения ВАСХНИЛ для координации и усиления научных исследований по сельскохозяйственной тематике на огромной восточной части страны. Приведены научно-исследовательские институты, входившие в Сибирское отделение. Описаны этапы реформирования СО ВАСХНИЛ: Сибирское отделение Россельхозакадемии, Федеральное агентство научных организаций (ФАНО), Сибирский федеральный научный центр агробиотехнологий Российской академии наук (СФНЦА РАН). Даны сведения о научных достижениях сибирских ученых: созданы и широко освоены более полутора тысяч новых сортов, разработаны сотни высокоэффективных агротехнологий возделывания зерновых, кормовых, плодовых, овощных и декоративных культур, получены десятки продуктивных пород, типов и линий животных, разработаны новые сельскохозяйственные машины и орудия, препараты, тест-системы и вакцины. Названы ученые-аграрии, добившихся выдающихся успехов в развитии сельского хозяйства.

Ключевые слова: аграрная наука, технологии, урожайность, ученые Сибири

TOUCHES ON THE HISTORY OF AGRARIAN SCIENCE IN SIBERIA

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A review of the origin, development, current state and scientific achievements of agrarian science in Siberia is given. Historical information about the development of agriculture during the period of resettlement of millions of peasants from the European part of the Russian Empire is given. The beginning of the first systematic scientific research in Siberia is described. The history of the creation of the Siberian Branch of the V.I. Lenin All-Union Academy of Agricultural Sciences (VASKhNIL), to coordinate and strengthen scientific research on agricultural topics in the vast eastern part of the country is presented. The research institutes that were part of the Siberian Branch are given. The stages of reforming the SB VASKhNIL are described: Siberian Branch of Rosselkhozakademy (the Russian Academy of Agricultural Sciences), Federal Agency of Scientific Organizations (FASO), Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences (SFSCA RAS). Information is given about the scientific achievements of Siberian scientists: more than one and

a half thousand new varieties have been created and widely developed, hundreds of highly effective agro-technologies of cultivation of grain, fodder, fruit, vegetable and ornamental crops have been developed, dozens of productive breeds, types and lines of animals have been obtained, new agricultural machines and tools, preparations, test-systems and vaccines have been developed. Agricultural scientists who have made outstanding achievements in the development of agriculture are named.

Keywords: agrarian science, technologies, yield, Siberian scientists

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The history of Siberia's development is inseparable from the period of resettlement of millions of peasants from the European part of the Russian Empire and is closely linked to ensuring the population's self-sufficiency in food and animal feed. It required thorough research into the climatic and soil conditions of the vast uncharted territory and, based on this, the development and application of effective agricultural practices.

In 1906, the Russian Empire's government recognized full freedom of resettlement and took measures to provide economic assistance to the settlers (the agrarian reform of P.A. Stolypin). The flow of migrants to the eastern regions of the country significantly increased: if from 1896 to 1906, 1.1 million people moved to Siberia, then from 1906 to 1914 – 3 million. The first scientific experiments in 1805–1809 near Tobolsk were conducted by von Kremmer on growing perennial and annual grasses, as well as other plants, for fodder. However, these were isolated one-off experiments [1].

The first scientific, though not state (treasury) institution – a Cossack experimental farm – was established near Omsk in 1828, which began studying plants, including forage crops. This date is considered the beginning of systematic scientific research in Siberia [2].

With the population growth in Siberia and the development of trade, the cultivated land no longer met the needs for grain and other crop products, and bringing new lands into cultivation was a very costly endeavor. Grains began to be allocated according to grain-producing areas, leading to decreased soil fertility and crop yields. The search for ways to increase land productivity began. In 1831, in the Turinsky district of the Tobolsk province, P.V. Budrin applied green-manured fallow, sowing lupine for green fertilizer [3]. Intensive searches for scientifically based methods to increase the yield of cultivated crops began.

Along with this, doubts were expressed about the possibility of agriculture in the harsh Siberian conditions. "Siberia has never produced and will not produce bread in quantities sufficient to satisfy its consumers," claimed the Russian Minister of Transportation M.I. Khilkov in 1896 [4].

Reality disproved this statement. From 1906 to 1914, grain crops in Siberia increased by 3.57 million dessiatines, or 86%. In 1913, 82 million poods of grain were transported by rail, including 23 million poods abroad. In 1911, there were more than 3,000 butter factories in Western Siberia, as the butter was of very high quality. Siberia provided 25% of the world's and 85–90% of Russia's butter export. In 1913, Russia exported 4.45 million poods of butter [5]. "Siberian butter-making produces twice as much gold as all the Siberian gold mining industry," P.A. Stolypin evaluated the significance of livestock farming [6].

As the population in Siberia increased and industry developed, especially during the Great Patriotic War and the years of developing virgin and fallow lands, it became clear that the level of scientific support for agriculture did not meet the emerging demands and needs. For instance, only 10–15% of the sown areas in Siberia were planted with locally bred varieties, while ran-

dom varieties, often unsuitable for local conditions and yielding very low harvests, were sown on the rest of the area. These and other problems needed to be addressed.

The USSR Government Decree No. 867 of November 14, 1969, on the establishment of the Siberian Branch of the VASKhNIL (All-Union Academy of Agricultural Sciences) and the construction of an agrarian science center funded by the earnings from the All-Union Communist Subbotnik (voluntary unpaid work day), was truly a historic decision. The development of productive forces in Siberia and the construction of the Baikal-Amur Mainline required coordination and strengthening of scientific research in agriculture across the vast eastern part of the country. This significant task was set before the newly established Siberian Branch of VASKhNIL. Academician I.I. Sinyagin, who was appointed the head of the Organizational Bureau, had to decide where the agrarian science center would be located. After extensive and challenging explorations and meetings with the leadership of Siberian regions, it was decided to build the scientific town near Novosibirsk.

The experience of building and operating the SB RAS (Siberian Branch of the Russian Academy of Sciences), along with the support of the Novosibirsk Region leadership, later confirmed the correctness of this decision. It is important to note that the Sibacademstroy company played a significant role in constructing the scientific town, which was named Krasnoobsk.

When organizing the Siberian Branch of the VASKhNIL in Novosibirsk, five institutes were included: the Siberian Research and Technological Design Institute of Animal Husbandry, Siberian Research Institute of Farming and Chemicalization of Agriculture, Siberian Research Institute of Fodder Crops, Siberian Research Institute of Mechanization and Electrification of Agriculture, Siberian Research Institute of Agricultural Economics, plus four experimental farms and three institutes within the region – the Siberian Research Institute of Agriculture (Omsk), Far North Agriculture Institute (Norilsk), All-Russian Research Institute of Soybean (Amur Region). In 1972, the first Presidium of the SB VASKhNIL was elected, which included academicians I.I. Sinyagin, A.P. Kalashnikov, A.I. Selivanov, M.I. Tikhomirov, the director of the Institute of Cytology and Genetics SB RAS D.K. Belyaev, and the rector of the Novosibirsk Agricultural Institute, Professor I.I. Gudilin. A comprehensive scientific agenda was formed, covering all the problematic directions of the Agricultural Industrial Complex of Siberia.

Irakli Ivanovich Sinyagin, a prominent scientist, became the inspiration for the entire ideology of the agro-town and the concept of scientific research from Kurgan to Norilsk, BAM regions, and Kamchatka. The role of the workers' settlement of Krasnoobsk, which became the center of agricultural science in Siberia, deserves special mention. Thanks to the initiative, perseverance, and organizational talent of Academician I.I. Sinyagin, the institute buildings rapidly emerged in the open field near Novosibirsk. Talented and inquisitive scientists, both young and experienced, from all over the country, converged on Krasnoobsk. It can be said without exaggeration: representatives from all the republics of the Soviet Union worked here. Krasnoobsk hosted and continues to host major scientific forums, including international ones, and is well-known to the scientific community in many countries and to Siberian agricultural producers.

Unfortunately, due to health reasons, I.I. Sinyagin left his post in 1978, but the vast and complex creative mechanism had been launched. The construction of the town was gaining momentum. Along with scientific facilities, social and cultural objects were being built, roads were laid, and large-scale greening was carried out, rapidly increasing the population. The scientific institutions intensively conducted research across the Siberian region, actively and systematically assisting agriculture. I.I. Sinyagin was convinced that "science only becomes a direct productive force of society to the extent that social production utilizes its achievements" [7].

Academician Alexander Nikolaevich Kashtanov, a talented organizer and prominent agronomist, succeeded I.I. Sinyagin. Despite his brief tenure at the helm of the Siberian Branch of the VASKhNIL, he left a notable mark on its history.

Special words of gratitude are due for the work of Academician Pyotr Lazarevich Goncharov, who chaired the Siberian Branch from 1979 for 25 years, leading agricultural science in Siberia. Under P.L. Goncharov's leadership, new institutes were established, housing was built, and the social sphere was strengthened. He also made a significant contribution to creating

new varieties of fodder and grain crops for Siberian conditions [8]. In 1979, by a decree of the Council of Ministers of the RSFSR, research institutes, breeding and experimental stations, design offices, and experimental production farms operating throughout Siberia and the Far East were transferred to the jurisdiction of the Siberian Branch of the VASKhNIL. In 1988, the Far Eastern Branch was separated from the Siberian Branch of the VASKhNIL.

By the resolution of the Council of Ministers of the RSFSR dated April 3, 1990, No. 107, the Siberian Branch of the VASKhNIL was transformed into the Siberian Branch of the Russian Academy of Agricultural Sciences. The Siberian regional branch of the Russian State Agricultural Academy, which included 31 scientific institutions, including the Central Scientific Agricultural Library, 7 breeding centers, and 26 experimental production farms, represented a powerful scientific and production complex. The activity zone of the Siberian Branch covered 13 subjects of the Russian Federation in Western and Eastern Siberia and the Far North.

The extensive network of experimental production farms, located across all soil-climatic zones of Siberia, functioned quite effectively. These farms served as sites for optimizing the most modern agro-technologies and had an educational-demonstration function.

Throughout the years, the Siberian Branch of the VASKhNIL received substantial business support from the leadership of the Russian State Agricultural Academy and personally from the president of the academy, Academician G.A. Romanenko.

From 2005 to 2016, the Siberian Branch was led by Academician A.S. Donchenko, who faced complex issues related to both the organization and continuation of scientific research and the processes of reforming agricultural science in Siberia, which were already gaining momentum.

The merger of the Russian State Agricultural Academy with the Russian Academy of Sciences in 2013 and the formation of the Federal Agency for Scientific Organizations (FASO) marked a new challenging phase in the life of the Siberian Branch of the Russian State Agrarian academy. The scientific institutions and experimental farms came under the jurisdiction of FASO.

In 2016, based on 12 scientific institutions, the Siberian Federal Scientific Centre of Agro-Bio-Technologies of the Russian Academy of Sciences (SFSCA RAS) was formed, led by Academician N.I. Kashevarov. Over five years, complex structural optimization of the institution was carried out, research directions were clarified, new youth laboratories were created, interaction with agricultural producers was strengthened, and five dissertation councils were established, including in universities, in the main scientific directions. The Siberian Research Institute of Agriculture and Peat (Tomsk), Kemerovo Research Institute of Agriculture, Research Institute of Veterinary Medicine of Eastern Siberia, and the "Elitnaya" experimental station were included in the Center as branches.

Since 2021, the center's director has been Dr. of Science in Biology, Corresponding Member of the Russian Academy of Education Kirill Sergeevich Golokhvast, who continues the work on enlarging the center by incorporating the Buryat, Irkutsk, and Tuva scientific institutions as branches.

Under FASO's decision, scientific centers were established: in Barnaul – the Federal Altai Scientific Center for Agrobiotechnology led by Candidate of Science in Agriculture Alexey Anatolyevich Garkusha; in Omsk – the Omsk Agrarian Scientific Center, director – Candidate of Science in Engineering Maxim Sergeevich Chekusov; and in Tyumen, Krasnoyarsk, Yakutsk, which are currently subordinate to the Ministry of Science and Higher Education of Russia.

The scientific and methodological guidance of agrarian profile institutions and universities has been entrusted to the Siberian Branch of the Russian Academy of Sciences (RAS). Constructive interaction with the Siberian Branch of the RAS is carried out through the joint scientific council of the SB RAS on agricultural sciences (see the figure).

Over the past decades, Siberian scientists have created and widely implemented more than one and a half thousand new varieties and developed hundreds of highly effective agrotechnologies for cultivating cereals, fodder, fruit, vegetable, and ornamental crops. More than 90% of all crops in the Siberian Federal District are occupied by Siberian varieties of cereals and fodder crops, characterized by high yield and comprehensive resistance. Dozens of productive breeds,

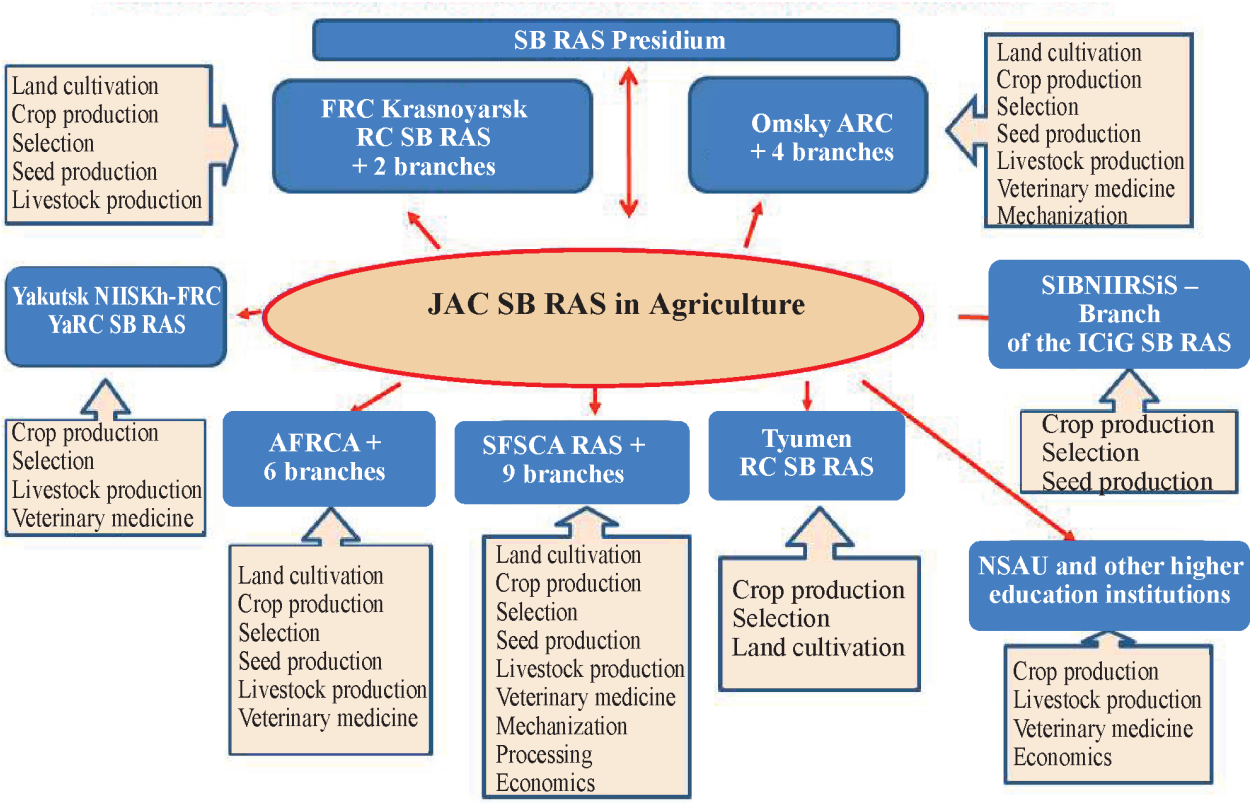
types, and lines of animals have been obtained, and new agricultural machines and tools, preparations, test systems, and vaccines have been developed (see the table).

In just the last two years (2022–2023), scientific institutions and universities in Siberia have created and are testing 62 varieties across 20 agricultural crops, with 51 varieties included in the State Register of the Varieties Approved for Use. According to 2020 data, the share of seeds of Siberian selection varieties produced by Siberian scientific institutions accounted for 80% of spring wheat, 84% of barley, and 95% of oats in the total volume of varietal seeds.

This enables achieving grain crop yields up to 50 centners per hectare and milk yields over 9-10 thousand kg per year in production conditions, comparable to the levels of advanced countries but located in significantly more favorable climatic zones. The agricultural complex of Siberia is developing steadily thanks to the adoption of scientific achievements, state support, the introduction of modern high-performance equipment, and the hard work of agricultural producers.

Over the years, more than 40 academicians and about 30 corresponding members of the VASKhNIL, the Russian State Agricultural Academy, and the RAS have productively worked in Siberia: legendary figures like twice Hero of Socialist Labor, honorary academician of the VASKhNIL T.S. Maltsev, Heroes of Socialist Labor academicians M.A. Lisavenko, B.A. Neunylov, V.A. Moroz; academicians A.P. Kalashnikov, A.I. Selivanov, M.M. Tikhomirov, G.K. Kazmin, A.A. Sviridov, V.A. Tikhonov, I.P. Kalinina, V.A. Kubyshev, V.R. Boev, A.N. Vlasenko, N.G. Vlasenko, P.M. Pershukevich, I.F. Khramtsov; corresponding members K.P. Afendulov, M.D. Chamukha, K.G. Aziev, V.G. Shelepov, G.E. Chepurin, and many others.

Academicians of the RAS V.V. Alt, G.P.



Scientific potential of ab– t 1000 researchers (more than 840 researchers) including more than 400 candidates and 110 doctors of sciences, 7 Academicians RAS, 13 corresponding members RAS

Структура компетенций аграрных научных учреждений и вузов, находящихся под научно-методическим руководством Сибирского отделения РАН

Structure of competencies of agrarian scientific institutions and universities under the scientific and methodological guidance of the Siberian Branch of the Russian Academy of Sciences

Результаты деятельности Сибирского отделения (ВАСХНИЛ) Россельхозакадемии, научно-исследовательских институтов, подведомственных Министерству образования и науки РФ в СО РАН за 1969–2021 гг.
Results of activities of the Siberian Branch (VASHNIL) of Rosselkhozakademy, research institutes subordinate to the Ministry of Education and Science of the Russian Federation in SB RAS for 1969–2021

In the field of crop production, the following varieties have been created	1639
In the field of agriculture, the following scientific developments have been completed	1241
In the field of livestock breeding the following have been created: breeds, types (lines)	 23 32 (15)
In the field of veterinary medicine the following scientific developments have been completed	1660
In the field of economics, the following scientific developments have been completed	1237
In the field of mechanization, the following has been made: experimental models of technology appliances and devices computer programs, databases and databanks	 518 102 51
The following scientific developments have been completed in the field of processing of agricultural products	250
Patents and certificates obtained	2591

Gamzikov, N.P. Goncharov, A.S. Donchenko, N.I. Kashevarov, V.A. Soloshenko, N.A. Surin, corresponding members of the RAS A.V. Goncharova, K.Ya. Motovilov, N.M. Ivanov, L.I. Inisheva, E.V. Rudoy, L.N. Vladimir, L.V. Budozhapov, A.Yu. Prosekov, N.A. Tsuglenok, A.A. Shpedt, etc., continue their active scientific work.

Over the years, many scientists have been awarded state awards for their significant contributions to the development of agricultural science. Among the laureates of the All-Union State Prize are V.S. Ilyin, I.P. Kalinina, A.K. Nikonov, O.A. Naumov, E.I. Panteleeva, T.M. Pletneva, M.A. Prokofiev, S.N. Khabarov, I.T. Skorik, F.F. Streltsov, E.E. Shishkina. A.P. Kalashnikov, Yu.V. Kolmakov, B.S. Koshelev, N.V. Krasnoschekov, I.T. Litvinenko, A.V. Makarov, A.F. Neklyudov, N.V. Nyushkov, A.I. Ovsyannikov, M.I. Ragimov, S.S. Sinitsyn, I.K. Khlebnikov were awarded the State Prize of the Council of Ministers of the USSR; and G.V. Alkov, S.S. Bednarzhevsky, A.N. Vlasenko, V.N. Tadykin, V.G. Tkachenko were awarded the State Prize of the Russian Federation.

More than 100 people have been awarded orders and medals and have received honorary titles such as "Honored Scientist of the Russian Federation," "Honored Worker of Agriculture," "Honored Agronomist of the Russian Federation," "Honored Inventor of the Russian Federation," "Honored Veterinary Doctor of the Russian Federation," "Honored Livestock Specialist of the Russian Federation," "Honored Worker of Culture." It is impossible to name all those who contributed to the construction of the scientific town in Krasnoobsk, scientific institutions in Siberia, those who worked selflessly for many years in laboratories, on experimental fields, and farms in a short publication. These are tens of thousands of people who have brought fame to Siberia, demonstrating that it is possible and necessary to achieve world-class results here.

Immense gratitude is extended to those who continue to work despite certain temporary difficulties and hardships. Thank you to all who are now enjoying a well-deserved retirement after many years of service in science. We preserve the memory of our comrades who are no longer with us. On the eve of the 300th anniversary of the establishment of the Russian Academy of Sciences, it must be acknowledged that science is going through a challenging period. However, we will be able to find the right answers to all the challenges of the times if we unite our efforts and focus our scientific potential on solving issues related to ensuring the food security of our country.

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РАЗВИТИЕ ЖИВОТНОВОДСТВА В СИБИРИ

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Создание Сибирского научно-исследовательского института животноводства приходилось на 1930-е годы, время, когда вся страна, пережив коллективизацию и голод, начинала формировать культурное животноводство с продуктивностью скота, способной обеспечить население региона молоком и мясом. Огромная протяженность территорий и разнообразие климатических условий требовали создания пород животных, способных адаптироваться к холодной длинной зиме и жаркому короткому лету, к которым не были приспособлены культурные европейские породы. В связи с этим перед сибирскими учеными ставилась задача создать новые типы молочного и мясного специализированного крупного рогатого скота, свиней, овец, лошадей, сочетающих в себе высокую продуктивность и выживаемость в экстремальных условиях. Если высокая, генетически обусловленная продуктивность достигалась за счет сочетания местного улучшенного скота с европейским породистым, то превзойти лучшие импортные породы или хотя бы удержать их уровень было невозможно из-за несоответствия природно-климатических условий и несопоставимых условий кормления и содержания. Необходимо создавать новые прорывные технологии в кормопроизводстве и содержании животных с более энергозатратными элементами, которые сделают производимую в Сибири животноводческую продукцию конкурентоспособной в сравнении с южными регионами России, не говоря о Германии, Франции, США, Австралии. Для этой цели целесообразно объединить усилия фундаментальной и прикладной наук в разработке прорывных технологий получения элитной деликатесной продукции, востребованной за рубежом. Необходимы экономические механизмы содействия указанному процессу, способному принести освоение и заселение удаленных малоосвоенных территорий.

Ключевые слова: Сибирский научно-исследовательский институт животноводства, продуктивность скота, конкурентоспособность, прорывные технологии

LIVESTOCK BREEDING DEVELOPMENT IN SIBERIA

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The establishment of the Siberian Research Institute of Animal Husbandry was in the 1930s, a time when the whole country, having survived collectivization and famine, was beginning to form a cultural animal husbandry with livestock productivity capable of providing the population of the region with milk and meat. The vast extent of the territories and the diversity of climatic conditions required animals capable of adapting to the cold long winters and hot short summers to which the cultivated European breeds were not adapted. In this regard, Siberian scientists faced the task of creating new types of dairy and meat specialized cattle, pigs, sheep, horses, combining high productivity and survivability in extreme conditions. If high genetically determined productivity was achieved by combining local improved cattle with European pedigree cattle, it was impossible to surpass the best imported breeds or at least maintain their level due to the inconsistency of natural and climatic conditions and incomparable feeding and housing conditions. It is necessary to create new breakthrough technologies in fodder production and animal housing with more energy-consuming elements, which

will make the livestock products produced in Siberia competitive in comparison with the southern regions of Russia, not to mention Germany, France, USA, Australia. For this purpose, it is advisable to combine the efforts of fundamental and applied sciences in the development of breakthrough technologies for obtaining elite delicacy products demanded abroad. There is a need for economic mechanisms to facilitate this process, which in return will bring development and repopulation of remote and underdeveloped territories.

Keywords: Siberian Research Institute of Animal Husbandry, **l**ivestock productivity, competitiveness, breakthrough technologies

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The development of animal husbandry in Siberia is inseparably linked to the history of its colonization. Unfortunately, many facts about the settlement of vacant territories have not been preserved. It is only known that the pioneers with their indigenous livestock were nomads, and later fugitives or settlers from the European part of Russia. In this case, it is difficult to speak of uniformity, let alone the breed of the livestock they brought [1, 2]. Despite the harsh climatic conditions of Siberia, extensive pastures allowed for the breeding of horses and large horned cattle in unlimited numbers, which provided butter, meat, milk, cheese with excellent taste qualities [3].

The originality of livestock products, determined by the diversity of plant raw materials and its special chemical composition, served as the basis for the creation of a scientific division in the Novosibirsk region in 1925 – the Zonal Siberian Central Agricultural Experimental Station – with a livestock department in its structure. In 1930, based on this department and the regional dairy testing laboratory, the Siberian Scientific Research Institute of Dairy Farming was established, later transformed into the Siberian Scientific Research Institute of Animal Husbandry, and then into the Siberian Research and Technological Design Institute of Animal Husbandry (SibNIPTIZh).

The leading branch of animal husbandry in the Siberian region was dairy cattle breeding, based on local Siberian cattle. Due to systematic underfeeding and primitive housing conditions, it was small and low-productive. Yields did not exceed 800-1000 kg of milk per year, and in breeding sets of 16 thousand cows, it was 1734 kg. However, the milk fat content reached 4.5%, so Siberian butter accounted for about 73% of Russia's total exports, and in some years, up to 95%, it was in demand abroad and supplied to the tables of nobles.

Local breed cows had a high adaptation capacity to the sharply continental climate of Siberia, for feeding which straw from the roofs of rural houses was often used.

The Siberian Scientific Research Institute of Animal Husbandry and other scientific institutions were tasked with creating high-productivity dairy herds to feed the starving country's population. The state leadership demanded to accelerate the process of intensifying animal husbandry, for which scientists recommended the method of crossbreeding with high-yielding Frisian cattle. Institute staff, realistically assessing the situation, were against such an approach. The feed base, personnel training, and farm infrastructure were not ready to accept foreign breeding stock at that time. Scientists who disagreed with this decision were subjected to repression.

From 1930 to 1960, under the coordination of SibNIPTIZh, the Siberian branch of the Holstein breed was formed in the region through absorptive crossbreeding of Siberian cows with Frisian bulls, later replaced by Holstein bulls. Material-technical base development lagged signifi-

cantly behind. By the present time, the farms of the region have a sufficient number of Holsteinized cattle for breeding work, with the population of animals of the Holstein breed accounting for 55%, Simmental – 30%, and Red Steppe – 15%. The process of absorbing domestic breeds has gone so far that there are practically no purebred herds of the Russian selection left, unique in some economically useful traits [4].

Undoubtedly, the infusion of blood from high-yielding foreign cattle has positively impacted the milk productivity of the local herds, reaching an average of 6,000 kilograms per herd in the Siberian region, with the best farms achieving 10–12 thousand kilograms of milk per cow per year.

Unfortunately, alongside the increase in milk yield, Holsteinized animals exhibited poorer reproductive properties compared to their Siberian purebred counterparts, lower productive longevity, increased feed requirements, and lower quality milk and meat [5]. According to average multi-year data (2006–2017), calf output from Holsteinized herds in Russia decreased to 76%, with productive longevity averaging 2.67 calvings.

Changes in the economically valuable traits of the dairy cattle population are influenced not only by breed characteristics but also by the quality of feed, housing conditions, and technologies copied from abroad, which are not adapted to our climatic conditions, along with an overall inadequate material-technical base. All these listed shortcomings can lead to the loss of unique adaptive qualities of local indigenous cattle and high yields inherited from purebred foreign animals.

The degeneration of the improved dairy and beef cattle, starting from the 1930s, has recurred in our country several times.

The statistically noted increase in productivity is linked to the expanded culling of low-productivity cows, resulting in a decrease in their number from 22 million heads in 1990 to 7 million at present. The deterioration in milk quality, and consequently butter and cheese, may be associated with the transition from feeding cattle natural mixed grass or hay to a monoculture feed of 2–3 crops cultivated on arable land. However, feeding cows with a productivity of over 6,000 kilograms of milk from pasture is a challenging task. Developing new feeding systems and technologies for obtaining next-generation feeds, which would enable the management of the qualitative component of livestock products, is a pressing issue in modern science achievable only through the interaction of fundamental and applied research.

The abundance of energy, land, and water resources in the vast territories of Siberia creates real conditions for increasing the production of valuable livestock products, which are in demand not only in Russia but also abroad.

In partnership with research institutes of Siberia, pedigree farms, and farm units, four types of dairy cattle and the Siberian breed, called Siberiachka, have been developed, ensuring an average yield in the region of over 6,000 kilograms of milk with a potential exceeding 12,000 kilograms. Key contributors to the dairy cattle breeding program included A.S. Khramov, P.T. Trebulkin, R.P. Matis, V.V. Kozyrev, L.D. Gerasimchuk, and many others. Research on increasing milk productivity in cows was deemed appropriate to accompany changes in the qualitative characteristics of milk, which were restrained by the absence of equipment.

A similar trend was observed in the breed-forming process of meat cattle breeding, pig farming, and sheep breeding. Through absorptive or complex reproductive crossbreeding, domestic low-productivity breeds were crossed with foreign breeds surpassing them in productivity. This resulted in Siberian types of beef cattle in Hereford (3), Simmental (1), and Kazakh White-headed (1) breeds. The productive potential of these new types of specialized beef cattle reaches 950–1360 grams per day, although the average production figures for beef in the Siberian region and the country as a whole fluctuate within 600–650 grams per day, indicating insufficient feed base. The most promising type of beef cattle for breeding in the extreme conditions of Siberia is the meat-type Simmental known as the Bagansky. However, this type requires improvement in meat qualities such as tenderness and marbling through the creation of hybrid herds based on them. Despite govern-

ment resolutions on the development of specialized meat cattle breeding in the 1990s-2010s, the industry only actively develops in the European part of Russia thanks to state investments. Premium-class marbled meat at very high prices has appeared in many regions of Russia. Apparently, subsidies were lacking for Siberia, although all conditions for intensifying the meat cattle breeding industry are present. The current geopolitical situation demands subsidies. With 93 years of accumulated knowledge, the Institute of Animal Husbandry could have done much for the development of the industry, starting from farm design, improvement of types and breeds, creation of efficient feed additives, and staff training. Significant contributions to the formation of a new direction for Siberia, namely "specialized meat cattle breeding," were made by N.G. Gamarnik, B.O. Inerbaev, as well as the directors of breeding farms P.T. Zolotarev, the Mamaev family, P.Ya. Beyfort.

During the Great Patriotic War, scientists at the institute already had significant scientific groundwork on the adaptation of various agricultural animals to the Siberian climate. Among these, the Siberian Northern and Kemerovo breeds of pigs stood out, widely spread in the Siberian region. Their products were in demand on the front lines, in agricultural work, and were indispensable for miners. The collective of authors was rightly awarded the Stalin Prize (M.O. Simon, A.I. Ovsiannikov, I.T. Skorik, P.I. Ternitsky, E.G. Savina, A.F. Lysakov, I.I. Gudilin). The improvement of pigs in Siberia culminated in the creation of ultra-fast-growing individuals of the Large White, early-maturing meat SM-1 breeds, and factory types such as Novosibirsky and Achinsky. In the breeding process, the best foreign meat breeds such as Landrace, Duroc, Pietrain were used, which, in combination with the Large White breed, supplied products to meat plants suitable for obtaining ribs, loin chops, as well as fast-food raw materials. Unfortunately, domestic lard and lard-meat breeds were liquidated in haste, although their products are necessary for the production of sausages. As a result, Russia is forced to purchase lard abroad in large quantities, although it had all the opportunities to produce higher-quality lard, as evidenced by the results of meat tasting of the Kemerovo and early-maturing meat (SM-1) breeds, with lower cholesterol content compared to Pietrain and other foreign hybrids. Studying the qualitative characteristics of pork products depending on feeding conditions, maintenance, interbreeding combinations is a prerogative topic for future joint research in applied and fundamental science [6]. Talented continuators of the school of famous Siberian pig breeders include A.G. Kryuchkovsky, V.A. Bekenev, A.P. Grishina, A.A. Arishin, and others.

Sheep farming developed more dramatically than other industries. Enormous effort was put into transforming Siberian indigenous coarse-wooled sheep into semi-fine and fine-wooled ones – suppliers of raw material for producing warm high-quality clothing. The best global producers from Australia, the Caucasus Republics, and the steppe zone of Ukraine were used as improving breeds. Altai fine-wooled, Transbaikal fine-wooled, Krasnoyarsk breeds, Siberian type of Soviet meat and wool breeds, and the mountainous Altai breed group were created. Work was carried out comprehensively across the entire Siberian region. Alongside breeding and improving sheep breeds, projects for pedigree sheep farms and fattening areas with elements of comprehensive mechanization were developed. Unjustified changes in energy prices had the most painful impact on sheep farming. From being a highly profitable sector of Siberian animal husbandry, producing a quarter of the fine wool volume, it turned into a loss-making one, with its cost exceeding the selling price by four times, leading to a sharp reduction in sheep population. For example, in agricultural enterprises of the Novosibirsk region, the number of sheep decreased by 51.3 times from 1990 to 2010 (from 600,000 heads to 11,700). However, small scientific teams of sheep breeders in Siberia continue their pioneering work, creating meat types and breeds of sheep. The Siberian school of sheep breeding is known throughout Russia. Figures such as S.S. Krymsky, V.Ya. Vovchenko, M.D. Chamukha, I.F. Nozdrachev, F.M. Dobrogorsky, A.E. Lushchenko, S.I. Sorozhuk, A.D. Volkov, who created the breeding base and technologies for the vast region, play a crucial role. Their role

will increase manifold with the development of complete processing of raw materials into warm woolen clothing, footwear, delicacy dairy, and meat products. Siberia, at its current pace of development, will require the restoration of the sheep farming industry. No synthetics in the Arctic winter can replace the clothing of military personnel, workers in extractive industries, reindeer herders, and other professions, not to mention natural food products. The vast territories of Siberia with diverse geobioclimatic conditions require breeders to create livestock herds not only with high productivity but also well-adapted to extreme local conditions, which foreign breeds do not possess.

There is a need to intensify breeding and technological work in yak breeding, reindeer husbandry, herd horse breeding, which are promising for Arctic regions, and to breed male sheep. Our scientists have also bred two fish breeds – Sarbayan carp and mirror carp (Z.A. Ivanova, I.V. Moruzi, V.A. Korovin).

Since 1970, a fundamentally new system of planning, organizing, and conducting comprehensive scientific research has been introduced in SibNIPTIZh and its branches, the idea of which belongs to Academician A.P. Kalashnikov. The research of scientists from various specialties focused on the development of technologies for milk, beef, pork production, and sheep farming products. More than 100 projects were developed, of which 18 were approved by the State Agrarian Industry of the RSFSR and recommended for mandatory use in agriculture. Based on this, the first mechanized dairy complex for 1200 cows, achieving a productivity of about 5,000 kg per lactation, was designed and built in the USSR at the Borovskoye state farm, which was an outstanding result for those times. More than 80 technical innovations were developed and implemented for mechanized farms of various livestock directions, 30 of which were included in the zonal and federal machinery systems with the organization of their production at industrial enterprises of the region. For the mentioned cycle of work, the institute's team was awarded by the Council of Ministers of the USSR and the Government of the Russian Federation (1975, 1991). Most of the institute's developments (413) are protected by author's certificates and patents.

As part of a large team of scientists (more than 30 research institutes and universities), SibNIPTIZh employees developed detailed feeding standards, which underwent three reprints and are still a handbook for livestock specialists, scientists, and students. Thanks to these standards, improved breeds of dairy cattle show productivity of over 6,000 kg of milk in many regions of Russia, with the growth of young animals during fattening reaching 650–700 g per day, and pigs – around 700 g. [7].

The feed base is of considerable importance, the quality of which was constantly worked on by institute scientists. The most complex problem of sugar deficit in feed, reaching 50%, was solved by SibNIPTIZh together with OOO "Sibbiopharm" through the production of feed syrup from grains little demanded by the population (rye, triticale, fodder wheat, barley). Equipment for these purposes allows solving the problem of dosing vitamins, trace elements, urea, and other low-volume components of rations [8]. From 1970 to 1975, the institute laid the foundation for the use of complete feed mixtures in animal husbandry, later widespread throughout the world.

The technology of preserving succulent feeds with electroactivated NaCl solution was approved by the Scientific and Technical Council of the Ministry of Agriculture of the Russian Federation in 1990 and spread throughout the Siberian region and Belarus. The equipment and raw materials (water, salt, electricity) were domestic and used in feed preparation for over 30 years. The institute's design bureau mastered the production of a wide range of equipment for feed preparation and animal husbandry: automated cow tie-ups, stall equipment, compound feed units, press oil separators, grain crushers, extruders, micronizers, thermoplastics, laboratory equipment for animals, and more. Thus, a technological breakthrough in animal feeding and management was achieved, which requires periodic improvement and renewal [10]. Digital technologies replaced the mentioned equipment: herd management programs, feeders, robotic milking machines, sensors for assessing the physiological condition of animals. Unfortu-

nately, years of underfunding of applied agricultural science led to a noticeable lag of domestic animal husbandry behind advanced foreign ones, especially in the field of breeding and production and processing technologies of livestock products.

During the years of the institute's operation, its employees have developed 10 breeds of farm animals (each requiring 25–30 years), 3 breed groups, 12 factory types, 5 factory lines and crosses, 4 varieties of fodder root crops, 6 livestock product production technologies, 3 feed preparation technologies, approved by the Scientific and Technical Councils of the State Agrarian Industry of the USSR and the RSFSR, 100 projects and project proposals for livestock farms, including those approved by the State Agrarian Industry of the RSFSR – 18, modernized and new technological means – 85, 29 handbooks and monographs have been published [11, 12].

SibNIPTIZh has made a significant contribution to the training of scientific personnel. 524 people have completed postgraduate studies at the institute, from 1976 to 2014, 549 dissertations were defended at the dissertation council of the institute, including 95 for the degree of Doctor of Sciences and 454 for the degree of Candidate of Sciences.

For scientific developments, SibNIPTIZh and its experimental production farm "Borovskoye" were awarded the Jubilee Honorary Badge of the Central Committee of the CPSU, the Presidium of the Supreme Soviet of the USSR, and the All-Union Central Council of Trade Unions (1979), the Order of "Badge of Honor" (1980), the passing Red Banner of the Council of Ministers of the RSFSR and the All-Union Central Council of Trade Unions (1982). For participation in regional, regional, and international exhibitions-fairs at the All-Union Exhibition of Achievements of the National Economy of the USSR and the All-Russian Exhibition Center of the Russian Federation, the scientific developments of the institute and their authors were awarded numerous silver and gold medals, diplomas, and certificates.

The listed achievements of the institute became possible thanks to the visionary leadership of prominent scientists: D.I. Petukhov (1930–1932), I.I. Vildman (1932–1934), Professor I.I. Ukhin (1934–1938), E.G. Mayorova (1938–1943), VASKhNIL Corresponding Member M.O. Simon (1943–1952 and 1955–1970), VASKhNIL Academician A.I. Ovsiannikov (1952–1955), Academician of the Russian Academy of Agricultural Sciences A.P. Kalashnikov (1970–1979), Corresponding Member of the Russian Academy of Agricultural Sciences M.D. Chamukha (1979–1989), Academician of the Russian Academy of Agricultural Sciences V.G. Gugli (1989–1998), Academician of the Russian Academy of Sciences V.A. Soloshenko (1998–2016). Since 2016, the institute has been headed by Doctor of Biological Sciences S.N. Mager.

As part of the Federal Scientific Center of the Russian Academy of Sciences, SibNIPTIZh will attempt to restore the coordination of scientific research in the field of animal husbandry throughout the network of scientific research institutions in Siberia, as it was before. The merger of the three academies under the auspices of the Russian Academy of Sciences with the subordination of all research institutes to the Presidium of the Russian Academy of Sciences and the restoration of the coordinating network of leading institutes creates prerequisites for expanding the spectrum of research, especially related to the quality of livestock products, with a reasonable combination of classical methods of animal science, the use of genomic technologies, and other fundamental discoveries applicable in animal husbandry.

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ВЛИЯНИЕ ПОЧВЕННЫХ УСЛОВИЙ НА СОСТОЯНИЕ ДРЕВЕСНЫХ НАСАЖДЕНИЙ В ЗЕЛЕНОЙ ЗОНЕ АСТАНЫ

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Создание и содержание зеленой зоны вокруг столицы Республики Казахстан – г. Астана – осложняется не только резко континентальным климатом, но и засоленностью почвы. В связи с этим для озеленения данных территорий выбирают растения, характеризующиеся устойчивостью к засухе, морозам и засолению почвы. Избежать или минимизировать воздействие негативных последствий при облесении засоленных участков можно, понимая суть механизмов, благодаря которым лесные деревья и кустарники способны выживать в таких условиях. Целью исследования являлось изучение содержания солей в почве под лесными культурами в зеленой зоне г. Астана и их влияния на состояние древесных растений. Объектами исследования стали искусственные насаждения вяза приземистого и клена ясенелистного 2015 года посадки. В качестве основного метода исследования использовали закладку пробных площадей в здоровых, ослабленных и погибших насаждениях. Клен ясенелистный оказался устойчивее к более высокому содержанию солей в почве, чем вяз приземистый. Установлено, что высокое содержание токсичных ионов и низкая концентрация катионов в почве связаны с состоянием культур, причем более токсичный тип засоления преобладает на участках с ослабленными и погибшими насаждениями. По результатам исследований видно, что почва здоровых участков отличается большим содержанием катионов Ca^{2+}, Mg^{2+} и Na^{+}, чем почва ослабленных насаждений. Анионы HCO_3^-, Cl^- и SO_4^{2-} присутствуют в значительном количестве в почве под ослабленными культурами, а содержание ионов HCO_3^- на участках с погибшими деревьями намного выше, что может быть одной из причин сильного засоления почвы и гибели растительности. Также было определено, что сульфатно-хлоридно-гидрокарбонатное засоление и магниево-кальциевый химизм с токсичностью более 0,17 мг-экв. HCO_3^- негативно влияют на состояние растений. На здоровых участках преобладает сульфатно-хлоридный тип засоления, в ослабленных и погибших насаждениях – более токсичный сульфатно-хлоридно-гидрокарбонатный тип.

Ключевые слова: содержание солей в почве, лесные культуры, вяз приземистый, клен ясенелистный, токсичные ионы, ослабленные и погибшие культуры, сульфатно-хлоридно-гидрокарбонатное засоление

EFFECT OF SOIL CONDITIONS ON THE STATE OF TREE PLANTATIONS IN THE GREEN ZONE OF ASTANA

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Creation and maintenance of a green zone around the capital of the Republic of Kazakhstan, Astana, is complicated not only by sharply continental climate, but also by soil salinity. In this regard, plants characterized by resistance to drought, frost and soil salinity are chosen for landscaping of these

areas. Avoiding or minimizing the impact of negative consequences of afforestation of saline areas can be achieved by understanding the mechanisms by which forest trees and shrubs are able to survive in such conditions. The purpose of the study was to investigate the salt content in the soil under forest crops in the green zone of the Astana city and their influence on the condition of woody plants. The objects of the study were artificial plantations of the dwarf elm and maple ash planted in 2015. The main research method used was the establishment of sample plots in healthy, weakened and dead plantations. Maple ash was found to be more tolerant to higher salt content in soil than the dwarf elm. It was found that high content of toxic ions and low concentration of cations in the soil are related to the condition of crops, with more toxic type of salinization prevailing in the areas with weakened and dead plantations. According to the research results, it can be seen that the soil of healthy plots is characterized by a higher content of Ca^{2+}, Mg^{2+} and Na^{+} cations than the soil of the weakened plantations. HCO_3^-, Cl^- and SO_4^{2-} anions are present in significant amounts in the soil under weakened crops, and the content of HCO_3^- ions is much higher in the areas with dead trees, which may be one of the reasons for severe soil salinization and vegetation death. It was also determined that sulfate-chloride-hydrocarbonate salinization and magnesium-calcium chemistry with toxicity greater than 0.17 mg-eq HCO_3^- negatively affected plant health. Sulfate-chloride type of salinization prevails on the healthy plots, in the weakened and dead plantations – the more toxic sulfate-chloride-hydrocarbonate type is found.

Keywords: soil salt content, forest crops, dwarf elm, maple ash, toxic ions, weakened and dead crops, sulfate-chloride-hydrocarbonate salinization

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INTRODUCTION

Creating and maintaining a green zone around the capital of Kazakhstan, Astana, is complicated not only by the sharply continental climate but also by soil salinity. To minimize the impact of adverse soil-climatic factors, a certain assortment of plants resistant to drought, frost, and soil salinity is selected. At the same time, the presence of toxic salts in the soil has a certain influence on the growth and condition of adapted tree and shrub species. Avoiding negative consequences when afforesting saline areas can be achieved by having a sufficient understanding of the mechanisms through which forest cultures of the used trees and shrubs can survive in these conditions [1].

Soil salinization weakens plants and increases their susceptibility to diseases [2], being one of the most significant stress factors adversely affecting growth and development. This leads to changes in the morphology and biochemical characteristics of plants, disrupts nitrogen metabolism[1]. Increased osmotic pressure, alkaline soil reaction, toxicity of readily soluble salts,

[1]*Anisova Zh.M., Sak M.M., Budkevich T.A., Yakushev B.I.* Exogenous regulation of mineral nutrition of coniferous and deciduous species under saline conditions // Mechanisms of resistance of plants and microorganisms to adverse environmental conditions: proceedings of the Annual Meeting of the Society of Plant Physiologists of Russia, All-Russian scientific conference with international participation and school of young scientists. Irkutsk, 2018, vol. 2, pp. 1029-1033.

and poor soil water-physical properties also contribute to the negative impact on plants. As a result, the availability of macro- and micronutrients decreases, mineral starvation occurs, susceptibility to pathogens and pests increases, which, in turn, leads to a decrease in plant survival and potential soil fertility[2][3, 4]. Climate aridization, promoting salt accumulation, also has a significant impact on soil salinization [5, 6]. In addition, ions contained in saline soils can have a toxic effect on plants, which is another negative effect of salinization [7, 8].

Bacteria and fungi positively affect the growth and resistance of plants growing on saline soils [9], but anthropogenic impact on surface humus reduces the activity of soil microorganisms [10].

It is widely recognized that the ecological condition, growth, and development of plantations are largely determined by a complex of various chemical and physical soil properties. The interaction of natural and anthropogenic factors leads to changes in the soil surface and the formation of sharp boundaries between horizons, which can negatively affect the condition of trees and shrubs, especially in arid climates [11, 12].

As indicated by literary sources, not only a dry climate affects soil salinization but also conditions of increased humidity due to the rise of groundwater levels. Under such conditions, the development of degradation processes, such as secondary salinization and salt crust formation, is possible [13].

Based on the above, it can be concluded that in the green zone of Astana, chemical amelioration is necessary, as well as the application of organic and mineral fertilizers to improve soil fertility and quality.

MATERIAL AND METHODS

The purpose of the study is to determine the salt content in the soil under forest crops in the green zone of Astana.

The object of the study is forest crops of dwarf elm (*Ulmus pumila* L.) and maple ash (*Acer negundo* L.) planted in 2015. The main research method was the laying of test plots in areas of forest crops. Test plots were laid out in the areas with healthy, weakened, and dead plantations, the categories of which were initially determined visually based on the condition of the trees, and then confirmed based on the methodology for determining viability by V.A. Alexeyev[3] with the help of a formula

$$H = \frac{100n_1 + 70n_2 + 40n_3 + 4n_4}{N}, \quad (1)$$

where H – relative vitality of the stand, %; n_1 – number of healthy trees, pcs.; n_2 – number of weakened trees, pcs.; n_3 – number of severely weakened trees, pcs.; n_4 – number of dying trees, pcs.; N – total number of the trees in the test plot, pcs.

A stand was considered healthy if it had a vitality index of 80 to 100, weakened if it had a vitality index of 50 to 79, and severely weakened if it had a vitality index of 20 to 49.

Soil pits were dug to the depth of the root zone layer (up to 60 cm) in triplicate on each test plot. Soil samples from the pits were sent for water-chemical analysis to the Kazakh Research Institute of Soil Science and Agrochemistry named after U.U. Uspanov. In the chamber conditions, based on the results of the analysis of water extraction (1:5), an assessment of saline soils was carried out, based on two criteria: the type of salinization and the degree of soil salinization under plantations characterized by different degrees of weakening[4, 5].

[2]*Ingole S.P.* A review on role of physicochemical properties in soil quality // Chemical science review and letters, 2015, vol. 4, pp. 57−66.

[3]*Alekseev V.A., Chertov O.G., Sergeichik G.A.* Forest ecosystems and atmospheric pollution. L.: Nauka, 1990, 200 p.

[4]*Bazilevich N.I., Pankova E.I.* Experience of soil classification by salinization // Eurasian Soil Science, 1968, N 11, p. 316.

[5]*Bazilevich N.I., Pankova E.I.* Experience of soil classification by the content of toxic salts and ions // Dokuchaev Soil Bulletin, 1972, N 5, pp. 36-42.

When determining the types of soil salinity, some authors use ratios of anions in water extraction (Cl^-/SO_4^{2-}, $HCO_3^-/Cl^- + SO_4^{2-}$), while others find it more convenient to use percentage ratios of anions[6]. Only those anions whose content exceeds 20.0% of the sum of the equivalent weight of substances (mg-equiv.) are proposed to be included in the name of the salinity type. In this case, the dominant anions are listed last in the name.

In this study, we used a classification of nine types of soil salinity based on the anion composition. If the soil contained CO_3^{2-} ions in an amount of less than 20.0% of the sum of the equivalent weight of anions, but more than 0.03 mg-equiv./100 g of soil (the toxicity threshold of CO_3^{2-}), then the name of the salinity was selected according to the determined type. Toxic salt calculations were made depending on the presence of bicarbonate soda exceeding the toxicity threshold of HCO_3 ions (0.8 mg-equiv.). If the elevated content of HCO_3 was due to the presence of Mg $(HCO_3)_2$, the salinity type was determined as hydrocarbonate one.

The determination of the soil salinity chemical behavior based on the anion composition was supplemented with the data on the composition of cations. The division of soil salinity chemistry based on the cation composition within the methodology of N.I. Bazilevich, E.I. Pankova was based on the ratios of individual cations, not their sum ($Na^+ + K^+$ к $Ca^{2+} + Mg^{2+}$), since all Mg salts are considered toxic.

N.I. Bazilevich, E.I. Pankova and other authors[7, 8] [14] proposed to evaluate the chemical behavior and degree of soil salinity based on the content of toxic ions, expressed as a percentage of the mass of absolutely dry soil.

The content of toxic salts was determined by the following formula [14] (see footnotes 7, 8):

$$\omega = c \cdot K, \quad (2)$$

where ω – mass fraction of toxic salts, % of the mass of absolutely dry soil; c – concentration of the ion being determined, mol (equiv.)/100 g of soil; K – dimensionless conversion coefficient depending on the type of ion: $K(CO_3^{2-}) = 0,03$; $K(HCO_3^-) = 0,061$; $K(Cl^-) = 0,0355$; $K(SO_4^{2-}) = 0,048$; $K(Na^+) = 0,023$; $K(Ca^{2+}) = 0,0204$; $K(Mg^{2+}) = 0,0122$.

RESULTS AND DISCUSSION

In Figure 1, it is visually evident that with an increase in the sum of salts, the growing conditions become extreme, leading to the death of trees. The average values of salt content range from 0.044 to 0.071% in the soil under the dwarf elm stands and from 0.048 to 0.065% under the maple ash stands.

The minimum values of salt content range from 0.014 to 0.022%, while the maximum values range from 0.069 to 0.108%. Therefore, the magnitude of the sum of salts in the soil affecting the condition of the dwarf elm and the maple ash stands is similar. However, maple ash can withstand a higher content of salt in the soil compared to dwarf elm. It can also be noted that the concentration of salts in the soil significantly affects the condition of the plants (healthy, weakened, or dead): healthy plantations grow on soils characterized by lower salt content, while with an increase in salt content, trees weaken and die.

It was found that in the areas occupied by the maple ash stands, the predominant type of soil salinity is sulfate-chloride-hydrocarbonate, accounting for 83.3% on all the test plots regardless of the condition of the stands. The second type of salinity is sulfate-soda (10.0%). The share of sulfate and sulfate-chloride types is 3.3% each. In the areas with healthy stands, the sulfate-chloride-hydrocarbonate type predominates (84.6%), while in weakened stands, sulfate-chloride-hydrocarbonate (70.0%) and sulfate-soda (30.0%) are predominant. In the areas

[6] *Egorov V.V., Ivanova E.N., Friedland V.M.* Classification and diagnostics of soils of the USSR. Moscow: Kolos, 1977, 225 p.

[7] *Pankova E.I., Vorobyeva L.A., Gadzhiev I.M.* Saline Soils of Russia. Moscow: Akademkniga, 2006, 854 p.

[8] Manual on saline soil management / Edited by R. Vargas, E.I. Pankova, S.A. Balyuk, P.V. Krasilnikov, G.M. Hasankhanova; Food and Agriculture Organization of the United Nations, Rome, 2017, 153 p.

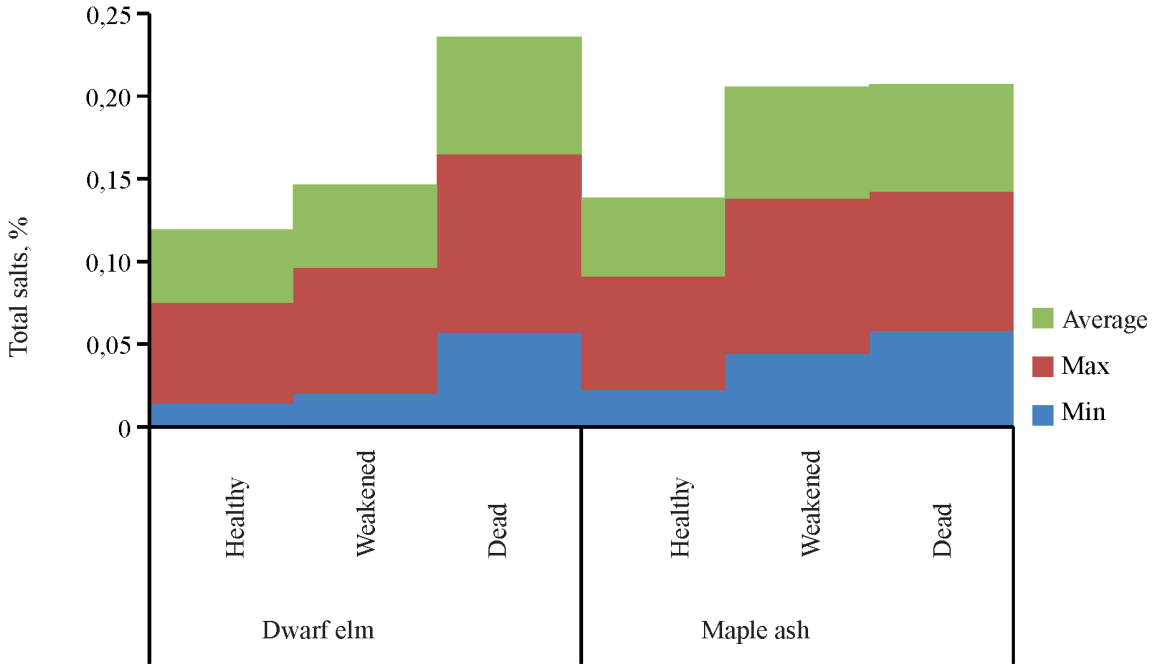

Рис. 1. Сумма солей в почве под лесными культурами *Ulmus pumila* L. и *Acer negundo* L. различного состояния

Fig. 1. The amount of salts in the soil under forest crops of *Ulmus pumila* L. and *Acer negundo* L. of various states

with dead maple ash stands, 100% sulfate-chloride-hydrocarbonate salinity is observed.

It was established that the soils under stands with the vitality categories "weakened" and "dead" are characterized by a high content of toxic ions (Na^+, HCO_3^-, SO_4^{2-}) and a lower level of cations (Ca^{2+}, Mg^{2+}) (see Fig. 2). In particular, the "dead stand" category has the highest levels of some of these ions in the soil, which may negatively affect the growth and health of plants. Calcium cation Ca^{2+} is more common in the soil under healthy trees, while sodium cation Na^+ predominates under weakened and dead stands. Regardless of the category, bicarbonate anion HCO_3^- is most frequently found in the soil, while under weakened and dead stands, chloride anion Cl^- predominates. The content of all these soil components under weakened and dead cultures is higher than under healthy plants, except for bicarbonate anion HCO_3^-, the concentration of which was lower in areas with dead stands than in healthy ones.

It was determined that $CO_3^{2-}$is only present in the areas with healthy stands, where it has a concentration ranging from 0.03 to 0.04 mg-equiv., indicating that this anion is not a significant component deteriorating the condition of maple ash (see Table 1).

Therefore, the quantity of ions in the soil, especially the high content of some of them, such as Na^+, HCO_3^- and и SO_4^{2-}, may indicate negative consequences for the growth and health of plants. It is also noteworthy that the cation Ca^{2+} is most prevalent in the soils in healthy areas, while in the areas with weakened and dead stands, the cation Na^+ predominates. The negative charge is highest for the HCO_3^- anion in the areas with weakened and dead stands, and for the Cl^- anion in healthy areas. The content of all components in the soil under weakened and dead trees is higher than in healthy areas, which may be associated with more intensive chemical processes in the soils with reduced fertility. However, the content of the HCO_3^- anion in the soils under dead plants is higher than in the soils under healthy cultures. It can be assumed that intensive decomposition of organic matter (leaves, branches, etc.) occurs in healthy areas, leading to a decrease in soil pH and a reduction in the content of this anion.

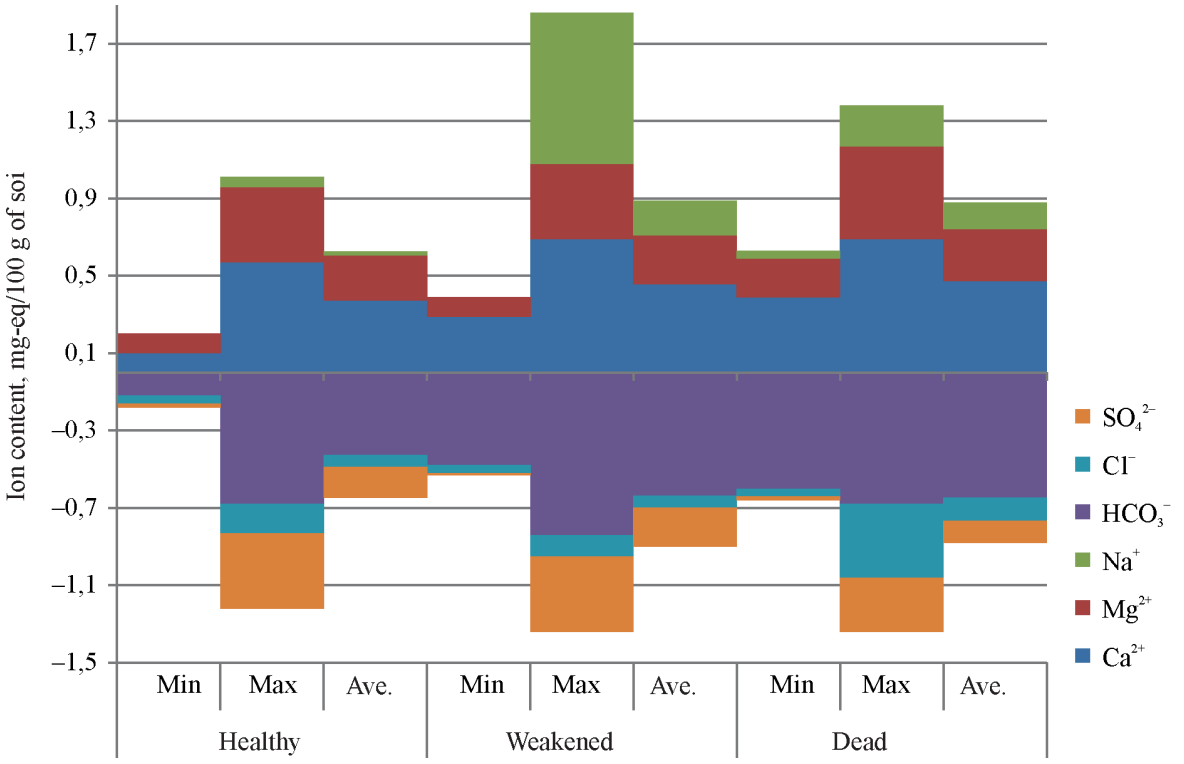

Рис. 2. Содержание легкорастворимых солей в почве под лесными культурами *Acer negundo* L. различного состояния

Fig. 2. Content of easily soluble salts in the soil under forest crops of *Acer negundo* L. of different condition

Табл. 1. Результаты анализа водной вытяжки почвы под лесными культурами *Acer negundo* L., мг-экв./100 г почвы

Table 1. Results of the analysis of soil water extract under forest crops of *Acer negundo* L., mg-eq/100 g of soil

Stand condition	Amount	Chemical element						
		Ca^{2+}	Mg^{2+}	Na^+	HCO_3^-	Cl^-	SO_4^{2-}	CO_3
Healthy	Min	0,100	0,100	0,000	0,120	0,040	0,020	–
	Max	0,570	0,390	0,050	0,680	0,150	0,390	0,040
	Average	0,373	0,232	0,022	0,428	0,061	0,159	0,003
Weakened	Min	0,290	0,100	0,000	0,480	0,040	0,010	–
	Max	0,690	0,390	0,780	0,840	0,110	0,390	–
	Average	0,458	0,253	0,176	0,636	0,062	0,203	–
Dying	Min	0,390	0,200	0,040	0,600	0,040	0,020	–
	Max	0,690	0,480	0,210	0,680	0,380	0,280	–
	Average	0,474	0,267	0,139	0,646	0,120	0,114	–

Furthermore, the degree of soil salinity was determined by isolating toxic ions from the total salt content (see Table 2). According to the results of the calculation of the sum of toxic salts, the degree of salinity was determined depending on the soil salinity chemical behavior on test plots of maple ash. It was found that in the soils under healthy forest stands, the ion content was 0.05 mg-equiv., indicating non-saline soils. In the test areas with weakened and dead stands, the content of HCO_3^- ions was higher, at 0.18 and 0.17 mg-equiv. respectively, indicating the presence of weak salinity.

Based on the obtained data, it can be assumed that sulfate-chloride-hydrocarbonate salinity by anion composition and magnesium-calcium chemical behavior by cation composition with a toxicity of more than 0.17 mg-equiv. HCO_3 negatively affect the condition of maple ash causing its weakening. However, to determine the exact cause of the deterioration of the plant condition, further research is needed, taking into account other factors such as soil physicochemical properties, climatic conditions, and the level and mineralization of groundwater.

From Figure 3 and Table 3, it can be seen that the content of readily soluble salts in the soil varies in areas with stands in different conditions. The content of Ca^{2+}, Mg^{2+} and Na^+ cations in the soil under healthy stands is higher than in the soils where weakened trees grow.

Anions HCO_3^-, Cl^- and SO_4^{2-} are present in greater quantities in the soils under weakened stands. In the soils under dead stands, the content of Ca^{2+}, Mg^{2+} and Cl^- ions is significantly lower, while Na^+, HCO_3^- and SO_4^{2-} are higher than in the soils where healthy and weakened cultures grow. Additionally, the soils under dead trees contain a small amount of the toxic ion CO_3^{2-}, which is absent in the areas with healthy and weakened plants.

It has been identified that in the areas occupied by forest stands of dwarf elm the most common type of salinization is sulfate-chloride-hydrocarbonate (72.2% of the total). In the areas with weakened and dead dwarf elm trees, the percentage of sulfate-chloride-hydrocarbonate salinization is lower than in the healthy areas, at 75.0%, 42.9%, and 84.6%, respectively. In equal proportions, sulfate and sulfate-chloride salinization is found in soils under healthy cultures (7.7% each). Areas with weakened stands are characterized by the prevalence of chloride-sodium and sulfate-sodium salinization (6.3% each), as well as sulfate salinization (12.5%). On the plots with dead dwarf elm trees, sulfate-sodium (42.9%) and chloride-sodium salinization (14.3%) are observed.

It has been established that in test areas with dead dwarf elm trees, there is strong salinization (0.39 mg-equiv.), while the soils under healthy and weakened cultures are not saline, with the

Табл. 2. Степень засоления почв по содержанию токсичных солей и сумме всех солей в зависимости от химизма засоления

Table 2. The degree of salinization of soils by the content of toxic salts and by the sum of all salts depending on the chemistry of salinization

Wood species	Stand condition	HCO_3 (toxic), mg-eq.	The sum of toxic salts, %	Degree of soil salinization by the sum of toxic salts
Dwarf elm	Healthy	0,08	0,09	Nonsaline
	Weakened	0,11	0,12	»
	Dead	0,39	0,41	Highly saline
Maple ash	Healthy	0,05	0,07	Nonsaline
	Weakened	0,18	0,20	Slightly saline
	Dead	0,17	0,19	»

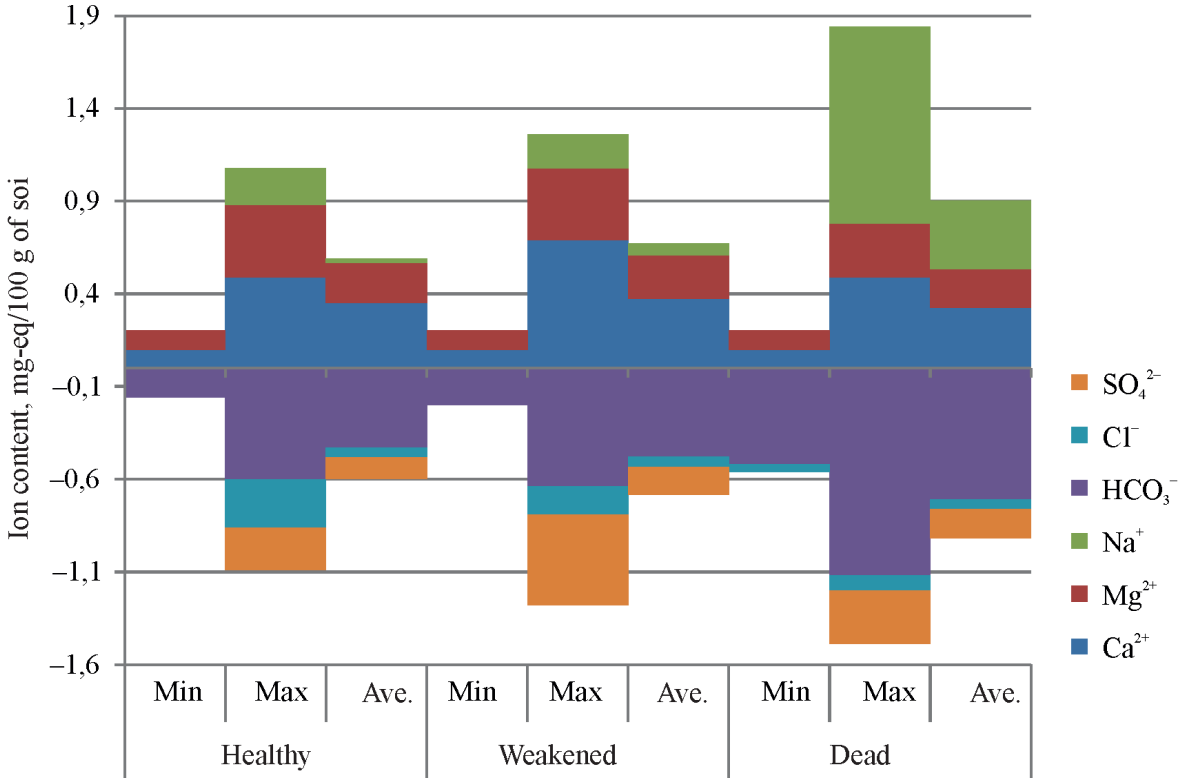

Рис. 3. Содержание токсичных солей в почве под лесными культурами *Ulmus pumila* L. различного состояния

Fig. 3. Content of toxic salts in the soil under forest crops of *Ulmus pumila* L. of different condition

Табл. 3. Результаты анализа водной вытяжки почвы под лесными культурами *Ulmus pumila* L., мг-экв./100 г почвы

Table 3. Results of the analysis of soil water extract under forest crops *Ulmus pumila* L., mg-eq/100 g of soil

Stand condition	Amount	Chemical element						
		Ca^{2+}	Mg^{2+}	Na^+	HCO_3^-	Cl^-	SO_4^{2-}	CO_3
Healthy	Min	0,100	0,100	0,000	0,160	0,000	0,000	–
	Max	0,490	0,390	0,200	0,600	0,260	0,230	–
	Average	0,349	0,218	0,023	0,431	0,052	0,116	–
Weakened	Min	0,100	0,100	0,000	0,200	0,000	0,000	–
	Max	0,690	0,390	0,180	0,640	0,150	0,490	–
	Average	0,371	0,238	0,063	0,480	0,055	0,148	–
Dying	Min	0,100	0,100	0,000	0,520	0,040	0,000	–
	Max	0,490	0,290	1,060	1,120	0,080	0,290	0,080
	Average	0,323	0,211	0,367	0,709	0,051	0,157	0,017

content of HCO_3^- ions in them being 0.08 and 0.11 mg-equiv., respectively. This indicates that the high content of HCO3– ions in the test areas with dead stands may be one of the reasons for strong salinization, which, in turn, leads to the death of vegetation.

Based on the presented results, it can be assumed that the degree of salinization determines the change in the condition of woody vegetation. In the soil under weakened and dead cultures, the more toxic sulfate-chloride-hydrocarbonate type of salinization predominates, while in the soil under healthy stands, the sulfate-chloride type predominates. Additionally, in the areas with weakened and dead plants, a higher percentage of soil salinization is observed compared to healthy stands. It is also worth noting that the soils under weakened and dead trees contain a greater amount of toxic salts (chlorides and sulfates) than in the areas with healthy cultures.

Therefore, measures need to be taken to protect and restore the soil cover in forest management areas, and systematic monitoring of soil conditions should be carried out to timely identify and mitigate the negative consequences of anthropogenic impact on the environment.

CONCLUSION

The quantity of anions and cations significantly affects the viability of forest cultures of woody plants. The main ions affecting the degree of soil salinity under forest stands in the green zone of Astana are Ca^{2+}, Mg^{2+}, Na^+, HCO_3^-, Cl^-, SO_4^{2-}. The content of these ions on the test plots differs from their content in areas with healthy cultures.

It cannot be unequivocally stated that the content of salts serves as the sole cause of weakening and death of stands. Many other factors, including planting technology disruption, untimely care, damage by pests and diseases, as well as anthropogenic factors, also affect the deterioration of plant condition. Nevertheless, soil salinity and fertility play a fundamental role in the preservation, stability, and growth of forest cultures in the green zone of Astana.

To increase soil fertility and reduce the degree of salinity, regular monitoring, the application of proper soil cultivation and treatment systems, and the implementation of ameliorative measures are necessary.

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ИСПОЛЬЗОВАНИЕ МАШИННОГО ОБУЧЕНИЯ И ВЕГЕТАЦИОННЫХ ИНДЕКСОВ ДЛЯ ПРОГНОЗИРОВАНИЯ УРОЖАЙНОСТИ ЯРОВОЙ ПШЕНИЦЫ

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Представлены результаты исследования по разработке и оценке точности предиктивных моделей урожайности яровой пшеницы на основе использования данных дистанционного зондирования Земли и методов машинного обучения. В работе использованы данные урожайности яровой пшеницы сорта Новосибирская 31, полученные в полевом опыте в центральной лесостепи Новосибирской области в 2019–2022 гг. При создании моделей учитывались как качественные предикторы (уровень интенсификации агротехнологий), так и количественные (атмосферные осадки в критические фазы развития растений пшеницы и показатели вегетационных индексов, характеризующих состояние посевов). Использование различных методов интеллектуального анализа данных, а также сочетание параметрических и непараметрических подходов в исследовании обеспечили достаточно высокую точность прогнозирования урожайности яровой пшеницы. Для прогнозирования урожайности яровой пшеницы использовали методы, включающие линейную регрессию, нелинейную модель на основе регрессионного сплайна (Regression Splines), дерево решений (CART), случайный лес (Random Forest), адаптивный бустинг (AdaBoost) и градиентный бустинг (Gradient Boosting). Установлено, что модели на основе алгоритмов случайный лес, градиентный и адаптивный бустинги характеризовались наиболее высокими прогностическими возможностями урожайности культуры в зависимости от складывающихся условий вегетации и управляющего воздействия (R^2 = 0,74–0,80). Разработка предиктивных моделей урожайности с использованием дистанционного зондирования Земли и машинного обучения представляют определенную научную новизну и практическую значимость для эффективного управления продуктивностью посевов в изменяющихся почвенно-климатических и хозяйственных условиях. Прогнозное моделирование сталкивается с многоуровневой неопределенностью окружающей среды и высокой вариативностью результирующих показателей на конкретном земельном участке. В связи с этим многоуровневый подход может представлять перспективное решение для эффективного прогнозирования урожайности яровой пшеницы.

Ключевые слова: вегетационные индексы, дистанционное зондирование, машинное обучение, урожайность яровой пшеницы, уровень интенсификации

UTILIZING MACHINE LEARNING AND VEGETATION INDICES FOR SPRING WHEAT YIELD FORECASTING

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The results of research on the development and assessment of the accuracy of predictive models of spring wheat yield based on the use of remote sensing data and machine learning methods are presented. Yield data of spring wheat variety Novosibirskaya 31 obtained in a field experiment in the central forest-steppe of the Novosibirsk region in 2019–2022 were used in this work. Both qualitative predictors (the level of agrotechnologies intensification) and quantitative predictors (atmospheric precipitation in critical phases of wheat plant development and indicators of vegetation indices characterizing the condition of crops) were taken into account when creating the models. The use of various methods of intellectual data analysis, as well as the combination of parametric and non-parametric approaches in the study provided a sufficiently high accuracy of spring wheat yield forecasting. The methods used

to predict spring wheat yield included linear regression, nonlinear Regression Splines based model, decision tree (CART), Random Forest, Adaptive Boosting (AdaBoost) and Gradient boosting. It was found that the models based on random forest, gradient and adaptive boosting algorithms were characterized by the highest predictive capabilities of crop yield depending on the emerging conditions of vegetation and controlling influence (R^2 = 0.74–0.80). The development of predictive yield models using remote sensing and machine learning represent a certain scientific novelty and practical significance for effective management of crop productivity in changing soil-climatic and economic conditions. Predictive modeling is faced with multilevel environmental uncertainty and high variability of the resulting indicators on a particular land plot. In this regard, the multilevel approach may represent a promising solution for effective forecasting of spring wheat yield.

Keywords: vegetation indices, remote sensing, machine learning, spring wheat yield, level of intensification

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The authors declare no conflict of interest.

INTRODUCTION

The yield of agricultural crops is one of the most important indicators of agricultural production. Yield forecasting allows for the optimization of processes involved in cultivating agricultural crops and facilitates informed decision-making in planning agricultural technologies used in farming. Currently, remote sensing of the Earth is actively employed for spatial assessment of vegetation conditions. The utilization of electromagnetic radiation spectra in the visible and infrared regions is successfully applied for monitoring vegetation cover, soil moisture, nitrogen deficiency, and crop yield [1, 2].

In particular, vegetation indices such as Normalized Difference Vegetation Index (NDVI) and Normalized Difference Moisture Index (NDMI) [1, 2] are widely used for assessing the condition of agricultural crops [3–7]. NDVI is a combination of the reflectance coefficient in the visible and near-infrared regions (VIS-NIR), associated with the absorption of specific solar radiation during photosynthesis. Its magnitude is primarily determined by the type of underlying surface, and changes in the index indicate the influence of adverse weather conditions, damage by pests and diseases, or inadequate nutrient supply [8]. Measuring NDVI is crucial for monitoring and managing crop productivity since changes in this indicator are closely related to plant growth processes, yield, and enable the assessment of areas with anomalous crop development. An important characteristic of NDVI is that changes in index values become more noticeable in arid vegetation conditions due to its close relationship with crop moisture levels[3] [9, 10]. In addition to NDVI, NDMI is used for a

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more accurate assessment of overall crop moisture levels. This index provides an indicator to evaluate the degree of vegetation water stress[4, 5].

The drawback of the vegetation indices is that they provide indirect information about actual crop yields. To improve the accuracy of agricultural crop yield forecasting, it is necessary to use not only vegetation indices but also additional information about the environment and management interventions. In this case, it is advisable to utilize machine learning capabilities when forming predictive models of crop yield, as one of the branches of artificial intelligence. Among the most well-known and applied machine learning algorithms are neural networks (NN), random forest (RF), support vector machine (SVM), and extreme gradient boosting (XGB). These models utilize meteorological data, management methods, and vegetation indices [11–13]. Overall, a comparative analysis of predictive models of spring wheat yield using vegetation indices and machine learning can be useful for determining the most effective approach to substantiating optimal management interventions.

The purpose of the research is to develop models for predicting spring wheat yield based on field experiment data, remote sensing of the Earth, and the application of machine learning methods.

MATERIAL AND METHODS

To build machine learning models, data on the yield of spring wheat variety Novosibirskaya 31 obtained from 2019 to 2022 in field stationary experiments conducted at the Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences (SFSCA RAS) were utilized. The experiment was located at the Elitnaya Experimental Farm of the SFSCA RAS in the central forest-steppe of the Novosibirsk region (54°55'27.45" N, 82°57'14.05" E). The soil of the experimental site is classified as medium loamy calcareous chernozem, medium-humic. The experiment consisted of continuous sowing of spring wheat cultivated at two levels of intensification, conventionally characterized as low-intensity (annual application of a starter dose of N_{30}) and high-intensity (application of N_{60} targeting the planned yield). The experiment employed a complex of plant protection measures against weeds, pests, and diseases (herbicides, fungicides, and insecticides). Primary soil tillage was performed using SibIME plows to a depth of 25–27 cm.

Remote sensing data of spring wheat crops, available in the public domain, were obtained using sentinel-hub (https://www.sentinel-hub.com) from the Sentinel-2 satellite with high spatial resolution (10 m). Multi-zone satellite images consist of 13 spectral channels with resolutions of 10, 30, and 60 m. For analysis, images acquired in June and July of each observation year were utilized, with the following spectral ranges: red – 650.0–680.0 nm, infrared – 784.5–899.5 nm, and short-wave infrared – 1564.5–1654.5 nm. Processing of the obtained materials (36 cloud-free images) was conducted using QGIS with open architecture (https://qgis.org/ru/site/). Normalized Difference Vegetation Index (NDVI) and Normalized Difference Moisture Index (NDMI) were used to visualize the vegetation condition and moisture content of crops.

NDVI is a relative value representing the ratio of the difference in spectral reflectance of the Earth's surface in the near-infrared (NIR) and red (Red) ranges to their sum:

$$NDVI = \frac{NIR - Red}{NIR + Red}.$$

NDVI is an indicator of radiative heat exchange; however, due to its high correlation with the amount of green biomass, it is used as an indicator of vegetation cover condition. At the same time, it is an indicator of the total amount and condition of agrocenosis biomass, not the

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yield of agricultural crops. Research shows that a larger biomass does not always correspond to high yield.

NDMI indicates the moisture content in plants and is determined as the ratio between the difference and the sum of the refracted radiation in the near-infrared (NIR) and short-wave infrared (SWIR) regions. It is a reliable indicator of the level of water stress in agricultural crops and is calculated by the formula

$$NDMI = \frac{NIR - SWIR}{NIR + SWIR}.$$

The value of the moisture content indicator in plant leaves is a key indicator for assessing hydration levels. Interpretation of the absolute value of NDMI allows the identification of agricultural crops experiencing water stress. One of the factors significantly affecting the accuracy of determining moisture content in plants is deviations caused by leaf internal structure and dry matter content. However, the combination of NIR and SWIR allows for the elimination of these deviations and increases the accuracy of moisture determination [14]. The amount of water present in the internal leaf structure plays a key role in controlling the spectral reflectance capability of the sample. Therefore, NDMI was used to assess the moisture level of wheat crops. The values of the mentioned indices range from -1 to 1.

To account for atmospheric humidity, meteorological data from the Ogurtsovo weather station located 1 km from the experimental site (http://www.pogodaiklimat.ru/monitor.php) were utilized. Moisture conditions during the growing seasons were considered in three temporal periods corresponding to the stages of spring wheat development: the first period – germination to tillering (late May to mid-June), the second period – tillering to stem elongation (late June to early July), and the third period – stem elongation to flowering (late July). Atmospheric moisture during these periods varied across the study years. For instance, in 2019 and 2020, there was a high level of moisture (precipitation exceeded the multi-year average) during all periods. In 2021 and 2022, the first period was dry, the second period relatively moist, and the third period dry during the crop vegetation (see Table 1).

The choice of statistical analysis methods was driven by the relatively small sample size, data distribution not conforming to the normal distribution law, and the presence of both qualitative and quantitative factors. To confirm the assumption of a relationship between spring wheat yield and atmospheric moisture, vegetation indices, and intensification background, and to determine the degree of deviation of probability distribution from normality, several statistical tests were conducted: Shapiro–Wilk, Lilliefors tests, and Q-Q plots. Pairwise comparisons of data variants in the experiment were performed using the non-parametric Mann–Whitney test. Spearman's rank correlation coefficient, analysis of variance (ANOVA), and principal component analysis (PCA) were applied to assess the relationship between spring wheat yield and quantitative characteristics. The significance level (p-value) was assessed at 0.05. Box plots were constructed to visualize the structure of the raw data and analysis results.

During the study, a group of models was built, including linear regression, a nonlinear model based on regression splines, decision tree (CART algorithm), random forest (RF algorithm), adaptive boosting (AdaBoost algorithm), and gradient boosting (Gradient Boosting algorithm). The original database consisted of 448 observations, which were divided into training and test samples in the ratio of 80 and 20% respectively.

Statistical calculations and graphical plots were performed using the Python programming language in the Jupyter interactive notebook and statistical computing and graphics language R in the integrated development environment R-Studio.

RESULTS AND DISCUSSION

The yield of spring wheat in the experiments varied depending on the year of the study and the level of intensification of cultivation techniques (see Fig. 1).

On average over the years of observation, the crop yield at the low-intensity level was 2.1 t/ha,

Табл. 1. Условия атмосферного увлажнения по периодам вегетации яровой пшеницы, мм
Table 1. Conditions of atmospheric moistening by periods of spring wheat vegetation, mm

Year	Spring wheat vegetation period			Total precipitation (III ten-day period of May-July)
	1st	2nd	3rd	
2019	63	36	66	165
2020	55	32	54	141
2021	32	66	4	102
2022	39	49	21	109
Average annual amount	47	36	46	129

Note. Here and in Table 2. 1st period – sum of precipitation for the third ten-day period of May and I-II ten-day periods of June; 2nd period – sum of precipitation for the third ten-day period of June and I ten-day period of July; 3rd period – sum of precipitation for the second and third ten-day periods of July.

while at the high-intensity level, it was 3.2 t/ha. The lowest and highest yield values were recorded in 2019 and 2020, at 1.2 t/ha for the low-intensity level and 4.2 t/ha for the high-intensity level, respectively. The least variability in spring wheat yield was observed at the low-intensity level in 2021 and 2022, with a minimum yield of 1.4 t/ha and a maximum of 2.6 t/ha. At the high-intensity level, the least variability was observed in 2020 and 2022, with a minimum grain yield of 3.0 t/ha and a maximum of 3.7 t/ha. Such fluctuations in spring wheat yield are explained by natural factors, primarily quantitative changes in atmospheric moisture. For example, the low yield in 2019 was due to atmospheric drought in June, when precipitation was 47% of the multi-year average, and low mean daily air temperatures of 15.4 and 16.9°C. The decrease in yield in 2021, regardless of the level of intensification, may have been influenced by the atmospheric moisture conditions during the early spring period.

The average values of vegetation indices over the years of study in June varied during the vegetation period from 0.4 NDVI units and 0.1 NDMI units. In July, NDVI values increased in all years of study due to biomass accumulation and averaged 0.7 units. NDMI values varied from 0.2 to 0.6 units during the study years due to changes in plant moisture content.

To create yield forecasting models, various factors influencing model accuracy must be considered. Identifying these factors and selecting the most informative predictors is a key step in improving predictive models' accuracy. Several methods are applied for these purposes. For example, the analysis of variance (ANOVA) method, used for preliminary data processing, helps determine the statistical significance of differences between factor groups. However, besides ANOVA, other methods can be used for preliminary data processing. For instance, principal component analysis (PCA) allows reducing the dimensionality of the original dataset by creating new variables that are linear combinations of the original variables[6]. Such an approach retains the maximum amount of information while reducing its volume, simplifying the analysis and processing of the original data.

Various methods were used to identify the most significant factors influencing crop yield under the analyzed conditions and to include them in the formation of spring wheat yield models. The results of the preliminary processing of the data sample are presented in Table 2.

A significant contribution determining the importance of influencing factors on crop yield was made by the level of intensification of cultivation technologies. With an increase in the level of intensification, including through in-

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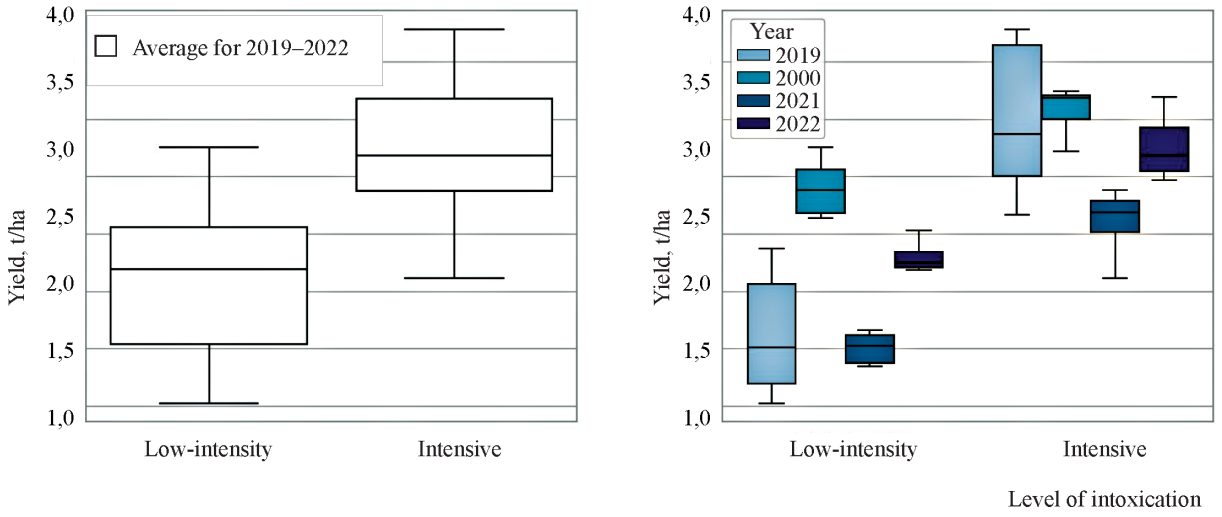

Рис. 1. Диаграмма размахов значений урожайности яровой пшеницы

На рисунке центральная линия показывает значение медианы, границы прямоугольника соответствуют значениям нижней и верхней квартилям (25 и 75 процентилям), ширина прямоугольника – размер выборочной совокупности, высота прямоугольника – интерквартильный размах (ИКР), длина верхних (нижних) «усов» диаграммы показывают границы распространения наибольшего (наименьшего) значения, находящегося в пределах 1,5 × ИКР.

Fig. 1. Box-plot of spring wheat yield values

In the figure, the center line shows the median value, the borders of the rectangle correspond to the values of the lower and upper quartiles (25th and 75th percentiles), the width of the rectangle is the size of the total sample, the height of the rectangle is the interquartile range (IQR), the length of the upper (lower) "whiskers" of the diagram show the boundaries of the distribution of the largest (smallest) value, which is within 1.5×IQR.

creased doses of mineral fertilizers, some leveling of the influence of vegetation conditions was established. In particular, the significance of the atmospheric moisture factor decreased to a certain extent at the high level of agricultural technology. For example, when analyzing field data on crop yield obtained at the high level of cultivation, none of the factors showed statistically significant influence (p-values > 0.05) on yield. At the low-intensity level, when analyzed by the same method, "precipitation in the second period" showed a statistically significant relationship (p-value < 0.05). Correlation analysis revealed that at the intensive level, "precipitation in the 1st and 3rd periods" had the strongest correlation with spring wheat yield (p-value < 0.05). At the low-intensity level, high correlation with crop yield was found for "NDMI in July" and "NDVI in June" (p-value < 0.05). Principal component analysis (PCA) with subsequent regression analysis identified statistically significant components for each dataset variant regarding yield, depending on the level of agricultural technology intensification. At the intensive wheat cultivation level, these were components PC2 and PC5 (p-value < 0.05).

It is important to note that atmospheric precipitation during the observed crop development periods was statistically significant in all conducted non-parametric analysis methods (p-value < 0.05). It was established that NDMI and NDVI indices, reflecting vegetation condition, are important predictors of crop yield, especially in different time periods. These indices allow for a more accurate assessment of crop conditions and prediction of their future productivity. The most significant and informative predictors of spring wheat yield identified were used to create machine learning models.

To forecast spring wheat yield, the following models were applied: linear regression, nonlinear regression using splines, decision tree (CART), random forest (RF), gradient boosting (Gradient Boosting), and adaptive boosting (AdaBoost). Ridge regression was optimized by iterating through regularization coefficients to control model overfitting, considering variable interdependencies. The regression spline was

Табл. 2. Перечень статистически значимых предикторов, влияющих на урожайность яровой пшеницы

Table 2. Statistically significant predictors affecting spring wheat yields

Method	Significant factors identified
ANOVA	NDVI (July): p = 0,0087 Precipitation (1st period): p = 0,0231 Precipitation (2nd period): p = 0,0004 Precipitation (3rd period): p = 0,0001
Correlation analysis	NDMI (July): correlation 0,67 NDVI (June): correlation 0,60 NDVI (July): correlation 0,61
Principal component method	PC1: Precipitation (3rd period), Precipitation (2nd period), Precipitation (1st period) PC2: Precipitation (2nd period), Precipitation (1st period), Precipitation (3rd period) PC3 Precipitation (1st period), Precipitation (3rd period), NDMI (June) PC4: NDMI (July), NDVI (July), Precipitation (1st period) PC5: NDMI (June), NDMI (July), NDVI (June)

optimized by spline degree (2nd degree chosen), allowing flexible modeling of complex nonlinear relationships in the data. Determination of the optimal spline degree was based on metrics such as MAE (mean absolute error), RMSE (root mean square error), and R^2 (coefficient of determination). Decision tree (CART) usage enabled data splitting into different groups based on predictor values, identifying the most important factors influencing wheat yield, and making forecasts. Random forest (RF) was used to create an ensemble of decision trees, allowing for various data variations and obtaining more stable and accurate forecasts. Gradient boosting and adaptive boosting were utilized to create model ensembles that combine several weak models to produce the strongest variant.

Statistical indicators assessing the accuracy of spring wheat yield forecasting models using machine learning algorithms are presented in Table 3.

Below is a graph demonstrating both the actual crop yield values and the values predicted by each of the considered models (see Fig. 2).

The analysis of modeling results and the assessment of their predictive accuracy showed that random forest (RF), gradient boosting, and adaptive boosting algorithms had the highest forecast accuracy (R^2 = 0.74–0.80). The highest coefficient of determination was achieved using the gradient boosting algorithm (GB), indicating its effectiveness in predicting crop yield in this study.

The high predictive ability of the boosting algorithm lies in the fact that each subsequent model in the ensemble is built taking into account the minimization of the error of previous models. The ensemble modeling principle significantly increases the accuracy of forecasts in conditions of relatively small datasets subject to high variability.

The linear regression model had the lowest prognostic characteristics, emphasizing the complexity of biological systems, the absence of linear relationships, multilevel variability of environmental conditions, and controlling factors affecting spring wheat yield.

CONCLUSION

Forecasting spring wheat yield is one of the important factors in agricultural activities. This process is the basis for decision-making aimed at optimizing production and efficiently allocating resources. To forecast crop yield, several factors need to be considered. Based on the obtained results, precipitation in different time periods, NDMI (July), and NDVI (June and July) are the most important factors for forecasting spring wheat yield.

The use of machine learning models allows for automatic processing of large volumes of data and finding hidden patterns, revealing non-obvious factors influencing spring wheat yield and improving forecast accuracy. It has been established that the application of machine learning methods is an effective tool for forecasting yield. Particularly effective were ensemble models based on random forest, gradient boosting, and adaptive boosting algorithms, which had the highest predictive abilities (R^2 = 0.74–0.80).

The implementation of an ensemble approach (a set of predictive models) using vegetation in-

dices significantly increased the accuracy of forecasting potential crop productivity. This approach is promising for solving the tasks of forecasting spring wheat yield considering the multilevel uncertainty of the environment and high variability of resulting indicators on a specific land plot.

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Табл. 3. Статистические показатели точности моделей машинного обучения
Table 3. Statistical measures of accuracy of machine learning models

№	Method	Predictor categories	Metrics		
			MAE (mean absolute error)	RMSE (root mean square error)	R^2 (determination coefficient)
1	Linear regression	Quantitative	0,54	0,74	0,13
2	Regression spline	»	0,35	0,51	0,64
3	Decision tree	Quantitative and qualitative	0,33	0,48	0,67
4	Random forest	The same	0,29	0,44	0,74
5	Gradient Boosting	»	0,29	0,40	0,80
6	Adaptive Boosting	»	0,28	0,42	0,78

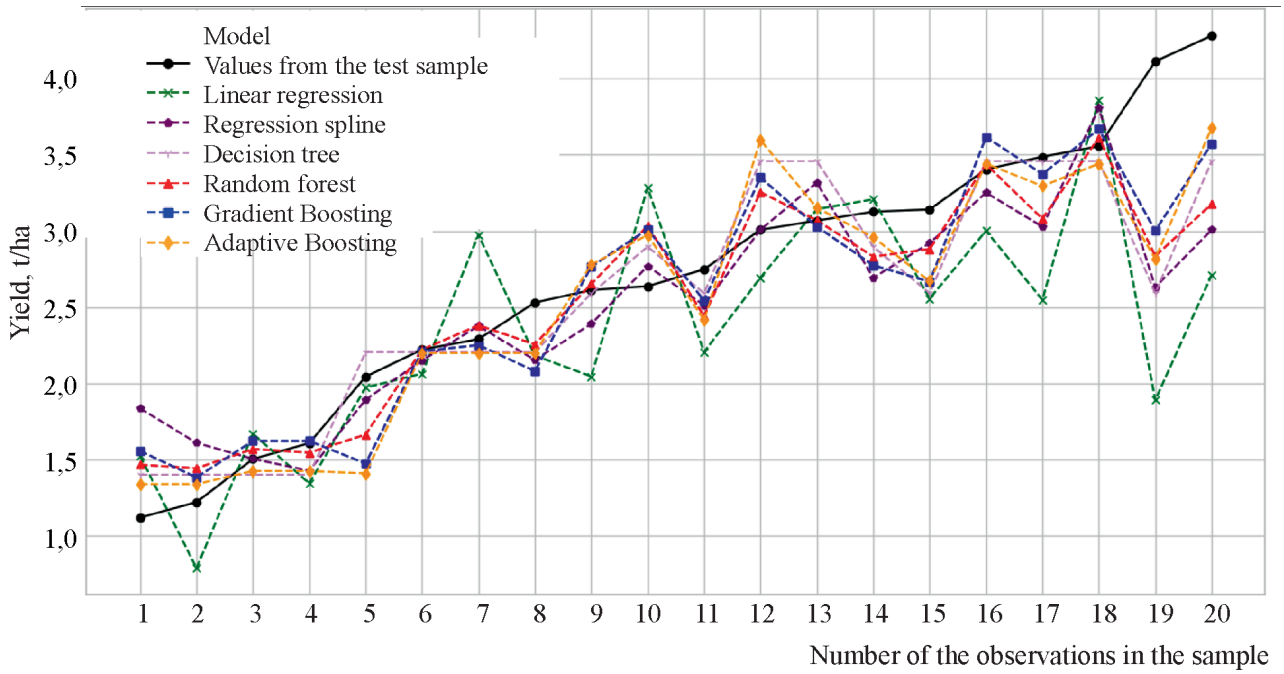

Рис. 2. Прогнозные значения урожайности яровой пшеницы и соответствующие значения из тестовой выборки

Fig. 2. Predicted values of spring wheat yield and corresponding values from the test sample

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СЕМЕНОВОДСТВО ЯРОВЫХ ЗЕРНОВЫХ КУЛЬТУР НА БАЗЕ ФЕДЕРАЛЬНОГО АГРАРНОГО НАУЧНОГО ЦЕНТРА СЕВЕРО-ВОСТОКА им. Н.В. РУДНИЦКОГО

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Семеноводство яровых зерновых культур является фундаментом продовольственной безопасности современного государства. Совместно с селекцией семеноводство обеспечивает получение продукции высокого качества в требуемом объеме. В Кировской области основными производителями оригинальных семян являются Федеральный аграрный научный центр Северо-Востока им. Н.В. Рудницкого (ФАНЦ Северо-Востока) и Вятский государственный агротехнологический университет. ФАНЦ Северо-Востока в 2017 г. был реорганизован, в результате чего в него вошли Северо-Восточный региональный аграрный научный центр, Фалёнская селекционная станция, Нижегородский, Марийский, Мордовский и Чувашский научно-исследовательские институты сельского хозяйства. В ФАНЦ Северо-Востока в г. Кирове с 1974 г. методом индивидуально-семейного отбора производятся оригинальные семена яровых зерновых культур. Оригинальные семена ежегодно продаются в хозяйства Кировской области и других регионов Российской Федерации для использования в питомниках размножения и суперэлиты. В статье проанализирована работа отдела семеноводства за 2019–2021 гг., отображена методика получения оригинальных семян яровых зерновых (овса, пшеницы, ячменя), описаны сорта, наиболее востребованные в Кировской области. Площадь посева оригинальных семян яровых зерновых на опытных полях ФАНЦ Северо-Востока за рассматриваемый период выросла на 23,4%, достигнув в 2021 г. 49 га. Из-за засушливой погоды в 2021 г. валовой сбор кондиционных семян яровых зерновых остался на уровне 2019 г. и составил 60,9 т. Выручка отдела семеноводства ФАНЦ Северо-Востока от реализации оригинальных семян возросла в 2021 г. на 47,53% по сравнению с 2019 г. и достигла 2,5 млн р. Оригинальные семена, как правило, реализуются предприятиям, обладающим своими подразделениями семеноводства: АО «Агрофирма “Дороничи”», СПК «Племзавод “Красный Октябрь”», СПК «Сельскохозяйственная артель “Красная Талица”», ООО «Зуринский агрокомплекс», ООО «Предуралье». Таким образом, отдел семеноводства ФАНЦ Северо-Востока является важным звеном в обеспечении продовольственной безопасности региона.

Ключевые слова: семеноводство, питомники испытания потомств и размножения, посевные площади, урожайность

SEED PRODUCTION OF SPRING CEREALS AT THE FEDERAL AGRARIAN SCIENTIFIC CENTER OF THE NORTH-EAST NAMED AFTER N.V. RUDNITSKY

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Seed production of spring grain crops is the foundation of food security of a modern state. Together with breeding, seed production provides high quality products in the required volume. In the Kirov region, the main producers of original seeds are the Federal Agrarian Scientific Center of the North-East named after N.V. Rudnitsky (FASC of the North-East) and Vyatka State Agrotechnological Uni-

versity. FASC of the North-East was reorganized in 2017 to include the North-East Regional Agrarian Research Center, Falyonskaya Breeding Station, Nizhny Novgorod, Mari, Mordovian and Chuvash Agricultural Research Institutes. The FASC of the North-East in Kirov has been producing original seeds of spring grain crops since 1974 by the method of individual-family selection. Original seeds are sold annually to the farms of the Kirov region and other regions of the Russian Federation for use in the nurseries of propagation and super elite. The article analyzes the work of the seed production department for 2019–2021, displays the methodology of obtaining original seeds of spring cereals (oats, wheat, barley), describes the varieties most in demand in the Kirov region. The area of sowing original seeds of spring cereals in the experimental fields of the FASC of the North-East increased by 23.4% during the period under review, reaching 49 ha in 2021. Due to dry weather in 2021, the gross harvest of conditioned spring cereal seed remained at the same level as in 2019 at 60.9 tons. The revenue of the seed division of the FASC of the North-East from the sale of original seeds increased by 47.53% in 2021 compared to 2019 to reach 2.5 million rubles. Original seeds are usually sold to the enterprises that have their own seed production units: AO Agrofirma "Doronichi", APC "Plemzavod "Krasny Oktyabr", APC "Agricultural Artel "Krasnaya Talitsa", OOO "Zurinsky Agrocomplex", OOO "Preduralye". Thus, the Seed Production Department of the FASC of the North-East is an important link in ensuring food security in the region.

Keywords: seed production, progeny nursery-gardens and propagation nurseries, sown areas, yields

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INTRODUCTION

The quality of seed material determines the yield of agricultural crops, the gross harvest, and ultimately the financial results of producers. For the Russian Federation, the full development of the breeding and seed production system under modern conditions becomes of paramount importance due to sanctions imposed by certain countries, territorial closures during epidemics, pandemics, and other factors. Currently, the demand of agricultural producers for high-quality domestic seed material is not fully met [1]. According to S.A. Golikova [2], the share of imported seeds in the Russian market volume is:

1) grains – до 5%;
2) corn for grain (hybrids) – 60–70%;
3) sunflower (hybrids) – 70–80%;
4) sugar beetroot (hybrids)) – 80–90%.

Additionally, up to 20% of crops for certain crops are sown with non-varietal seeds, leading to significant yield losses, low quality of the resulting products, and the occurrence of epiphytotic outbreaks [3].

Due to the peculiarities of the territorial location of the Kirov region (being part of the Non-Black Earth Zone), the agriculture of the region is oriented towards the production of livestock products [4]. According to the Ministry of Agriculture and Food of the Kirov region, in 2021, the size of sown areas in the region amounted to 834.5 t/ha, with the main share in the structure of agricultural land occupied by hayfields and pastures, and only 319.8 t/ha accounted for grain crops[1, 2].

[1]Official website of the Ministry of Agriculture and Food of the Kirov region [Electronic resource]. URL: http://www.dsx-kirov.ru (date of reference: 20.10.2022).

[2]*Vasina V.N.* General assessment of agriculture in the Kirov region // Modern Science Success, 2017, vol. 1, N 6, pp. 135-139.

The main direction of using spring barley, spring wheat, and spring oats in the region is for grain and forage. Only with the comprehensive solution of a number of problems is it possible to satisfy the needs of the region's livestock industry in the necessary volumes of fodder grain [5]. On one hand, this involves expanding areas, which leads to significant expenses, and on the other hand, it involves the use of technologies adapted to the territory's conditions and regular variety renewal and rotation [6].

Therefore, the objectives of this study are to examine the current state and identify trends in the development of the seed industry in the Kirov region.

MATERIAL AND METHODS

In the Kirov region, the main producers of original seeds are the Federal Agrarian Scientific Center of the North-East named after N.V. Rudnitsky (FASC of the North-East) and the Vyatka State Agrotechnological University (Vyatka SAU) [7].

The FASC of the North-East operates a seed breeding department, which was established in 1974. The main activities of the department are as follows:

1) primary seed breeding of zoned varieties of grain crops and perennial grasses;

2) development of efficient technologies for managing the production process of spring grain crops, ensuring the production of quality seeds in the conditions of global climate change.

Initially, the seed breeding department produced seeds of zoned varieties: barley – Moskovsky 121, Viner, Vostok; spring wheat – Leningradka, Rubin, Falyonskaya; oats – Nadezhny, Falyonsky 1; peas – Krasnoufimsky 70; buckwheat – Kalininskaya. Later, the production of original seeds of the varieties developed at the FASC of the North-East began. Currently, the department is engaged in the production of original seeds of spring grain crops: wheat – Bazhenka, Priokskaya, Svecha; barley – Zazersky 85, Ekolog; oats – Sapsan, Vyatsky, Persheron.

The Bazhenka spring wheat variety was created by intraspecific hybridization followed by targeted individual selection. Zoned and promising varieties of the world gene pool with different ecological and geographical origins were taken as parental varieties. The progenitor of the variety was the hybrid population Tulaikovskaya Jubilee × Priokskaya, which in the second hybrid generation (F2) was crossed with the Iren variety. The authors of the variety are: Yu.E. Vederikov, L.V. Volkova, L.A. Koryakovtseva, A.V. Kharina. Originator: FASC of the North-East. The variety is mid-ripening (matures in 79-80 days), of medium height (average stem height 75-90 cm). The average yield reaches 3.5 t/ha, with a maximum of 5.9 t/ha. Highly resistant to lodging, shedding, root sprouting. Included in the list of high-quality wheat varieties. Grain weight 753 g/l, vitreousness 56%, crude gluten content of the first quality group 27%, 1000 grain weight 35.4 g. The volume yield of bread from 100 g of flour is 560 ml, the overall bread-baking score is 4 points. Characterized by high resistance to kernel smut, moderate susceptibility to loose smut, and juvenile resistance to Fusarium root rot [8]. The variety responds well to fertilizer application and is recommended for cultivation using intensive technologies[3].

The Priokskaya spring wheat variety was developed by individual selection from a hybrid population (line 1833-76H427 × Moskovskaya 35) F1 × Saratovskaya 54. Originators: Moscow Scientific Research Institute of Agriculture "Nemchinovka", Ryazan Scientific Research Institute of Agriculture, Vladimir Scientific Research Institute of Agriculture. The bush of this variety is semi-erect, the stem is thick, of medium height. The spike is loose, cylindrical, yellow with a cream tint, of medium length. The grain is round, red, with an orange tint in wet years, of medium size, with a 1000 grain weight of 29–38 g. Mid-ripening. Resistance to lodging is above average – high (4–5 points). Drought resistance is average - below average. It is characterized by rapid growth after emergence. Moderately affected by loose smut, moderately susceptible to damage by frit fly. Baking qualities are good. Included in the list of high-quality wheat variet-

[3]*Koryakovtseva LA, Volkova L.V., Kharina A.V.* Creation of early maturing variety of spring soft wheat Bazhenka // Agricultural Science Euro-North-East, 2012, N 5 (30), pp. 8-10.

ies. Protein content in grain 13.1–15.3%, crude gluten 32.2–36.3%, bread volume from 100 g of flour 900-1110 ml, overall bread-baking score 3–4 points[4].

The Ecolog spring barley variety was obtained by selection from a hybrid population (Domen × Keystone) × Domen. Authors: N.A. Rodina, S.A. Kutz, Z.N. Domracheva, N.F. Prokasheva. Originator: FASC of the North-East. The variety is mid-ripening (matures on average in 81 days), high-yielding (average yield is 6.5 t/ha, maximum - 8.0 t/ha). High yield is achieved due to good productivity of long (over 7 cm), weakly collapsing spike and large grain (1000 grain weight is 40-53 g). The variety is characterized by group resistance to diseases - genetically protected from loose smut, practically resistant to black and kernel smut, moderately resistant to stripe disease, comparatively resistant to root rots. Resistant to lodging and collapsing of the spike. It has high malting qualities, good brewing qualities [9].

Variety of spring barley Zazersky 85 was obtained through hybridization with the mutant variety Favorite (NE 481), isolated by exposure to X-rays (100 Gy). Originators: Tula Scientific Research Institute of Agriculture, Tver State Agricultural Academy, Vladimir Scientific Research Institute of Agriculture. It's an intensive type variety. It has high lodging resistance (7–9 points). It is moderately affected by loose smut and net blotch. The grain is of medium size, with a weight of 1000 grains ranging from 38 to 43 g. The protein content in the grain is 13.4%, starch 60.2%. It is characterized by good brewing qualities. It is a medium-late variety, with a growing period of 86–100 days[5].

Variety of spring aristulate oats Sapsan. Origin: (Freya × Ulav) × Ulav. Authors: G.A. Batalova, M.V. Tulyakova, I.I. Rusakova, E.N. Vologzhanina, N.V. Krotova, G.P. Zhuravleva. Originators: Federal Agricultural Scientific Center of the North-East, and Falyonskaya Breeding Station, a branch of the Federal Agricultural Scientific Center of the North-East. *Mutica* variety – white grain, awnless. It has an erect growth habit. It is a versatile variety. It's medium-early, adaptive, productive in grain (up to 9.1 t/ha) and dry matter yield (up to 9.64 t/ha), flexible, with high grain quality. It belongs to the category of tolerant to edaphic stress caused by low pH and aluminum ion toxicity. The grain has increased protein (13.62%), fat (4.02%), and starch (40.73%) content. The yield of groats is 68.2%. It is resistant to lodging and shattering, resistant in field conditions to loose smut, crown rust, and stem rust. Suitable for production of grain of high energy value for fodder and food purposes, production of green mass[6].

Variety of spring naked oats Vyatsky was obtained by individual selection from a sample of the VIR Adam collection (Czech Republic), followed by multiple culling based on the characteristic of the aristulate condition. Authors: G.A. Batalova, L.N. Efremidi, N.S. Solovyova, N.A. Lobanova, M.V. Tulyakova, I.I. Rusakova, N.V. Yemeleva. Originator: Federal Agricultural Scientific Center of the North-East. *Inermis* variety. Intermediate growth habit. Aristulate condition in the grain is absent. The grain is of medium size. The weight of 1000 grains reaches 26–32 g. The average yield in the region is 2.7 t/ha, with a maximum yield of 6.7 t/ha. It's medium-early, with a growing period of 78–92 days. It is resistant to lodging, with drought resistance at the level up to average standards. Valuable in quality. The protein content is 14.9–16.5%. Grain weight is 570–680 g/L. It is susceptible to bacterial blight, highly susceptible to loose smut and crown rust[7] [10].

Variety of naked oats Percheron. Origin: OA 503/1 (Canada) × Ulav (Russia). Authors: G.A. Batalova, N.A. Lobanova, M.V. Tulyakova, A.I. Churakova, I.I. Rusakova, S.V. Permyakova, O.A. Zhuykova, E.N. Vologzhanina. Originator: Federal Agricultural Scientific Center of the North-East. *Inermis* variety. Naked-grain variety. Intermediate growth habit. The plant is medium

[4]*Davydova N.V., Kazachenko A.O.* Features of selection of source material for selection of spring soft wheat in the conditions of the Central Non-Black Earth Region // Bulletin of Altai State Agricultural University, 2013, N 5 (103), pp. 5-9.

[5]*Semenov V.A., Grib S.I.* New variety of spring barley Zazersky 85 // Breeding and Seed Production, 1986, N 5, pp. 32-34.

[6]*Batalova G.A., Mukhamadyarov F.F., Rusakova I.I., Antonov V.G., Tulyakova M.V., Shikhova L.N.* On the creation of adaptive varieties of filmy oats Sapsan and Avatar // Agricultural Science Euro-North-East, 2013, N 2 (33), pp. 4–7.

[7]*Batalova G.A*. Oats in the Volgo-Vyatsky region. Kirov, 2013, 288 p.

in height. Awns are absent or very weak. The grain varies from small to medium in size. The weight of 1000 grains ranges from 20 to 31 g. The average yield in the region is 2.4 t/ha, with a maximum yield of 5.2 t/ha. It's medium-early. It is resistant to lodging, with drought resistance at the level of standard varieties Vyatsky and Tyumensky naked oats. Valuable in quality. The protein content is 13.7–22.1%. Grain weight is 560–690 g/L. Highly susceptible to loose smut. In field conditions, it is moderately damaged by frit fly[8].

Production of original seeds is carried out at the experimental field of the Federal Agricultural Scientific Center of the North-East located in the village of Krasnoye. The soils of the experimental field are moderately clayey podzolic. The climate of this area is moderately warm with uneven precipitation. The plant vegetation period lasts 157–160 days, of which 115–120 days have an average daily air temperature above 10°C, which is favorable for the growth and development of spring cereal crops.

The soil of the plot ranges from light to heavy clayey loam and is formed on the eluvium of Permian clays. According to the results of the agrochemical research conducted at the Agrochemical Service Center "Kirovsky," the content of available phosphorus ranged from high (197 mg/kg) to very high (483 mg/kg), exchangeable potassium ranged from medium (128 mg/kg) to high (223 mg/kg), and the humus content ranged from 1.17% to 1.87%. The soil solution reaction (pH) varied from strongly acidic (3.9) to neutral (6.4), depending on the field.

The main and pre-sowing soil treatments were carried out in accordance with zonal recommendations: plowing to a depth of 20–22 cm in autumn, followed by double harrowing with heavy-toothed harrows in two passes in the spring of the following year and cultivation in two passes to a depth of 7–8 cm. Fertilizer application (basic background) – nitroammophoska at a rate of $N_{48}P_{48}K_{48}$ per 1 ha (between cultivations) [11].

The production of original seeds of spring cereal crops is carried out using the method of individual-family selection according to the "Methodological recommendations for the production of elite grains, legumes, and cereal crops." The method includes the selection of elite spikes, the establishment of test nurseries for the offspring of the 1st and 2nd years (P-1 and P-2) and reproduction nurseries for the 1st and 2nd years (R-1 and R-2). A statistical analysis is conducted on the grain mass of elite spikes and families using the Microsoft Excel computer program. The average arithmetic characteristics (x) and standard deviation (σ) are determined. Only typical offspring whose grain mass falls within $x - \sigma$ (lower limit) and $x + 2\sigma$ (upper limit) are used for establishing test nurseries.

RESULTS AND DISCUSSION

The yield and area harvested of grain crops in the Kirov region for 2019–2021 are presented in Table 1.

During 2019–2021, there was a significant increase (by 38,957 ha) in the harvested areas occupied by grain crops in the Kirov region, due to the expansion of the areas cultivated with spring wheat and oats. Consequently, there has been a growing demand for planting material year by year. Due to unfavorable conditions in 2021, there was a 27.2% reduction in the yield. As noted by I.G. Generalov [12], there is a strong influence of yield on the profitability of agricultural producers and, as a result, a decrease in the population's quality of life. All these aspects require ensuring the availability of high-quality varieties adapted to the growing conditions in this region.

For 48 years, the seed production department of the Federal Agricultural Scientific Center of the North-East has been engaged in primary seed production of barley, wheat, oats, and other crops, supplying original seeds to elite seed farms in the Kirov region and other regions for elite production. The department has been led by the Candidate of Science in Agriculture Yu.E. Vederikov for 24 years.

The start of original seed production in the department is associated with the selection of elite spikes. Each year, during the full ripening phase of the crops in purebred nursery fields,

[8]*Batalova G.A*. About completed scientific developments on oat breeding // Agricultural Science Euro-North-East, 2009, N 4 (15), pp. 14-19

[9]*Bolshakov N.V., Kuvarin V.V., Khorshev V.V.* Methodical recommendations on production of elite seeds of cereals, leguminous and cereal crops. Moscow, 1990, 39 p.

2.5–3.0 thousand elite plants (typical for the variety, healthy, without signs of pest damage and disease) are selected. In the laboratory, the spikes are manually threshed, the seeds from each plant are weighed separately and placed in individual bags. Then, a mathematical analysis of the grain mass from the elite plant is conducted for further selection and establishment of nursery P-1.

In the first-year progeny testing nursery, seeds from one plant are sown in a single row 1 meter long (row by row) using a cassette seeder SKS-6-10. After every 40 rows, a control row is sown (seeds from the second-year multiplication nursery).

During the vegetation period in nursery P-1, progeny selection is carried out: rows with low field germination, atypical morphological characteristics for the variety, prone to lodging, disease-affected, or low survival are removed. All selected progenies are manually harvested row by row, threshed individually using a bundle thresher MTPU-500, placed in separate bags labeled inside and outside, weighed in the laboratory. Then, a statistical analysis based on grain mass from the family is conducted: progenies within $-\sigma \leq x \leq +2\sigma$ are retained. The best progenies are sown in nursery P-2 the following year.

The second-year progeny testing nursery is established on the plots of different sizes (from 1.3 to 3.7 m^2) depending on the amount of seeds. Sowing is done with a small-sized portion seeder SSFK-6. A control plot is placed every 40 plots. Throughout the vegetation period, phenological observations, care, and selection of atypical, sparse, lodged, and disease-affected progenies (plots) are carried out.

The best families from nursery P-2 are harvested by combine harvester Sampo-130, dried in chamber-type dryers in seed mode. Seed sorting for grain crops is done using grain cleaning machines SM-0.15 (progeny testing nurseries) and "Petkus Gigant" K 531A (multiplication nurseries).

Combined families from nursery P-2 are sown in the first-year multiplication nursery and subsequently in the second-year multiplication nursery using seeder SZ-4.2, and harvesting is carried out using combine harvesters Niva Nova-340 and Sampo-500.

Data on the yield and volume of the obtained original seeds of spring grain crops from multiplication nurseries R-1 and R-2 at the experimental field of the Federal Agricultural Scientific Center of the North-East for 2019–2021 are presented in Table 2.

The area of planting original seeds over three years increased by 23.4%, reaching 49 hectares, which is associated with an increased demand among farms for original seeds of spring grain crop varieties adapted to local conditions. However, the gross seed harvest slightly decreased. This can be attributed, firstly, to changing weather conditions during the growing season (for example, in 2021, there was dry weather from May to August, which hindered the full potential of varieties and resulted in lower yields), and secondly, to changes in the assortment of cultivated varieties (for example, the Vyatsky naked oat variety yields low harvest, and increasing the planting area for this variety reduces the overall gross seed harvest).

Табл. 1. Урожайность и уборочная площадь зерновых культур в Кировской области (без кукурузы)
Table 1. Yield and harvesting area of grain crops in the Kirov region (without corn)

Culture	2019		2020		2021		2021 to 2019	
	Harvested area, ha	Yield, t/ha	Sowing area, ha	Yield, t/ha	Sowing area, ha	Yield, t/ha	Sowing area, %	Yield, %
All grain crops	280 880	2,61	310 207	2,00	319 837	1,90	+13,87	–27,20
Including:								
wheat	74 160	2,40	74 783	1,90	79 412	2,50	+7,08	+4,17
barley	99 828	2,90	103 849	2,50	99 083	2,10	–0,75	–27,59
oats	43 807	2,81	44 112	2,20	45 063	1,80	+2,87	–35,94

Табл. 2. Площадь посева, урожайность и валовой сбор семян яровых зерновых культур в питомниках ПР-1 и ПР-2

Table 2. Area, yield and gross harvest of spring grain seeds in nurseries PR-1 and PR-2

Culture	Variety	Nursery, reproduction	Sowing area, ha			Yield, t/ha			Conditioned seeds obtained, tons		
			2019	2020	2021	2019	2020	2021	2019	2020	2021
Wheat	Priokskaya	PR-1	–	–	9,0	–	–	2,5	–	–	15,2
		PR -2	11,0	–	–	1,86	–	–	15,6	–	–
	Bazhenka	PR -1	–	8,2	–	–	2,2	–	–	13,7	–
Barley	Ecolog	PR -1	4,0	5,5	–	2,1	2,2	–	6,4	9,8	–
	Zazersky 85	PR -1	–	27,0	23,0	–	1,85	1,8	–	40,0	29,8
		PR -2	12,0	–	–	3,0	–	–	24,2	–	–
Oats	Persheron	PR -1	10,0	–	–	2,26	–	–	16,5	–	–
		PR -2	–	7,0	–	–	1,2	–	–	4,9	–
	Sapsan	PR -1	–	–	8,0	–	–	1,9	–	–	9,7
	Vyatsky	PR -1	1,9	–	9,0	1,3	–	1,0	1,4	–	6,2
		PR -2	–	3,0	–	–	1,9	–	–	4,4	–
Total			39,7	50,7	49,0				64,1	72,8	60,9

Note. «–» – this reproduction was not grown this year.

Nevertheless, the revenue of the seed production department of the Federal Agricultural Scientific Center of the North-East increased by 47.53% and reached 2.542 million rubles due to the increase in the selling price of the seeds and the sale of seed material from previous years. Original seeds are sold to large enterprises in the region and other regions of the Russian Federation, such as AO "Agrofirm Doronichi" (Kirov region), "Krasny Oktyabr" collective farm (Volgograd region), "Krasnaya Talitsa" agricultural cooperative (Kirov region), OOO "Zurinsky Agrocomplex" (Udmurtia), OOO "Preduralye" (Perm Krai).

CONCLUSION

The production of high-quality food and feed products largely depends on the quality of the seed material used. Moreover, crop yield and gross harvest largely depend on the quality of seed material. Achieving a higher volume of marketable products from a smaller area has a positive financial effect and influences the cost price of the products. This effect can only be achieved by using tested and regionally suitable varieties and hybrids.

In the Kirov region, grain-forage crops are in high demand. From 2019 to 2021, the areas occupied by grain crops in the region increased by 38,957 hectares. Consequently, there is a growing annual demand for seeds of zoned varieties of spring grain crops highly adapted to local conditions. In addition to ongoing breeding and research on the potential of new varieties and hybrids, specialists at the Federal Agricultural Scientific Center of the North-East named after N.V. Rudnitsky are engaged in the multiplication of the most promising samples. Responding to demand, the seed production department of the Federal Agricultural Scientific Center of the North-East systematically increases the planting areas of the entire seed production structure, conducts trials of new varieties, and cultivation techniques. Thus, the area of planting original seeds increased by 23.4% during the specified period (up to 49 hectares), and the revenue of the department increased by 47.53% (up to 2.542 million rubles). Currently, the seed assortment includes seven varieties of various spring grain crops. Over the years of research, the department has produced 197.8 tons of original certified seeds of grain crops.

The production of original seeds of varieties and hybrids highly adapted to the region's conditions is an important component of the prosperity of agricultural enterprises and the region as a whole.

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ХОЗЯЙСТВЕННО-БИОЛОГИЧЕСКАЯ ХАРАКТЕРИСТИКА СОРТА МЯГКОЙ ОЗИМОЙ ПШЕНИЦЫ КРАСНООБСКАЯ ОЗИМАЯ

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Одна из основных задач современной селекции – создание сортов, устойчивых к воздействию негативных факторов среды и дающих стабильно высокие урожаи в условиях изменяющегося климата. С 2021 г. в Государственный реестр селекционных достижений внесен сорт мягкой озимой пшеницы Краснообская озимая, созданный методом рекомбинационной селекции. Его родословная включает в себя, наряду с сортами пшеницы, пшенично-пырейный гибрид и тритикале. Была проведена оценка данного сорта по хозяйственно ценным признакам и свойствам. Исследования проводили в 2015–2022 гг. в Новосибирской области. Стандартом служил районированный сорт Новосибирская 40, контролем – районированный сорт Новосибирская 3. Сорт Краснообская озимая рекомендуется для возделывания в лесостепной зоне Западно-Сибирского региона. Является среднеспелым, обладает достаточно высокой зимостойкостью (60,0%) и устойчивостью к полеганию (4,1 до 4,7 балла) при высоте растений до 101 см. Масса 1000 зерен в среднем составляет 37,9 г. Сорт имеет высокий коэффициент продуктивного кущения (5,3 шт.). За годы исследования средняя урожайность сорта составила 5,03 т/га. В среднем по результатам испытаний на госсортоучастках Новосибирской области урожайность составила 4,34 т/га, максимальная урожайность отмечена на Маслянинском сортоучастке – 4,9 т/га, что на 1,14 т/га выше показателей стандарта. По результатам экологического испытания урожайность превзошла сорта Новосибирская 40 и Новосибирская 3 на 0,74 и 0,41 т/га соответственно, зимостойкость находилась на уровне стандартов. Высокая и стабильная урожайность данного сорта формируется за счет ряда хозяйственно ценных признаков: продуктивная кустистость, масса 1000 зерен, устойчивость к полеганию, зимостойкость. По результатам изучения определено, что оптимальным сроком посева сорта Краснообская озимая является 1 сентября со сдвигом на 1–3 сут в обе стороны.

Ключевые слова: пшеница мягкая озимая, сорт, селекция, урожайность, зимостойкость

ECONOMIC AND BIOLOGICAL CHARACTERISTICS OF SOFT WINTER WHEAT VARIETY KRASNOOBSKAYA OZIMAYA

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One of the main tasks of modern breeding is to create the varieties that are resistant to negative environmental factors giving consistently high yields in a changing climate. Since 2021, the variety of soft winter wheat Krasnobskaya ozimaya, created by recombination breeding, has been included in the State Register of Breeding Achievements. Its pedigree includes, along with wheat varieties, triticum-agropyrum hybrid and triticale. This variety was evaluated for its economically valuable traits and properties. The studies were carried out in 2015–2022 in the Novosibirsk region. Novosibirskaya 40 was the standard, Novosibirskaya 3 was the control. Krasnobskaya ozimaya variety is recommended for cultivation in the forest-steppe zone of the West Siberian region. It is medium maturing, has rather high winter hardiness (60.0%) and resistance to lodging (4.1 to 4.7 points) with plant height up to 101 cm. The weight of 1000 grains averages 37.9 g. The variety has a high coefficient of productive tillering (5.3 pcs.). Over the years of the study, the average yield of the variety was

5.03 t/ha. On average, according to the results of the tests in the state variety test plots of the Novosibirsk region the yield amounted to 4.34 t/ha, the maximum yield was observed at the Maslyaninsky variety test plot – 4.9 t/ha, which is 1.14 t/ha higher than the standard. According to the results of the ecological test, the yield exceeded the varieties Novosibirskaya 40 and Novosibirskaya 3 by 0.74 and 0.41 t/ha, respectively, winter hardiness was at the level of the standards. High and stable yield of this variety is formed due to a number of economically valuable features: productive bushiness, weight of 1000 grains, resistance to lodging, winter hardiness. According to the results of the study, it was determined that the optimal sowing date of the Krasnobskaya ozimaya variety is September 1 with a shift of 1–3 days in both directions.

Keywords: soft winter wheat, variety, breeding, yield, winter hardiness

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INTRODUCTION

Grain production is the main direction of agricultural production in our country. Currently, the Russian Federation is the leading exporter of grain in the world, with wheat accounting for up to 90.0% of the exported grain. Soft winter wheat in Russia is one of the most important, valuable, and high-yielding grain crops [1–3].

Throughout the country, soft winter wheat plantings occupy more than 15.5 million hectares out of a total of 80.5 million hectares of all sown areas[1]. Winter wheat has a high biological productivity reserve, the utilization of which largely depends on the conditions under which it is cultivated. For example, in the West Siberian region, the share of winter wheat in the sown area structure is insignificant. According to data from 2021, it ranged from 0.4% in the Omsk region to 3.6% in the Altai region.

The quality of wheat production is influenced by significant differences in climatic conditions, sharp fluctuations in soil characteristics, and other factors not only territorially but also from year to year. The natural-climatic conditions of Western Siberia do not allow for consistently high yields of high-quality wheat. Based on an analysis of wheat cultivation practices in the region, unstable crop yields over the years can be observed. The main limiting abiotic factors include harsh wintering conditions and unfavorable hydrotrophic conditions during the growing season [5]. The negative impact of natural factors leads to significant variability in crop yield and grain quality [6, 7].

The yield of winter wheat is an integral indicator of plant productivity, the result of the close interaction of the genetic component of the variety with the growing conditions. The variety plays a leading role in yield and grain quality formation [8–10].

In addition to high yields, new varieties must possess a number of positive qualities necessary for effective grain production, such as resistance to lodging and major diseases, high grain quality,

[1]https://fedstat.ru.

drought resistance, winter and frost resistance, and high quantitative traits. Achieving such a result is a complex task due to the fact that most important indicators are negatively correlated with each other [1, 9, 11].

Academician A.A. Zhuchenko asserts that the role of the variety is greater the worse and more heterogeneous the external environmental conditions are[2]. Therefore, the development of variety models and the creation of new varieties should be carried out taking into account specific soil and climatic zones [7, 12, 13].

The characteristic instability and unpredictability of the weather factors during the growing season, as well as the soil-climatic conditions of the region, place increased demands on the selection of winter wheat varieties in Western Siberia. Therefore, the significance of a new variety here is very high.

One of the main tasks of modern breeding is to create winter wheat varieties resistant to the influence of negative abiotic and biotic environmental factors, providing consistently high yields in conditions of climate change [14–16]. Additionally, varieties should have high productivity, adaptability, ecological plasticity, and grain quality [3].

Significant progress has been made in winter wheat breeding in recent years. Nevertheless, the creation of varieties resistant to biotic and abiotic environmental factors remains relevant [1, 17, 18].

Thus, the expansion of winter wheat sown areas in Siberia largely depends on the creation of the varieties that combine a high potential for winter hardiness and productivity, as well as further improvement of their cultivation technology [5].

The purpose of the study is to assess the economically valuable characteristics and properties of the Krasnoobskaya ozimaya wheat variety in the conditions of the forest-steppe of Western Siberia.

MATERIAL AND METHODS

The study was conducted from 2015 to 2022 in the experimental fields of the Siberian Research Institute of Plant Growing and Selection (SibNIIRS). The soil cover of the experimental field consisted of moderately humus-rich medium loamy chernozem with an alkaline reaction. The humus content in the plowed layer ranged from 4.0% to 5.0%, with a soil potassium content of 104 mg/kg and phosphorus content of 284 mg/kg. The agronomic cultivation techniques were standard for this zone, with autumn fallow being the preceding crop. The seeding rate was 6 million viable seeds per hectare. The object of the study was the variety of soft winter wheat, Krasnoobskaya ozimaya. The released variety Novosibirskaya 40 was used as a standard, and one of the parental forms, Novosibirskaya 3, served as the control. The seeding for the competitive variety trial was carried out from August 26 to September 1 using a selection seeder (SSFK-7) on the plots with a measured area of 16 m² in four replications.

Field trials, phenological observations, registration and evaluation were conducted in accordance with the methodology of field experiments[3] and the "Methodology of State Variety Testing of Agricultural Crops"[4].

During the study, agrometeorological indicators of wintering conditions varied from year to year. The coldest November was observed in 2016, with an average monthly temperature of –12.9°C (deviation from the multi-year average by -4.6°C). In 2019, the average November temperature reached –10.7°C, but there was a prolonged absence of snow cover with air temperatures dropping to –28.5°C, negatively affecting the wintering of winter wheat. The coldest December was noted in 2018, with an average air temperature of –19.5°C (5.5°C below the norm), and the minimum temperature recorded was –36.5°C. The coldest January occurred in 2021, with an average monthly temperature of

[2]*Zhuchenko A.A*. Adaptive plant breeding: ecological and genetic bases: in 2 vol., M., 2001, vol. 1, 780 p.

[3]*Dospekhov B.A.* Methodology of field experiment: with the basics of statistical processing of research results. M.: Kolos, 1979, 416 p.

[4]Methodology of state variety testing of agricultural crops. Moscow: Gosagroprom of the USSR, 1989, 162 p.

–21.7°C (multi-year average – 17.0°C). In February, the lowest average monthly temperature was recorded in 2019: it was –16.4°C, which is 1.6°C below the multi-year average. The winter of 2016/17 was the snowiest, resulting in a snow cover height reaching 70 cm in March 2017. The temperature at the node formation depth did not drop below –10°C during the years of the study.

The weather conditions during the spring-summer growing season varied in terms of temperature regime and moisture supply. Drought conditions occurred in 2022: the hydrothermal coefficient (HTC) was 0.68, and the total precipitation was 94 mm. The vegetation period with insufficient moisture was observed in 2020 and 2021 (HTC = 0.81–0.85; total precipitation of 124 and 125 mm, respectively). Optimal hydrothermal conditions for vegetation occurred in 2015 and 2016 (HTC = 1.22–1.24; total precipitation of 179 and 155 mm). Excessive moisture was observed during the vegetation periods of 2017 and 2019 (HTC = 1.33–1.43; total precipitation for vegetation of 195 and 172 mm).

RESULTS AND DISCUSSION

Eight varieties of soft winter wheat recommended for cultivation in the West Siberian region have been developed and included in the State Register of the Russian Federation at SibNIIRS. Since 2021, a new variety of soft winter wheat, Krasnoobskaya ozimaya, has been added to the State Register of Breeding Achievements, combining productivity with a high level of winter hardiness.

This variety was created using intervarietal hybridization followed by individual selection from the hybrid population of Novosibirskaya 3 × Omskaya 6. The pedigree of the variety includes, along with varieties of winter wheat (Krasnodarskaya 39, Yubileynaya 50, Odesskaya 16, Krasnodarsky karlik 1), a wheat-rye hybrid (Wheat-Rye Hybrid - Krasnodarskaya 39 × Elytrigia intermedia (Host) Nevski) and triticale LMK 462. The variety is recommended for cultivation in the forest-steppe zone of the West Siberian region.

Botanical characteristics. Variety *Lutescens.* Anthocyanin coloring of the coleoptile is absent. The bush is interspacial – semi-trailing, the plant is of medium or long length. The wax coating on the ear varies from weak to moderate, on the upper internode of the straw and the sheath of the flag leaf – from moderate to strong. The ear is pyramidal, short or medium in length, of medium density, and has a white color. Awns at the tip of the ear range from very short to short. The pubescence of the top segment of the ear axis on the convex side ranges from moderate to strong. The glume is lanceolate-ovate. The shoulder is straight, of medium width. The beak is straight or slightly curved, very short or short. The lower glume on the inner side has very weak or weak pubescence. The grain is colored, ovoid in shape[5].

Biological features. The variety is mid-ripening, with an average vegetation period of 324 days (from 320 to 328 days) (see Table 1). The variety is characterized by relatively high winter hardiness (60.0%), comparable to the standard variety Novosibirskaya 40. It has high resistance to lodging – during the years of research, it ranged from 4.1 to 4.7 points. Plant height is at the standard level – 101 cm. The weight of 1000 grains averaged 37.9 g, which is higher than that of the standard but lower than that of the control. Krasnoobskaya ozimaya has a high coefficient of productive tillering – from 4.4 to 7.6 shoots (average – 5.3). Increased tillering ensures high grain numbers (174 pcs.) and grain weight per plant (5.59 g). This indicator also positively influences the number of productive shoots per 1 m². Over the years of research, the number of shoots of Krasnoobskaya ozimaya averaged 563 pcs./m². Regarding grain quality parameters, there were no significant deviations from the standard for this variety.

Over the years of research, the average yield of the Krasnoobskaya ozimaya was 5.03 t/ha, which is 0.6 t/ha more than that of the standard variety Novosibirskaya 40 (see Table 2). The lowest yield (3.13 t/ha) was recorded in 2016. The highest yield was obtained in 2017 (6.73 t/ha).

[5]https://reestr.gossortrf.ru.

Табл. 1. Характеристика сорта Краснообская озимая в конкурсном сортоиспытании (2015–2022 гг.)
Table 1. Characteristics of the Krasnoobskaya ozimaya variety in the competitive variety testing (2015–2022)

Indicator	Novosibirskaya 40 (standard)	Novosibirskaya 3 (control)	Krasnobskaya ozimaya
Winter hardiness, %	61 ± 8	56 ± 15	60 ± 12
Vegetation period, days	322 ± 3	324 ± 3	324 ± 3
Resistance to lodging, score	4,3 ± 0,3	4,3 ± 0,3	4,4 ± 0,2
Weight of 1000 grains, g	37,1 ± 2,7	41,0 ± 3,0	37,9 ± 1,8
Number of productive shoots, pcs./m^2	478 ± 104	513 ± 189	563 ± 185
Productive tillering coefficient, pcs.	5,0 ± 0,9	5,2 ± 1,1	5,3 ± 1,1
Plant height, cm	103 ± 10	100 ± 12	101 ± 12
Number of grains per plant, pcs.	160 ± 50	164 ± 54	174 ± 61
Grain weight per plant, g	5,81 ± 1,85	6,44 ± 2,15	6,59 ± 1,69
Grain unit, g/l	797 ± 11	796 ± 25	805 ± 27
Vitreousness, %	47 ± 6	51 ± 6	53 ± 7
Gluten content, %	28,9 ± 4,1	24,6 ± 4,1	25,1 ± 4,0
Flour strength, a.u.	294 ± 78	235 ± 94	301 ± 96
Bread volume, cm^3/100 g of flour	766 ± 85	617 ± 76	654 ± 133
Total baking grade, score	3,7 ± 0,2	3,7 ± 0,6	3,8 ± 0,5

State variety testing of the Krasnoobskaya ozimaya variety was conducted in 2018–2020. The standard on the state variety sites was the variety Novosibirskaya 32. The minimum yield was recorded on the Northern variety site – 3.76 t/ha, compared to the standard variety yield of 2.74 t/ha (see Table 3). The maximum yield was formed on the Maslyaninsky variety site – 4.90 t/ha, which is 1.14 t/ha higher than that of the standard. On average, according to the results of trials on state variety sites in the Novosibirsk region, the Krasnoobskaya ozimaya variety showed the yield of 4.34 t/ha, exceeding the indicators of the standard variety Novosibirskaya 32 by 0.83 t/ha. The winter hardiness of the studied variety was at the level of 4.4 points. The vegetation period was 319 days, i.e., at the standard level. Krasnoobskaya ozimaya formed larger grains compared to the standard variety. The average weight of 1000 grains was 42.2 g. At the same time, the test weight was lower compared to the standard – 779 g/l versus 805 g/l.

The ecological test of the Krasnoobskaya ozimaya variety was conducted in the Toguchinsky district of the Novosibirsk region in 2016 and 2017 (see Table 4). The plot area was 300 m²,

Табл. 2. Урожайность сорта Краснообская озимая в конкурсном сортоиспытании, т/га (2015–2022 гг.)
Table 2. Yield of the Krasnoobskaya ozimaya variety in the competitive variety testing, t/ha (2015–2022)

Year	Novosibirskaya 40 (standard)	Novosibirskaya 3 (control)	Krasnobskaya ozimaya	LSD_{05}
2015	5,11	5,42	6,66	0,35
2016	2,83	3,10	3,13	0,47
2017	5,74	5,53	6,73	0,20
2019	4,73	4,40	4,99	0,19
2020	3,54	1,52	3,29	0,73
2021	5,57	6,04	6,35	0,34
2022	3,57	2,89	4,04	0,84
Average	4,44	4,13	5,03	–
CV, %	25,40	40,50	31,40	–

with a threefold repetition. According to the test results, the winter hardiness of the studied variety was at the level of the standard and control varieties Novosibirskaya 40 and Novosibirskaya 3. Resistance to lodging was higher than that of the Novosibirskaya 40 variety but at the same level as the Novosibirskaya 3 variety. In terms of yield, the Krasnoobskaya winter wheat variety exceeded the Novosibirskaya 40 and Novosibirskaya 3 varieties by 0.74 and 0.41 tons per hectare, respectively.

Since 2018, the influence of the sowing dates on the yield of the Krasnoobskaya ozimaya variety has been studied. Sowing was conducted on August 20, September 1, and September 10. In 2019, the minimum yield (4.07 tons per hectare) was observed for the late sowing date, while the maximum yield (4.64 tons per hectare) was recorded for the early sowing date (see Table 5). In 2021 and 2022, the minimum yield was observed for the third sowing date (4.57 and 4.79 tons per hectare, respectively), while the maximum yield was for the second sowing date (5.32 and 5.76 tons per hectare). On average over three years, the highest yield was obtained when sowing was done on the second date.

CONCLUSION

The soft wheat variety Krasnoobskaya ozimaya was developed at the Siberian Research Institute of Plant Growing and Selection through intervarietal hybridization followed by individual selection. This variety was included in the State Register of Breeding Achievements of the Russian Federation in 2021 (patent No. 11706 dated May 27, 2021) and zoned for the 10th region.

The variety has a high yield potential: the maximum yield in competitive variety trials was 6.73 t/ha. In state variety trials, the maximum yield reached 4.90 t/ha. The average yield on variety plots in the Novosibirsk region was 4.34 t/ha. According to the results of the ecological test,

Табл. 3. Результаты испытаний сорта Краснообская озимая на госсортоучастках Новосибирской области (2018–2020 гг.)

Table 3. Test results of the Krasnoobskaya ozimaya variety at the state variety testing plots of the Novosibirsk region (2018–2020)

Variety	Yield, t/ha				Average for the region			
	Severny*	Maslyaninsky*	Vengerovsky	Average	Vegetation period, days	Weight of 1000 grains, g	Grain unit, g/l	Winter hardiness, score
Novosibirskaya 32 (standard)	2,74	3,76	4,04	3,51	318	38,1	805,0	3,9
Krasnobskaya ozimaya	3,76	4,90	4,36	4,34	319	42,2	779,0	4,4
Deviation	+1,02	+1,14	+0,33	+0,83	+1	+4,1	–26,0	+0,5
LSD_{05}	0,43	0,34	0,19	0,32	–	–	–	–

* Test results in 2019

Табл. 4. Результаты экологического сортоиспытания сорта Краснообская озимая

Table 4. Results of the ecological variety testing of the Krasnoobskaya ozimaya variety

Variety	Winter hardiness, %	Resistance to lodging, score	Yield, t/ha
Novosibirskaya 40 (standard)	60	4,2	3,68
Novosibirskaya 3 (control)	63	4,5	4,01
Krasnobskaya ozimaya	62	4,5	4,42

Табл. 5. Урожайность сорта Краснообская озимая при различных сроках посева, т/га*
Table 5. Productivity of the Krasnoobskaya ozimaya variety with different sowing dates, t/ha*

Sowing time	2019	2021	2022	Average	CV, %
August 20	4,64	4,67	5,36	4,89	6,8
September 1	4,40	5,32	5,76	5,16	11,0
September 10	4,07	4,57	4,79	4,48	6,7
Average	4,37	4,85	5,30	4,84	

* LSD_{05} = 0,07.

the studied variety exceeded the Novosibirskaya 40 and Novosibirskaya 3 varieties in terms of yield, showing a yield of 4.42 t/ha. The high and stable yield of this variety is due to a combination of economically valuable traits: high productive tillering, 1000-grain weight, lodging resistance, and winter hardiness. According to the study, the optimal sowing date for the Krasnoobskaya ozimaya variety is the medium sowing date (September 1) with a shift of 1–3 days in either direction. The average yield over three years when sowing at this date was 5.16 t/ha.

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АДАПТИВНОСТЬ СОРТОВ ГРЕЧИХИ В ЛЕСОСТЕПИ КРАСНОЯРСКОГО КРАЯ

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В статье представлены результаты исследования восьми сортов гречихи (Дикуль (стандарт), Даша, Диана, Дизайн, Жданка, Землячка, Наташа, Яшьлек) на предмет адаптивности в условиях Красноярской лесостепи. Для каждого сорта определены следующие показатели: коэффициент пластичности, мера стабильности, интенсивность, индекс стабильности, показатель уровня стабильности сорта, гомеостатичность, селекционная ценность сорта, коэффициент адаптивности. Гидротермический коэффициент показал, что в 2021 г. период со II декады мая по I декаду сентября оказался засушливым, в 2020 и 2022 гг. – избыточно увлажненным. Индекс условий среды при этом был со знаком «–» только в 2022 г. (–2,942). В 2020 и 2021 гг. он был со знаком «+» (+2,821 и +0,121 соответственно). Это позволило определить способность изучаемых сортов гречихи адаптироваться в контрастных условиях. На основе коэффициента пластичности в сочетании с мерой стабильности сделан вывод о способности сортов Землячка, Диана, Дизайн, Дикуль, Яшьлек давать высокий урожай в благоприятных условиях. Но Диана, в отличие от трех остальных сортов, в неблагоприятных условиях может заметно снижать урожай. У сортов Дизайн, Дикуль и Яшьлек в такой же ситуации наблюдалось незначительное снижение урожая. Сорта Даша и Наташа в худших условиях могут давать повышенный урожай. При этом сорт Даша способен в любых условиях давать как высокий, так и низкий урожай, что указывает на его высокую метеонезависимость, тем более что величина урожая у данного сорта по годам мало различается. В то же время сорт Жданка может резко снижать урожай в отдельные годы. Коэффициент адаптивности показал, что Яшьлек, Дизайн и Диана обладают очень высокой степенью адаптивности. Дикуль также можно отнести к сортам с высокой способностью адаптироваться к стрессовым условиям. По результатам исследования, Яшьлек является наиболее адаптивным сортом (сумма рангов составила 22). Немного ему уступили сорта Диана, Дизайн, Даша и Дикуль (сумма рангов 24–33).

Ключевые слова: гречиха, адаптивность, коэффициент пластичности, интенсивность, индекс стабильности, показатель уровня стабильности сорта, гомеостатичность, коэффициент адаптивности

ADAPTABILITY OF BUCKWHEAT VARIETIES IN THE FOREST-STEPPE OF THE KRASNOYARSK TERRITORY

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The article presents the results of the study of eight buckwheat varieties (Dikul (standard), Dasha, Diana, Design, Zhdanka, Zemlyachka, Natasha, Yashlek) for adaptability in the conditions of the Krasnoyarsk forest-steppe. For this purpose, the following indices were determined for each variety: plasticity coefficient, stability measure, intensity, stability index, variety stability level index, homeostaticity, breeding value of the variety, and adaptability coefficient. The hydrothermal coefficient showed that in 2021 the period from the second ten-day period of May to the first ten-day period of September was dry, in 2020 and 2022 – excessively humidified. The index of environmental conditions was with the sign "–" only in 2022 (–2.942). It was with a "+" sign in 2020 and 2021 (+2.821 and +0.121, respectively). This made it possible to determine the ability of the studied buckwheat varieties to adapt under contrasting conditions. Based on the plasticity coefficient in combination with

the measure of stability, the conclusion was made about the ability of the varieties Zemlyachka, Diana, Design, Dikul, Yashlek to give high yield in favorable conditions. But Diana, unlike the other three varieties, in unfavorable conditions can noticeably reduce the yield. The varieties Design, Dikul and Yashlek showed slight yield reduction in the same situation. Dasha and Natasha varieties can produce higher yields under the worst conditions. At the same time variety Dasha is able to give both high and low yields in any conditions, which indicates its high meteorological dependence, especially since the value of the yield of this variety varies little from year to year. At the same time, the Zhdanka variety can sharply reduce yields in some years. The adaptability coefficient showed that Yashlek, Design and Diana have a very high degree of adaptability. Dikul can also be attributed to the varieties with a high ability to adapt to stressful conditions. According to the results of the study, Yashlek is the most adaptive variety (sum of the ranks amounted to 22). Diana, Design, Dasha and Dikul were slightly behind (sum of the ranks was 24–33).

Keywords: buckwheat, adaptability, coefficient of plasticity, intensity, stability index, indicator of the level of stability of the variety, homeostaticity, coefficient of adaptability

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Conflict of interest
The author declares no conflict of interest.

INTRODUCTION

Buckwheat is one of the most famous and important honey and cereal crops in Russia[1, 2]. According to some researchers, biological peculiarities are the underlying cause of low seed productivity of this crop[3]. In this regard, many high-yielding buckwheat varieties have been developed at the Federal Scientific Center of Legumes and Groat Crops in recent years. In addition, these varieties have the ability to adapt to a wide range of soil and climatic conditions [1]. According to V.A. Sapega, G.Sh. Tursumbekova and O.V. Levakova [2, 3], the increase in yield is in close connection with the ability of the variety to resist the complex of biotic and abiotic factors that contribute to yield reduction. According to A.G. Klykov et al. [4, 5], adaptability should be judged mainly by plasticity and yield stability. At the same time, the evaluation of the varieties for these traits is possible in the process of study in sharply contrasting environmental conditions for several years. From the point of view of I.Sh. Fatykhov et al. [6], the environmental stability of the varieties becomes very important under unfavorable conditions. Adaptive varieties, according to K.N. Habibullin et al. [7], are able to ensure stable productivity in different cultivation conditions. Introduction into production of the varieties with high adaptive potential stabilizes the harvest in the years with significantly different weather conditions. Such varieties with proper agronomic practices are able to offset the negative impact of abiotic factors [8, 9].

The purpose of the study was to investigate the adaptive response of buckwheat varieties to contrasting environmental conditions.

MATERIAL AND METHODS

Field studies were conducted as part of competitive variety testing at the Uyarsk state crop testing site in 2020-2022 in the conditions of the

[1] *Kuvshinova L.S.* Ecological adaptability of buckwheat varieties in the conditions of the southern zone of the Amur region: materials of the XIX regional scientific and practical conference "Youth of the XXI century: step into the future" (Blagoveshchensk, May 23, 2018): in 3 vol., Blagoveshchensk, 2018, vol. 2, pp. 127-128.

[2] *Efimenko D.Ya., Barabash G.I.* Buckwheat. M.: Agropromizdat, 1990, 192 p.

[3] Buckwheat culture: monograph: in 3 parts / Edited by E.S. Alekseeva. Kamyanets-Podolsky, 2005, part 1: History of culture, botanical and biological features, 192 p.

Krasnoyarsk forest-steppe in accordance with the methods of state variety testing[4, 5]. The soil was leached chernozem. The forecrop – spring wheat. The experiments were laid in fourfold repetition with randomization within each repetition. The accounting area of plots was 25m^2. The sowing method was row sowing. The seeding rate was 2 million germinated seeds/ha. The soil treatment was carried out in accordance with agrotechnical requirements adopted for the given soil-climatic zone[6]. Soil agrochemical parameters: pH 6.7; humus content - 8.9%; N - 14.6 mg/100 g of soil; P_2O_5 - 28.8 mg/100 g; K_2O - 25.7 mg/100 g (data for 2020). The following fertilizers were applied: chicken manure (50 t/ha), ammonium nitrate N-NO_3 (44 kg/ha), double superphosphate P_2O_5 (52 kg/ha). The sowing was carried out using a Wintersteiger selection planter. The harvesting was carried out using a combine harvester of selection type Sampo-500. Sowing dates: 16.05.2020, 20.05.2021, 18.05.2022.

V.I. Mazalov and V.P. Naumkin [10] recommend considering the adaptability of a variety taking into account such parameters as plasticity, stability and homeostaticity. To determine the adaptability of the studied varieties, the following parameters were calculated:

1) plasticity coefficient (bi) and the index of environmental conditions (Ij) were calculated according to the method of S.A. Eberhart, W.A. Russell[7];

2) the stability measure (S^2d) was determined according to the method of S.A. Eberhart, W.A. Russell as described by the authors of the textbook "Adaptive Features of Breeding and Seed Production of Agricultural Plants"[8];

3) intensity (I) was determined according to the method of R.A. Udachin, A.P. Golovchenko[9];

4) stability index (L`) was determined according to V.A. Zykin[10];

5) Variety Stability Level Index (VSLI) was determined according to the method of E.D. Nettevich, A.I. Morgunov, M.I. Maksimenko[11];

6) homeostaticity (Hom) was calculated according to the method of V.V. Khangildin[12];

7) selection value of the variety (Sc) was determined according to the method of V.V. Khangildin[13] improved by N.A. Orlyansky;

8) adaptability coefficient (AC) was calculated according to the method of L.A. Zhivotkov, Z.A. Morozova, L.I. Sekatueva[14];

9) hydrothermal coefficient (HTC) was calculated according to G.T. Selyaninov[15].

The following varieties were involved in the research: Dikul (standard), Dasha, Diana, Design, Zhdanka, Zemlyachka, Natasha, Yashlek.

The climate of the Krasnoyarsk forest-steppe zone is sharply continental. And if one looks at the indicators for 2020-2022, one can notice their significant difference from the mean annual values (see Fig. 1-3).

Meteorological conditions of the study years differed both among themselves and in comparison with the mean annual (over three years)

[4]Methodology of state varietal testing of agricultural crops. M., 2019, Issue 1: General part, 329 p.

[5]Methodology of state variety testing of agricultural crops. M., 1989, Issue. 2: Grain crops, cereals, grain legumes, corn and fodder crops, 194 p.

[6]Farming system of the Krasnoyarsk Territory on the landscape basis: scientific and practical recommendations. Krasnoyarsk, 2015, 591 p.

[7]*Eberhart S.A., Russell W.A.* Stability parameters for comparing varieties // Crop Science, 1966, vol. 6, N 1, pp. 36–40.

[8]*Korzun O.S., Bruylo A.S.* Adaptive features of breeding and seed production of agricultural plants: textbook, Grodno, 2011, 140 p.

[9]*Udachin R.A., Golovchenko A.P.* Methodology for assessing the ecological plasticity of wheat varieties // Breeding and Seed Production, 1990, N 5, pp. 2-6.

[10]*Zykin V.A., Meshkov V.V., Sapega V.A*. Parameters of ecological plasticity of agricultural plants, their calculation and analysis: method. recommendations, Novosibirsk, 1984, 24 p.

[11]*Nettevich E.D., Morgunov A.I., Maksimenko M.I.* Increasing the efficiency of spring wheat selection for yield stability and grain quality // Bulletin of Agricultural Science, 1985, N 1, pp. 66-73.

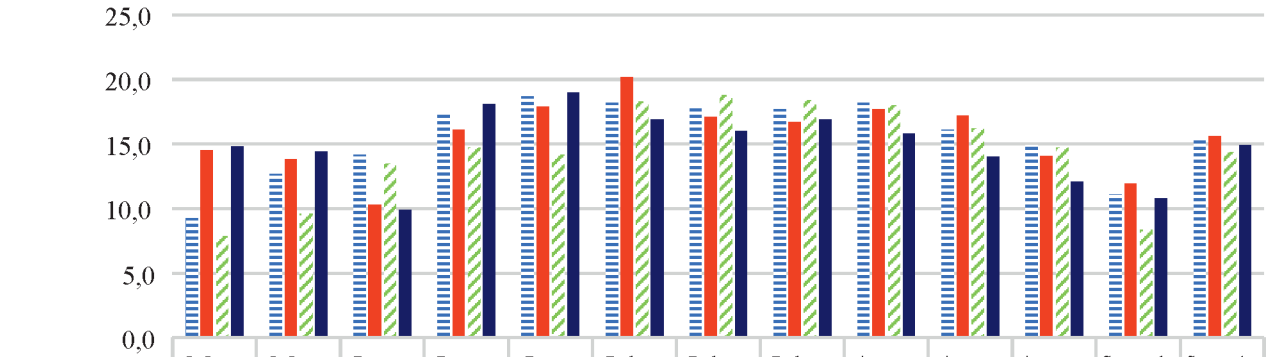
[12]*Khangildin V.V.* On the principles of modernization of the intensive type varieties // Genetics of quantitative traits of agricultural crops. Moscow: Nauka, 1978, pp. 111-116.

[13]*Orlyansky N.A*. Breeding and seed production of grain corn for the increase of adaptability in the conditions of the Central Black Earth Region: Extended abstract of the Doctor's thesis in Agriculture, Belgorod, 2004, 42 p.

[14]*Zhivotkov L.A., Morozova Z.A., Sekatueva L.I.* Methodology for identifying the potential productivity and adaptability of varieties and breeding forms of winter wheat on the indicator "Yield" // Breeding and Seed Production, 1994, N 2, pp. 3-6.

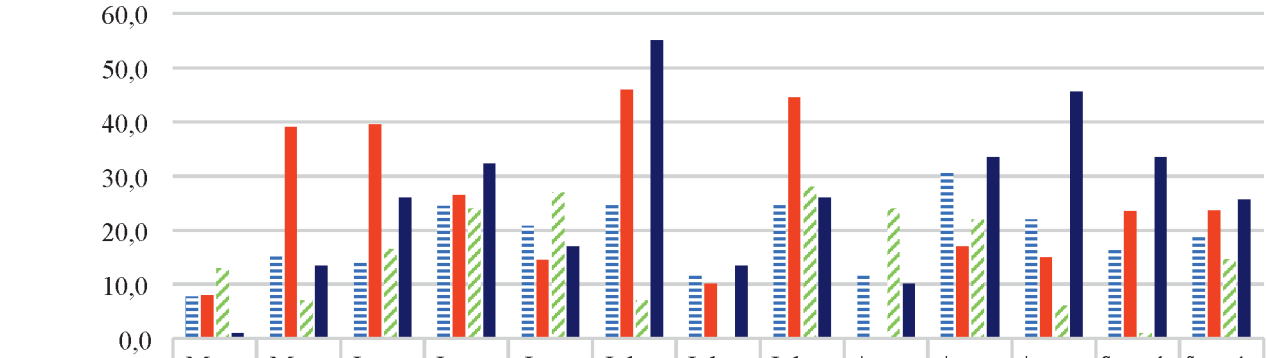
[15]*Selyaninov G.T.* On agricultural assessment of the climate // Works on agricultural meteorology, L., 1928, Issue 20, pp. 169-178.

values. For the period from the second ten-day period of May to the first ten-day period of September, the coolest was the first ten-day period of September (the average temperature for three years was 10.4 ºC, which is 0.7 ºC below the long-term average), while the warmest was the first ten-day period of July (the average temperature reached 18.5 ºC, which is 0.3 ºC above the long-term average) (see Fig. 1). According to Fig. 2, the least precipitation fell in the second ten-day period of May (on average for three years – 7.3 mm, which is 0.4 mm less than the



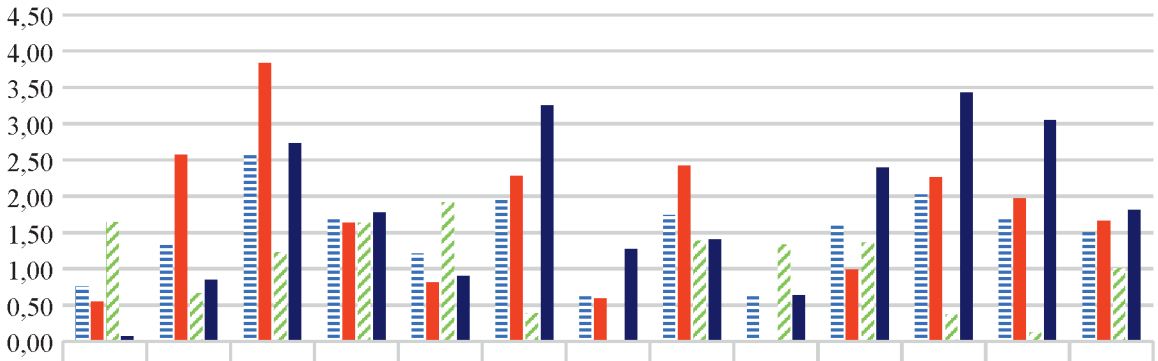
	May II Dec.	May III Dec.	June I Dec.	June II Dec.	June III Dec.	July I Dec.	July II Dec.	July III Dec.	August I Dec.	August II Dec.	August III Dec.	September I Dec.	September
Average	9,3	12,7	14,2	17,4	18,7	18,2	18,0	17,7	18,2	16,1	14,9	11,1	15,5
2020	14,5	13,8	10,3	16,1	17,9	20,2	17,1	16,7	17,7	17,2	14,1	11,9	15,6
2021	7,9	9,6	13,5	14,7	14,2	18,3	18,8	18,4	18,0	16,2	14,7	8,4	14,4
2022	14,8	14,4	9,9	18,1	19,0	16,9	16,0	16,9	15,8	14,0	12,1	10,8	14,9

Рис. 1. Температура воздуха во II декаде мая – I декаде сентября 2020–2022 гг.
Fig. 1. The air temperature in the 2nd ten-day period of May – 1st ten-day period of September 2020–2022



	May II Dec.	May III Dec.	June I Dec.	June II Dec.	June III Dec.	July I Dec.	July II Dec.	July III Dec.	August I Dec.	August II Dec.	August III Dec.	September I Dec.	September
Average	7,7	15,5	14,4	24,4	20,7	25,2	11,6	25,0	11,8	31,1	21,9	16,8	18,8
2020	8,0	39,0	39,5	26,5	14,5	46,0	10,0	44,5	0,0	17,0	15,0	23,5	23,6
2021	13,0	7,0	16,5	24,0	27,0	7,0	0,0	28,0	24,0	22,0	6,0	1,0	14,6
2022	1,0	13,5	26,0	32,3	17,0	55,0	13,5	26,0	10,0	33,5	45,5	33,5	25,6

Рис. 2. Количество осадков во II декаде мая – I декаде сентября 2020–2022 гг.
Fig. 2. Precipitation in the 2nd ten-day period of May – 1st ten-day period of September 2020–2022



	May II Dec.	May III Dec.	June I Dec.	June II Dec.	June III Dec.	July I Dec.	July II Dec.	July III Dec.	August I Dec.	August II Dec.	August III Dec.	September I Dec.	September
Average	0,75	1,36	2,59	1,68	1,21	1,97	0,62	1,74	0,65	1,58	2,02	1,71	1,49
2020	0,55	2,57	3,83	1,64	0,81	2,28	0,59	2,42	0,00	0,99	2,26	1,97	1,66
2021	1,64	0,66	1,22	1,63	1,91	0,38	0,00	1,38	1,33	1,36	0,37	0,12	1,00
2022	0,07	0,85	2,73	1,78	0,90	3,25	1,28	1,41	0,63	2,39	3,43	3,05	1,81

Рис. 3. Гидротермический коэффициент во II декаде мая – I декаде сентября 2020–2022 гг.
Fig. 3. Hydrothermal coefficient in the 2nd ten-day period of May – 1st ten-day period of September 2020–2022

mean annual values), the most precipitation fell in the first ten-day period of July (on average – 36.0 mm, which exceeds the mean annual values by 10.8 mm). The lowest HTC was recorded in the second 10-day period of July (0.62), the highest – in the first 10-day period of June (2.59) (see Fig. 3).

The HTC value can be used to characterize the degree of wetting for a certain period with a high degree of probability. The period from the second ten-day period of May to the first ten-day period of September in 2021 can be called dry, in 2020 and 2022 – excessively humid. The every ten days analysis of weather conditions showed that the second ten-day period of May, second ten-day period of July and first ten-day period of August were dry, and the third ten-day period of May and third ten-day period of June were moderately humid. Sufficient moisture was characteristic of the second ten-day period of August, and excessive – of the first and second ten-day periods of June, the first and third ten-day periods of July, the third ten-day period of August, and the first ten-day period of September (see Fig. 3).

The index of environmental conditions (Ij) with the sign "−" was noted only in 2022 (−2.942). With the sign "+" it was in 2020 (+2.821) and 2021 (+0.121), respectively. Consequently, 2020 can be called the most favorable and 2022 the least favorable.

RESULTS AND DISCUSSION

According to Table 1, Yashlek is one of the highest yielding buckwheat varieties (1.60 t/ha). In 2020 and 2022, it was outperformed by Dasha (in 2022), Diana, and Design (both in 2020). On average over the three years, the highest yields were observed in the varieties Yashlek, Design and Diana.

The shortest duration of the sowing - sprouting period for three years was observed in 2020 (8−10 days). In subsequent years it was 14−17 and 13−18 days, respectively (see Table 2). From May 16 to 23−25, 2020. The HTC in all varieties was equal to 0.00. In 2021 and 2022 it was 0.40−1.19. It is possible that the lack of precipitation at this time resulted in a shorter duration of the period under consideration. The period of sprouting - full flowering, on the contrary, in 2020 became the longest (38−46 days). In 2021, its length reached 31−40 days, in 2022 − 33−43 days. In 2020, the HTC during this period was 2.00−2.32 by the varieties. In 2021−2022 it did not exceed 1.89. Thus, it can be concluded that

Табл. 1. Урожайность сортов гречихи, т/га
Table 1. Yield of buckwheat varieties, t/ha

Variety	2020	2021	2022	Average
Dikul (standard)	1,82	1,40	1,01	1,41
Dasha	1,12	1,36	1,27	1,25
Diana	2,00	1,50	1,08	1,53
Design	2,08	1,52	1,05	1,55
Zhdanka	1,13	1,57	0,94	1,21
Zemlyachka	1,61	0,82	0,81	1,08
Natasha	0,74	0,54	0,47	0,58
Yashlek	1,97	1,60	1,23	1,60
LSD_{05} A (variety)				0,58
LSD_{05} B (year)				0,35
LSD_{05} A × B				1,00

in our experience the growth of the HTC in the period of sprouting − full flowering led to an increase in its duration.

Later, during the whole period of seed ripening, the dependence of the duration of the interphase periods on moistening looks less unambiguous. In 2020, the period of full flowering − browning of the first fruits was the longest (56−70 days). It was the shortest in 2022 (31−37 days). It was slightly longer in 2021 (33−44 days). In 2020, the period of the first fruits browning − economic maturity, similar to the period of sowing − sprouting, was the shortest (2−12 days). In 2021, its duration was 29−37 days (the longest in three years). In 2022 it reached 25−29 days. The vegetation period (sprouting − economic maturity) was the shortest in 2022 (93−100 days). In 2020 and 2021 this period was almost the same − 107−111 and 102−110 days, respectively (see Table 2).

The average duration of the sowing – sprouting period for the years of the study was noted in the variety Diana (12.3 days) – only in this variety this parameter was less than 13 days. The closest to the others were varieties Dasha, Zemlyachka, Yashlek (13 days each) (see Fig. 4). The duration of the period of sprouting – full flowering in most varieties almost did not differ

Табл. 2. Продолжительность межфазных периодов, дни
Table 2. Duration of interphase periods, days

Variety	S − G	S − FB	FB − BFF	BFF − EM	S − EM
2020					
Dikul (standard)	9	39	64	5	108
Dasha	9	39	63	7	109
Diana	9	40	63	7	110
Design	10	46	62	3	111
Zhdanka	9	38	70	2	110
Zemlyachka	8	39	62	8	109
Natasha	10	40	64	4	108
Yashlek	9	39	56	12	107
2021					
Dikul (standard)	16	31	43	30	104
Dasha	15	32	38	36	106
Diana	15	32	43	30	105
Design	14	40	37	33	110
Zhdanka	15	33	36	37	106
Zemlyachka	16	32	38	32	102
Natasha	17	32	44	29	105
Yashlek	15	31	33	37	101
2022					
Dikul (standard)	16	35	32	28	95
Dasha	15	34	37	27	98
Diana	13	37	35	27	99
Design	16	43	32	25	100
Zhdanka	16	33	33	28	94
Zemlyachka	15	35	34	29	98
Natasha	18	35	36	25	96
Yashlek	15	34	31	28	93

Note. S – G – sowing – germination; S – FB – sprouting – full bloom; FB – BFF – full bloom – browning of the first fruits; BFF – EM – browning of the first fruits – economic maturity; S – EM – sprouting – economic maturity (vegetation period).

(34.7–36.3 days). Compared to them, the Design variety had a noticeably longer period (43 days). Similarly, varieties Design and, especially, Yashlek stood out in the period of full flowering – browning of the first fruits. The length of the period for the mentioned varieties was 43.7 and 40.0 days, respectively. The closest to them

was Zemlyachka variety (44.7 days). The period of first fruit browning – economic maturity was less than 20 days (19.3 days) only for Natasha variety. It was followed by the varieties Design (20.3 days) and Dikul (21 days) (see Fig. 4). On average for three years, the shortest growing season was observed in the varieties Yashlek (100.3 days), Dikul (102.3 days), Zemlyachka and Natasha (103 days each) (see Fig. 5). Design, like Yashlek, significantly stood out by this indicator, but to a greater extent – its vegetation period amounted to 107 days.

The plasticity coefficient (bi) indicates the degree of adaptability of the variety. According to Table 3, Zemlyachka variety can be attributed to the ecologically plastic type (bi > 1, $S^2d > 0$). Such a variety in favorable conditions is capable of producing high yields. In unfavorable conditions, on the contrary, the yield value may significantly decrease. Diana, Design, Dikul, and Yashlek can also give high yield in favorable conditions, but, unlike Zemlyachka, in unfavor-

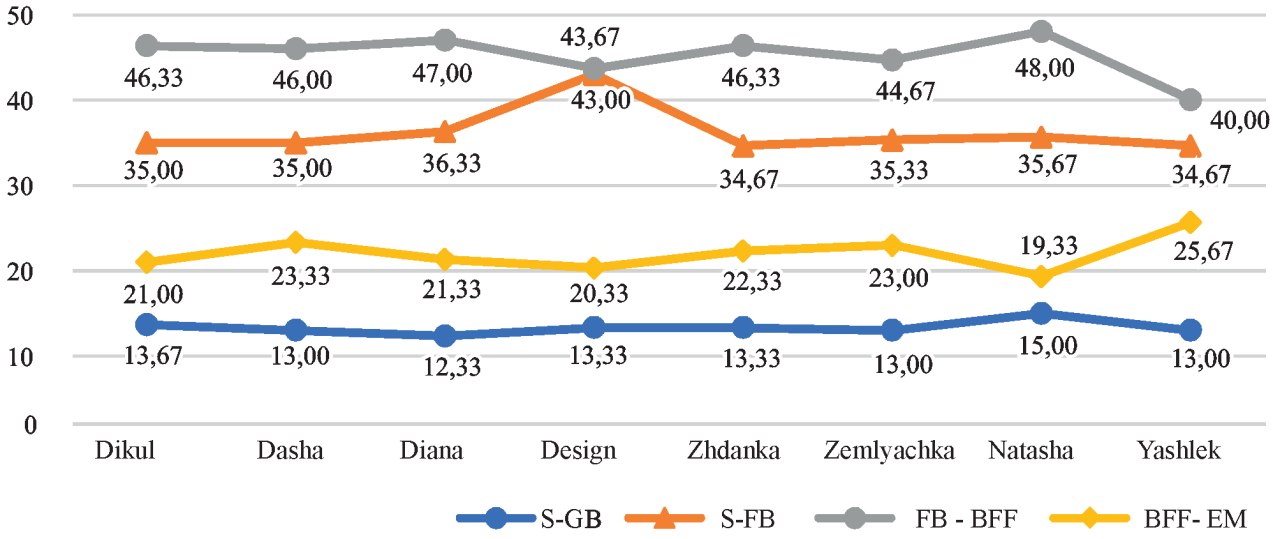


Рис. 4. Средняя продолжительность межфазных периодов по сортам, дни
Fig. 4. Average duration of interphase periods by varieties, days

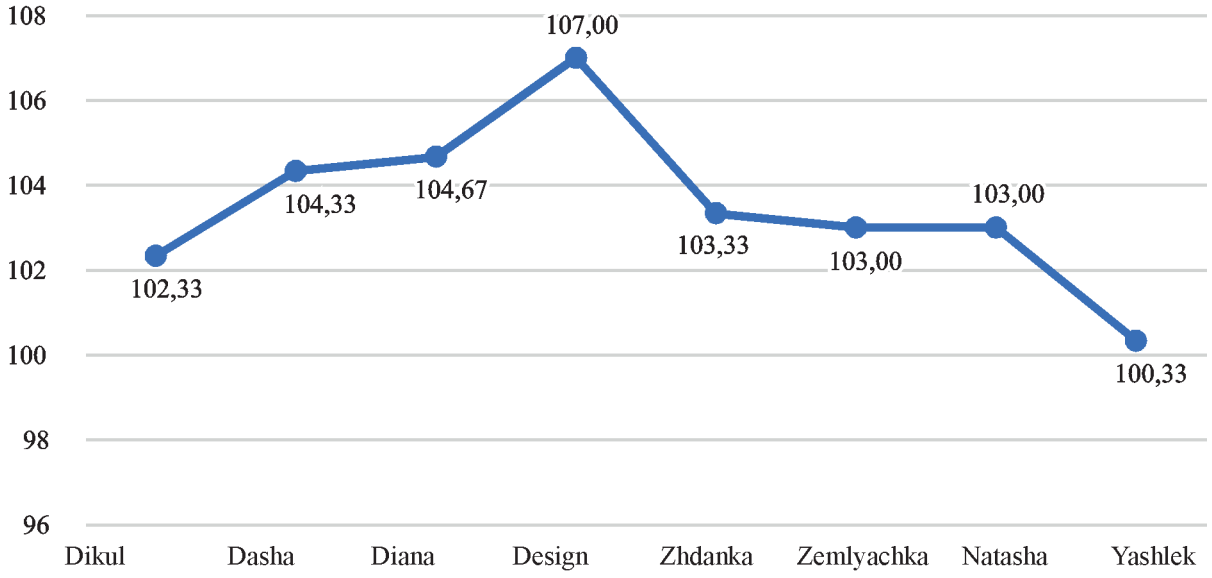


Рис. 5. Средняя продолжительность вегетационного периода по сортам, дни
Fig. 5. Average duration of vegetation period by varieties, days

able conditions the yield reduction will not be so significant (bi > 1, S^2d= 0).

Dasha and Natasha varieties can give high yields under unfavorable conditions (bi < 1, S^2d= 0). In addition, Dasha can be slightly more independent of the weather conditions (due to lodging, as a variant) than the other varieties presented here (its bi has a "–" sign). Thus, this variety can give both large and small yields under any weather conditions. In contrast, Zhdanka's yield can decrease sharply in some years (bi < 1, S^2d> 0), which is almost the main difference between Zhdanka and Dasha and Natasha in this situation.

Intensity (I) shows the reaction of a variety to a favorable background. A.V. Golovchenko defines this parameter as "the ratio of the difference of the yield values obtained under alternative conditions to the average value in the experiment, expressed as a percentage" [11]. The most intensive varieties are Zemlyachka, Design, Diana, Dikul (I = 57.45-74.07%), semi-intensive varieties are Natasha and Yashlek (46.29 and 46.25%), extensive varieties are Zhdanka and Dasha (see Table 3).

Stability index (L`) shows the ability of a variety to give a stable yield close to the average annual yield every year. Dasha variety is significantly superior to all other varieties in this parameter, whose stability index is noticeably higher than that of other varieties (0.129). The closest to it is Yashlek (0.069). Other varieties have a stability index of 0.024-0.051 (see Table 3). VSLI also shows how stable a variety is in terms of yield. Dasha variety is noticeably superior to the other varieties in this parameter (0.16). The varieties Diana, Design, Dikul, Zhdanka are closest to it (0.06-0.08) (see Table 3).

Homeostaticity (Hom) shows the ability of a variety to a smaller reduction in yield when the growing conditions deteriorate [11, 12]. Dasha variety significantly exceeds all in this respect (10.42). Zhdanka is slightly inferior to it (7.75). The other reported varieties are strongly inferior to them in terms of homeostaticity (see Table 3). The highest selection value (Sc) was observed in Dasha and Yashlek varieties (1.77 and 1.60). These varieties responded to growing conditions better than other varieties presented here (see Table 3). Yashlek, Design, and Diana showed the highest adaptability (AC = 1.20 −1.25). Dikul, whose AC is 1.10, can also be called a variety with a high level of adaptability, although inferior to the best varieties in this parameter. The adaptability coefficient is the ratio of the yield of each variety to the average variety values (see Table 3).

The ranked evaluation allows us to state that Yashlek is the most adaptive variety (Σ ranks = 22), which is confirmed by the studies of A.N. Kadychegov, P.R. Tomov [13]. The varieties Diana, Design, Dasha, and Dikul were slightly inferior to it (Σ ranks = 24-33). At the same time, Zemlyachka and Zhdanka showed almost the worst result (Σ ranks = 45-46). The result was worse only for Natasha variety (Σ ranks = 55) (see Fig. 6).

Yashlek was not among the three best varieties in two out of eight indicators. At the same time, only in two cases it became the best. At the same time, the variety Dasha (holder of the four first places) showed the fourth result according to the sum of the ranks. Two eighth places in the parameters indicating the plasticity of the vari-

Табл. 3. Показатели адаптивности сортов гречихи
Table 3. Indicators of adaptability of buckwheat varieties

Variety	bi	S^2d	I	L`	VSLI	Hom	Sc	CA
Dikul (standard)	1,40	0,00	57,45	0,049	0,07	2,45	1,10	1,10
Dasha	–0,25	0,02	19,20	0,129	0,16	10,42	1,77	0,98
Diana	1,59	0,00	60,26	0,051	0,08	2,53	1,26	1,20
Design	1,78	0,00	66,45	0,047	0,07	2,33	1,21	1,21
Zhdanka	0,37	0,19	15,66	0,046	0,06	7,75	1,22	0,95
Zemlyachka	1,36	0,11	74,07	0,025	0,03	1,46	0,59	0,85
Natasha	0,46	0,00	46,29	0,024	0,01	1,26	0,22	0,46
Yashlek	1,28	0,00	46,25	0,069	0,11	3,46	1,60	1,25

ety contributed to this (see Table 4).

CONCLUSIONS

1. Lack of precipitation during the sowing – germination period can shorten the duration of this period. An increase in the wetting factor during the germination – flowering period can increase the duration of this period.

2. According to the results of the study, the variety Yashlek is the most adaptive. The closest to it are the varieties Diana, Design, Dasha, and Dikul. At the same time, in contrasting conditions, variety Dasha showed minimal dependence on the growing conditions, forming a high yield in not the most favorable conditions and, conversely, a low yield in more favorable conditions. At the same time, the difference between the maximum and minimum yields of this variety was minimal.

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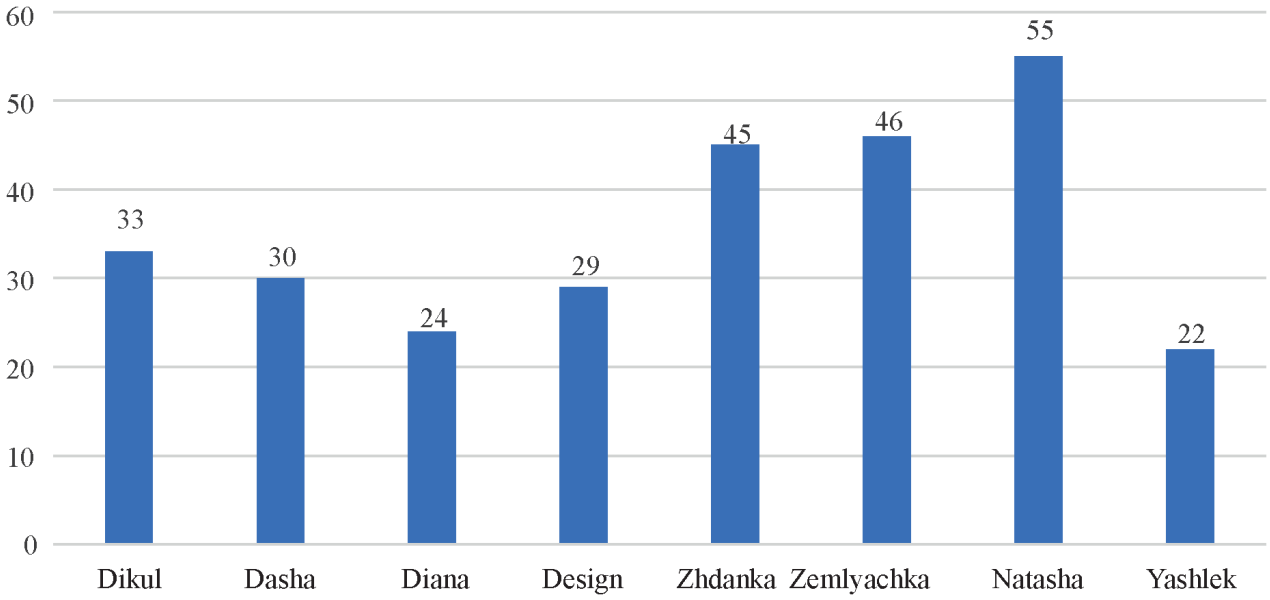

Рис. 6. Сумма рангов сортов гречихи по параметрам адаптивности

Fig. 6. The sum of the ranks of buckwheat varieties according to the parameters of adaptability

Табл. 4. Ранжирование сортов гречихи по показателям адаптивности

Table 4. Ranking of buckwheat varieties by adaptability indicators

Variety	bi	S^2d	I	L`	VSLI	Hom	Sc	CA
Dikul (standard)	3	2	4	4	5	5	6	4
Dasha	8	5	8	1	1	1	1	5
Diana	2	3	3	3	3	4	3	3
Design	1	4	2	5	4	6	5	2
Zhdanka	7	7	7	6	6	2	4	6
Zemlyachka	4	6	1	7	7	7	7	7
Natasha	6	4	5	8	8	8	8	8
Yashlek	5	1	6	2	2	3	2	1

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АГРОБИОЛОГИЧЕСКАЯ ОЦЕНКА СОРТОВ И СОРТООБРАЗЦОВ УЗКОЛИСТНОГО КОРМОВОГО ЛЮПИНА

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Резервом увеличения производства высокобелковых кормов является возделывание зернобобовых культур, в том числе люпина узколистного (*L. angustifolius* L.). Содержание белка в семенах люпина узколистного составляет 33–35%, в сухом веществе зеленой массы – 17–19%. Он является одним из лучших предшественников полевых культур, так как способен накапливать в биомассе симбиотического азота 150–300 кг/га. Исследования проведены в юго-западной зоне Центрального региона (Брянская область). Почва полей – дерново-подзолистая суглинистая, имеет средний уровень плодородия, pH 5,1–5,6. Погодные условия не вполне отвечали биологическим требованиям культуры. Представлены результаты изучения сортов и сортообразцов узколистного люпина в конкурсном сортоиспытании 2020–2022 гг. по урожайности зерна и зеленой массы, адаптивности, содержанию алкалоидов и продолжительности вегетационного периода. За стандарт принят включенный в Государственный реестр сортов Российской Федерации по шести регионам сорт Витязь. Сорта Брянский кормовой и Белорозовый 144 районированы по всем регионам страны. Урожайность зерна разных сортов и сортообразцов по годам изучения варьировала в диапазоне 1,59–3,74 т/га. Максимальный показатель получен по Гибриду 1246 в 2020 г. По средней урожайности зерна за 3 года испытания выделились СН 39-20 и Гибрид 1246 (2,86 и 2,76 т/га). Коэффициент адаптивности составил 121 и 117%. Содержание алкалоидов в семенах данных сортов варьировало от 0,010 до 0,046%, среднегодовой показатель равен 0,028%. Менее 0,04% алкалоидов в семенах имели сортообразцы СБС 56-15-1, Узколистный 53-02 и Гибрид 1314. Продолжительность вегетационного периода по годам испытания варьировала в диапазоне 78–95 дней, календарный срок созревания – конец июля – II декада августа. Все они входят в группу «очень ранних» (71–100 дней). Минимальный срок созревания отмечен в 2021 г., максимальный – в 2020 г. Более продолжительный (на 6–9дней) вегетационный период по сравнению с сортом-стандартом Витязь имеют сорт Белорозовый 144 и Гибрид 1314. Они отличаются высокорослостью и интенсивным боковым ветвлением. Срок технологической готовности к уборке на зеленую массу наступал в I декаде июля. Все изучаемые в опыте сорта и сортообразцы люпина превзошли стандарт по урожайности зеленой массы на 3,1–8,8 т/га.

Ключевые слова: люпин узколистный, сортоиспытание, урожайность семян и зеленой массы, вегетационный период, алкалоидность

AGROBIOLOGICAL EVALUATION OF THE VARIETIES AND CULTIVARS OF NARROW-LEAFED FODDER LUPINE

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The reserve for increasing the production of high-protein fodder is the cultivation of leguminous crops, including narrow-leafed lupine (*L. angustifolius* L.). Protein content in the narrow-leafed lupine seeds is 33–35%, in the dry matter of green mass – 17–19%. It is one of the best forecrops for field crops, as it is able to accumulate 150-300 kg/ha of symbiotic nitrogen in its biomass. The research was conducted in the southwestern zone of the Central Region (Bryansk region). The soil of the fields is sod-podzolic loamy with an average fertility level, pH 5.1–5.6. The weather conditions did not quite meet the biological requirements of the crop. The results of the study of the varieties and cultivars of

narrow-leafed lupin in the competitive variety trial 2020–2022 on grain and green mass yield, adaptability, alkaloid content and duration of the growing season are presented. The Vityaz variety included in the State Variety Register of the Russian Federation in six regions is taken as a standard. The varieties Bryansky kormovoy and Belorozovy 144 are released in all the regions of the country. Grain yield of different varieties and cultivars varied in the range of 1.59–3.74 t/ha during the years of study. The maximum value was obtained for Hybrid 1246 in 2020. SN 39-20 and Hybrid 1246 (2.86 and 2.76 t/ha) stood out in terms of average grain yield over the 3 years of the trial. The adaptability coefficient was 121 and 117%. The alkaloid content in the seeds of these varieties ranged from 0.010 to 0.046%, with an annual average of 0.028%. Less than 0.04% of alkaloids in the seeds were observed in the varieties SBS 56-15-1, Narrow-leafed 53-02 and Hybrid 1314. The duration of the growing season varied in the range of 78–95 days by year of the trial, the calendar maturity date was the end of July – the 2nd ten-day period of August. All of them are in the "very early" group (71–100 days). The minimum maturity date was observed in 2021 and the maximum in 2020. The varieties Belorozovy 144 and Hybrid 1314 have a longer (6–9 days) vegetation period compared to the standard variety Vityaz. They are characterized by high stature and intense lateral branching. The term of technological readiness for harvesting on green mass came in the first ten days of July. All lupine varieties and cultivars studied in the experiment exceeded the standard in green mass yield by 3.1-8.8 t/ha.

Keywords: narrow-leafed lupin, variety testing, seeds and green mass yield, vegetation period, alkaloid content

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INTRODUCTION

The problem of plant protein deficiency and soil fertility reproduction for intensively developing livestock breeding and farming in various regions of the country is urgent. For its successful solution, it is necessary to expand the sowing of leguminous crops, including lupine [1-3]. Narrow-leafed lupine (*L. angustifolius* L.) in comparison with other cultivated annual species has a number of inherent advantages[1]. It is relatively resistant to anthracnose, a fungal disease that has recently become widespread in crops of other cultivated species, and is also characterized by rapid maturity and fast growth rate. It has practically no root leaf rosette phase, and active stem growth and root system development begin after sprouting and seedling emergence. Currently, there are varieties with a growing season of 85-95 days, which indicates that narrow-leafed lupine can be cultivated in the central, northern and northwestern regions of the Non-Black Earth Zone and in Siberia, where the cultivation of other lupine species is difficult due to late maturity [4]. In favor of this annual crop it should be noted that narrow-leafed lupine uses the bioclimatic potential of the zone very well due to a short growing season, resistance to spring frosts and high productivity. Grain yield of modern va-

[1] *Takunov I.P.* Lupin in the agriculture of Russia. Bryansk: Pridesenie, 1996, 372 p.

rieties of narrow-leafed lupine under favorable growing conditions reaches 4.0-4.5 t/ha[2, 3] [5, 6]. According to the results of ecological variety testing at the Irkutsk State Agrarian University named after A.A. Ezhevsky, grain yield of some varieties of narrow-leafed lupine of our selection reaches 5.0 t/ha.

Protein content in the seeds of narrow-leafed lupine is 33-35%, in the dry matter of green mass – 17–19%, with a favorable ratio of amino acids for animal feeding and almost complete absence of trypsin inhibitors. Mowing ripeness occurs on the 50-60th day of vegetation.

Lupine is a good forecrop for a number of crops, especially winter crops. Due to intensive initial growth, narrow-leafed lupine can be grown for green fodder not only in fallow fields, but also in post-cropping and stubble crops. Lupine has a multifaceted effect on soil fertility both through the fertilizing effect of biomass and through the improvement of its biological and physical-chemical properties due to the vitality of nodule bacteria (*Rhizobium lupini*). Its cultivation in farms with different levels of technical support does not present difficulties, as the same technical means are used as for grain crops.

The efficiency of lupine sowing largely depends on the variety diversity of this crop, which is constantly being improved by the breeders' efforts. A variety is a self-reproducing genetically stable system of plants with a certain potential of biological productivity and adaptability, providing high yield and quality of products under certain technological conditions of cultivation. It is one of the most important means of agricultural production. The problem of adaptation of lupine varieties and varietal samples of hybrid origin to changing environmental conditions is urgent. The ability to maintain the consistency of self-regulation processes both in a population and in a single organism is vital and should be expressed in the stabilization of positive economic and biological traits. One of the priority directions in breeding is the unification of environmental stability, productivity and early maturity in one genotype. The trait of early maturity is extremely important for all zones of lupine sowing, as it determines the success in expansion of the areas under crops and increase in seed productivity of lupine [7]. Early maturing lupine varieties should also have an intensive plant growth rate, which makes it possible to increase biomass faster, avoid the effects of summer moisture deficit, and compete with weed vegetation [8].

The purpose of the research is to create a new variety of narrow-leafed lupine, exceeding the standard in grain and herbage yield, early maturing, having low alkaloid content of the grain.

The objectives of the research are to identify promising lupine varieties and varietal samples in terms of yield, adaptive potential, duration of vegetation period and grain alkalinity.

MATERIAL AND METHODS

All-Russian Research Institute (VNII) of Lupine – branch of the Federal Williams Research Center of Forage Production and Agroecology is located in the South-West zone of the Central region. The soils of the field plots are sod-podzolic loamy, cultivated, have an average fertility level, humus content – 2.0–2.3% (according to Tyurin), the soil solution reaction pH 5.1–5.6.

The object of research were ten fodder varieties and varieties of narrow-leafed lupine of own selection, created as a result of many years of purposeful breeding work. The sowing of competitive variety trials in the years of research (2020-2022) was conducted at the end of April or in the first ten-day period of May with a breeding seeder SKS-6-10, the plot area – 16.5m^2, 4-fold repetition; harvesting for grain by combine harvester Sampo-130 in the I or II ten-day period of August. The article presents

[2]*Ivanova E.I., Husnidinov Sh.K., Zamashchikov R.V., Ageeva P.A*. Features of fruiting of narrow-leafed lupine (*Lupinus angustifolius* L.) in the Irkutsk region // Actual issues of the agro-industrial complex in Russia and abroad: Proceedings of the All-Russian scientific conference with international participation, dedicated to the 85th anniversary of Doctor of Agricultural Sciences, Professor Sh.K. Husnidinov, Irkutsk: Irkutsk SAU, 2021, pp. 60-66.

[3]*Kuptsov N.S., Takunov I.P.* Lupin (genetics, selection, heterogeneous crops): monograph. Bryansk: Klintsovsky city printing house, 2006, 576 p.

the results of the study in the competitive variety trial of the released varieties (Vityaz, Bryansky kormovoy and Belorozovy 144) and seven new varieties. Varieties Bryansky kormovoy and Belorozovy 144 are zoned in all regions of the Russian Federation. Vityaz variety was adopted as a standard – indeterminant, early maturing, medium resistance to diseases and pests. When tested at the state variety plots of the country, its grain yield varied from 1.5 to 4.0 t/ha, herbage yield – from 30.0 to 60.0 t/ha. When analyzing the adaptive potential, we used the methodology of the Myronivskiy Research Institute of Wheat [9]. It is based on the dominance of varietal adaptation reactions of plants over specific features of their morphogenesis. The studied samples react simultaneously to the emerging environmental factors as a single-species system [10, 11]. The criterion of the norm is the indicator of study for all years and varieties (average yield). This indicator is taken as 100%, the yield of individual varieties is expressed in relation to it as a percentage.

Planting of experiments, visual observations and records, biochemical analyses were carried out according to the methods generally accepted in breeding work[4,5]. Recommendations on cultivation of narrow-leafed lupine[6] and lupine cultivation technology developed at our institute[7] were used in the research work [12].

The weather conditions were different in the years of the experiment. In 2020 and 2021, heavy rains were observed at the beginning of the growing season (see Fig. 1) with subsequent high-temperature periods that severely compacted and dried the soil. Severe drought in critical phases of growth and development of narrow-leafed lupine had a negative impact on yield formation, as conditions for nitrogen fixation and realization of symbiotic capacity of lupine were unfavorable. In 2022, sowing of selection trials of narrow-leafed lupine was delayed in May due to high soil moisture. The temperature regime during the month was 2.1°C below the norm. The third ten-day period of May and the first ten-day period of June were characterized by increased precipitation. Their total amounted to 116.3 mm with a norm of 50.0 mm, which, as in previous years, strongly compacted the soil. In June, air temperature exceeded the multiyear average by 3.8°C.

Moisture regime in the second and third ten-day periods of June was close to the norm, it promoted friendly and abundant flowering of narrow-leafed lupine and good bean setting. Water and heat regime in July was close to the average multiyear norm. Maturation of the indeterminant varieties of lupine came in mid-August, when the weather was dry and hot (HTC = 0.026), favorable for grain harvesting.

RESULTS AND DISCUSSION

In the scheme of studying breeding material, competitive variety trials are the final stage. Grain yield is an integral indicator that takes into account all plant functions. This indicator in different varieties and cultivars varied in the range of 1.59-3.74 t/ha (see Table 1). The maximum indicator was obtained for Hybrid 1246 in 2020. According to the average grain yield for 3 years of the trial, the new promising varieties CH 39-20 and Hybrid 1246 stood out (2.86 and 2.76 t/ha).

A variety is classified as potentially productive with an increased level of adaptability, if the ratio of two indicators exceeds 100%. In the presented experiment, this group included varieties CH 39-20, Hybrid 1246, Narrow-leafed 53-02 UV and Hybrid 1314. These varieties were more resistant to lodging, which generally had a positive effect on their grain productivity under stress conditions caused by heavy rains with winds.

For normal growth and development of narrow-leafed lupine one of the critical moments is the period of flowering and bean formation, it

[4]Methodology of the State variety testing of agricultural crops. M., 1985, 269 p.

[5]*Dospekhov B.A*. Methodology of field experiment. Moscow: Agropromizdat, 1985, 351 p.

[6]Cultivation and use of fodder narrow-leafed lupine: Practical recommendations edited by Dr. I.P. Takunov / All-Russian Research Institute of Lupine, Bryansk, 2001, 54 p.

[7]*Takunov I.P., Slesareva T.N., Lukashevich M.I. et al.* Innovative experience of fodder lupine production. Moscow: FSBRI "Rosinformagroteh", 2012, 77 p.

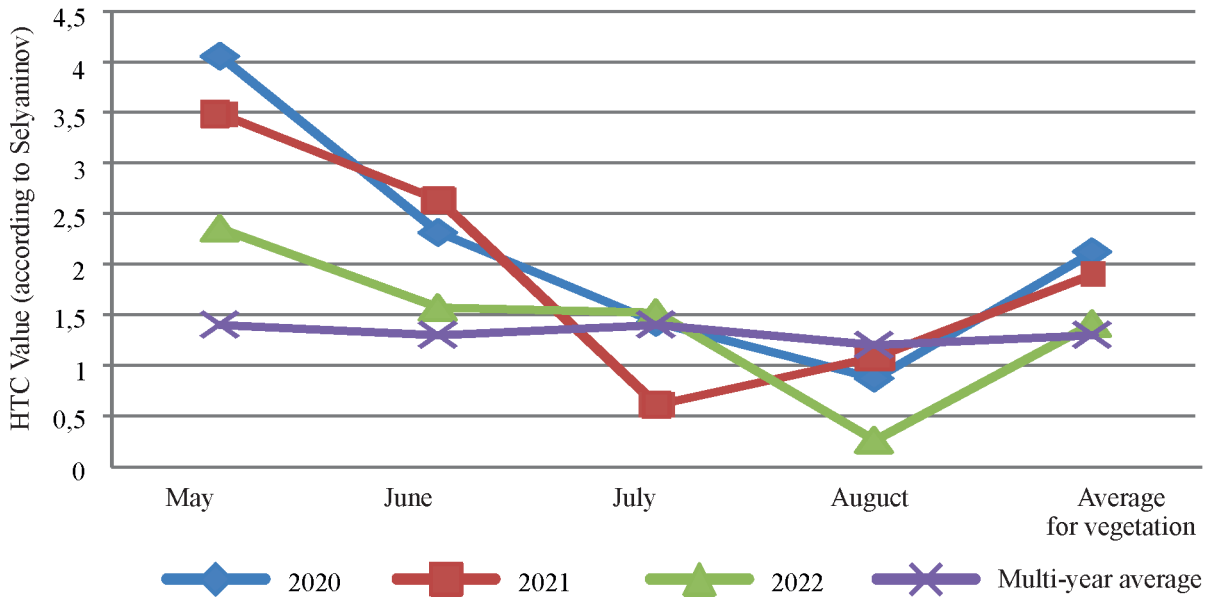

Рис. 1. Гидротермический коэффициент 2020–2022 гг.
Fig. 1. Hydrothermal coefficient in 2020–2022

requires sufficient moisture supply and air temperature within 20-25 °C. If these conditions are violated, lupine shows abortion of buds, flowers and ovaries. 2022 was the most favorable for the realization of grain yield of narrow-leafed lupine. The year conditions index is equal to 0.25. Excess of the standard on the average grain yield of all the variants amounted to 0.02-0.92 t/ha.

Most of the new economically valuable traits and properties in modern varieties of narrow-leafed lupine are determined by mutant genes identified by the breeders in recent de-

Табл. 1. Результаты изучения районированных и перспективных сортов узколистного люпина по урожайности зерна
Table 1. Results of the study of the released and promising varieties of narrow-leafed lupine on grain yields

Variety, varietal specimen	Grain yield, t/ha				Adaptability coefficient, %
	2020	2021	2022	Average	
Vityaz, standard	1,74	1,67	2,42	1,94	83
Bryansky kormovoy	2,18	2,01	2,68	2,29	97
Belorozovy 144	1,94	1,81	2,43	2,07	88
Hybrid 1314	3,12	19,3	2,25	2,43	103
CH 78-07	1,59	1,82	2,47	1,96	83
Hybrid 1246	3,74	2,06	2,48	2,76	117
CH 39-20	3,43	2,17	2,99	2,86	121
SBS 56-15-1	1,96	2,18	2,86	2,33	99
Narrow-leafed 53-02 UV	2,16	2,55	2,91	2,54	108
BSv 51-19	2,50	2,01	2,53	2,35	100
Average variety yield	2,44	2,02	2,60	2,35	100
Index of year conditions	0,09	–0,33	0,25		
LSD_{05}	0,24	0,22	0,19		

cades. Creation of the varieties with reduced content of alkaloids suitable for animal feeding through selection is one of the main tasks. At all stages of the selection process, the alkaloid content is constantly monitored. It includes qualitative methods of determination in vegetative plants and seeds, as well as the quantitative method[8]. The largest number of alkaloids is accumulated in seeds, while the green mass of narrow-leafed lupine contains several times less alkaloids. Varieties with less than 0.025% of alkaloids in seeds are classified as sweet and can be used for food purposes. Seeds or grain forage of lupine with 0.025-0.100% alkaloids content belong to the fodder group - they can be fed to any animals and birds without fear. According to GOST[9] such fodder from lupine grain belongs to the first class. Lupine grain with alkaloid content of 0.2 and 0.3% belongs to the second and third classes of fodder; it can also be used for fodder, following the recommendations.

According to the classifier of the genus Lupinus L.[10], the varieties and cultivars presented in this work belong to the group with consistently low alkaloid content. The content of alkaloids by varieties in the years of study varied from 0.010 to 0.060% (see Table 2). The varieties Hybrid 1246 and CH 39-20 are characterized by low average content of alkaloids in the seeds (0.028%). In the released variety Belorozovy 144 this indicator is equal to 0.033%. The varieties SBS 56-15-1, Narrow-leafed 53-02 UV and Hybrid 1314 have less than 0.04% of alkaloids in the seeds.

In the conditions of Russia, the problem of plant precocity is often crucial for agricultural production. N.I. Vavilov noted in his works: "... if for the countries of Western Europe or even the United States differences in the varieties by vegetation period are of limited importance, then we are forced to cultivate mainly early maturing varieties". Cultivation of short-ripening varieties of narrow-leafed lupine gives the grower a number of advantages - the maturity of the crop occurs in August, when the weather is usually good. Harvesting at a favorable time is always economically less expensive and gives better quality seeds. The green mass is formed earlier, so there is a prospect of postharvest and stubble utilization of lupine. Early-ripening varieties of narrow-leafed lupine are excellent leguminous forecrop predecessors for winter crops, freeing the fields early on.

The duration of the vegetation period of the varieties created at the All-Russian Research Institute of Lupine varied from 78 to 99 days. The calendar maturity date was the end of July - II ten-day period of August. All of them are included in the group of "very early" (71–100 days). The minimum ripening date was noted in 2021, the maximum – in 2020. Compared with the standard, variety Vityaz, the variety Belorozovy 144 and Hybrid 1314 have 6-9 days longer vegetation period. They are characterized by increased linear growth and intensive lateral branching.

Green mass of the narrow-leafed lupine is characterized by high fodder quality: the dry matter contains 16–18% of crude protein, 45–60 mg/kg of carotene, 0.005-0.012% of alkaloids. It is well eaten by all kinds of farm animals[11] [13]. Silage, haylage, grain haylage and other types prepared on its basis are valuable high-protein fodder. There are 50 c of dry matter and one ton of protein in 300 c of green mass of lupine, i.e. as much as it is contained in 90 c of barley grain or 700 c of green mass of corn[12]. Green mass is most often used in feeding farm animals not from pure lupine crops, but from various grass mixtures with it. Grass mixtures are more complete in terms of necessary nutrients. Most often

[8]*Artyukhov A.I., Yagovenko T.V., Afonina E.V., Troshina L.V.* Quantitative determination of alkaloids in lupine. Methodical recommendations: Bryansk, "Chitay-gorod", 2012, 16 p.

[9]GOST R 54632 - 2011 Fodder lupine. Technical conditions. Moscow: Standardinform, 2013, 8 p.

[10]*Stepanova S., Nazarova N., Korneichuk V. Lehman Hr., Mikolajczyk J.* Broad unified CMEA classifier and International CMEA classifier of the genus *Lupinus* L. / VIR. L., 1983, 39 p.

[11]*Artyukhov A.I., Efimenko E.A., Kadyrov F.G., Ageeva P.A.* Recommendations on the practical application of the narrow-leafed lupine fodder in the diets of farm animals. Bryansk: Chitai-gorod, 2008, 65 p.

[12]Resource-saving technologies of grain legume crops production in the Republic of Belarus (recommendations). Zhodino, 2010, 38 p.

Табл. 2. Характеристика вариантов по алкалоидности зерна и продолжительности вегетационного периода

Table 2. Characterization of the variants by grain alkaloid content and duration of the vegetation period

Variety, varietal specimen	Alkaloid content in grain, %				Vegetation period variation, days
	2020	2021	2022	Average	
Vityaz, standard	0,043	0,035	0,059	0,046	82–92
Bryansky kormovoy	0,055	0,060	0,047	0,052	81–89
Belorozovy 144	0,033	0,041	0,023	0,033	90–95
Hybrid 1314	0,039	0,028	0,045	0,037	90–99
CH 78-07	0,044	0,063	0,054	0,054	80–95
Hybrid 1246	0,010	0,029	0,046	0,028	78–95
CH 39-20	0,010	0,045	0,030	0,028	82–93
SBS 56-15-1	0,030	0,044	0,045	0,034	85–91
Narrow-leafed 53-02 UV	0,033	0,027	0,043	0,035	85–93
BSv 51-19	0,045	0,032	0,029	0,041	85–93

lupine is sown together with the following cereals, oilseeds and legumes: oats, barley, spring wheat, millet, rape, field pea, vetch and others. The maximum yield of green mass in lupine in clean sowing comes in the period of shiny bean formation. In general, in the presented experiment, the yield index varied in the range of 26.8–45.5 t/ha, the average sort yield was 35.4 t/ha (see Table 3).

The maximum yield of green mass (42.6–45.5 t/ha) was obtained by new varieties Hybrid 1314, Hybrid 1246 and SBS 56-15-1. The most favorable conditions for the formation of green-mowing products were formed in 2020. The year conditions index amounted to 1.1. All lupine varieties and cultivars studied in the experiment surpassed the average yield of the standard by 3.1–8.8 t/ha. The maximum gain (29.3%) was obtained for Hybrid 1246. When analyzing the adaptability in the group of promising for further breeding included along with Hybrid 1246, variety Belorozovy 144, as well as the variants SBS 56-15-1, Hybrid 1314 and CH 39-20. The adaptability coefficient was 106–112%. The term of technological readiness for harvesting for green mass came in the first ten days of July. Its duration varied within 50–60 days by the varieties in different years of the trial. The general trend is that the variants with a longer vegetation period are able to realize a higher yield of green-maize products.

According to the results of analysis of variance, the difference in green mass yield of a number of varieties is significant.

Graphical representation of the tabulated data on grain yield, green mass and the duration of the growing season (average for 3 years of the trial) is presented in Fig. 2. The vegetation period for the experiment variants varied in the range of 84–95 days. In terms of green mass yield (37.5–38.8 t/ha), both early maturing varieties Hybrid 1246, CH 39-20 and SBS 56-15-1 and the varieties with a longer growing season (95 days) stood out. According to the classifier (see footnote 10), all variants of the competitive variety trial were included in the very early group (71-100 days) in terms of the growing season length. In terms of the grain yield, most variants of the trial outperformed the standard variety Vityaz.

Табл. 3. Урожайность зеленой массы сортов узколистного люпина
Table 3. Green mass yield of the narrow-leafed lupine varieties

Variety, varietal specimen	Green mass yield, t/ha				Adaptability coefficient, %
	2020	2021	2022	Average	
Vityaz, standard	26,8	32,2	31,0	30,0	85
Bryansky kormovoy	31,8	36,2	32,7	33,6	95
Belorozovy 144	39,5	35,0	37,9	37,5	107
Hybrid 1314	38,0	34,8	42,6	38,5	109
CH 78-07	30,1	32,6	36,5	33,1	94
Hybrid 1246	45,0	37,5	34,0	38,8	112
CH 39-20	38,5	37,8	36,9	37,7	106
SBS 56-15-1	45,5	35,3	33,3	38,0	107
Narrow-leafed 53-02 UV	35,0	33,5	33,7	34,0	95
BSv 51-19	34,5	32,3	33,2	33,3	94
Average variety yield, t/ha	36,5	34,7	35,2	35,4	100
Index of year conditions	1,1	–0,7	–0,2		
LSD_{05}	1,72	3,46	1,15		

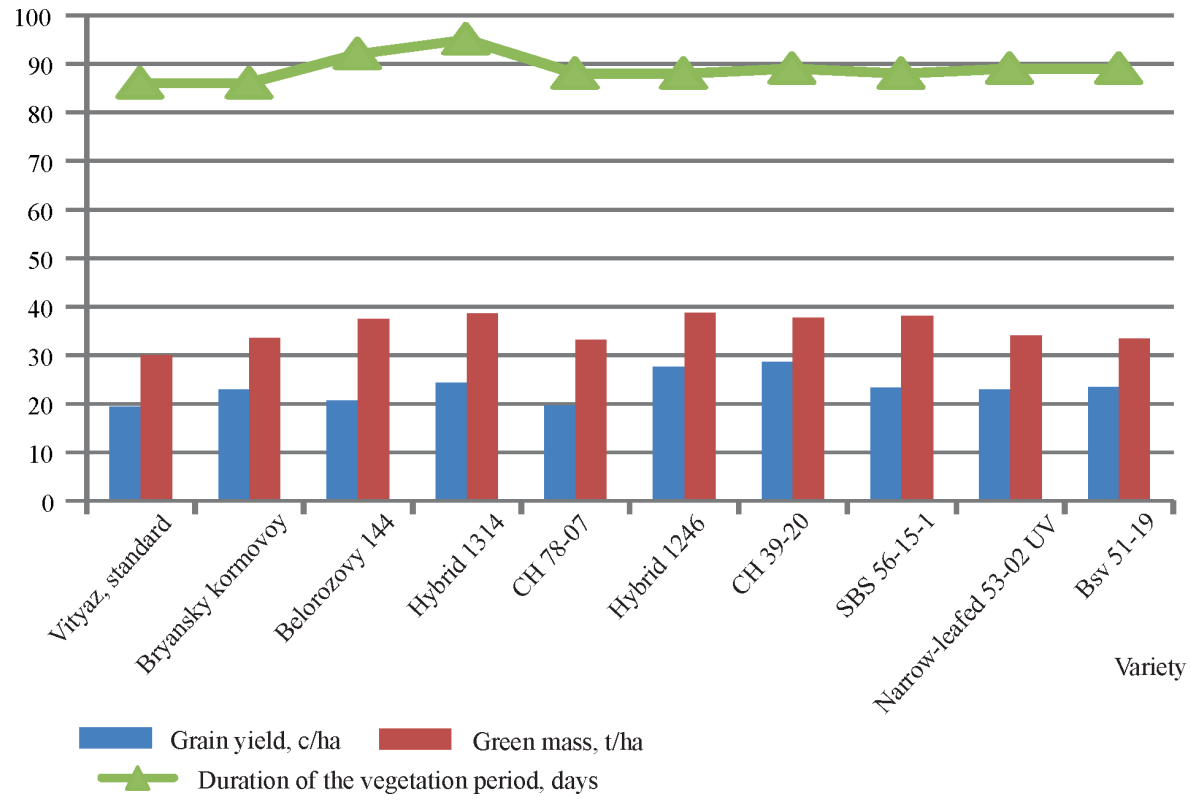

Рис. 2. Урожайность зерна, зеленой массы и продолжительность вегетационного периода сортов и сортообразцов узколистного люпина (среднее за 2020–2022 гг.).

Fig. 2. Grain yield, green mass and vegetation period duration of the varieties and cultivars of narrow-leafed lupine (average for 2020–2022).

CONCLUSION

As a result of long-term studies identified promising varieties with a high level of adaptability, exceeding the standard in grain yield and green mass. Varieties CH 39-20 and Hybrid 1246 surpassed the standard variety Vityaz in grain yield by 0.92 and 0.82 t/ha, in green yield by 8.8 and 7.7 t/ha. Their adaptability coefficient for the first indicator is 117 and 121%, for the second – 106 and 112%. They are characterized by early maturity and low content of alkaloids in seeds.

Modern varieties of narrow-leafed lupine due to their biological features are a source of valuable fodder for all kinds of animals and poultry when cultivated in different regions of the Russian Federation.

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СОДЕРЖАНИЕ ЦИНКА В МОЛОКЕ КОРОВ И ЕГО КОРРЕЛЯЦИИ С АМИНОКИСЛОТНЫМ СОСТАВОМ

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Цинк – один из эссенциальных элементов для всех форм жизни на Земле. Исследование уровня цинка в молоке является актуальной задачей для молочного животноводства и перерабатывающей промышленности. Представлена динамика содержания цинка в молоке коров на протяжении 6 мес. Молоко получали от коров черно-пестрой породы в возрасте 3–4 лет (2–3-я лактации). Установлена сила и направление корреляций с аминокислотным составом молока. В работе исследовано 132 образца молока из племенного хозяйства Краснодарского края. С января по июль 2022 г. (за исключением апреля) из дойного стада сформирована случайная выборка из 22 лактирующих коров. Для точного определения уровня цинка в молоке использованы атомно-адсорбционный анализ с электротермической атомизацией, дейтериевой и Зеемановской коррекцией. Получены соотношения между аминокислотами и цинком в образцах молока коров (в зимне-весенне-летний период), а также коэффициенты корреляции (r) и коэффициенты детерминации (r^2) при определенных уровнях значимости. От месяца к месяцу содержание цинка в молоке сильно варьирует. Незначительные различия относительно января установлены в мае (выше на 1,54%), июне (выше на 9,72%) и июле (ниже на 7,66%). Значительные достоверные различия установлены в феврале – выше на 58,15% ($p < 0,001$) – и в марте – выше на 97,34% ($p < 0,001$) относительно января. Все полученные корреляции цинка с аминокислотами в молоке носят положительный характер, например для треонина в январе $r = 0,50$ ($r^2 = 0,25$, $p = 0,02$), в феврале $r = 0,82$ ($r^2 = 0,67$, $p < 0,01$), в марте $r = 0,25$ ($r^2 = 0,06$, $p = 0,04$), в мае $r = 0,35$ ($r^2 = 0,12$, $p < 0,01$).

Ключевые слова: молоко коров, цинк, микроэлементы, биохимия, элементный анализ

ZINC CONTENT IN COW MILK AND ITS CORRELATION WITH AMINO ACID COMPOSITION

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Zinc (Zn) is one of the essential elements for all life forms on Earth. Investigation of zinc levels in milk is a topical issue for dairy farming and processing industry. The dynamics of zinc content in milk of cows during 6 months is presented. Milk was obtained from Black-and-White cows at the age of 3–4 years (2–3rd lactation). The strength and direction of correlations with the amino acid composition of milk were established. 132 milk samples from a breeding farm (Krasnodar Territory) were studied in this work. A random sample of 22 lactating cows was drawn from the dairy herd from January through July 2022 (excluding April). Atomic-adsorption analysis with electrothermal atomization, deuterium and Zeeman correction were used in order to accurately determine the level of zinc in milk.Correlations between amino acids and zinc in cow milk samples (in winter-spring-summer period) were obtained, as well as correlation coefficients (r) and coefficients of determination (r^2) at certain levels of significance. The zinc content of milk varies greatly from month to month. Insignificant differences relative

to January were established in May (higher by 1.54%), June (higher by 9.72%) and July (lower by 7.66%). Significant reliable differences were found in February – higher by 58.15% ($p < 0.001$) – and in March – higher by 97.34% ($p < 0.001$) relative to January. All obtained correlations of zinc with amino acids in milk are positive, e.g. for threonine in January $r = 0.50$ ($r^2 = 0.25$, $p = 0.02$), in February $r = 0.82$ ($r^2 = 0.67$, $p < 0.01$), in March $r = 0.25$ ($r^2 = 0.06$, $p = 0.04$), in May $r = 0.35$ ($r^2 = 0.12$, $p < 0.01$).

Keywords: cow milk, zink, microelements, biochemistry, elemental analysis

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INTRODUCTION

Zinc is an essential trace element that functions as a cation (Zn^{2+}) in the body. After ferrum, it is the second most abundant in the human body [1]. The balance of zinc absorption and its endogenous secretion by pancreatic and interstitial cells in healthy adults is zero [2]. For better zinc absorption, the diet should contain more protein foods and less carbohydrates[1]. Children, adolescents and the elderly are most susceptible to deficiencies. In estimating the intake of major nutrients by Chinese residents, J. Jiang et al. Jiang et al.[2] found that the total zinc intake is 7.47 mg per day. Milk and dairy products account for only 0.346 mg of zinc per day. The recommended norms are 10 –20 mg [2]. The experience of A.D. Kapsamun et al. [3] shows that at the intake of 314.8 mg (292.30 mg) of zinc per day with the diet, its assimilation in the body of cows is 24.58% (10%), and 56.84 mg (55.11 mg) is excreted with milk, which is about 3 mg/l of zinc in milk. Atomic adsorption analysis [4], plasma emission atomic spectrometry [5] are most often used to accurately determine the level of zinc in milk. Studies show that many factors have the greatest influence on the level of zinc. In the work of S. Zain et al.[3] the metal content in industrially produced milk from different countries of the world for the purpose of identifying the region of origin of the product was considered. It was found that among other regions, industrial milk from Malaysia had the highest zinc content (5.05 mg/kg) against the minimum amount (3.09 mg/kg) in Azerbaijan. E.O. Krupin et al. [6] note that the zinc content in cow milk increases on the 60th day of lactation compared to

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[3] *Zain S.M., Behkami S., Bakirdere S., Koki I.B.* Milk authentication and discrimination via metal content clustering – a case of comparing milk from Malaysia and selected countries of the world // Food Control, 2016, vol. 66, pp. 306–314. DOI: 10.1016/j.foodcont.2016.02.015.

the 30th day from 2.3 to 6.9%. According to S. Kinal et al.[4], there is also an increase in the level of zinc in the milk of cows by the 3rd month of lactation in comparison with the first by 18%. The study of the influence of breed characteristics in the work of R. Pilarczyk does not give significant differences in the level of zinc in milk of Simmental dairy cows and Holstein-Friesian cows, the difference is 7.63%[5].

Under organic farming conditions, where cows consume more green matter from pasture and less concentrated feeds and supplements, N. Qin et al. [7] showed significant differences in zinc levels. Conventional milk has more zinc by 0.5 mg/kg compared to organic milk. The authors note that the highest level of zinc was found in March (8.21 mg/kg) and the lowest in May (3.72 mg/kg). Regions with a high level of anthropogenic impact require special control of zinc intake into milk [8].

The study of zinc levels in milk is an urgent task for dairy farming and processing industry. The information obtained can be used to produce products with low and high zinc content for various functional purposes.

The absorption ratio of zinc is partly due to the presence of high amounts of proteins in milk, which increases the likelihood of zinc chelate complexes with amino acids that are better absorbed, so we estimated correlations for zinc and amino acids in milk.

The purpose of the work is to examine in detail the monthly dynamics of zinc content in milk of cows, as well as correlations of zinc and amino acid content in milk.

MATERIAL AND METHODS

The studies were carried out in 2022 on the basis of a breeding plant in the Krasnodar Territory and in the laboratory of the Federal Research Center for Animal Husbandry – VIZh named after Academy Member L.K. Ernst (Department of Physiology and Biochemistry of Farm Animals). Milk was obtained from 3–4-year-old Black-and-White cows (2–3rd lactation). The observation group, which included 22 dairy cows, was formed in January 2022. A total of 132 milk samples were investigated (from January to July, excluding April due to technical reasons). Milk was sampled during control milkings in the morning and evening. A mixed sample of morning and evening milk (1 : 1) was prepared for the study.

Sample preparation was performed using a microwave system "ETHOSEASY" (Italy) using nitric acid and hydrogen peroxide. In a sample preparation vessel with a protective lid, automatic high-pressure valve and protective screen, 0.5 ml of milk sample was placed, 1.0 ml of 30% hydrogen peroxide and 5.0 ml of 65% concentrated nitric acid (CH) were added. The vessels were then placed in a rotor and placed in an ETHOSEASY microwave system. The temperature in the microwave system was raised to 195 °C for 20 min and held for 15 min, after which the samples were cooled to 30 °C. Control over heating of samples is carried out according to the schedule of temperature rise. Zinc level analysis was performed on atomic adsorption spectrometer (with electrothermal atomization) ZEEnit 650 P (AnalytikJenaAG) with deuterium and Zeeman correction. The detection mode is single-beam optical, wavelength 213.9 nm, lamp – LPC, current – 15 mA, gain – 6 mA, slit – 0.8 nm, without any modifier. An autosampler was used to feed the sample into the graphite furnace. Calibration was performed using ICP multi-element standard solution IV (Sigma-Aldrich). Amino acids were analyzed using LC-20 AD Prominence HPLC system (Shimadzu, Japan) with a reaction module for post-column derivatization ARM-1000 (Sevko&Co, Russia) for the analysis of amino acids in protein hydrolysates. The following amino acids were determined: Asparagic acid (ASP), threonine (THR), serine (SER), glutamic acid (GLU), glycine

[4]*Kinal S., Korniewicz A., Słupczyńska M., Bodarski R., Korniewicz D., Čermák B.* Effect of the application of bioplexes of zinc, copper and manganese on milk quality and composition of milk and colostrum and some indices of the blood metabolic profile of cows // Czech Journal of Animal Science, 2007, vol. 52, N 12, pp. 423–429. DOI: 10.17221/2338-CJAS.

[5]*Pilarczyk R., Wojcik J., Czerniak P., Sablik P., Pilarczyk B., Tomza-Marciniak A.* Concentrations of toxic heavy metals and trace elements in raw milk of Simmental and Holstein-Friesian cows from organic farm // Environmental Monitoring and Assessment, 2013, vol. 185, pp. 8383–8392. DOI: 10.1007/s10661-013-3180-9.

(GLY), alanine (ALA), cysteine (CYS), valine (VAL), methionine (MET), isoleucine (ILE), leucine (LEU), tyrosine (TYR), phenylalanine (PHE), histidine (HIS), lysine (LYS), arginine (ARG), proline (PRO).

The obtained results were processed in Microsoft Excel program using "Analysis Package" add-on, "Descriptive Statistics" function. Zinc levels in February, March, May, June and July were compared relative to the results obtained in January. For comparison the one-factor analysis of variance, Student's *t*-criterion and Bonferroni correction ("α nev" for 6 comparison groups equaled 0.008) were used, having previously assessed the nature of distribution of the studied data and equality of variance between the results for each month.

Pearson's correlation coefficient was used to verify the presence of a linear relationship between zinc and the studied amino acids in the milk of cows, having previously assessed the nature of the distribution of the studied data.

RESULTS AND DISCUSSION

The obtained new data of zinc content analysis in milk are presented in Table 1.

When evaluating the results obtained by the variation coefficient (VC), all periods of the study were characterized by high variability of data (VC > 5%). In January, the highest variation was observed, VC = 35%. During the observation period (from January to July), the minimum value of zinc level (1596 μg/l) in milk of cows was found in January and the maximum (10 488 μg/l) – in March. In January relative to May, June and July minimal differences were established. The differences amounted to 1.54; 9.72 and 7.66%, respectively. Significant differences were also found for March relative to February ($p < 0.001$). The data obtained are comparable

Табл. 1. Данные по исследованию содержания цинка в молоке коров, мкг/л
Table 1. Data on the study of zinc content in milk of cows, μg/l

Indicator	Time of the year					
	January	February	March	May	June	July
	n = 22					
Lactation days	25–30	55–60	85–90	145–150	175–180	205–210
Average	3702,1	5854,7*	7305,7*^	3759,0	4062	3418,6
Statistical error	386,0	241,2	576,2	169,6	164,7	145,2
Median	3830,0	5898	7880	3759	4047	3436
Statistical deviation	1280,1	835,7	2077,5	831,1	806,9	649,5
Excess	–1,0	–0,112	–0,019	0,689	3,08	–0,752
Asymmetry	–0,3	0,118	–0,664	0,311	0,50	0,058
Interval	3756,2	2880	7428	3482	4318	2216
Minimum	1595,8	4320	3060	2166	2108	2378
Maximum	5352	7200	10488	5648	6426	4594
CV, %	35	14	28	22	20	19
CA	–0,574	0,226	–1,271	0,596	0,957	0,111
CE	–0,957	–0,107	–0,018	0,660	2,949	–0,720

Note. *$p < 0{,}001$ for other groups relative to January; ^ $p < 0{,}001$ for March relative to February; CV – coefficient of variation; CA – coefficient of asymmetry; CE – coefficient of excess.

with the study performed by N. Qin et al. [7], where the highest level of zinc was observed in March (8.21 mg/kg), the lowest - in May (3.72 mg/kg). M.M. Dolgaya et al.[6] also note the relative maximum of zinc concentration in the spring period in comparison with other seasons. A.D. Kapsamun et al. [9] note that the trends of zinc metabolism in cows do not depend on the feeding ration characteristic of summer and winter periods. Zinc supplied with feed is fixed in the muscles and tissues of animals. It enters milk from the muscle tissue. At the same time, the body regulates its absorption quite effectively on the principle of feedback. The absorption coefficient increases with zinc deficiency in the body and decreases with its excess[7]. Accordingly, to maintain a zero balance, the rate of its excretion is increased or decreased. In February and March there is an increased excretion of zinc with milk, which by May becomes comparable to the data of January and remains at this level (with small fluctuations) until July.

Throughout the observations, positive correlations of varying degrees of strength were established for almost all zinc values with each of the amino acids (see Table 2).

January, February, March and May turned out to be the most indicative, so we present them within the framework of this work. For the majority of amino acids, positive correlations be-

Табл. 2. Корреляции между цинком и аминокислотами молока
Table 2. Correlations between zinc and milk amino acids

Indicator	January			February			March			May		
	n = 22											
	r	r^2	*p*	*r*	r^2	*p*	*r*	r^2	*p*	*r*	r^2	*p*
ASP	0,59	0,35	0,01	0,77	0,59	< 0,001	0,34	0,12	0,01	0,20	0,04	0,09
THR	0,50	0,25	0,02	0,82	0,67	< 0,001	0,25	0,06	0,04	0,35	0,12	< 0,01
SER	0,63	0,40	< 0,01	0,51	0,26	< 0,001	0,31	0,10	0,01	0,44	0,19	< 0,001
GLU	0,61	0,37	< 0,01	0,70	0,49	< 0,001	0,50	0,25	< 0,01	0,39	0,15	< 0,001
GLY	0,57	0,32	0,01	0,73	0,53	< 0,001	0,20	0,04	0,09	0,29	0,08	0,02
ALA	0,56	0,31	0,01	0,61	0,37	< 0,001	0,32	0,10	0,01	0,30	0,09	0,01
CYS	–0,09	0,01	0,36	0,72	0,52	< 0,001	0,28	0,08	0,02	–0,12	0,01	0,24
VAL	0,64	0,41	< 0,01	0,73	0,53	< 0,001	0,48	0,23	< 0,001	0,36	0,13	< 0,001
MET	0,21	0,04	0,24	0,52	0,27	< 0,001	0,41	0,17	< 0,001	0,23	0,05	0,06
ILE	0,55	0,30	0,01	0,71	0,50	< 0,001	0,63	0,40	< 0,001	0,40	0,16	< 0,001
LEU	0,72	0,52	< 0,01	0,70	0,49	< 0,001	0,50	0,25	< 0,001	0,38	0,14	< 0,001
TYR	0,20	0,04	0,25	0,71	0,50	< 0,001	0,40	0,16	< 0,001	0,34	0,12	0,01
PHE	0,43	0,18	0,04	0,64	0,41	< 0,001	0,47	0,22	< 0,001	0,33	0,11	0,01
HIS	0,59	0,35	0,01	0,64	0,41	< 0,001	0,31	0,10	0,01	0,20	0,04	0,09
LYS	0,09	0,01	0,36	0,75	0,56	< 0,001	0,17	0,03	0,14	0,09	0,01	0,30
ARG	0,53	0,28	0,01	0,37	0,14	< 0,001	0,08	0,01	0,32	-0,18	0,03	0,12
PRO	0,41	0,17	0,05	0,62	0,38	< 0,001	0,61	0,37	< 0,001	0,39	0,15	< 0,001

Note. *r* – correlation coefficient, r^2 – coefficient of determination, *p* – level of significance.

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tween the values of amino acids and zinc in milk were established for the first time throughout the entire period of studies in varying degrees of severity, which was assessed using the Cheddock scale [10]. For example, for ASP, from high (maximum r = 0.77 in February) to very weak (minimum r = 0.20 in May), and for GLU, from high (maximum r = 0.70 in February) to weak (minimum r = 0.39 in May). This is due to the tendency to form complex compounds between ME and amino acids [10, 11], especially between zinc and ASP, or GLU, which have a functional (side) carboxyl group (having a significant negative charge on oxygen atoms when the molecule is ionized) to coordinate with ME (having a large positive charge when dissociated in solutions).

A similar trend is also pronounced for THR from strong (maximum r = 0.82 in February) to very weak (minimum r = 0.25 in March) or for SER from medium (maximum r = 0.63 in January) to weak (minimum r = 0.31 in March). This is due to the possibility of complex compounds forming between zinc and THR or SER that have a functional (side) hydroxyl group (having a "partial" negative charge on the oxygen atom when the dipole is pointed at the OH group) to coordinate with ME (which has a large positive charge when dissociated in solutions), although these complexes have lower binding energy and stability than zinc complexes with ASP or GLU.

In addition, positive (but very weak) correlation coefficient values for zinc values with MET, TYR, LYS (in January), THR, GLY, CYS, LYS, ARG (in March), ASP, GLY, MET, HIS, LYS (in May) are established. Individual negative correlations for zinc with CYS (in January and May) and ARG (only in May) are very weak and insignificant.

Amino acids tend to form chelate complexes with many trace elements [12]. The interaction of amino acids and trace elements is complicated by the multicomponent nature of the system. According to L.M. Pavlov et al. [13], the sorption affinity to mushroom mass as a sorbent corresponds to the following series: Bi ≈ Sn ≈ Pb ≈ Fe ≈ Hg ≈ (Sb) ≈ Cr ≥ Cd ≈ Zn ≈ Cu ≈ V ≈ Se ≥ Co ≈ Mn ≈ (Sb) ≈ As ≈ Ni ≈ Sr, which reflects the complexity of the nature of the mutual influence of elements in a multicomponent system. In addition, the conditions in which the formation of complexes of amino acids with zinc is possible are largely individual for each amino acid, depend on the pH level and a number of other conditions accompanying the digestion process.

Based on the data obtained within the model under consideration, we found that the general trend of positive correlations between zinc and amino acids with rare exceptions persists from month to month. In addition, the coefficient of determination, defined as the proportion of variance that can explain the correlation between zinc and a particular amino acid from month to month, varies with the strength of the correlation. Thus, using SER as an example, the following coefficients of determination were obtained: 0.40 (in January), 0.26 (in February), 0.10 (in March), and 0.19 (in May).

It is worth noting that the formation of trace element-amino acid complexes is possible at each stage of digestion, absorption and metabolism in different parts of the cell [14-16] and even at the time of milk secretion. Consequently, the conditions for the formation of complex compounds between amino acids and zinc are always changing and each stage makes its own adjustments to this process.

CONCLUSION

From January to July, higher zinc content is found in February and March, 37 and 49% higher compared to January. In May-July, zinc intake in milk is close to the January level. Thus, milk obtained in February and March may be more valuable for meeting the daily zinc requirement. Not only correlations between amino acids and zinc in cow milk samples (in winter-spring-summer period), but also correlation coefficients (r) and determination coefficients (r^2) at certain significance levels were obtained for the first time. It is shown that for the majority of amino acids there are significantly high positive correlations between the values of AA and zinc in milk during the whole period of research in different degrees of severity. For example, for ASP – from high (maximum r = 0.77 in February) to very weak (minimum r = 0.20 in May), for GLU -

from high (maximum r = 0.70 in February) to weak (minimum r = 0.39 in May). A similar trend is also pronounced for THR - from high (maximum r = 0.82 in February) to very weak (minimum r = 0.25 in March), for SER - from medium (maximum r = 0.63 in January) to weak (minimum r = 0.31 in March). This is due to the tendency to form complex compounds between ME and such amino acids that have functional (carboxyl or hydroxyl) groups in the radicals for strong coordination with ME (which has a large positive charge when dissociated in solutions). Of course, the formation of complexes of a number of amino acids with zinc is unlikely, and correlations with zinc in milk for CYS, MET, ARG are poorly expressed. In the future, it is planned to obtain new data and quantitative relationships (correlation and determination coefficients at certain significance levels) between all amino acids and zinc in cow milk samples in other months of the year to clarify the obtained patterns.

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ВОЗДЕЙСТВИЕ РАЗЛИЧНЫХ ФОРМ ХРОМА НА МИКРОБИОМ СЛЕПОЙ КИШКИ ЦЫПЛЯТ-БРОЙЛЕРОВ

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Изучено влияние микроэлементов на кишечную микрофлору слепой кишки цыплят-бройлеров. Одной из причин снижения функции кишечного переваривания у птиц является чрезмерный рост микробной флоры в просвете кишечника, что приводит к снижению продвижения химуса и преждевременной деконъюгации первичных желчных кислот. Избыточная микробная флора может привести к повреждению эпителия тонкой кишки, поскольку метаболиты некоторых микроорганизмов цитотоксичны. Определение количества микроорганизмов в слепой кишке бройлеров является важным этапом мониторинга жизнеспособности организма. Кишечная микробиота является самой крупной и сложной микроэкосистемой животных. Микрофлора не только участвует в различных метаболических путях регулирования обмена веществ, но также играет важную роль посредника между пищей и хозяином. Разнообразие кишечной микробиоты и здоровье организма птиц влияют и формируют друг друга, а кишечная микробиота поддерживает относительно сбалансированное состояние с хозяином при устойчивом регулировании внешней среды. Микробиота кишечника играет важную регуляторную роль в обмене питательных веществ и иммунной защите. В работе представлено исследование влияния различных форм хрома (Cr): хлорида ($CrCl_3$), ультрадисперсных частиц (УДЧ Cr) и пиколината (CrPic) – на кишечную микрофлору слепой кишки цыплят-бройлеров. В группе, получавший с рационом CrPic, род *Bacteroides* занимал более 50%, что составляет больше половины всей численности данного таксона, количество *Clostridium XlVb* было значительно менее многочисленным и составляло 0,6%. В совокупности настоящее исследование охарактеризовало динамические изменения микробного сообщества слепой кишки цыплят-бройлеров под воздействием различных форм Cr. Добавление в рацион цыплят-бройлеров CrPic значительно повлияло на микробное разнообразие слепой кишки и вызвало изменения в микробном сообществе, характеризующиеся увеличением филума *Bacteroidetes*, где основным являлся вид *Bacteroides*.

Ключевые слова: хром, микробиота, цыплята-бройлеры, слепая кишка, секвенирование, пиколинат хрома, хлорид хрома

IMPACT OF DIFFERENT FORMS OF CHROME ON THE INTESTINUM CECUM MICROBIOME OF BROILER CHICKENS

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The effect of trace elements on intestinal microflora of the intestinum cecum of broiler chickens was studied. One of the causes of reduced intestinal digestive function in birds is the overgrowth of microbial flora in the intestinal lumen, resulting in decreased chyme advancement and premature deconjugation of primary bile acids. Excess microbial flora can cause damage to the small intestinal epithelium because the metabolites of some microorganisms are cytotoxic. Determination of the number of microorganisms in the intestinum cecum of broilers is an important step in monitoring the viability of the organism. The intestinal microbiota is the largest and most complex microecosystem of animals. Microflora is not only involved in various metabolic pathways to regulate metabolism, but also plays an important role as an intermediary between food and host. Gut microbiota diversity and avian body health influence and shape each other, and the gut microbiota maintains a relatively

balanced state with the host under sustained environmental regulation. The gut microbiota plays an important regulatory role in nutrient metabolism and immune defense. The paper presents a study of the effect of different forms of chromium (Cr): chloride ($CrCl_3$), ultrafine particles (UFP Cr) and picolinate (CrPic) on the intestinal microflora of the intestinum cecum of broiler chickens. In the group receiving CrPic with the diet, the genus *Bacteroides* occupied more than 50%, which is more than half of the total abundance of this taxon, the number of *Clostridium XlVb* was much less abundant at 0.6%. Collectively, the present study characterized the dynamic changes in the microbial community of the intestinum cecum of broiler chickens under exposure to different forms of Cr. The addition of CrPic to the diet of broiler chickens significantly affected the microbial diversity of the intestinum cecum and caused changes in the microbial community characterized by an increase in the phylum *Bacteroidetes*, where *Bacteroides* species was the main one.

Keywords: chromium, microbiota, broiler chickens, intestinum cecum, sequencing, chromium picolinate, chromium chloride

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INTRODUCTION

Chromium (Cr) is an important trace element and has a positive effect on bird health[1] [1]. Supplementation of the diet with trivalent Cr (Cr (III)) can be achieved by using $CrCl_3$ salt. Other sources of Cr such as low molecular weight organic chromium complexes, forms of picolinic acid salts provide many benefits due to higher organic bioavailability[2] [2]. The search for new economically viable sources of Cr is necessary for use in industry and agriculture. Currently, it is relevant to study the effect of Cr on the microbiome of the gastrointestinal tract. In recent years, works have been published on the composition of intestinal microbiota of broiler chickens and its relationship with bird productivity and health [3]. The intestinal microbiota is involved in the maintenance of the intestinal mucosal barrier, maturation of the immune system, nutrient absorption and metabolism. The gut microbial community inhabits the intestine, this may lead to systemic effects [4]. The gut microbiota can serve as a central or contributing factor in a multitude of diseases, affecting near and far organ systems.

The gastrointestinal tract of birds is inhabited by an active microbial community that interacts and evolves with genetic and environmental factors of the host [5]. The development of metagenomics has allowed an intensive study of the microbial genome and has shown that the intestinal microbiota plays an important role in physiology [6].

The purpose of the study was to investigate the effect of different forms of chromium on

[1]*Farag M.R., Alagawany M., El-Hack M.E.* et al. Role of chromium in poultry nutrition and health: beneficial applications and toxic effects // Int J Pharmaco, 2017, vol. 13, pp. 907–915. DOI: 10.3923/ijp.2017.907.915.

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the intestinal microflora of the blind intestine of broiler chickens.

MATERIAL AND METHODS

In vivo studies were performed on broiler chickens of the meat chicken cross "Arbor Aikres". Experimental studies on animals were carried out in accordance with the instructions "Rules for carrying out work using laboratory animals" (attached to the order of the Ministry of Health of the USSR from 12.08.1977 № 755) and "Guide for the care and use of laboratory animals" (publishing house of the National Academy Washington, D.C., 1996). For the experiment, 120 seven-day-old broilers were selected and then divided into four groups (n = 30) by the group-analogy method. The control group of birds received the basic diet. Broilers of the experimental groups were additionally fed $CrCl_3$ ($CrCl_3 \cdot 6H_2O$, containing 19.5% Cr, pure for analysis, production of AO "Reakhim", Russia) in the diet of the 1st group on the 8th – 42nd day, and in the 2nd experimental group – UFP Cr_2O_3 (OOO "Platina", Ltd. Moscow, hydrodynamic diameter 124 nm, specific surface area9m^2/g, Z-potential 93 ± 0.52 mV, contained 99.8% Cr), in the 3rd experimental group – chromium picolinate (CrPic) ($Cr(C_6H_4NO_2)_3$ produced by ZAO "Evalar", Altai region (Biysk, Russia) contains 10% organic chromium). During the experiment, all birds were kept under the same conditions. Broilers were decapitated on the 42nd day of the experiment. The composition of microbiota was investigated from the blind intestine of birds.

The dosage of 100 μg/kg of feed was chosen taking into account the previously conducted experiment to evaluate the biological effect of various sources of Cr, where a positive effect on growth and biochemical parameters of broiler chickens was obtained [7].

Samples of cecal contents were taken immediately after slaughter using sterile disposable forceps and scalpel (Nuova Aptaca SRL, Italy) and placed in a sterile Eppendorf chamber in microtubes with snap-on lids (Nuova Aptaca SRL, Italy), frozen at minus 70 °C (cryofreezer ULUF65 "ARCTICO", Denmark). DNA libraries were prepared and sequenced at the Institute of Cellular and Intracellular Symbiosis of the Ural Branch of the Russian Academy of Sciences (Orenburg, Russia). The results obtained in the studies were processed using the Excel program package from the software package "Microsoft Office XP", "Statistics 10.0", including the determination of the arithmetic mean (M), standard error of the mean(m). Differences at $p \leq 0.05$ were considered reliable.

RESULTS AND DISCUSSION

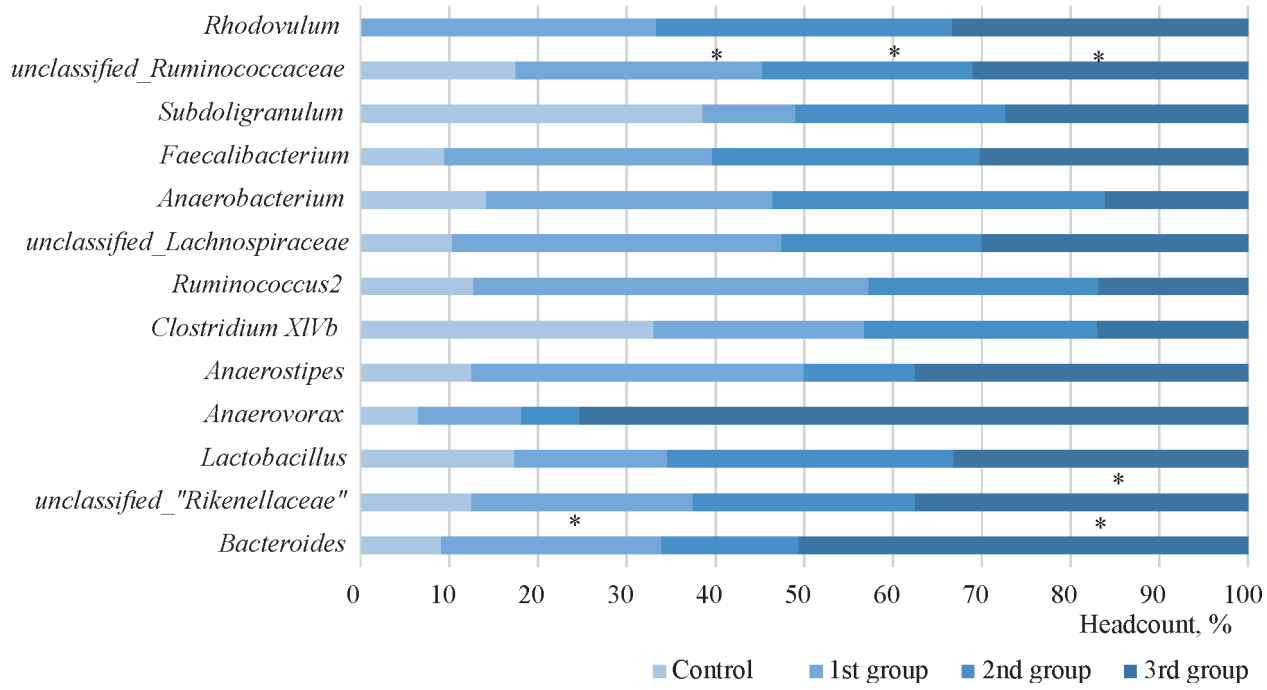
The intestinal microbiota is a collective name for the trillions of microorganisms living in the intestine of birds, comprising more than 35,000 diverse species of known bacteria. The relative percentage of dominant bacteria at different taxonomic levels was estimated by the distribution of microbial taxa. We found significant variability in the gut bacterial community in samples from all groups.

Consideration of the taxonomic profile at the level of families and genera (see Fig. 1, 2) showed that when CrPic was fed to broiler chickens (group 3), the share of *Barnesiellaceae* families within the *Bacteroidia* class increased by 13.72% in comparison with the control group indicators.

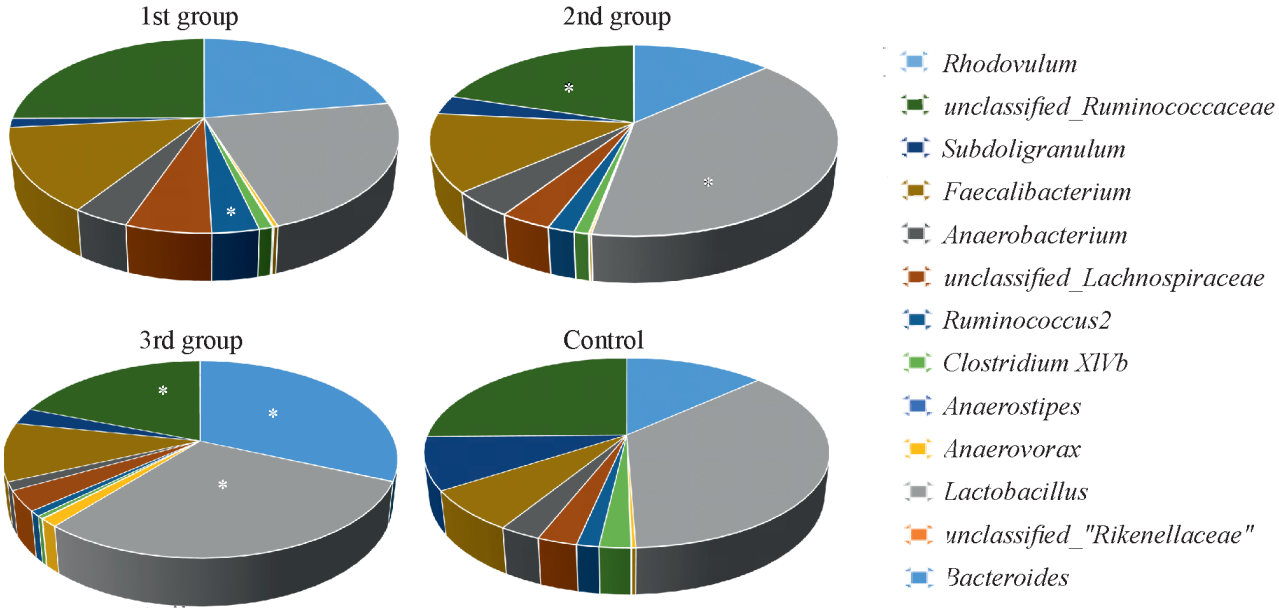
The number of Rikenellaceae decreased in all experimental groups compared to the control: by 7.33% in Group 1, by 6.03% ($p \leq 0.05$) in Group 2 and by 17.35% ($p \leq 0.05$) in Group 3. Within the Bacilli class, the proportion of the Ruminococcaceae family increased when CrCl3 (in group 1) was added to the diet of broiler chickens by 23.6% ($p \leq 0.05$), when Cr was added to the diet (in group 2) by 22.4%, and when CrPic (in group 3) by 23.4% ($p \leq 0.05$) compared to the control.

The study of microbial diversity of the blind intestine of broiler chickens of the control group showed that more than 54% of microorganisms in the microbiota belonged to the taxon *Bacteroidetes*, 45% – to *Firmicutes* and less than 1% – to other taxa.

In the control group, three genera, *Lactobacillus*, *Bacteroides* and *unclassified_Lachnospiraceae*, were prominent and their contents were 36.15; 13.26 and 25.29%. The abundance of other classes was less than 25.3%.



Puc. 1. Микробиом цыплят-бройлеров на уровне семейства
Здесь и в рис. 2. *Различия с контролем достоверны $p \leq 0{,}05$.
Fig. 1. The microbiome of broiler chickens at the family level
Here and in Fig. 2. *Differences with the control are reliable at $p \leq 0.05$.



Puc. 2. Метагеномный анализ содержимого слепой кишки цыплят-бройлеров на уровне рода
Fig. 2. Metagenomic analysis of intestinum cecum contents of broiler chickens at the genus level

The study of the microbiome of the blind intestine of broiler chickens in experimental groups revealed changes in the number of certain species. Thus, when $CrCl_3$ was added to the diet of birds compared to the control, a decrease in the number of *Lactobacillus* (0.1%), *Clostridium XlVb* (0.11%) and *Subdoligranulum* (1.22% ($p \leq 0.05$)) was observed.

At addition of UFP Cr there was an increase in the number of bacteria belonging to the genera *Lactobacillus* (12.55% ($p \leq 0.05$)) and *unclassified_Ruminococcaceae* (6.39% ($p \leq 0.05$)). At

the same time, the abundance of *Anaerovorax* and *Anaerostipes* did not tend to change and amounted to only 0.05 and 0.01%, which was almost identical to its content in the control.

In the group receiving CrPic with the diet, the genus *Bacteroides* occupied more than 50%, which is more than half of the total abundance of this taxon, the number of *Clostridium XlVb* was significantly less abundant at 0.6% ($p \leq 0.05$).

Thus, in-depth sequencing analysis not only contributes to a better understanding of the microflora of the blind intestine of broiler chickens, but also provides an opportunity to identify potential risk factors for its viability. Research is needed to understand the factors that control the populations of this microflora.

Cr is an essential element in improving productivity that can be utilized in the diet of broiler chickens [8]. The amount of Cr present in poultry feed ingredients is assumed to have low bioavailability and its addition to the diet is expected to improve the productivity of the livestock, including broiler chickens.

In the present study, the birds were not subjected to any stress that could prevent the impact of Cr having the most complete beneficial effect on the productive qualities of experimental broiler chickens.

The blind intestine of broiler chickens is home to a variety of bacteria [9]. The gastrointestinal tract of birds, especially the blind intestine, contains a diverse and dynamic microbial ecosystem that plays a vital role not only in digestion, but also in nutrient absorption, vitamin production and defense against pathogens [10].

In our experiment, there is an increase in the proportion of the *Ruminococcaceae* family when different sources of Cr are added to the diet. Scientists believe that *Ruminococcaceae* are beneficial gut bacteria that are involved in positive regulation of the intestinal environment and immune system [11].

The most remarkable aspect of the present study was the significant increase in the microbiocenosis of the blind intestine in the 3rd experimental group. There is evidence that other dietary components affect Cr absorption and utilization [12]. The improvement of production characteristics due to the addition of UFP Cr and CrPic to the diet was reflected in the productivity of the poultry [13].

The phylum *Bacteroidetes* was represented more by the class *Bacteroidia*, occupying 51.2% of the total bacterial communities and more than half of the total abundance of this taxon.

Thus, when CrPic was added, *Bacteroides* was the dominant and diverse species, with an abundance of over 50%.

CONCLUSION

Taken together, the present study characterized the dynamic changes in the microbial community of the blind intestine of broiler chickens under the influence of different forms of Cr. When $CrCl_3$ was added to the diet of birds, the abundance of the genus *Lactobacillus*, *Clostridium XlVb* and *Subdoligranulum* decreased. In turn, the use of UFP Cr in the diet was accompanied by an increase in the number of bacteria belonging to the genera *Lactobacillus* and *unclassified_Ruminococcaceae*. The introduction of CrPic into the diet of broiler chickens significantly affected the microbial diversity of the blind intestine and caused changes in the microbial community characterized by an increase in the phylum *Bacteroidetes*, where the main species was *Bacteroides* species.

Cr had no negative effect on the microbiome of birds in our experiment. The results of this experiment confirm the need for further studies to investigate the effect of different forms of Cr on the microbiome of broiler chickens.

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ЭФФЕКТИВНОСТЬ ИСПОЛЬЗОВАНИЯ БЫКОВ РОССИЙСКОЙ И ИМПОРТНОЙ СЕЛЕКЦИИ НА МАТОЧНОМ ПОГОЛОВЬЕ КРАСНОЙ СТЕПНОЙ И ЧЕРНО-ПЕСТРОЙ ПОРОД В ХОЗЯЙСТВАХ ОМСКОЙ ОБЛАСТИ

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Изучены возможности повышения генетического потенциала маточного поголовья крупного рогатого скота молочных пород посредством использования семени быков-производителей, принадлежащего российским организациям по искусственному осеменению сельскохозяйственных животных и завезенного по импорту. Проведен анализ использования семени быков-производителей голштинской породы российской и импортной селекции на маточном поголовье красной степной и черно-пестрой пород в условиях хозяйств Омской области. Полученные результаты исследований выявили улучшающую способность быков-производителей российской селекции, использующихся на маточном поголовье красной степной породы, по основным продуктивным показателям первой и наивысшей лактации. Удой первотелок на 150 кг, или 2,4%, превышал уровень продуктивности у аналогов импортного корня, превышение по жиру и белку составило 0,10 и 0,08% соответственно. Коэффициент устойчивости лактационной деятельности в этой группе животных был максимальным среди всего поголовья – 92%. На маточном поголовье черно-пестрой породы выявлено превосходство у животных импортного корня по основным продуктивным показателям: удой (+769 кг), содержание жира и белка (+0,04 и +0,13% соответственно), выход молочного жира и белка (+13 и +17%). Также в процессе исследований определено улучшающее влияние генетического потенциала быков-производителей импортной селекции на всем маточном поголовье красной степной породы и на маточном поголовье черно-пестрой породы с уровнем продуктивности 8000 кг. Выявлен улучшающий эффект по удою быков российской селекции при их подборе к маточному поголовью с уровнем продуктивности до 7000 кг.

Ключевые слова: красная степная порода, черно-пестрая порода, быки-производители российской и импортной селекции

EFFICIENCY OF THE USE OF BULLS OF THE RUSSIAN AND IMPORTED SELECTION ON THE BREEDING STOCK OF THE RED STEPPE AND BLACK-AND-WHITE BREEDS AT THE FARMS OF THE OMSK REGION

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The possibilities of increasing the genetic potential of the breeding stock of dairy cattle by using the seed of stud bulls belonging to Russian organizations for artificial insemination of farm animals and the imported ones have been studied. The use of the Holstein breed bulls' seed of the Russian and imported selection on the breeding stock of the Red Steppe and Black-and-White breeds in the conditions of the Omsk region farms has been analyzed. The obtained results of researches have revealed the improving ability of stud bulls of the Russian selection, used on the breeding stock of the Red Steppe breed, on the main productive indices of the first and the highest lactation. The milk yield of the first heifers by 150 kg, or 2.4%, exceeded the productivity level of the imported root counterparts, the excess in fat and protein amounted to 0.1 and 0.08%, respectively. The coefficient of stability of lactation activity in this group of animals was maximum among the whole livestock – 92%. The superiority of imported rootstock animals on the main productive indicators has been identified on the breeding stock of the Black-and-White breed: milk yield (+769 kg), fat and protein content (+0.04 and +0.13%, respectively), milk fat and protein yield (+13 and +17%). Also, in the process of

research the improving influence of the genetic potential of stud bulls of the imported selection on the whole breeding stock of the Red Steppe breed and on the breeding stock of the Black-and-White breed with the level of productivity of 8000 kg has been determined. The improving effect on the milk yield of the bulls of the Russian selection when they are selected to the breeding stock with the level of productivity up to 7000 kg has been found.

Keywords: Red Steppe breed, Black-and-White breed, stud bulls of domestic and imported breeding

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The author declares no conflict of interest.

INTRODUCTION

The main task facing breeders engaged in breeding dairy cattle is to improve the genetic potential of animals. At present, both the seed of bulls-producers, which are the result of Russian breeding and belong to the organizations for artificial insemination of farm animals, and the seed purchased on import, are sold on the Russian market. Improvement of the genetic potential of breeding bulls is carried out by enterprises and highly qualified specialists all over the world[1, 2] [1]. The use of the bulls of Russian and imported selection on the breeding stock of dairy breeds in each specific region has its own peculiarities. Thus, in the Udmurt Republic cows originating from bulls of the Russian selection, including Novosibirsk and Udmurt breeding [2, 3], realize their genetic potential for productivity more effectively. Also in this region, the study of the genetic potential of the bulls of different selection revealed that the mothers of the imported bulls of the Dutch selection were characterized by the highest productive indices (16 359 kg) with fat content of 3.93% and protein content of 3.19%, and those of the German selection – by fat and protein content of 4.46 and 3.35%, respectively [4]. When studying the productive longevity of Simmental cows in 14 regions of Russia, it turned out that the total milk yield of animals of the Russian selection was higher and amounted to 14,423 kg, milk fat – 561 kg, milk protein – 457 kg, total productive days – 959, and the duration of use of cows – 2.91 lactation. When determining the prediction of the breeding value of productive longevity of cows, the advantage of the imported rootstock animals was confirmed, which had higher indicators in comparison with domestic counterparts (+35.8 kg of milk fat, +27.5 kg of milk protein, +44 productive days, +0.117 lactations of age at retirement) [5]. Studies on the stock of the Kholmogory breed of cows in the conditions of the Vologda region allowed us to draw conclusions about the ambiguous manifestation of the productive qualities in cows of the Russian and imported selection. In the animals of domestic breeding a weak positive correlation between the indicators of fat content in cow's milk and the age at the first calving (r = 0.26), with the age of the first fruitful insemination (r = 0.25) was established. Milk yield was positively correlated with live weight at the first fruitful insemination of

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the heifers (r = 0.23). Cows of imported selection had moderate correlation in the following indicators: milk yield and service period (0.33), protein content in milk with the age of the first fruitful insemination (0.48), protein content in milk with the age of the first calving (0.47) [6]. In the Omsk region, the influence of the imported selection bulls on the Red Steppe pedigree stock was positive, showing the best results of the milk yield by 16–19%, as well as high stability of the lactation activity of cows. The duration of the economic activity of cows of domestic rootstock was higher by 1.1 lactation, which entailed an increase in lifetime milk yield by 24-46% than in the animals originating from the bulls of imported selection[3]. In the conditions of the Vologda region farms, cows-daughters of the Ayrshire breed, originating from imported bulls, were characterized by low fat content during the whole period of economic use. In order to increase productive longevity, the authors recommend to use the bulls originating from the Vologda and Yaroslavl regions in the breeding process. In order to increase the mass fraction of fat, it is recommended to use the bulls from the Moscow and Leningrad regions [7]. In the study conducted in the Moscow region, within the framework of bull selection in the population of Holstein and Holsteinized Black-and-White cattle, the use of the breeding value selection index was suggested.

In this case, its calculation should be carried out in each animal population individually [8]. In the conditions of Kazakhstan, the best results of milk productivity of cows of the Holstein breed of the Dutch selection, as well as their crosses with Black-and-White breed were determined [9]. Studies conducted on the herd of the Black-and-White cows showed that the results of the milk yield of the daughters of the Danish bulls were an order of magnitude lower during the milking period. But the amount of milk in basic fatness in these animals exceeded the same indicator in the cows of American and Canadian selection [10]. The superiority of Hungarian and German cows over domestic cows in the studies conducted in the Penza region was observed in the main productive indicators. But first-calf cows of the Russian genealogy were characterized by high milk yields and fat and protein content in milk [11]. Thus, based on the conducted scientific research, an ambiguous picture of the results of using the genetic potential of the bulls of Russian and imported selection was revealed. In the conditions of the Omsk region the main dairy breeds of cattle are the Red Steppe and Black-and-White breeds. The number of the animals of the Red Steppe breed in our region is 18.5% of the all-Russian and 31.2% of the population of the Siberian Federal District (SFD), including cows – 18.2 and 32.0%, respectively. The number of the Black-and-White cattle is about 1% of the total number of cattle in the country and about 7% in the SFD[4].

The purpose of the study is to investigate the influence of genetic potential of the stud bulls of the Russian and imported selection on the productive performance of the Red Steppe and Black-and-White cows under the conditions of the farms of the Omsk region.

The main objectives of the study are:

1) study of milk productivity indicators of the cows according to the results of the first and highest lactation;

2) determination of the difference between the productivity of daughters and their mothers based on the results of the first and highest lactations;

3) study of the influence of selection of the stud bulls of different selection to the pedigree stock of different productivity levels.

MATERIAL AND METHODS

The data of breeding and zootechnical records of the farms of the Omsk region (using the software IAS "Selex-Milk Cattle") were used

[3]*Perminova O.V.* Influence of genetic potential of both foreign and domestic bulls on milk productivity and duration of economic use of Red Steppe breed cows // Agrarian science in the context of global challenges of the world food crisis: problems, trends, solutions. Proceedings of the International scientific correspondence conference, dedicated to the 55th anniversary of the Siberian Research Institute of Poultry Breeding. Editor-in-Chief A.B. Dymkov, Omsk, 2022, pp. 45-49.

[4]Yearbook on the breeding work in dairy cattle breeding in the farms of the Russian Federation (2022). Moscow: publishing house FSBRI VNIIPlem, 2023, 254 p. https://vniiplem.com/wp-content/uploads/2023/04/Ежегодник-мол.-КРС.2022.pdf.

for the research. The breeding stock was divided into groups depending on: breed affiliation (Red Steppe and Black-and-White breeds), origin of the Holstein bull (Russian or imported selection). In the process of research, the main productive indices for the first and highest lactations were determined in cows and their mothers: milk yield for 305 days of lactation (kg), fat and protein content (%), milk fat and protein content (kg), lactation stability coefficient. The primary information on the animals was generated through the "Card Index Structure" of the IAS "Selex-Milk Cattle" and then imported into the Microsoft Office Excel program, where the main statistical calculations were performed in the tabs "Data Analysis" and "Summary Tables". Reliability was assessed using the table of Student's *t*-values, taking into account the number of the degrees of freedom(n-2), where n is the number of the paired variants.

RESULTS AND DISCUSSION

The influence of genetic potential of Holstein breed bulls, the seed of which belonged to domestic organizations for artificial insemination of farm animals or was imported from abroad, on the indicators of milk productivity of the Red Steppe and Black-and-White cows in the conditions of the farms of the Omsk region was considered in the research. The list of the bulls is presented in Table 1.

To improve the genetic potential of the Red Steppe breed breeding stock, Holstein bulls of the Red-and-White breed were used, and for the Black-and-White breed - the Black-and-White breed bulls, accordingly.

The most representative characteristics of cow milk productivity are considered to be the results of the first lactation, which allows predicting the future productive ability of the cow, and the highest lactation, when the animals show

Табл. 1. Быки российской и импортной селекции голштинской породы, улучшающие маточное поголовье

Table 1. Bulls of the Russian and imported selection of Holstein breed improving the breeding stock

Bull number	Bull's name	Bull's seed belonging
Red Steppe breed		
426087690	Lego-M	Russian seed
50996384	Leer-M	» »
466306	Lupoldi-M	» »
449885055	Pablo-M	» »
462490	Fantastic-M	» »
70299144	AltaDo Red	Foreign seed
70690940	AltaIxpi Red	» »
72615044	AltaTLS-Red	» »
63026616	Arisotle (Cole)	» »
9104500	Baculum Red	» »
170079468	Crock Red	» »
104862628	Skyfire Red	» »
105177655	Spectrason Red	» »

Bull number	Bull's name	Belonging to the seed of the bull
Black-and-White breed		
2371402577	Saks	Russian seed
3372305987	Stoker	» »
3372306127	Spring	» »
3372306157	Seoul	» »
66626618	Brit	Foreign seed
69791585	Databank	» »
70626152	Jennings	» »
71441877	Jill	» »
55716840	Ziggy	» »
68731878	Lidus	» »
3009554529	Multiplay	» »
68886533	Oblidge	» »
69486155	Prescot	» »
3010974866	Fearless	» »
3011001279	Freedom	» »
72150287	Hulk	» »
72190820	Hotshot	» »

their genetic potential to the maximum. Indicators of the milk productivity of cows coming from the bulls of different selection are given in Table 2.

First-calf heifers of the Red Steppe breed, descended from the bulls of the Russian selection, surpassed their foreign counterparts in terms of milk yield by 150 kg, or 2.4% ($p< 0.95$) (see Table 2). In terms of milk quality parameters, namely fat and protein content, these animals were also better by 0.1 and 0.08%, respectively ($p < 0.95$). The difference in milk fat and protein yield was also unreliable and amounted to 13.3 and 10.0 kg (+5.3 and +5.0%). The coefficient of stability of lactation activity in this group of animals was the highest among the whole herd – 92% ($p < 0.95$). The opposite picture was observed in the Black-and-White first-calf heifers. Thus, animals of the foreign rootstock surpassed their counterparts from Russian producers by all indicators. Their milk yield for the first lactation (7316 kg) exceeded by 769 kg this indicator of first heifers of the Russian selection ($p < 0,95$). The superiority in fat and protein content was 0.04 and 0.13%, respectively, in milk fat and protein yield – 35.2 kg (+13%) and 35.4 kg (+17%). No significant differences in these indicators were revealed.

According to the results of the highest lactation, animals of the Red Steppe breed of domestic origin repeated the leading position in all indicators of milk productivity. The cows of the Black-and-White breed, originating from the Russian stud bulls, surpassed the milk yield of their imported counterparts by 936 kg, or 11% ($p < 0.95$). Milk quality parameters of the latter animals were higher in fat content by 0.04% and protein content by 0.02%. Milk fat and protein yields were better in cows of Russian selection by 30.4 kg (+8.3%) and 26.5 kg (+9.4%). The most stable character of lactation activity was characterized by animals of foreign origin – more than 91.

Табл. 2. Молочная продуктивность дочерей быков разной селекции по результатам первой и наивысшей лактации

Table 2. Milk productivity of the daughters of the bulls of different breeding according to the results of the first and highest lactation

Indicator	Daughters of the Holstein bulls of different origins			
	Russian		Foreign	
	Improveable breeding stock			
	Red Steppe breed	Black-and-White	Red Steppe breed	Black-and-White
First lactation (305 days)				
Number of daughters	727	63	500	342
Milk yield, kg	6347 ± 1012,3	6547 ± 599,8	6197 ± 1139,4	7316 ± 850,8
Fat content, %	4,15 ± 0,15	4,0 ± 0,09	4,05 ± 0,20	4,04 ± 0,08
Milk fat quantity, kg	264,8 ± 44,26	261,6 ± 23,1	251,5 ± 31,72	296,8 ± 33,7
Protein content, %	3,30 ± 0,12	3,19 ± 0,02	3,22 ± 0,09	3,32 ± 0,09
Milk protein quantity, kg	210,0 ± 36,47	208,9 ± 19,3	200,0 ± 40,18	244,3 ± 31,87
Lactation stability coefficient	92,0 ± 14,7	89,1 ± 8,14	89,0 ± 12,4	91,9 ± 8,52
Highest lactation				
Milk yield, kg	7044 ± 1328,8	9130 ± 1114,9	6824 ± 1082,4	8194 ± 1090,6
Fat content, %	4,16 ± 0,15	4,00 ± 0,09	4,13 ± 0,11	4,04 ± 0,08
Milk fat quantity, kg	292,3 ± 57,59	365,0 ± 42,0	281,7 ± 46,04	334,6 ± 40,6
Protein content, %	3,29 ± 0,11	3,36 ± 0,08	3,21 ± 0,09	3,38 ± 0,05
Milk protein quantity, kg	232 ± 47,61	306,7 ± 40,4	219,2 ± 31,44	280,2 ± 36,14
Lactation stability coefficient	89,0 ± 14,6	87,8 ± 9,8	91,0 ± 12,53	91,6 ± 9,28

Selection of the male and female ancestors plays an important role in breeding and pedigree work to improve herd performance. Table 3 shows the difference in the main productive indicators of the first and highest lactations of daughters and their mothers ("D-M") depending on the belonging to fathers of different breeds of the Russian and foreign breed selection.

The superiority of daughters over their mothers was observed almost by all productive indices. But the magnitude of these differences was different. Thus, in the first-calf heifers of the Russian selection of both Red Steppe and Black-and-White breed it was noted at the level of 653–692 kg, while in the animals of foreign root – 869– 1174 kg. As a consequence, the difference in milk fat and protein yield was greater in the animals originating from imported bulls: Red Steppe breed – 25.1– 41.6 kg and Black-and-White breed – 47.1–52.2 kg, respectively.

Bulls of foreign origin failed to improve the protein content in milk of first-calf heifers of the Red Steppe breed (– 0.06%), and in first-calf heifers of the Black-and-White breed – bulls of domestic origin (–0.02%).

According to the results of the highest lactation, the maximum superiority of the daughters over their mothers in terms of milk yield was observed in the cows of domestic breed by 792-1959 kg. In terms of protein content in milk, only the daughters of the Black-and-White breed surpassed their mothers by 0.10–0.11%.

The results of the influence of selection of the bulls of different breeding to the pedigree stock of different productivity levels are clearly presented in Fig. 1 and 2.

Positive difference "D-M" was shown by those bulls, which worked as milk yield improvers on the given herd.

All bulls of the foreign rootstock showed improving qualities on milk yield of their daughters of the Red Steppe breed (see Fig. 1). The bulls of domestic rootstock worked as improvers only on the Red Steppe breed breeding stock with milk yield up to 7000 kg.

Apparently, for high-yielding cows (with milk yields over 7000 kg), individual selection of bulls with specific improving qualities was not carried out, so that the high genetic potential of these animals was not utilized to produce out-

Табл. 3. Разница показателей продуктивности дочерей и их матерей («Д–М») в зависимости от происхождения от быков разной селекции

Table 3. The difference in productivity indicators of the daughters and their mothers («D–M») depending on the origin of the bulls of different breeding

Indicator	Bull fathers			
	Russian		Foreign	
	Improveable breeding stock			
	Red Steppe breed	Black-and-White	Red Steppe breed	Black-and-White
First lactation (305 days)				
Milk yield, kg	+692	+653	+869	+1174
Fat content, %	+0,09	+0,01	+0,11	+0,05
Milk fat quantity, kg	+35,1	+26,9	+41,6	+52,2
Protein content, %	+0,05	–0,02	–0,06	+0,11
Milk protein quantity, kg	+26,1	+20,0	+25,1	+47,1
Highest lactation				
Milk yield, kg	+792	+1959	+672	+483
Fat content, %	0	0	+0,03	0
Milk fat quantity, kg	+21,2	+78,4	+29,9	+23,1
Protein content, %	0	+0,11	–0,07	+0,10
Milk protein quantity, kg	+16,9	+73,6	+17,1	+26,7

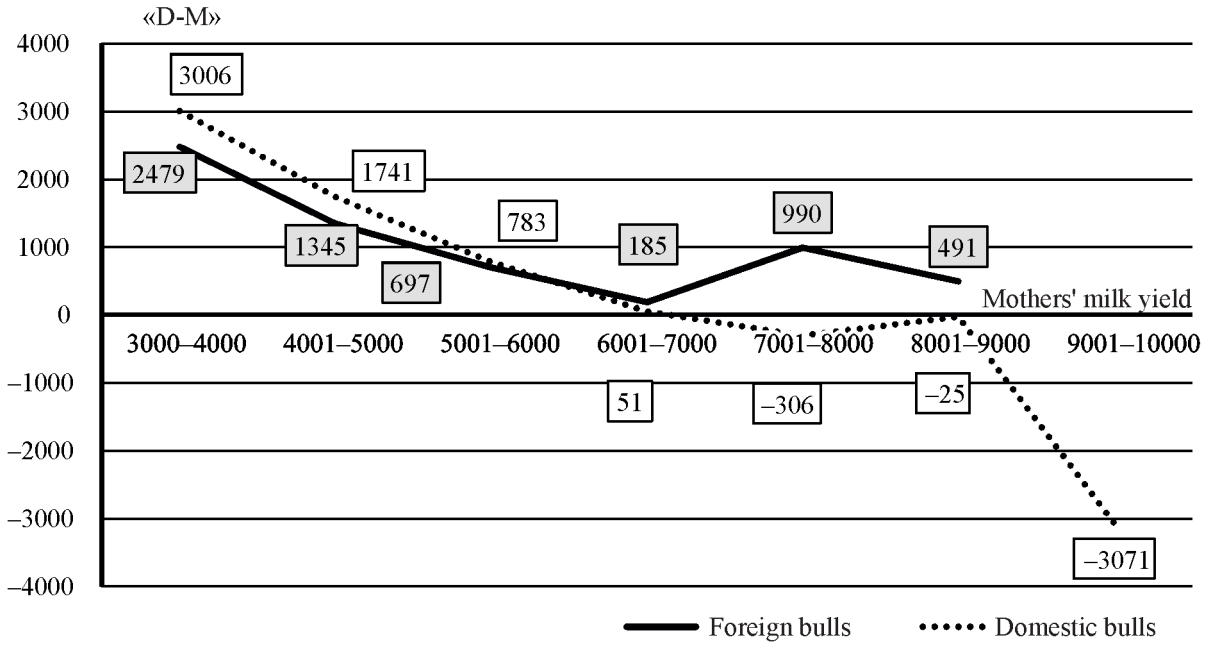

Рис. 1. Разница «Д–М» по удою за первую лактацию в зависимости от удоя матерей красной степной породы, кг

Fig. 1. The difference "D–M" in the milk yield for the 1st lactation depending on the milk yield of the Red Steppe breed mothers, kg

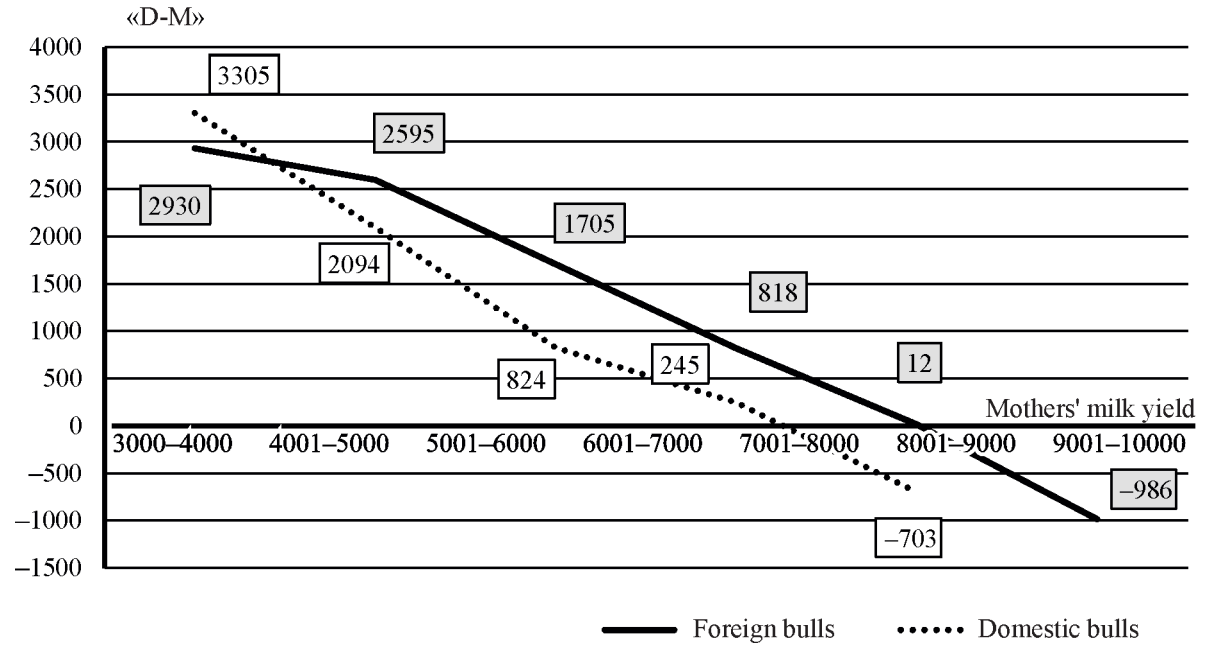

Рис. 2. Разница «Д–М» по удою за первую лактацию в зависимости от удоя матерей черно-пестрой породы, кг

Fig. 2. The difference "D–M" in the milk yield for the 1st lactation depending on the milk yield of the Black-and-White breed mothers, kg

standing progeny.

Foreign breeding bulls of the Black-and-White breed worked as improving breeders on the pedigree stock when selecting sows with milk yield up to 8000 kg, and the Russian bulls – up to 7000 kg (see Fig. 2).

CONCLUSION

The effect of daughters' milk yield improvement occurs only when the bulls of the Russian selection are matched to the mothers with milk yield up to 7000 kg. Foreign bulls for all cows of the Red Steppe breed were improvers, for cows of the Black-and-White breed – only with the level of milk yield of 8000 kg. With increasing productivity of mothers, the effect of using such bulls decreases. Improving ability of stud bulls with high genetic potential will be promoted by individual selection of highly productive cows to them with careful analysis of their genealogical affiliation.

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МЕТОД ПАРАМЕТРИЧЕСКОЙ ОПТИМИЗАЦИИ ГИДРОСООРУЖЕНИЙ ДЛЯ ОТРИЦАТЕЛЬНЫХ ТЕМПЕРАТУР

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Представлен метод оптимизации конструкционно-геометрических параметров с использованием «упрощенного» моделирования процесса охлаждения воды. Данный метод позволяет решать вопросы эксплуатационной технологичности в аспекте создания энерго- и ресурсосберегающих конструкций водонакопительных емкостей. В исследовании для определения размеров подземной и надземной частей водонакопительной емкости принят критерий минимальности теплопотерь и составлена математическая модель теплообмена воды с грунтом при условии его однородности и стационарности теплового режима. Установлено соотношение между высотой и радиусом подземной части при минимальности значения коэффициента теплопередачи от воды к грунту через металлическую стенку. Используя уравнение теплового баланса, найдено аналитическое выражение, определяющее температуру жидкости в надземной части для любого момента времени. На основе теории дифференциального исчисления выявлено условие минимальности темпа охлаждения воды, отдающей тепло через боковые стенки в окружающую среду и воздушное пространство под крышей емкости, что сделало возможной оптимизацию размеров ее надземной части. Определена взаимосвязь радиуса и общего объема водонапорной емкости для среднестатистических значений температуры окружающей среды и скорости ветра, зарегистрированных в регионе проведения исследований. Разработанный алгоритм метода «упрощенного» моделирования и его представление в виде блок-схемы могут быть реализованы при цифровизации расчетно-аналитических процедур для подбора конструкционно-геометрических параметров емкости по критерию минимума тепловых потерь. Графически проиллюстрированы функции радиуса и высоты подземной, а также надземной частей емкости от аргумента ее общего объема.

Ключевые слова: водонакопительная емкость, заглубление, охлаждение, моделирование, оптимизация

METHOD OF PARAMETRIC OPTIMIZATION OF HYDRAULIC STRUCTURES FOR SUBZERO TEMPERATURES

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A method for optimizing design and geometric parameters using a "simplified" simulation of the water-cooling process is presented. This method allows solving the issues of operational manufacturability in the aspect of creating energy- and resource-saving constructions of water storage tanks. In the study to determine the size of underground and above-ground parts of the water storage tank the criterion of heat loss minimization is accepted and the mathematical model of water heat exchange with the ground under the condition of its homogeneity and stationarity of the thermal regime is compiled. The relationship between the height and the radius of the underground part at the minimum

value of the heat transfer coefficient from water to the ground through the metal wall is established. Using the heat balance equation, an analytical expression is found that determines the aboveground fluid temperature for any instant of time. On the basis of the theory of differential calculus the condition of minimality of the cooling rate of water, which gives up heat through the side walls to the environment and air space under the roof of the vessel, was revealed, which made possible to optimize the size of its above-ground part. The relationship of the radius and the total volume of the water holding capacity was determined for the average values of ambient temperature and wind speed recorded in the region of the research. The developed algorithm of the method of "simplified" modeling and its representation in the form of a block diagram can be implemented at digitalization of calculation-analytical procedures for selection of structural and geometrical parameters of the vessel according to the criterion of minimum heat losses. The functions of the radius and the height of the underground and above-ground parts of the vessel from the argument of its total volume are graphically illustrated.

Keywords: water storage capacity, deepening, cooling, modeling, optimization

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INTRODUCTION

Water consumption by production and technological facilities of the agro-industrial complex during a day is characterized by extreme irregularity [1, 2]. In this regard, it is advisable to use permanently filled water storage tanks when operating hydraulic structures. These tanks create a stable head in water distribution networks and perform the function of compensation of daily discreteness of water consumption regime regardless of the periods of negative ambient temperatures, during which the formation of ice with subsequent destruction of both the tanks and water flow control mechanisms is possible. The relevance of this provision is confirmed by the practice of operation of water storage tanks in winter at critically low air temperatures (-25 °C), when regular renewal and mixing of the accumulated water mass is necessary to avoid icing and failure of the hydraulic structure[1]. However, during night hours, the period of "zero" flow rate is not excluded, which leads to water freezing and, as a consequence, to disruption of water supply.

At present, water storage hydraulic structures are still being improved, especially in the aspect of preventing intra-volume ice formation. The proposed improved design solutions[2] [3] are original and interesting, but the issue of operational manufacturability, hence, and economic efficiency in most cases remains open. This represents a serious obstacle to the introduction of new technical systems in water supply technologies [4-9]. In this regard, at present, designers are particularly interested in energy- and resource-saving ways of realizing heat exchange processes in the development of mechanisms and devices for water supply systems [10–12].

One of the approaches to energy saving is partial burial of the water storage tank into the supporting ground[3] [13], since it is a reliable fact that the presence of the underground part of the

[1]*Shatalina I.N., Tregub G.A.* Ice problems of construction and operation of hydraulic structures monograph. SPb.: VNIIG, 2013, 451 p.

[2]Pat. No. 2446262C2 Russian Federation, IPC E 04 H 12/30 (2006.01) / V.G. Petko, A.B. Ryazanov. Water tower; No. 2010111539; applied 25.03.2010; publ. 27.03.2012.

[3]*Asmankin E., Ushakov Yu., Shakhov V., Kargaev I., Neifeld E.* Experience and Prospects for the Development of Water Pressure Tanks // AIP Conference Proceedings ICMTMTE 2021: AIP Publishing, USA, 2022, 7 p.

tank due to the reduction of the water-cooling rate will contribute to the increase of its resistance to icing.

The analysis of theoretical studies has shown that the issue of dimensional characteristics of the underground and aboveground parts of a hydraulic structure has not been recently actualized as a research issue. In this connection, there are no methods for calculating the relevant design parameters, but the essence of practical necessity and theoretical value of providing ice resistance of water storage tanks is a motivating impulse to create the basis for the theoretical base of design works in this direction.

The purpose of the research is to substantiate the method of optimizing the design and geometric characteristics of buried water storage tanks with the function of minimizing heat losses during periods of negative ambient air temperatures.

The analysis is based on a fragment of the operating condition of a cylindrical tank with structural and geometric parameters, on the basis of which modeling of the water-cooling process for the minimum heat loss mode was carried out.

MATERIAL AND METHODS

In the proposed method, a differentiated analysis of the above-ground and underground parts of the tower, which are cylindrical-shaped vessels, is assumed to take into account the influence of thermophysical parameters of the underground part of the hydraulic structure on the overall functional scheme of heat exchange (see Fig. 1).

The procedure of mathematical modeling of the heat exchange process between water and soil in the underground part of the tank is based on the following assumptions:

– the ground mass around the vessel is homogeneous and its temperature field is stationary;

– temperature change from the ground surface to the base level of the underground part will be assumed to be equal to average statistical values determined by climatological tables of the region under consideration[4].

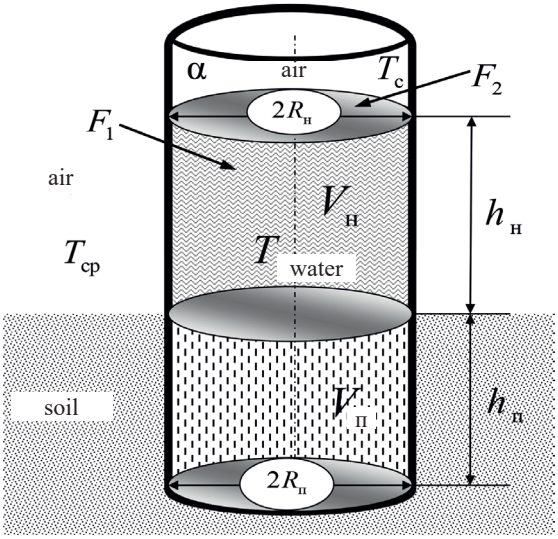


Рис. 1. Расчетная схема для водонакопительной емкости невысотного типа с надземной и подземной частями гидросооружения

Fig.1. Calculation scheme for a low-rise water storage tank with above-ground and underground parts of a hydraulic structure

Due to the instability of the temperature state of the ground at a shallow depth, especially in winter, the criterion of optimality of the underground part can be considered as preservation of the maximum temperature level of water in it: its optimal dimensions should correspond to the condition of minimum value of the heat transfer coefficient between water and ground.

If the underground part of the vessel is represented as a vertical cylinder in a semi-confined massif, then in this case the heat transfer coefficient is calculated according to the formula[5] (see Fig. 1)

$$k_{гр} = 2\pi h_п \lambda_{гр} / \ln \frac{2h_п}{R_п}, \qquad (1)$$

where kгр – heat transfer coefficient of the underground part of the vessel, W/(m² - °C); hп – height of the underground cylinder, m; λgr – heat conductivity coefficient of the ground, W/(m - °C); Rn – radius of the underground cylinder, m.

[4]*Volkov M.M., Mikheev A.L., Konev K.A.* Handbook of the gas industry worker: monograph. Moscow: Nedra, 1989, 144 p.

[5]*Kutateladze S.S.* Fundamentals of the theory of heat transfer. M.: Nauka, 1970, 660 p.

Equality (1) should be considered as a dependence of the heat transfer coefficient on the height of the underground cylinder with other parameters being constant. As a result of differentiation of this function, the condition of minimality of the coefficient krp is determined:

$$k'_{гр}(h_п) = \left(\frac{2\pi h_п \lambda_{гр}}{\ln \frac{2h_п}{R_п}} \right)' = \frac{2\pi\lambda_{гр} \cdot \ln \frac{2h_п}{R_п} - 2\pi h_п \lambda_{гр} \cdot \frac{R_п}{2h_п} \cdot \frac{2}{R_п}}{\ln^2 \frac{2h_п}{R_п}} = \frac{2\pi\lambda_{гр}\left(\ln \frac{2h_п}{R_п} - 1 \right)}{\ln^2 \frac{2h_п}{R_п}}. \quad (2)$$

According to the necessary condition of extremum by means of mathematical operations the stationary point is determined:

$$\ln(2h_п / R_п) - 1 = 0, \text{ т.е. } h_п = eR_п / 2, \quad (3)$$

when passing through which the sign of the derivative changes from minus to plus.

Consequently, the function krp(hп) reaches a minimum, and the obtained ratio makes it possible to optimize the dimensions of the underground part of the hydraulic structure.

For the analysis of the above-ground part of a hydraulic structure, the method involves working with its simplified formalization model, where the following conditions are assumed (see Fig. 1):

– the tank walls are only a heat transfer medium and do not participate in the cooling process with their heat content;

– heat flow through the bottom base of the above-ground part is not taken into account due to the stable temperature state of the separating layer;

– the cooled surface area F of the above-ground part is the sum of the side surface area of the cylinder F1 and the area of the circle F2 (see Fig. 1).

For realization of calculation and analytical procedures of the thermal state of a functioning tank it is necessary to operate with temperature indices of water at any moment of time. The proposed method involves the construction of a mathematical model of the water cooling process in the tank, which is based on the heat balance equation of the functional system under study, expressing the law of conservation and transformation of energy. During modeling, it was taken into account that the change in the heat content of water in the aboveground part of the tank occurs due to heat outflow through the side walls and air space under the roof of the tank, which is a consequence of convective heat exchange between water and air in conjunction with heat consumption for evaporation.

Accordingly, the heat balance equation will be as follows

$$\Delta Q = - Q_{бок} - Q_к - Q_и, \quad (4)$$

where ΔQ is the change of heat content of the above-ground part of water at temperature change by the value dT, J; Qbok is the absolute value of heat outflow from water to air through the side walls of the tank for the time interval dt, J; Qk is the heat given off in the process of convective heat exchange with air for dt, J; Qi is the heat of water evaporation into the air space under the roof of the tank for the same time interval dt, J.

Further investigation is aimed at determining the temperature of water in the tank for any moment of operation time, but in this case, it is necessary to consider the components of the heat balance.

In the left part of the equality (4), the calculation of the change in the intrinsic heat of water is performed by the formula

$$\Delta Q = V_н \rho c dT, \quad (5)$$

where Vn – water volume of the above-ground part of the tank, m^3; c – heat capacity of water, J/(kg - °C); ρ – density of water, kg/m^3.

The right side of the equation (4) calculates the amount of the heat released from water to air through the separating solid wall::

$$Q_{\text{бок}} = k_{\text{возд}} F_1 (T - T_{\text{ср}}) dt, \quad (6)$$

where kвозд – heat transfer coefficient through the side walls of the above-ground part of the tank, W/(m² - °C); F1 – area of the side surface of the above-ground part of the tank, m²; T – water temperature at a given time, °C; Tcp – ambient temperature, °C; t – time, s.

Based on the Newton's empirical law on the magnitude of convective heat transfer between the water surface and air, the equality was introduced into the calculation and analytical algorithm of the proposed method

$$Q_{\text{к}} = \alpha F_2 (T - T_{\text{c}}) dt, \quad (7)$$

where α – heat transfer coefficient from water surface to air in the air space zone due to convection, W/(m² – °C); F2 – water surface area under the tank roof, m²; Tc – air temperature above the water surface in the tank, which is assumed to be equal to the average between ambient and tank water temperatures, °C.

As a result of algebraic transformations, taking into account the condition for Tc, the equation follows

$$Q_{\text{к}} = \alpha F_2 (T - T_c) dt =$$

$$= \alpha F_2 \left(T - \frac{T + T_{\text{ср}}}{2} \right) dt = \alpha F_2 \left(\frac{T - T_{\text{ср}}}{2} \right) dt =$$

$$= \frac{\alpha}{2} F_2 (T - T_{\text{ср}}) dt, \quad (8)$$

characterizing convective heat exchange.

According to the proposed method, although it is allowed to calculate the heat input for evaporation by empirical formulas, but since the amount of heat given up for evaporation depends on the same factors as for convective heat exchange[6], in the approximate model it can be assumed and considered that Qи ≈ Qк.

Thus, the heat balance equation of the above-ground part of the vessel takes the following form

$$V_{\text{н}} \rho c dT =$$

$$= -k_{\text{возд}} F_1 (T - T_{\text{ср}}) dt - 2 \cdot \frac{\alpha}{2} F_2 (T - T_{\text{ср}}) dt. \quad (9)$$

After algebraic simplification the equation (9) is reduced to the form

$$-(k_{\text{возд}} F_1 + \alpha F_2)(T - T_{\text{ср}}) dt = V_{\text{н}} \rho c dT. \quad (10)$$

Equation (10) is a differential with separable variables (time t is an argument, T is a time-dependent function), which after their separation is transformed into the equality Integration of both parts (11)

$$\frac{dT}{T - T_{\text{ср}}} = -\frac{(k_{\text{возд}} F_1 + \alpha F_2) dt}{V_{\text{н}} \rho c}. \quad (11)$$

Integration of both parts (11)

$$\int \frac{dT}{T - T_{\text{ср}}} = -\int \frac{(k_{\text{возд}} F_1 + \alpha F_2) dt}{V_{\text{н}} \rho c} \quad (12)$$

finally gives the equation

$$\ln \left| T - T_{\text{ср}} \right| = -\frac{k_{\text{возд}} F_1 + \alpha F_2}{V_{\text{н}} \rho c} t + C. \quad (13)$$

To unambiguously determine the dependence between the above variables, it is necessary to set the initial conditions. If at the initial moment of time the water temperature in the above-ground part of the hydraulic structure was everywhere the same and equal to T0, i.e. at t = 0

T = T0, then further the integration constant C = ln|T0 - Tcp| can be determined and after transformations by the property of logarithms the equality takes the form

$$\ln \left| \frac{T - T_{\text{ср}}}{T_0 - T_{\text{ср}}} \right| = -\frac{k_{\text{возд}} F_1 + \alpha F_2}{V_{\text{н}} \rho c} t. \quad (14)$$

Potentiation of both parts of equality (14) gives the ratio

$$T = T_{\text{ср}} + \left(T_0 - T_{\text{ср}} \right) \cdot e^{-\frac{(k_{\text{возд}} F_1 + \alpha F_2) t}{c \rho V_{\text{н}}}}, \quad (15)$$

allowing to determine the temperature T of water at any moment of time.

The obtained dependence between the temperature of water in the above-ground part of

[6] *Gotlib Ya.L., Zhidkikh V.M., Sokolnikov N.M.* Thermal regime of reservoirs of hydroelectric power plants. L.: Gidrometeoizdat, 1976, 204 p.

the vessel and the ambient temperatures, as well as water at the initial moment of time, heat transfer and heat transfer coefficients, cylinder dimensions and cooling time allows us to set the condition of thermal losses minimization. In this case, the time interval of zero consumption t, heat capacity and density of water should be considered as constant values. In this case, the minimum corresponds to the fraction $\frac{k_{возд}F_1 + \alpha F_2}{V_н}$. According to the known formulas, for the area of the side surface of the cylinder $F_1 = 2\pi R_н h_н$, the area of the "mirror" of water $F_2 = \pi R_н^2$ and the volume of the cylindrical body $V_н = \pi R_н^2 h_н$, the relation is formalized as follows

$$\frac{k_{возд}F_1 + \alpha F_2}{V_н} = \frac{k_{возд} \cdot 2\pi R_н h_н + \alpha \cdot \pi R_н^2}{\pi R_н^2 h_н} = \frac{2k_{возд}}{R_н} + \frac{\alpha}{h_н} = \frac{2k_{возд}}{R_н} + \frac{\alpha \cdot \pi R_н^2}{V_н}. \quad (16)$$

As a rule, technical conditions specify a constant value of the volume of the above-ground part of the cylinder Vn, therefore, it can be stated that expression (16) depends only on one variable – the radius of the cylinder, the determination of which is one of the tasks of the optimization process.

The result of the further solution of the mathematical problem of finding the extremum of a function using the derivative

$$\left(\frac{k_{возд}F_1 + \alpha F_2}{V_н}\right)' = -\frac{2k_{возд}}{R_н^2} + \frac{\alpha \cdot 2\pi R_н}{V_н} = \frac{2(\alpha \cdot \pi R_н^3 - k_{возд}V_н)}{V_н R_н^2} \quad (17)$$

is the expression which is equated to zero for finding the stationary points

$$\alpha \cdot \pi R_н^3 - k_{возд}V_н = 0,$$

$$\text{т.е. } R_н = \sqrt[3]{k_{возд}V_н/(\alpha\pi)}. \quad (18)$$

Taking into account the ratio between the volume and height of the above-ground part of the water storage tank, the following equation is obtained

$$h_н = R_н\alpha / k_{возд}, \quad (19)$$

determining its optimal dimensions while minimizing heat losses.

In the absence of additional conditions, a relationship shall be established between the total volume of the vessel and the radius of the above-ground portion of the vessel.

It is clear that the total volume of the water tower is the sum of the volumes of its aboveground Vн and underground Vп parts

$$V = V_н + V_п. \quad (20)$$

In order to create a structure with minimum thermal losses in design calculations, the equations (3) and (22) are taken into account, as well as the formula for the volume of the cylinder, allowing to formalize the ratio at a given total volume:

$$V = \pi R_н^2 h_н + \pi R_п^2 h_п = \pi \cdot R_н^2 \cdot R_н \cdot \frac{\alpha}{k_{возд}} + \pi \cdot R_п^2 \cdot \frac{eR_п}{2} = \frac{\pi\alpha}{k_{возд}} R_н^3 + \frac{\pi e}{2} R_п^3. \quad (21)$$

To build a simplified model of the cooling process of a hydraulic structure, Rн = Rп is assumed. Then

$$V = \frac{\pi\alpha}{k_{возд}} R_п^3 + \frac{\pi e}{2} R_п^3 = \pi\left(\frac{\alpha}{k_{возд}} + \frac{e}{2}\right) R_п^3 = \frac{\pi(2\alpha + ek_{возд})R_п^3}{2k_{возд}}. \quad (22)$$

The final desired result is represented by the formula

$$R_п = \sqrt[3]{\frac{2k_{возд}V}{\pi(2\alpha + ek_{возд})}}, \quad (23)$$

which is the quintessence of the method with the use of a simplified functional model in determining as well as further optimization of parametric characteristics (in the presented variant radius Rобщ = Rн = Rп) of a cylindrical hydraulic

structure tank under the given technical conditions of its manufacturing material and design volume for the actually established temperature parameters of the ambient air.

RESULTS AND DISCUSSION

As one of the technological options, the design and mode initial parameters for calculating the optimal dimensions of water storage tank type are as follows:

– total vessel volume V = 10 m^3;

– minimum of mean temperature for the coldest winter month Tav.min = –19.3 °C and mean winter wind speed υ = 3.1 m/s recorded in the region under consideration;

– initial water temperature T0 = 4 °C;

– vessel steel wall thickness δ = 0,005 m and steel thermal conductivity coefficient λ = 47 W/(m · °C).

The proposed method, which allows to determine the optimal radius and heights of the underground and above-ground parts of the vessel of a given volume, is represented by the following algorithm of actions.

1. For practical realization of the method it is necessary to find the value of the heat transfer coefficient according to the environmental parameters and thermophysical characteristics of the metal vessel. Since the water tank is thin-walled, for its determination the calculation is carried out as for a flat wall according to the formula[7]

$$k_{\text{возд}} = 1/\left(\frac{1}{\alpha_1}+\frac{\delta}{\lambda}+\frac{1}{\alpha_2}\right), \qquad (24)$$

where α1 is the heat transfer coefficient from water to the wall, W/(m^2 · °C); δ is the thickness of the tank wall, m; λ is the thermal conductivity coefficient of the steel wall, W/(m · °C); α2 is the heat transfer coefficient from the wall to the air due to free convection, W/(m^2 · °C).

Considering the range of possible values, the study assumes α1 = 500 W/(m^2 · °C).

In the presence of wind, the heat transfer coefficient from the metal wall to the air is determined by the empirical relationship[8]:

$$\alpha_2 = 5{,}6 + 4 \cdot \upsilon, \qquad (25)$$

where υ – wind speed, m/s.

In this connection, the formula for calculating the heat transfer coefficient through the side walls, taking into account the wind, takes the following form

$$k_{\text{возд}} = 1/\left(\frac{1}{500}+\frac{\delta}{\lambda}+\frac{1}{5{,}6+4\cdot\upsilon}\right), \qquad (26)$$

according to which the value of kвозд ≈ 17.34 W/(m^2 · °C) was found for the initial parameters.

2. Due to the impossibility of selecting an empirical formula based on the experiment, it is considered reasonable to calculate the heat transfer coefficient α using the formula for free convection of air along horizontal surfaces[9]

$$\alpha = 2{,}15 \cdot \sqrt[4]{T_0 - T_c}, \qquad (27)$$

where T0 – initial temperature of water in the tank, °C; Tc = (T0 + Tcp)/2 – air temperature above the water surface, °C.

With the given initial data, the value of the heat transfer coefficient from the water surface to the air in the airspace zone is α ≈ 3.97 W/ (m^2 · °C).

3. The radius of the underground and aboveground parts of the vessel is determined by the formula (23):

Rн = Rп ≈ 1,26 m.

4. As a result of the calculation, the height of the underground part was: hп ≈ 1,71 m.

5. The volume of the underground part of the hydraulic structure is calculated: Vп ≈ 8,56 m^3.

6. The volume of the above-ground part is defined as Vн = V – Vп ≈ 1,44 m^3.

7. The height of the above-ground part of the vessel is calculated by the formula (19) hн ≈ 2,29 m.

[7] *Isachenko V.P., Osipova V.A., Sukomel A.S.* Heat Transfer. Textbook for universities. Ed. 3rd, revised and supplement. M.: Energia, 1975, 488 p.

[8] *Kuhling H.* Reference book on physics: transl. from German, E.M. Leikin, 2nd ed. M.: Mir, 1985, 520 p.

[9] *Machinsky A.D.* Heat Transfer in Construction. M.: GOSSTROYIZDAT, 1939, 343 p.

Thus, the given example of the proposed variant demonstrates a characteristic ratio of the heights of the aboveground (0.29 m) and underground (1.71 m) parts of water storage tanks to ensure protection from ice formation in case of "zero" water consumption mode by technological facilities. Such redistribution of water mass is economically justified in the aspect of energy saving using geothermal energy, but the lability of the temperature characteristics of the environment leads to the need to implement automatic control systems of water storage taking into account the reduction or increase of the risk of freezing and destruction of hydraulic structures. It is about operative change of the liquid volume ratio in the above-ground and underground parts of the water storage tank with the possibility of filling the maximum volume, but with complete blocking of the ice formation process in its internal cavity. Creation of the control programs for such systems may well be based on the calculation algorithms developed by the method of "simplified" modeling (see Fig. 2).

In accordance with the initial parameters for the given example, the software visualization potential is quite sufficient to represent the dependence of the radius of the cylindrical vessel (see Fig. 3, a), as well as the heights of the underground (see Fig. 3, b) and above-ground parts (see Fig. 3, c) of the hydraulic structure on the given volume at the given values of ambient temperature and wind velocity.

However, this method also allows to obtain similar dependencies for other types of water towers, velocities and ambient air temperatures. Fig. 4 shows the graphs for the radii of the water storage tank at the change of wind speed in the range of three values of the interval of the investigated ambient temperatures.

CONCLUSION

As a result of the conducted research, a method is proposed, the peculiarity of which is the optimization of structural and geometric parameters of water storage tanks with the use of "simplified" mathematical models designed to analyze the conditions of homogeneity and stationarity of the temperature fields of the environment, as well as the supporting soils in contact with the underground part of the tank.

Despite the fact that the issues of precision are not a priority in the design of hydraulic structures with water storage tanks, the proposed method can be developed in the aspect of digitalization of the process of selection of tank sizes for specific volumes of accumulated liquid, thermophysical parameters of structural elements, ambient temperature, and wind speed. Selection of the optimal size ratio of the functional elements of the hydraulic structure will allow the technological object, effectively utilizing the geothermal energy of the supporting soils, not only to operate in the energy-saving mode, but

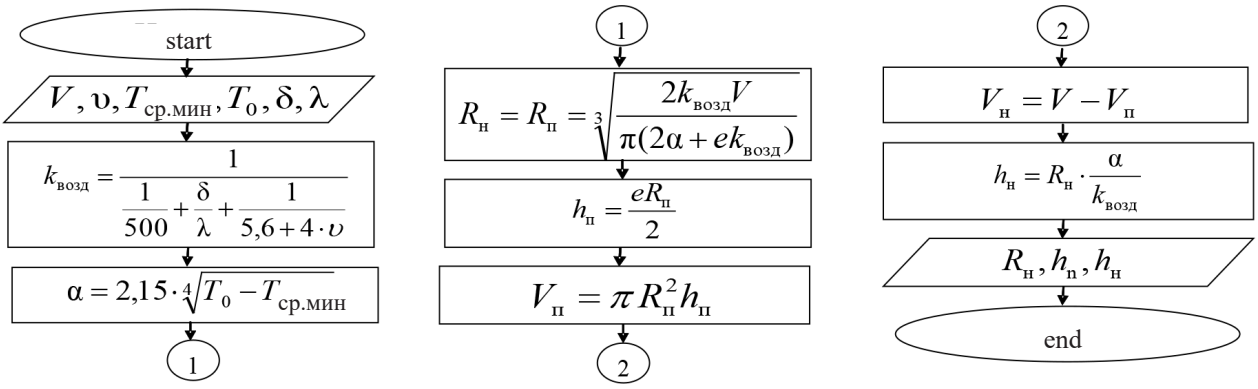
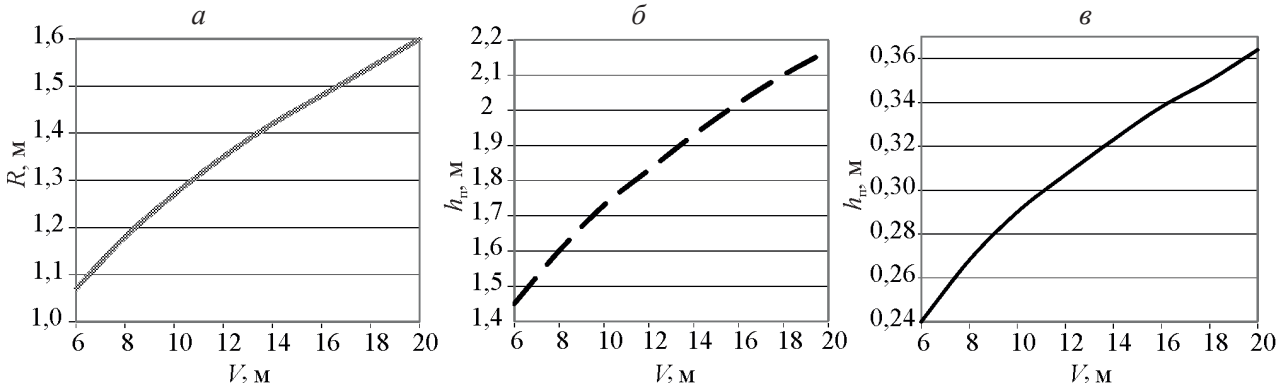


Рис. 2. Блок-схема алгоритма «упрощенной» модели расчетно-аналитического процесса для подземной и надземной частей водонакопительной емкости

Fig. 2. Block diagram of the algorithm of the "simplified" model of the calculation and analytical process for the underground and aboveground parts of the water storage tank



$(T_{ср.мин} = -19{,}3\ ^\circ\text{C},\ \upsilon = 3{,}1\ \text{м/с},\ T_0 = 4\ ^\circ\text{C},\ \delta = 0{,}005\ \text{м}\ \text{и}\ \lambda = 47\ \text{Вт/(м}\cdot{}^\circ\text{C)})$.

Рис. 3. Конструкционно-геометрические параметры водонакопительной емкости в зависимости от ее общего объема, рассчитанные по минимальности тепловых потерь

Fig. 3. Structural and geometric parameters of the water storage tank depending on its total volume and calculated by the minimum heat loss

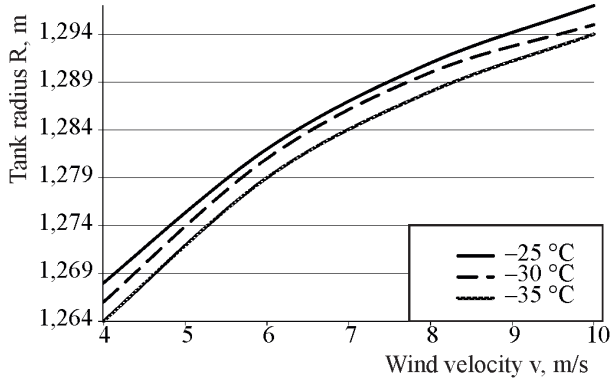


Рис. 4. Зависимость радиуса водонакопительной емкости от скорости ветра в интервале исследуемых значений температур окружающей среды

Fig. 4. Dependence of the radius of the water storage capacity on the wind speed in the range of the studied values of ambient temperatures

also to save material resources, since this method involves, first of all, the creation of water storage tanks of low-height type with nominal pressure characteristics for domestic and industrial water consumption.

In the future, the possibility of developing the calculation and analytical process to create programs for the dimensioning of hydraulic structures in the declared technological spaces of production facilities is not excluded.

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НИКОЛАЮ ИВАНОВИЧУ КАШЕВАРОВУ– 70 ЛЕТ

Доктору сельскохозяйственных наук, академику РАН, профессору, заслуженному деятелю науки Российской Федерации, руководителю научного направления Сибирского научно-исследовательского института кормов, известному ученому в области кормопроизводства и растениеводства Николаю Ивановичу Кашеварову 3 января 2024 г. исполнилось 70 лет.

Николай Иванович родился в с. Анисимовка Карасукского района Новосибирской области. После окончания агрономического факультета Новосибирского сельскохозяйственного института начал трудовую деятельность в СибНИИ кормов, где прошел все ступени карьерного роста, с 1993 по 2023 г. был директором этого института. В 2001–2005 гг. работал одновременно главным ученым секретарем, в 2005–2012 гг. – первым заместителем председателя Сибирского отделения Россельхозакадемии.

В 1983 г. Н.И. Кашеваров защитил кандидатскую диссертацию, в 1993 г. – докторскую, в 1997 г. избран членом-корреспондентом, в 2005 г. – академиком Россельхозакадемии. В 2005 г. ему присвоено звание профессора, в 2008 г. – звание «Заслуженный деятель науки РФ».

Научная деятельность Николая Ивановича посвящена решению теоретических и методических направлений функционирования отрасли кормопроизводства, разработке практических вопросов максимальной реализации биологического потенциала кормовых культур в Сибири.

Н.И. Кашеваров внес значительный вклад в разработку теоретических вопросов роли и значимости кормопроизводства в системе ландшафтного земледелия, принципов размещения отрасли по агроклиматическим зонам региона. Под его руководством в условиях Сибирского региона проведены комплексные исследования по возделыванию различных по скороспелости гибридов кукурузы, обоснована и в значительной степени реализована в производстве эффективная система кормопроизводства, обеспечивающая повышение эффективности отрасли в 1,5–2,0 раза.

Николаем Ивановичем совместно с коллегами проведены обширные научные и производственные эксперименты по совершенно новому для Западной Сибири направлению – адап-

тации сои сибирской селекции в качестве зернобобовой и кормовой культуры, разработана технология возделывания и рекомендована система защиты кормовых бобов. Проводится интродукция новых для Сибири культур.

Н.И. Кашеваровым создана и успешно функционирует научная школа по подготовке кадров высшей квалификации, где его ученики успешно подготовили и защитили более 15 кандидатских и докторских диссертаций. Им опубликовано более 280 научных работ, в том числе лично и в соавторстве 17 монографий, получено 10 авторских свидетельств на сорта кормовых растений. В научных трудах отражена роль основных обработок почвы, приемов ухода за посевами, большого набора почвенных гербицидов, видов, доз и способов внесения минеральных удобрений, густоты стояния, сроков посева и уборки, определяющих урожайность посевов, экономическую и биоэнергетическую эффективность силосных культур.

Николаем Ивановичем впервые в условиях региона проведены комплексные исследования по возделыванию в едином агроценозе различных по скороспелости гибридов кукурузы с целью повышения устойчивости посевов к условиям произрастания и повышения качества сырья, а также ультраранних спелых гибридов с высокобелковыми культурами. Научные труды ученого являются весомым вкладом в развитие работ по растениеводству и кормопроизводству в Сибирском регионе и имеют существенное научное и народнохозяйственное значение.

Н.И. Кашеваров является куратором совместных исследований по кормопроизводству и растениеводству с научными учреждениями Китая, Болгарии, Беларуси, Украины, Казахстана и Монголии, руководит координацией научных исследований, проводимых научными учреждениями Сибири.

В качестве вице-президента и члена президиума Сибирского отделения Российской академии наук Николай Иванович ведет большую работу по совершенствованию научно-исследовательской деятельности научных учреждений Сибирского региона. В 1995–2012 гг. Николай Иванович руководил специализированным советом по защите докторских и кандидатских диссертаций по трем специальностям. В настоящее время он член редколлегий журналов «Вестник Россельхозакадемии», «Кормопроизводство» и «Сибирский вестник сельскохозяйственной науки».

Научные достижения Николая Ивановича отмечены государственными наградами. Он кавалер медали ордена «За заслуги перед Отечеством II степени», награжден золотым знаком «Общественное признание», медалью «За служение Кузбассу», почетными грамотами различного уровня.

Коллектив СибНИИ кормов СФНЦА РАН сердечно поздравляет Николая Ивановича со знаменательной датой, желает ему крепкого здоровья, семейного благополучия и новых научных достижений.

ИВАН МИХАЙЛОВИЧ МИГУНОВ

Коллектив Сибирского федерального научного центра агробиотехнологий РАН и его филиал Научно-исследовательский институт ветеринарии Восточной Сибири с прискорбием сообщают, что на 91-м году ушел из жизни замечательный человек, известный ученый, доктор ветеринарных наук, Заслуженный ветеринарный врач РСФСР, Почетный гражданин Читинской области Иван Михайлович Мигунов.

Иван Михайлович родился 29 октября 1933 г. в с. Верхняя Куэнга Сретенского района Читинской области в семье крестьянина. В 1949 г. окончил 7 классов и поступил в Иркутский сельскохозяйственный техникум на ветеринарное отделение, которое с отличием окончил в 1953 г. С 1953 по 1954 г. работал ветфельдшером Улюнского ветеринарного участка Баргузинского района Бурятской АССР. В 1959 г. с отличием окончил ветеринарный факультет Бурятского сельскохозяйственного института. С 1959 по 1960 г. работал ветврачом-эпизоотологом Агинской окружной ветеринарной лаборатории. В 1962 г. окончил курсы повышения квалификации при Ленинградском ветеринарном институте. С 1960 по 1973 г. – директор Агинской окружной ветлаборатории. В 1971 г. был награжден орденом «Знак почета». В 1972 г. без отрыва от производства окончил заочную аспирантуру при ВНИИВВС (Москва) и защитил кандидатскую диссертацию. С 1973 г. – заведующий лабораторией паразитологии Научно-исследовательского института ветеринарии Восточной Сибири, заместитель директора Читинского филиала Института экспериментальной ветеринарии Сибири и Дальнего Востока Сибирского отделения ВАСХНИЛ. С 1974 г. И.М. Мигунов был членом координационного совета СО ВАСХНИЛ по ветеринарии. В 1980 г. Ивану Михайловичу присвоено ученое звание старший научный сотрудник. В 1998 г. он защитил докторскую диссертацию «Энтомозы (эстроз, вольфартиоз и мелофидоз) овец Забайкалья и меры борьбы с ним».

Иван Михайлович был избран членом Агинского райкома КПСС, депутатом Ингодинского районного Совета депутатов трудящихся Читы, восемь раз избран секретарем партбюро

Научно-исследовательского института ветеринарии Восточной Сибири, был председателем внештатной партийной комиссии Агинского РК КПСС, заместителем председателя Агинского окружного комитета профсоюза работников сельского хозяйства.

И.М. Мигунов – известный ученый и практик в области животноводства и ветеринарии. Он автор и соавтор более ста научных трудов, опубликованных в научных изданиях, лучшие из которых утверждены на уровне ГУВ МСХ СССР И РСФСР в качестве нормативных документов. Им разработано, утверждено и издано более 10 методических рекомендаций по вопросам профилактики и борьбы с различными заболеваниями животных, которые широко внедрены в ветеринарную практику Забайкалья.

Научные изыскания И.М. Мигунова, особенно в области арахноэнтомозов животных, широко внедрены в ветеринарную практику Забалькалья.

Все, кто знал Ивана Михайловича и работал с ним, сохранят светлую память об этом человеке.

К.С. Голохваст, А.С. Донченко, А.М. Захаренко, В.В. Альт,
В.А. Солошенко, Н.А. Шкиль, С.К. Димов, В.А. Марченко, В.Г. Черных, А.М. Третьяков,
А.А. Ежинов, Н.И. Гантимуров, А.Г. Церенжапов, Н.С. Мельников, И.В. Волков

AUTHOR GUIDELINES

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

The journal publishes original articles on fundamental and applied issues by the following directions:

- general agriculture and crop production;
- plant breeding, seed production and biotechnology;
- agrochemistry, soil science, plant protection and quarantine;
- fodder production;
- infectious diseases and animal immunology;
- private zootechnics, feeding, technology of feed preparation and production of livestock products;
- breeding, selection, genetics, and animal biotechnology;
- technologies, machinery and equipment for the agro-industrial complex;
- food systems.

The article sent to the editorial board must correspond to the thematic sections of the journal "Siberian Herald of Agricultural Science":

Section name	**Code and name of the scientific specialty in accordance with the Nomenclature of Scientific Specialties, for which academic degrees are awarded**
Agriculture and chemicalization	4.1.1. General agriculture and crop production 4.1.3. Agrochemistry, soil science, plant protection and quarantine
Plant growing and breeding	4.1.1. General agriculture and crop production 4.1.2. Plant breeding, seed production and biotechnology
Plant protection	4.1.3. Agrochemistry, soil science, plant protection and quarantine
Fodder production	4.1.1. General agriculture and crop production 4.1.2. Plant breeding, seed production and biotechnology 4.1.3. Agrochemistry, soil science, plant protection and quarantine 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 Scientific relations From the history of agricultural science Brief reports From dissertations	4.1.1. General agriculture and crop production 4.1.2. Plant breeding, seed production and biotechnology 4.1.3. Agrochemistry, soil science, plant protection and quarantine 4.2.3. Infectious diseases and animal immunology 4.2.4. Private zootechnics, feeding, technology of feed preparation and production of livestock products 4.2.5. Breeding, selection, genetics, and animal biotechnology 4.3.1. Technologies, machinery and equipment for the agro-industrial complex 4.3.3. Food systems

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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.

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- 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;
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3. Non-reviewed materials (scientific chronicles, reviews, book reviews, materials on the history of agricultural science and activities of institutions and scientists) are sent to the e-mail: sibvestnik@sfsca.ru and are registered by the executive secretary.

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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).
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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.
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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.

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EXAMPLE OF REFERENCES in Russian and English and FOOTNOTES

REFERENCES (in Russian):

Monograph

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

Part of a book

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

Periodical publication

Pakul A.L., Lapshinov N.A., Bozhanova G.V., Pakul V.N. Technological grain qualities of spring common wheat depending on the system of soil tillage // Siberian Herald of Agricultural Science. 2018. vol. 48. № 4. pp. 27-35. DOI: 10.26898/0370-8799-2018-4-4.

REFERENCES (in English):

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

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

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FOOTNOTES:

Quated text$_1$.

1*Klimova E.V., Andreeva O.T., Temnikova G.P.* Ways to stabilize food production in Transbaikalia // Problems and prospects of perfecting zonal farming systems in modern conditions: materials of the scientific and practical conf. (Chita, October 16-17 2008). Chita, 2009, pp.36-39.

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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.

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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.).

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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.

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

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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:

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The Editorial Board of the “Siberian Herald of Agricultural Science” follows the conventional ethical principles for scientific periodicals and guidelines of the “Publication Ethics Code” developed and approved of by the Committee on Publication Ethics (COPE) and demands that all those involved in the publishing process should obey these principles.

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THE SCIENTIFIC JOURNAL

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