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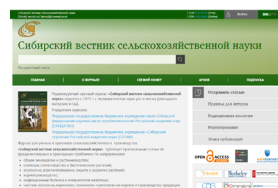
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Фитопатологическое тестирование генотипов льна на устойчивость к антракнозу

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Среди большого числа вредоносных и распространенных грибных болезней льна одной из доминирующих является антракноз. Высокоустойчивых сортов к этому патогену в производстве нет. Поиск и формирование коллекции разнообразного устойчивого материала льна составляет одну из задач современной селекции, что и явилось целью нашей работы. В Северо-Западном регионе Тверской области были проведены лабораторные и полевые исследования с использованием синтетической популяции возбудителя антракноза по определению устойчивости льна к патогену. Объектом исследований служили коллекционные образцы из «Национальной коллекции русского льна» ФНЦ ЛК, селекционные линии льна, полученные методом биотехнологии, и биообразцы возбудителя антракноза из «Коллекции микроорганизмов – возбудителей основных болезней льна». За годы исследований (2019–2023) «Коллекция микроорганизмов – возбудителей болезней льна» пополнилась 41 биообразцом возбудителя антракноза. Доминирующее положение заняли сильновирulentные штаммы – 55,6%, слабовирulentные биообразцы составили 18,4%. Скрининг 384 коллекционных образцов льна на инфекционном фоне выявил низкое содержание устойчивых образцов, только 36 образцов были относительно устойчивыми (50,0–68,0%), а 90,6% образцов коллекции оказались восприимчивыми. Выделено 7 генотипов, показавших относительную устойчивость к патогену на уровне 60,1–68,0%: Г-60-505-9, Д238/2/15/119-13, Д14/№3896хАР_с, Л-2897-6-6, 0-15247-6-13, 0-15157-7-5, К-3774*. Селекционные линии НП_р-1-7 и НП_р-2-3 льна-долгунца, полученные в результате использования биотехнологических методов, подтвердили свою устойчивость на инфекционном фоне в полевых условиях (61,1–75,0%). Высокоустойчивых образцов льна к антракнозу не выявлено. Использование 9 источников, характеризующихся устойчивостью на уровне 60,1–75,0%, в селекционной программе позволит повысить эффективность селекционной работы по созданию устойчивых к болезням сортов льна.

Ключевые слова: лен, возбудитель болезни, коллекционный образец, устойчивость, штамм

Phytopathological testing of flax genotypes for anthracnose resistance

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Among the large number of harmful and common fungal diseases of flax, anthracnose is one of the dominant ones. There are no highly resistant varieties to this pathogen in production. The search and formation of a collection of diverse sustainable flax material is one of the tasks of the modern selection, which was the purpose of our work. Laboratory and field studies using a synthetic population of anthracnose pathogen to determine flax resistance to the pathogen were conducted in the Northwest area of the Tver region. The object of research were collection samples from the

“National Collection of Russian flax” of the Federal Research Center for Bast Crops, flax selection lines obtained by biotechnology and the bio samples of the anthracnose pathogen from the “Collection of microorganisms - pathogens of major flax diseases”. Over the years of research (2019–2023), the “Collection of microorganisms - pathogens of flax diseases” has been replenished with 41 biological samples of the anthracnose pathogen. The dominant position was occupied by highly virulent strains – 55.6%, weakly virulent biological samples made up 18.4%. Screening of 384 collection flax samples against an infectious background revealed a low content of resistant samples, only 36 samples were relatively resistant (50.0–68.0%), and 90.6% of the collection samples were susceptible. 7 genotypes were identified, showing relative resistance to the pathogen at the level of 60.1–68.0%: G-60-505-9, D238/2/15/119-13, D14/No.3896hAR6, L-2897-6-6, 0-15247-6-13, 0-15157-7-5, K-3774*. The breeding lines NP_r-1-7 and NP_r-2-3 of fiber flax, obtained as a result of using biotechnological methods, have confirmed their resistance against an infectious background, in the field (61.1–75.0%). No highly resistant flax samples to anthracnose have been identified. The use of 9 sources characterized by resistance at the level of 60.1–75.0% in the breeding program will increase the efficiency of breeding work to create disease-resistant flax varieties.

Keywords: flax, pathogen, collection sample, resistance, strain

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Conflict of interest

The authors declare no conflict of interest.

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INTRODUCTION

Cultivated flax is one of the most important technical crops in Russia and the main source of natural raw materials for many sectors of the national economy [1-3]. One of the most universal biological effects to which flax plants are exposed is pathogenic microorganisms. About 200 species of fungi, viruses and bacteria have been recorded on flax, many of them are pathogens that cause certain damage to the crop¹. [4, 5]. The main condition for obtaining high and

stable yields of the crop is the protection of crops from diseases. Anthracnose is one of the dominant fungal diseases of flax among a large number of fungal diseases² [6].

Flax anthracnose (*Colletotrichum lini* Manns et Bolley. *C. lini*) is currently a widespread and damaging disease in the crop area. Anthracnose can occur in all phases of flax development and growth. The main damage it causes in the phase of sprouting with the appearance of yellow-orange spots, sores or wiring on the roots

¹Nekhvedovich S.I. Pathogenic complex of fungi parasitizing on oilseed flax // Proceedings of the International Conference of Young Scientists, 2018, Minsk, Republican enterprise Publishing House “Belarusian Science”, 2018, pp. 159–175.

²Kudryavtseva L.P., Proletova N.V., Loshakova N.I., Pavlova L.N., Vinogradova E.G., Sokolova N.S. Methods of evaluation and selection of source material in the selection of fiber flax for resistance to anthracnose. Tver, 2013, 51 p.

and stems of plants, often leading to the death of young plants [7, 8]. This pathogen does not have a wide parasitic specialization and does not affect crops preceding flax in the crop rotation, but it can develop and sporulate on dead remains of many plant species (garden pea, red clover, lamb's-quarters, etc.), which it uses as a nutrient substrate, which confirms its belonging to semi-parasites. In the years of epiphytotics, yield losses due to anthracnose can be as high as 15–30% [9, 10].

All over the world, the development of resistant varieties is the most important element in the system of integrated plant protection against diseases, including anthracnose. According to the results of evaluation of the released and prospective for release flax varieties in 2020–2023 in the conditions of the Tver region, no varieties with high resistance to the pathogen have been identified. Three varieties (Caesar, Diplomat, Tonus) of fiber flax with medium resistance to anthracnose³ are included in the State Register of Breeding Achievements. [11]. The main reason constraining breeding for anthracnose resistance is the lack of highly resistant sources and donors of resistance [12].

One of the directions of work on the search for resistant genotypes to the pathogen is the use of the world flax collection located in N.I. Vavilov All-Russian Institute of Plant Genetic Resources (VIR), which maintains in viable condition 2,485 long-flax samples from 48 countries, and the “National Collection of Russian flax” of the Scientific Research Institute of Flax – a separate division of the Federal Research Center for Bast Fiber Crops (SD SRIF FRC BFC), which has more than 2,500 fiber flax samples. These collections include both local and thick-set flaxes collected from different regions of Russia and flax-growing countries of the world

(Romania, Holland, India, USA, Canada, etc.), domestic and foreign breeding varieties, lines and donors. According to many researchers, the flax gene pool of VIR and FRC BFC is not rich in sources and donors of anthracnose resistance [12, 13].

In addition to traditional methods of selection for resistance by hybridization followed by individual selection in split populations, new modern methods are used, such as biotechnological methods [14].

In order to search for and develop highly resistant varieties to diseases, special breeding programs are needed, in which the key issue is the methods of creating artificial infection backgrounds that allow to assess the immunity of the tested material at all stages of the selection process.

The criterion of stability of crop varieties is the study of their infestation in field conditions under artificial infection. The main requirement for artificial infectious material is to characterize the virulence of the strains included in the artificial pathogen population⁴.

For these purposes, the “Collection of microorganisms – pathogens of flax diseases”, which includes biosamples of anthracnose pathogen, was created and maintained in a biologically pure state at the All-Russian Research Institute of Flax (VNIIL) in 1990–2023 on the basis of working collections (1981–1989) of biosamples of anthracnose pathogens. The work on the maintenance of the collection and reproduction of biomaterial is an important element of scientific support of selection, genetic and biotechnological programs in fiber flax⁵.

The purpose of the research is to identify sustainable sources of fiber flax with the use of flax collection samples, breeding material obtained by biotechnological methods and biomaterial of

³Proletova N.V., Kudryavtseva L.P. Changes in the biochemical composition of culture filtrate in the process of growth and development of fungi *Colletotrichum lini* // Proceedings of the VI International Scientific and Practical Conference, February 26–28, 2019, Mytishchi, pp. 66–68.

⁴Loshakova N.I., Krylova T.V., Kudryavtseva L.P. Methodical recommendations for the creation, maintenance, storage and practical use of “Collection of microorganisms - pathogens of flax diseases”. Torzhok, 2006, pp. 5–8.

⁵Loshakova N.I., Krylova T.V., Kudryavtseva L.P. Methodological guidelines on phytopathological assessment of fiber flax resistance to diseases. Moscow, 2000, pp. 22–26.

the pathogen from the “Collection of microorganisms – pathogens of flax diseases” to create new varieties of the crop.

MATERIAL AND METHODS

Field and laboratory studies were carried out in 2019–2023 in the experimental field and in the laboratory of breeding technologies of the FRC BFC. The object of research was 384 collection samples of flax, 2 breeding lines and 41 biosamples of anthracnose pathogen from the “Collection of microorganisms – pathogens of flax diseases”.

To create an artificial population, strains of the pathogen were collected by sampling affected vegetative plants and infected flax seeds. Samples of infectious material were analyzed by microscopy and nutrient medium according to the method of the Flax Institute (see footnote 4).

The study of culture-morphological parameters and virulence is an integral part of the maintenance of collection bio-samples “Collection of microorganisms – pathogens of flax diseases”. Determination of cultural and morphological properties of anthracnose pathogen isolates was carried out on the 14th day of cultivation. Colony coloring, mycelium growth and development rates, sporulation intensity, conidia size and shape were recorded. According to the intensity of sporulation, isolates were conditionally divided into abundantly sporulating (more than 10 thousand spores/ml), moderately sporulating (6.0–10.0 thousand spores/ml) and weakly sporulating (0–5.0 thousand spores/ml).

Virulence of anthracnose pathogen strains was determined on a light installation, in laboratory conditions on two varieties contrasting in resistance (susceptible – K-5789, Penjab and resistant – K-6297, Leona). Strongly virulent strains were classified as those causing lesions of the resistant standard (0–25%) and death of the susceptible one (75–100%), while weakly virulent strains were classified as those not af-

fecting the resistant standard and causing a medium degree of lesions (50.0%) on susceptible varieties (see footnote 4).

Evaluation of 384 flax collection samples for anthracnose resistance was carried out on an infectious background in the field, using provocative conditions (wide-row, sparse, late sowing) for better development of the infection⁶ (see footnote 5).

To obtain the pathogen biomaterial, pure culture strains were propagated on autoclaved oat grains for 3–4 weeks. During sowing, a 25–30-day pure culture of anthracnose pathogen, which is a synthetic population consisting of 50% of highly virulent and 25% each of medium- and weakly virulent strains of the pathogen (7–8 g per one linear meter) was introduced into the rows deepened to 6–7 cm. Counting of anthracnose development was carried out at the stage of 4–6 true leaves during the mass development of the disease on a 5-point scale. The results of classifications of the collection material for a number of years were used to identify the samples with resistance to the disease, regardless of the variability of environmental conditions over the years. Samples were studied for 2–3 years. Samples affected to a strong degree were studied within a year, medium resistant were studied within 2–3 years, resistant were evaluated annually. According to the evaluation results, the samples were differentiated into: highly resistant (degree of disease development 0–20%), resistant (degree of disease development 21–30%), moderately resistant (31,0–50,0%), susceptible (51,0–75,0%) and highly susceptible (above 75,0%).

Studies in field conditions were conducted on medium loamy slightly acidic soil with average potassium content of 98.6–93.8 mg/kg and high phosphorus content in soil (268–279 mg/kg). Grain crops served as a forecrop for flax. The size of the record plot in the nursery was 0.5 lin. m. Seeding rate – 25 seeds per plot with a three-fold repetition of the experiment.

⁶ Methodological guidelines for phytopathological assessment of fiber flax resistance to diseases. Moscow: Publishing house of the Russian Academy of Agricultural Sciences, 2006, pp. 23–29.

Weather conditions in the years of research differed both in average daily air temperature and precipitation. Meteorological conditions of the vegetation periods from the calculation of hydrothermal coefficient (HTC) of Selyaninov, 2019 (HTC–1.8) and 2020 (HTC–2.2) can be characterized as wet, 2021 (HTC–1.1) and 2023 (HTC–1.1) as slightly arid, 2022 (HTC–0.87) showed pronounced aridity⁷.

Mathematical processing of the data was performed by analysis of variance using Biostat and Microsoft Office Excel⁸ software packages.

RESULTS AND DISCUSSION

To obtain unbiased data on the resistance of collection samples, varieties and breeding material to the anthracnose pathogen, on the one hand, the artificial infectious background should consist of biosamples with a sufficiently high level of virulence. On the other hand, in terms of obtaining the biomaterial for immunological studies, preference is given to the most sporulating on nutrient medium. Highly sporulating, fast-growing isolates with a high level of virulence are ideal in this regard. To create an infectious background for anthracnose, biosamples from the “Collection of microorganisms - pathogens of major flax diseases” were used. The collection of flax anthracnose pathogen strains is the only one in the country (SD SRIF FRC BFC), its replenishment and maintenance in a viable state, as well as the creation of an artificial population of the pathogen for breeding purposes represent the elements of novelty of this work. Currently, the collection of anthracnose pathogen biosamples totals 616 storage units.

As a result of the studies conducted in 2019–2023, 266 samples of the seeds and plants affected by anthracnose were collected. From them, 68 isolates were isolated, and 41 isolates were characterized for culture and morphological characters and virulence. The strains dif-

fered among themselves in properties and virulence. The color of the colonies was mainly dominated by gray strains. There were 60.6% of the strains with abundant sporulation and rapid growth; moderately sporulating pathogen samples accounted for 25.0%. Spore parameters were in the following ranges: length – 14.8–20.1 μm ; width – 1.7–2.5 μm . Most of the pathogen strains in our studies turned out to be highly virulent for anthracnose susceptible variety of Penjab flax. Strains #836, 840, 831, 827-1, 834 and other strains were highly virulent for the relatively disease-resistant Leon (USA) flax sample as well. Over the entire period of operation (2019–2023), 55.6% of pure anthracnose culture samples were strongly virulent strains, while 18.4% were weakly virulent. Among the highly virulent strains, abundant-nosporulating strains prevailed and accounted for 74.1%.

Thus, every year there were strains with different virulence and cultural and morphological characteristics to create an infection-provocation background for anthracnose. The anthracnose damage of susceptible varieties (Penjab, Slavny 82, etc.) when infected with these strains amounted to 65.0–85.0% or more.

As a result of the research in 2019–2023, 41 strains of anthracnose pathogen were isolated from the local population (Tver region), multiplied, included in the “Collection of microorganisms - pathogens of flax diseases” and stored. Thus, strains of different virulence were available to determine the resistance of genotypes to anthracnose, which made it possible to qualitatively assess the flax collection material.

It is known that for the development of artificial population of anthracnose in the field nursery a complex of conditions is necessary: availability of quality and sufficient quantity of infectious material and favorable meteorological conditions for pathogen development. Weather conditions occurring within 8–12 days after sowing are decisive for the development

⁷Weather archive. Tver. URL.: <https://tver.nuipogoda.ru/%D0%BF%D0%BE%D0%B3%D0%BE%D0%B4%D0%B0-2021>.

⁸Dospekhov B.A. Methods of field experiment (with the basics of statistical processing of research results). Moscow: Book on Demand, 2012, 352 p.

of the infection process and mass spread of the pathogen. The intensity of anthracnose development in the field infection and provocation nursery was different in different years. Optimal conditions in this period are considered to be air temperature 19–22 °C, air humidity above 70–75%. Such conditions were formed in 2019–2022, but especially meteorological conditions were favorable in 2020, 2022, when the weather was warm with precipitation in the first ten-day period of June. The average weekly air temperature during this period was 22–24 °C. Precipitation was 92–139% of the norm. Relative humidity of 72–80%, all this complex of weather conditions, as well as quality infection contributed to epiphytotic development of the disease in the infection-provocation nursery. The susceptible standard Penjab was affected by 75–84.9%. Less favorable was 2023. During the sprouting phase of flax, the weather was cool with insignificant precipitation. Average weekly air temperature during the week after sowing was 12 °C, which is 2.9 °C below the norm. Precipitation was 20% of the norm, relative humidity was 65%, which restrained strong development of the pathogen. Susceptible test varieties were affected within the range of 50.0–60.0%.

In the course of research in the field, characteristic signs of anthracnose damage were observed on flax seedlings and especially in the period of appearance of 4–6 true leaflets. Observation of the course of infection development, evaluation and analysis of the source material for resistance to anthracnose of flax indicate a very low content of reliable sources of resistance to this disease in the gene pool. Out of the total amount of material tested for anthracnose resistance, 36 samples were relatively resistant (resistance 50.0–68.0%) and 348 were susceptible. There were 29 genotypes with average resistance of 50.0–57.9%. The structure of resistance of flax collection samples to anthracnose is presented in Table 1. The level of resistance of the samples exceeding the 60% barrier averaged 2.0% by year. In 2019, no samples with resistance exceeding 60.0% were identified (see Table 1).

Табл. 1. Структура устойчивости коллекционных образцов льна к антракнозу (полевой инфекционно-провокационный питомник, 2019–2023 гг.)

Table 1. Structure of resistance of flax collection samples to anthracnose (field infectious and provocative nursery, 2019–2023)

Year of research	Number of samples	
	Total studied	Of which the resistant ones (more than 60,0%)
2019	69	0
2020	92	3
2021	92	2
2022	98	1
2023	33	1

Immunological analysis of the flax collection revealed 7 genotypes with resistance level of 60.1–68.0%, which are of interest for use as starting material for breeding for disease resistance: G-60-505-9, D238/2/15/119-13, D14/#3896xAR6, L-2897-6-6-6, 0-15247-6-13, 0-15157-7-5, K-3774*, as shown in Table 2. Genotypes characterizing high resistance (over 75.0%) were not detected from the SD SRIF FRC BFC collection at the present stage (see Tables 1, 2).

A new stage in the development of phytoimmunology and practical breeding began with the development of biotechnology methods, which makes it possible to obtain lines resistant to anthracnose by *in vitro* methods. Thus, evaluation in the field infection-provocation nursery for anthracnose of 2 breeding lines: NP_r-1-7 and NP_r-2-3, obtained as a result of research using the developed selective systems “flax - culture filtrate of *Colletotrichum lini*”, confirmed their resistance at the level of 61.1–75.0% (see Table 2).

CONCLUSION

As a result of research in the conditions of the Tver region 384 collection samples and 2 breeding lines of fiber flax on the infectious background in the field on resistance to anthracnose in comparison with resistance indicators of test

Табл. 2. Источники устойчивости льна к антракнозу (средние данные за 2019–2023 гг.)
Table 2. Sources of flax resistance to anthracnose (average data for 2019–2023)

Collector's item	Resistance, %
G-60-505-9	62,5
D238/2/15/119-13	65,3
D14/№3896xAP ₅	61,7
L-2897-6-6	64,8
0-15247-6-13	65,0
0-15157-7-5	68,0
K-3774*	60,1
JVM-6	57,9
NP _p -1-7	61,1
NP _p -2-3	75,0
K-3529*	51,0
B-96	50,0
L-2685-6-7	50,0
AET 153/07051-0-536	50,0
8515-88	55,9
B-100	50,0
K-7214	56,6
K-7443	56,3
LSD ₀₅	26,2
Penjab, susceptible standard	28,9

varieties, 36 genotypes were identified, showing resistance by 50.0–75.0%. The most valuable source material for breeding programs are 7 collection samples (G-60-505-9, D238/2/15/119-13, D14/#3896xAP₆, L-2897-6-6-6, 0-15247-6-13, 0-15157-7-5, K-3774*) and 2 breeding lines: NPr- 1-7 and NP_r- 2-3, which showed a higher level of resistance (60.1–75.0%).

Identification of resistant genotypes to the most common diseases is of strategic importance in the conditions of modern flax production. The area under cultivation of the crop has significantly decreased over the last 15–20 years, so the issue of cultivation of the most productive and resistant to fungal diseases varieties is relevant. Creation of new resistant varieties will reduce

the potential of infection in nature and reduce the protective chemical measures in flax crops.

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Флуоресценция хлорофилла в листьях проростков сортов пшеницы при совместном действии хлоридного засоления и инфицирования *Bipolaris sorokiniana*

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Представлены результаты исследований фотосинтетической активности проростков трех сортов яровой мягкой пшеницы и их адаптивных реакций на совместное действие инфицирования возбудителем обыкновенной корневой гнили злаков *Bipolaris sorokiniana* Shoem. (*B. sorokiniana*) и хлоридного засоления по параметрам флуоресценции хлорофилла (ФлХ). Проростки выращивали из инфицированных патогеном 3-суточных проросших семян на растворе хлорида натрия (опыт) и на водопроводной воде (контроль) в заданных климатических условиях. ФлХ регистрировали у 10, 12, 14 и 16-суточных проростков флуориметром Dual-PAM-100/F в режиме Slow Kinetics. Исследования проводили в 2022, 2023 гг. Подтверждена информативность параметров ФлХ $Y(II)$, ETR , qP , $Y(NPQ)$, qN и $Y(NO)$ в качестве биомаркеров фотосинтетической активности и оценки устойчивости сортов к совместному действию *B. sorokiniana* и хлоридного засоления. Параметры F_v/F_0 и F_v/F_m оказались менее чувствительными. Максимальные достоверные межсортовые различия (от 1,8 до 4,3 раза) выявлены по шести параметрам ФлХ. Наименьшие изменения параметров ФлХ относительно контроля были у более устойчивого сорта Сибирская 21 по сравнению с менее устойчивыми сортами Новосибирская 41 и Новосибирская 29. Сильное стрессовое состояние на 16-е сутки культивирования проростков сортов Новосибирская 29 и Новосибирская 41 привело к синхронному увеличению параметра нерегулируемого нефотохимического тушения ФлХ $Y(NO)$ на 45,8 и 59,9% и к снижению параметров регулируемого фотохимического тушения $Y(NPQ)$ и qN от 44,5 до 58,9% соответственно. Это указывает на снижение эффективности защитных регулирующих механизмов при фотосинтезе, что может служить диагностическим показателем при оценке стрессоустойчивости сортов. Сделан вывод о возможности применения параметров ФлХ для оценки фотосинтетической активности, выявления адаптивных компонент и фенотипирования сортов пшеницы по устойчивости при совместном действии *B. sorokiniana* и хлоридного засоления.

Ключевые слова: пшеница, сорт, устойчивость, комбинированный стресс, фотосинтез, параметры флуоресценции хлорофилла

Chlorophyll fluorescence in the leaves of wheat seedlings under the combined effect of chloride salinity and infection with *Bipolaris sorokiniana*

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The results of the studies of photosynthetic activity of the seedlings of spring soft wheat three varieties and their adaptive responses to the combined effect of infection with the pathogen of common root rot of cereals *Bipolaris sorokiniana* Shoem. (*B. sorokiniana*) and chloride salinization on the parameters of chlorophyll fluorescence (ChlF) are presented. The seedlings were grown from pathogen-infected 3-day-old germinated seeds on sodium chloride solution (experiment) and on tap water (control) under specified climatic conditions. ChlF was recorded in 10, 12, 14, and 16-day-old seedlings using a Dual-PAM-100/F fluorimeter in a Slow Kinetics mode. The studies were carried out in 2022, 2023. The informativeness of the ChlF parameters $Y(II)$, ETR , qP , $Y(NPQ)$, qN and $Y(NO)$ as biomarkers of photosynthetic activity and assessment of the resistance of the varieties to the combined effects of *B. sorokiniana* and chloride salinity was confirmed. The F_v/F_0 and F_v/F_m parameters

turned out to be less sensitive. The maximum significant intervarietal differences (from 1.8 to 4.3 times) were detected in six parameters of the ChlF. The smallest changes in ChlF parameters relative to the control were found in the more resistant variety Sibirskaya 21 compared to the less resistant varieties Novosibirskaya 41 and Novosibirskaya 29. Severe stress condition on the 16th day of cultivation of the Novosibirskaya 29 and Novosibirskaya 41 seedlings resulted in a synchronous increase in the parameter of unregulated non-photochemical quenching of ChlF $Y(NO)$ by 45.8 and 59.9% and a decrease in the parameters of the regulated photochemical quenching $Y(NPQ)$ and qN from 44.5 to 58.9%, respectively. This indicates a decrease in the efficiency of protective regulatory mechanisms during photosynthesis, which can serve as a diagnostic indicator in assessing the stress tolerance of varieties. It is concluded that it is possible to use ChlF parameters to assess photosynthetic activity, identify adaptive components and phenotyping of wheat varieties for resistance under the combined action of *B. sorokiniana* and chloride salinity.

Keywords: wheat, variety, resistance, combined stress, photosynthesis, chlorophyll fluorescence parameters

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Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Under constantly changing environmental conditions, plants are exposed to the simultaneous action of biotic and abiotic stressors that limit crop yields. The productivity of wheat, the most widely cultivated crop adapted to a wide range of agroclimatic factors, is of primary importance for global food security [1, 2]. According to current projections, stress interactions between abiotic and biotic environmental factors will become even more widespread due to observed and projected climate change [3]. One of the ways to overcome the negative impact of stress factors may be the development and use of tolerant varieties in agrotechnologies, especially of local selection, adapted to combined stress¹ [4, 5]. In this regard, there is a need in

breeding work and physiological research to study the adaptive potential of varieties and assess their stress tolerance, especially in the early stages of plant development, to accelerate the screening of a large volume of samples with the identification of resistant genotypes² [6].

Elements of specific and nonspecific resistance are distinguished in plant responses to damaging factors³ [7]. The nonspecific component of adaptation mechanisms formed under stress effects includes, among others, the processes of photosynthesis inhibition, changes in cell membrane permeability and cell membrane potential, and inhibition of cell growth and division⁴ [8, 9]. Our study aims at evaluating photosynthetic activity and stress tolerance of wheat varieties at the seedling stage under the com-

¹Vlasenko N.G., Kulagin O.V., Egorycheva M.T., Ivanova I.A. Influence of variety and cultivation technology on the formation of phytosanitary situation in spring wheat crops in the forest-steppe of Priobie // Plant Protection Bulletin, 2018, N 2, pp. 21–28.

²Gurova T.A., Osipova G.M. Problem of combined stress resistance of plants under climate change in Siberia // Siberian Herald of Agricultural Science, 2018, vol. 48, N 2, pp. 81–92.

³Kuznetsov V.V., Dmitrieva G.A. Plant Physiology: textbook for universities. Moscow: Publishing house “Yurait”, 2020, vol. 1, 437 p.

⁴Pronina N.B. Ecological stresses (causes, classification, testing, physiological and biochemical mechanisms). Moscow: MSKhA, 2000, 189 p.

bined effects of salt stress and infection with the cereal root rot pathogen *Bipolaris sorokiniana* Shoem. (*B. sorokiniana*). These stressors are among the factors that negatively affect the growth and development of wheat in the main grain-growing areas of the world, including the West Siberian region [10–12]. These factors can disrupt the normal metabolism of wheat plants, negatively affecting key physiological processes, including photosynthesis, which leads to a decrease in crop productivity [13, 14]. Information on the efficiency of photosynthesis and the integrity of the photosynthetic apparatus at the earliest stages of stress development can be obtained by recording chlorophyll fluorescence (ChlF) [15]. Changes in the value of ChlF are proportional to the fraction of light energy used in photochemical reactions and dissipated into heat [16, 17]. By measuring the characteristics of ChlF, it is possible to estimate the work of the photosynthetic apparatus, including the share of the energy used for photosynthesis [18]. The method is nondestructive, highly sensitive, and widely used in physiological studies, including for determining the response of plants to combined stress⁵. The application of ChlF induction method has been demonstrated under the combined effects of *Bipolaris sorokiniana* (Sacc.) and elevated temperature in barley seedlings⁶, salinity and ameliorative effects of salicylic acid and silicon in mung bean⁷, water deficit and heat stress in millet [19], low temperature and cadmium in wheat seedlings [7].

Plants are known to react ambiguously to combined biotic and abiotic stress - from amplification to compensation of the negative effect

of the stressors arising from their simultaneous action⁸ [20, 21]. In most cases, simultaneous action of abiotic stressors (drought, extreme temperature, nutrient stress or salinity) leads to weakening of plant immunity and increased sensitivity to biotic stresses⁹ [22].

In some combinations of biotic and abiotic stressors, plants respond more strongly to one of the stressors involved in the combination [23]. At the same time, the response of the plants to the combination of different stressors is unique and cannot be extrapolated from the response of each of the individual stressors¹⁰ [8]. These ambiguous results indicate that the positive or negative effects of the combination of stressors may be determined by the specific genotype of the plant, variety, species, timing and intensity of stresses.

Previously, we conducted the studies of adaptation of four wheat varieties under the simultaneous action of *B. sorokiniana* and chloride salinity on morphometric parameters, disease development and permeability of cell membranes of seedlings [24]. It was found that under the simultaneous action of these two stressors two types of adaptive reactions were formed: strengthening of the negative action of stressors (loss of resistance, susceptibility) and compensation of the negative action of stressors (acquisition of resistance, tolerance). We also previously investigated the formation of adaptive reactions of three varieties of soft spring wheat (Sibirskaya 21, Novosibirskaya 29, Novosibirskaya 41) under infection with *B. sorokiniana* according to the changes in the parameters of ChlF [13].

⁵Goltsev V.N., Kaladzhi H.M., Paunov M., Baba V., Horacek T., Mojski J., Kotsel H., Allakhverdiev S.I. Use of variable chlorophyll fluorescence to assess the physiological state of the photosynthetic apparatus of plants // Plant Physiology, 2016, vol. 63, N 6, pp. 881–907.

⁶Abramchik L.M., Serdyuchenko E.V., Pashkevich L.V., Makarov V.N., Zenevich L.A., Kabashnikova L.F. Stress reactions of barley green seedlings under the conditions of infection by pathogenic fungus *Bipolaris sorokiniana* (Sacc.) Shoem and elevated temperature // Proceedings of the National Academy of Sciences of Belarus, 2015, N 2, pp. 38–43.

⁷Ghassemi-Golezani K., Lotvi P. The impact of salicylic acid and silicon on chlorophyll a fluorescence in mung bean under salt stress // Russian Journal of Plant Physiology, 2015, vol. 62, N 5, pp. 611–616.

⁸Suzuki N., Rivero R.M., Shulaev V., Blumwald E., Mittler R. Abiotic and biotic stress combinations // New Phytologist, 2014, vol. 203 (1), pp. 32–43. DOI: 10.1111/nph.12797.

⁹Kissoudis C., Chowdhury R., Van Heusden S., Van de Wiel C., Finkers R., Visser R.G., Bai Y., Van der Linden G. Combined biotic and abiotic stress resistance in tomato // Euphytica, 2015, vol. 202, N 2, pp. 317–332. DOI: 10.1007/s10681-015-1363-x.

¹⁰Kissoudis C., Chowdhury R., Van Heusden S., Van de Wiel C., Finkers R., Visser R.G., Bai Y., Van der Linden G. Combined biotic and abiotic stress resistance in tomato // Euphytica, 2015, vol. 202, N. 2, pp. 317–332. DOI: 10.1007/s10681-015-1363-x.

The purpose of the work was to investigate adaptive reactions of soft spring wheat varieties under the joint action of chloride salinity and *B. sorokiniana* according to ChlF parameters in order to establish their informativeness in assessing stress tolerance of varieties at the seedling stage.

MATERIAL AND METHODS

Experimental work was carried out at the Siberian Institute of Physics and Technology SFSCA RAS in the laboratory of the physical processes' studies in agrophytocenoses.

To study the adaptive reactions, laboratory experiments were conducted in roll culture¹¹ against the background of simulated joint action of sodium chloride and *B. sorokiniana* on the seedlings of middle-early released varieties of spring wheat Novosibirskaya 41, Sibirskaaya 21 and Novosibirskaya 29 of the SibNIIRS - ICIG SB RAS selection.

Experiment options:

- control (no stress load);
- *B. sorokiniana* seed infection + chloride salinization.

Stress levels— conidial suspension of *B. sorokiniana* 7000 conidia/grain and sodium chloride (NaCl) concentration 1,3%.

Our previous studies have shown that under co-stress, chloride salinity is a stronger stress factor with a major destructive effect compared to the pathogen. In this regard, to increase the amplitude of varietal differences, the stress load of conidial suspension of *B. sorokiniana* was increased to 7000 conidia/grain (instead of the previously established stress load of 5000 conidia/grain), allowing differentiation of wheat varieties of Siberian selection when evaluating their resistance to the pathogen [25].

Wheat seeds were pre-sterilized with 96% ethyl alcohol for 1 min followed by three times rinsing with distilled water. After that, the seeds were placed in Petri dishes with moistened filter paper and germinated in the thermostat at 22

°C for three days. The seeds were infected in the germination phase (on the 3rd day of cultivation) with a conidial suspension of a mixture of medium pathogenic isolates of *B. sorokiniana* prepared on 0.1% water agar (one drop per grain). Further plants were grown in roll culture on tap water (control) and sodium chloride (infectious background + chloride salinity) in the climatic chamber “Biotron-7” (development of SibPhTI SFSCA RAS) at day-night photoperiod 16 and 8 h, respectively, illumination 253.0 and 0 $\mu\text{mol m}^{-2} \text{s}^{-1}$ (day-night), temperature 22 and 18 °C (day-night), humidity 60%.

The parameters of ChlF FS II were recorded using a Dual-PAM-100/F fluorimeter (Heinz Walz, Germany) using the amplitude-pulse modulation method in the mode of recording slow kinetics of dark induction curves with pulse saturation analysis (Slow Kinetics)¹². The delay time for recording the induction curves after determining the minimum and maximum chlorophyll fluorescence is 40 s, which is sufficient for complete reoxidation of acceptors (opening of reaction centers). The interval between the saturation pulses when recording the induction curves was 20 s, the data recording time was about 4 min. Excitation of chlorophyll molecules was carried out by a “blue” LED with a wavelength of 460 nm, fluorescence detection was carried out by a “red” photodiode with a wavelength of 680 nm. The operation of the fluorimeter was controlled using specialized software. Before fluorescence measurement, 10-16-day-old wheat seedlings were adapted to darkness in the sample chamber for 30 min to reach the fully oxidized state of FS II acceptors. The intensity of the measuring light was 0.1–1.0 $\mu\text{mol quanta/m}^2 \cdot \text{s}$, and the intensity of the saturating light was 8000 $\mu\text{mol quanta/m}^2 \cdot \text{s}$ with a duration of 0.8 s.

The following ChlF parameters were recorded: F_0 , F_m - minimum and maximum fluorescence level caused by a pulse of light after adaptation of the leaves to darkness; F_0' , F_m'

¹¹Diagnostics of plant resistance to stress effects: method. recommendations / edited by G.V. Udovenko, Leningrad, 1988, 228 p.

¹²Product catalog of the German company “Heinz Walz GmbH”. <http://www.heinzwalz.ru/>

– minimum and maximum fluorescence level caused by a pulse of light after adaptation of the leaves to light; F – fluorescence yield; F_v / F_m – maximum photochemical quantum yield of FS II after adaptation of the leaves to darkness; $Y(II)$ – effective photochemical quantum yield of FS II after adaptation of the leaves to light; qP – photochemical fluorescence quenching coefficient; qN – non-photochemical fluorescence quenching coefficient; $Y(NPQ)$ – quantum yield of the regulated non-photochemical quenching of fluorescence; $Y(NO)$ – quantum yield of the unregulated non-photochemical quenching of fluorescence; ETR – electron transport velocity. The variable (variability) ChlF was calculated: $F_v = F_m - F_0$ and photochemical quantum yield of FS II at blocking of electron transfer from the primary acceptor plastoquinone (QA) after adaptation of the leaves to darkness by the formula F_v / F_0 [26].

Variety response was determined by the relative change (K) of the measured parameters of the seedlings ChlF after exposure of the plants under combined stress conditions:

$$K = \frac{|A_o - A_k|}{A_k} \cdot 100,$$

where A_k – control sample parameter; A_o – prototype parameter.

The lower the K index, the more resistant the variety is in the studied group of varieties. Representative sample consisted of 45 plants; the repetition of experiments was threefold. Statistical processing of the data was carried out in Microsoft Excel 2010 using a standard data analysis package. The ChlF parameters recorded during 4 min were analyzed. The mean error did not exceed 1.5–2.0%. Three series of experiments were performed. Student's t -test was used to determine the significance of the differences between the mean values. The mean values were calculated over the entire experimental data set.

RESULTS AND DISCUSSION

Stress caused by simultaneous action of *B. sorokiniana* and chloride salinity significantly

($p \leq 0.05$) compared to the control increased the inhibition of photosynthetic activity from 12 to 16-day-old seedlings of all the varieties (see the Table). In 10-day-old seedlings, no significant change in photochemistry parameters compared to the control was found. In seedlings of Sibirskaya 21 and Novosibirskaya 41 varieties, reliable ($p \leq 0.05$) inhibition of photochemistry parameters $Y(II)$ and ETR on the 12th day amounted to 18.6 and 28.6%, respectively. On the 16th day of cultivation, $Y(II)$ and ETR parameters varied in the range from 52.7% (Sibirskaya 21) to 91.7% (Novosibirskaya 41). The increase in inhibition was 1.8–3.2 times compared to the values of the parameters of 12-day-old seedlings of these varieties. The increase in inhibition of photochemistry parameters of Novosibirskaya 29 seedlings was observed from 14-day-old and amounted to 1.4 times by the end of cultivation. The qP parameter on the 16th day of cultivation significantly ($p \leq 0.05$) decreased in Novosibirskaya 29 and Novosibirskaya 41 varieties by 53.4 and 63.0% compared to the control and did not change significantly in Sibirskaya 21.

Increasing the exposure time under stress conditions resulted in different nature of changes in the parameters of non-photochemical quenching of ChlF. In seedlings of Novosibirskaya 41 variety, a reliable decrease of $Y(NPQ)$ and qN parameters from 12 to 16 days of plant development in the range of 18.7–58.9% was observed, in Novosibirskaya 29 variety there was a sharp increase of $Y(NPQ)$ and qN parameters up to 178.2% on the 14th day with a subsequent decrease on the 16th day of cultivation. On the 16th day of cultivation in seedlings of Novosibirskaya 29 and Novosibirskaya 41 varieties a significant ($p \leq 0.05$) decrease in the values of $Y(NPQ)$ and qN parameters was 34.9–58.9%, respectively, compared with the control. In contrast to the first two varieties, Sibirskaya 21 showed non-significant changes in $Y(NPQ)$ and qN parameters by the end of cultivation. However, in the seedlings of this variety, a gradual increase in the values of parameters $Y(NPQ)$ and qN from 10 to 14 days of age in

Параметры флуоресценции хлорофилла в листьях 12, 14 и 16-суточных проростков пшеницы изученных сортов в контроле и при совместном действии хлоридного засоления и *B. sorokiniana*
Chlorophyll fluorescence parameters in the leaves of 12, 14 and 16-day-old wheat seedlings of the studied varieties in control and under the joint action of chloride salinity and *B. sorokiniana*

Age, days	Variant	ChlF parameters							
		Y(II)	Y(NPQ)	Y(NO)	qP	qN	ETR	F_v/F_m	F_v/F_o
Novosibirskaya 41									
12-th	Control	2,9 ± 0,1	3,1 ± 0,2	5,9 ± 0,1	1,8 ± 0,1	5,1 ± 0,1	141,1 ± 3,7	0,66 ± 00,1	1,95 ± 0,1
	<i>B. sorokiniana</i> + NaCl	2,2 ± 0,1*	2,7 ± 0,1*	7,1 ± 0,3*	1,6 ± 0,1	4,2 ± 0,1*	100,8 ± 2,1*	0,68 ± 0,1	2,17 ± 0,1
14-th	Control	2,3 ± 0,1	3,0 ± 0,2	6,7 ± 0,2	1,6 ± 0,1	2,3 ± 0,2	241,3 ± 6,3	0,68 ± 0,01	2,1 ± 0,2
	<i>B. sorokiniana</i> + NaCl	1,9 ± 0,1*	2,9 ± 0,3	4,9 ± 0,2	1,5 ± 0,1	2,9 ± 0,3*	239,8 ± 6,3	0,67 ± 0,02	2,0 ± 0,1
16-th	Control	2,2 ± 0,1	3,5 ± 0,2	6,2 ± 0,1	1,7 ± 0,1	5,4 ± 0,2	104,4 ± 2,2	0,60 ± 0,01	1,54 ± 0,1
	<i>B. sorokiniana</i> + NaCl	0,5 ± 0,06*	1,6 ± 0,09*	9,9 ± 0,3*	0,6 ± 0,06*	2,2 ± 0,1*	8,6 ± 0,3**	0,59 ± 0,01	1,44 ± 0,1
Novosibirskaya 29									
12-th	Control	5,9 ± 0,1	1,1 ± 0,01	5,0 ± 0,1	3,3 ± 0,1	2,6 ± 0,1	238,5 ± 7,1	0,72 ± 0,02	2,6 ± 0,2
	<i>B. sorokiniana</i> + NaCl	5,6 ± 0,2	1,0 ± 0,01	5,4 ± 0,2	3,2 ± 0,1	2,3 ± 0,1	226,1 ± 6,1	0,73 ± 0,01	2,7 ± 0,2
14-th	Control	6,1 ± 0,2	0,9 ± 0,1	4,9 ± 0,1	3,4 ± 0,3	2,5 ± 0,1	245,3 ± 6,1	0,72 ± 0,02	2,58 ± 0,1
	<i>B. sorokiniana</i> + NaCl	1,9 ± 0,1*	2,7 ± 0,1**	7,2 ± 0,2*	1,5 ± 0,1*	4,1 ± 0,2*	88,6 ± 3,1*	0,67 ± 0,01	2,10 ± 0,1*
16-th	Control	2,7 ± 0,1	2,7 ± 0,2	6,5 ± 0,1	1,7 ± 0,1	4,4 ± 0,3	129,4 ± 4,2	0,65 ± 0,01	1,91 ± 0,1
	<i>B. sorokiniana</i> + NaCl	0,7 ± 0,01*	1,8 ± 0,1*	9,5 ± 0,1*	0,8 ± 0,01*	2,4 ± 0,1*	18,9 ± 0,1**	0,63 ± 0,01	1,74 ± 0,1
Sibirskaya 21									
12-th	Control	3,4 ± 0,1	2,4 ± 0,1	6,1 ± 0,1	2,0 ± 0,1	4,1 ± 0,1	167,7 ± 5,1	0,72 ± 0,01	2,65 ± 0,1
	<i>B. sorokiniana</i> + NaCl	2,8 ± 0,1*	3,2 ± 0,1	5,9 ± 0,1	1,9 ± 0,1	5,1 ± 0,1*	136,6 ± 4,9*	0,67 ± 0,01	2,08 ± 0,1*
14-th	Control	2,1 ± 0,07	1,8 ± 0,09	8,1 ± 0,3	1,5 ± 0,03	2,9 ± 0,1	96,4 ± 2,7	0,65 ± 0,01	1,86 ± 0,1
	<i>B. sorokiniana</i> + NaCl	1,9 ± 0,09	3,2 ± 0,1**	6,9 ± 0,2*	1,7 ± 0,04*	4,7 ± 0,2*	85,4 ± 2,4	0,65 ± 0,01	1,93 ± 0,09
16-th	Control	2,2 ± 0,1	2,7 ± 0,1	7,1 ± 0,2	1,5 ± 0,03	4,1 ± 0,2	99,9 ± 2,2*	0,67 ± 0,01	2,03 ± 0,1
	<i>B. sorokiniana</i> + NaCl	1,2 ± 0,02*	2,7 ± 0,1	8,1 ± 0,3*	1,3 ± 0,03*	3,9 ± 0,1	47,3 ± 2,2*	0,60 ± 0,01	1,5 ± 0,08*

Note. Differences with control are reliable at significance levels: * $p \leq 0.05$; ** $p \leq 0.01$. Mean values of data and their standard errors are presented.

the range from 19.5 to 73.5% was found. The parameter $Y(NO)$ also had varietal specificity – in the variety Sibirskaya 21 it significantly ($p \leq 0.05$) decreased by 14.5% only on the 14th day of cultivation and did not change significantly compared to the control on the 16th day. Gradual increase of $Y(NO)$ parameter from 12 to 16-day-old seedlings in the range of 19.6–59.9% was observed in the seedlings of Novosibirskaya 41 variety; in the seedlings of Novosibirskaya 29 variety there was a sharp increase of $Y(NO)$ in 14-day-old seedlings up to 46.3% with preservation of such value of the parameter in 16-day-old seedlings.

Photochemical quantum yield of FS II at blocking of electron transfer from the primary acceptor plastoquinone (QA) after adaptation of the leaves to darkness F_v/F_0 significantly decreased compared to the control by 24.7% in the variety Sibirskaya 21, in other varieties it changed insignificantly, as well as the parameter F_v/F_m in all the varieties.

The greatest inter-variety differences under the joint action of salinity and pathogen were observed on the 16th day of seedlings cultivation. The resistance of the varieties varied in descending order: Sibirskaya 21 – Novosibirskaya 29 – Novosibirskaya 41. The decrease in $Y(II)$ and ETR by 45.4 and 52.7%, increase in $Y(NO)$ up to 13.8% with unreliable changes in $Y(NPQ)$ and qN compared to the control indicated greater lability of the defense systems of the variety Sibirskaya 21. The greatest destabilizing effect of the joint stress was found in Novosibirsk 41 (decreased $Y(II)$ and ETR by 79.7 and 91.7%, decreased $Y(NPQ)$ and qN by 54.7 and 58.9%, increased $Y(NO)$ by 59.9% compared to the control) (see Figs. 1, 2). Novosibirsk 29 showed a decrease in $Y(II)$ and ETR by 75.0 and 85.4%, a decrease in $Y(NPQ)$ and qN by 34.9 and 44.5%, and an increase in $Y(NO)$ by 45.8% compared to the control. Thus, in the studied varieties, the actions of two stressors resulted in the loss of resistance. The level of negative impact of the stressor combination was determined by the

specific genotype of the variety, timing and intensity of the stress load.

A strong positive linear correlation dependence $r = 0.97 \dots 0.99$ ($p < 0.01$) between the parameters $Y(II)$, ETR and qP was established. The obtained dependence is due to the fact that these parameters characterize the process of photochemical quenching of ChlF. A strong negative linear correlation relationship $r = -0.98 \dots -0.99$ ($p < 0.01$) was established between the parameters of non-photochemical quenching of ChlF $Y(NPQ)$, $Y(NO)$ and qN . The high level of correlation between the parameters is due to the fact that they reflect the process of thermal dissipation of energy of excited chlorophyll FS II - regulated, $Y(NPQ)$ (stimulated by the xanthophyll cycle) and unregulated, $Y(NO)$ (promotes the formation of active oxygen radicals AFC). The qN coefficient describes the total contribution of non-photochemical processes to the quenching of ChlF, based on the concept of open and closed RCs of FS II [27]. Under the experimental conditions, a reliable ($p \leq 0.05$) increase in the values of relative changes in the parameter $Y(NO)$ in the variant of joint stress in the varieties Novosibirskaya 29 and Novosibirskaya 41 from 45.8 to 59.9% on the 16th day of cultivation was observed. The increase in the $Y(NO)$ parameter indicates a decrease in the efficiency of defense regulatory mechanisms and a decrease in photochemical energy conversion under stress¹³. The values of relative changes in the parameters $Y(NPQ)$ and qN decreased significantly ($p \leq 0.05$) in these varieties in almost the same range, from 44.5 to 58.9%.

Similar results were observed when corn was infected with various types of fungal infections under severe stress conditions [28]. In the more resistant variety Sibirskaya 21, the relative changes in non-photochemical quenching parameters were unreliable. The higher tolerance of Sibirskaya 21 may be due to the low level of AFC formation. Thus, six out of eight investigated parameters of ChlF reflect the efficiency of energy utilization of light reactions of pho-

¹³Korneev D. Yu. Information possibilities of the method of chlorophyll fluorescence induction. Kiev: Alterpress, 2002, 188 p.

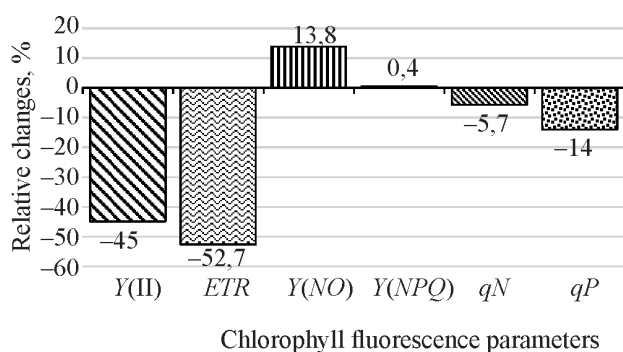


Рис. 1. Относительные изменения параметров флуоресценции хлорофилла в листьях 16-суточных проростков сорта Сибирская 21 при совместном действии хлоридного засоления и *B. sorokiniana*

Fig. 1. Relative changes of chlorophyll fluorescence parameters in the leaves of 16-day-old seedlings of the variety Sibirskaya 21 under the combined action of chloride salinity and *B. sorokiniana*

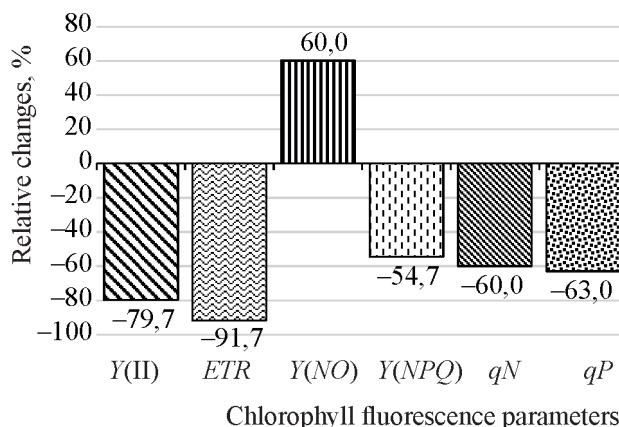


Рис. 2. Относительные изменения параметров флуоресценции хлорофилла в листьях 16-суточных проростков сорта Новосибирская 41 при совместном действии хлоридного засоления и *B. sorokiniana*

Fig. 2. Relative changes of chlorophyll fluorescence parameters in the leaves of 16-day-old seedlings of the variety Novosibirskaya 41 under the combined action of chloride salinity and *B. sorokiniana*

tosynthesis in the formation of organic matter in the dark reactions of photosynthesis and can be used to assess the photosynthetic activity of wheat seedlings under the combined action of *B. sorokiniana* and chloride salinity.

CONCLUSIONS

1. The conducted studies confirm the informativeness of ChlF parameters $Y(II)$, ETR , qP , $Y(NPQ)$, qN and $Y(NO)$ as biomarkers of photosynthetic activity and assessment of resistance of soft spring wheat varieties to the combined action of the common root rot pathogen *B. sorokiniana* and chloride salinity.

2. Reduction of $Y(II)$ and ETR by 45.4 and 52.7%, increase of $Y(NO)$ up to 13.8% with unreliable changes of $Y(NPQ)$ and qN compared to the control indicated greater lability of defense systems of variety Sibirskaya 21. The greatest destabilizing effect of joint stress was revealed in the variety Novosibirskaya 41 (decrease of $Y(II)$ and ETR by 79.7 and 91.7%, decrease of $Y(NPQ)$ and qN by 54.7 and 58.9%, increase of $Y(NO)$ by 59.9% in comparison with the control). Under experimental conditions, the parameters F_v/F_0 and F_v/F_m were less sensitive.

3. Severe stress load (16th day of seedling cultivation) in Novosibirskaya 29 and Novosibirskaya 41 varieties resulted in a synchronous increase in the parameters of unregulated non-photochemical quenching of ChlF $Y(NO)$ by 45.8 and 59.9% and a decrease in the parameters of regulated photochemical quenching $Y(NPQ)$ and qN from 44.5 to 58.9%, respectively. This indicates a decrease in the efficiency of defense regulatory mechanisms and photochemical energy conversion under stress conditions, which can serve as a diagnostic indicator in assessing the adaptability and stress tolerance of varieties.

4. Significant intervarietal differences (from 1.8 to 4.3 times) were revealed for six parameters of ChlF. The smallest changes in parameters relative to the control were in the more resistant variety Sibirskaya 21.

5. The results obtained allow us to conclude that it is possible to use ChlF parameters to assess photosynthetic activity, identify adaptive components and phenotyping of wheat varieties for resistance under the joint action of *B. sorokiniana* and chloride salinity in variety trials.

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Влияние метеоусловий на продолжительность вегетационного периода и хозяйственно ценные признаки и свойства сортов сои отечественной и зарубежной селекции

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Определено влияние метеорологических условий региона на продолжительность вегетационного периода и продукционный процесс сои отечественной и зарубежной селекции. Исследования проведены в период 2021–2023 гг. в Брянской области. В качестве объекта исследований взяты 18 сортов сои, внесенные в Реестр селекционных достижений, допущенных к использованию. По продолжительности вегетационного периода сорта разделены на три группы спелости: скороспелые – Вита, Лира, Лидер 10, Амадея, Лиссабон, Вера, раннеспелые – Протина, Волма, Кора, Зуша, Мезенка, Осмонь, Султана, среднеспелые – Скульптор, Припять, Пума, Сирелия, Рось. Выявлено, что в среднем с увеличением вегетационного периода увеличивалась и высота растений: скороспелые – 75,8 см, раннеспелые – 77,3, среднеспелые – 83,0 см. Выделены четыре генотипа (22%) с низким прикреплением нижних бобов: Вера, Кора, Припять, Сирелия, 11 сортов (61%): со средним: Вита, Лира, Лидер 10, Амадея, Лиссабон, Волма, Зуша, Осмонь, Султана, Скульптор, Пума, три сорта (17%) – с высоким: Протина, Мезенка, Рось. Рассчитана масса 1000 семян – сорта с более крупными выполненными семенами – Султана (176 г), Рось (177), Лиссабон (162), Вита (158), Вера (158), Сирелия (158 г). Выявлены сорта с наибольшей урожайностью семян: Рось (25,3 ц/га), Зуша (22,8), Скульптор (22,2), Припять (22,2), Лиссабон (22,1 ц/га). Определен сырой протеин по методу Кьельдаля, сырой жир – по Сокслету. Высокое содержание сырого протеина сформировали сорта отечественной селекции Пума (36,66%), Мезенка (35,95), Осмонь (35,75), Вера (35,34%), зарубежные сортообразцы Сирелия (39,05%), Султана (38,27), Припять (36,17%). Содержание сырого жира в семенах изменялось как по годам, так и по сортам. Максимальное значение жира отмечено у генотипов Рось (23,78%), Мезенка (23,72), Скульптор (23,18), Зуша (22,45), Султана (22,36%).

Ключевые слова: соя, сорт, вегетационный период, урожайность, сырой протеин, сырой жир

Influence of weather conditions on the duration of the growing season and economically valuable traits and properties of soybean varieties of domestic and foreign selection

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The influence of meteorological conditions of the region on the duration of the vegetation period and production process of domestic and foreign soybean breeding was determined. The research was conducted in the period 2021–2023 in the Bryansk region. 18 soybean varieties included in the Register of breeding achievements admitted to use were taken as an object of research. According to the duration of the vegetation period varieties are divided into three groups of ripeness: fast-ripening – Vita, Lira, Leader 10, Amadea, Lisbon, Vera, early-maturing – Protina, Volma, Kora, Zusha, Mezenka, Osmon, Sultana, medium-maturing – Sculptor, Pripyat, Puma, Sirelia, Ros. It was revealed that, on average, plant height increased with the increasing vegetation period: fast-ripening – 75.8 cm, early-maturing – 77.3, medium-maturing – 83.0 cm. It was revealed that, on average, with an increase in the growing season, the height of plants increased: precocious – 75.8 cm, early-maturing – 77.3 cm, middle-maturing – 83.0 cm. 4 genotypes (22 %) with low attachment of the lower beans were identified: Vera, Kora, Pripyat, Sirelia, 11 varieties (61 %) with medium attachment of the lower beans: Vita, Lira, Leader 10, Amadea, Lisbon, Volma, Zusha, Osmon, Sultana, Sculptor, Puma, 3 varieties (17 %)

with a high attachment: Protina, Mezenka, Ros. The weight of 1000 seeds was calculated – varieties with larger filled seeds: Sultana (176), Ros (177), Lisbon (162), Vita (158), Vera (158), Sirelia (158). Varieties with the highest seed yield were identified: Ros (25.3 c/ha), Zusha (22.8), Sculptor (22.2), Pripyat (22.2), Lisbon (22.1 c/ha). Crude protein was determined by the Kjeldahl method, crude fat by the Soxhlet. The high content of crude protein was formed by the varieties of domestic breeding: Puma (36.66%), Mezenka (35.95%), Osmon (35.75%), Vera (35.34%); foreign varieties: Sirelia (39.05%), Sultana (38.27%), Pripyat (36.17%). The crude fat content in the seeds varied both by year and by variety. The maximum fat value was noted in the genotypes: Ros (23.78%), Mezenka (23.72%), Sculptor (23.18%), Zusha (22.45 %), Sultana (22.36%).

Keywords: soy, variety, vegetation period, yield, crude protein, crude fat

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Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

The expansion of the soybean cultivation area has been associated with its advancement to more northern regions for more than 100 years [1, 2]. According to Rosstat data (2023), in Russia the area under soybean cultivation by 2023 amounted to 3.6 million hectares, which is 4.6% more than in the previous year. The gross harvest also increased by 13.7%. In 2023, grain yield growth was 7.4% higher compared to 2022¹. Nationwide, soybeans are expanding their boundaries, becoming an increasingly popular and profitable commercial crop for agricultural producers every year [3–6].

At present, soybean is one of the leading leguminous crops in the world in terms of quality. Its grain contains protein (about 40%) and vegetable fat (up to 25%) with a balanced amino acid composition. In this regard, soybean is considered a valuable crop in demand on the world market. It is widely used for fodder, food,

technical, pharmaceutical and medical purposes² [7–14].

With the introduction of new cultivation technologies, the importance of the variety has been preserved. Variety remains not only a means of increasing yields, but also becomes a factor without which it is impossible to realize the achievements of science and technology. A new variety has the greater value, the more optimally, at a high level it combines the most important biological, economic and technological properties [7–14]. The first field experiments on soybean in the Bryansk region were conducted in the 1980s at the Bryansk State Agricultural Academy under the leadership of I.Y. Moiseenko. Later, the soybean varieties Bryanskaya 11 and Bryanskaya Miya were transferred to the State Register of Breeding Achievements allowed for use in the Central (3) region.

Currently, scientists of the Bryansk State Agrarian University are studying issues relat-

¹Gross harvest and yield of agricultural crops in the Russian Federation: annual bulletins of the Federal State Statistics Service (Rosstat). <https://rosstat.gov.ru/>.

²Yusova O.A., Asanov A.M., Omelyanyuk L.V. Yield and grain quality of soybean varieties of Siberian NIISKh selection in the southern forest-steppe of Western Siberia // Oil crops. Scientific and Technical Bulletin of the All-Russian Research Institute of Oil Crops, 2017, N 4 (172), pp. 18–24.

ed to the need to cultivate soybean varieties of the northern ecotype, which would mature in the soil and climatic conditions of the region and give a stable high grain yield, as well as agro-ecological evaluation of new varieties is carried out.

Considering the great value of soybean, especially in solving the problem of protein deficiency, it is necessary to comprehensively develop fundamental and applied research aimed at creating a scientific and methodological basis for a significant increase in yield, expansion of genotypic diversity of this crop and the cultivation area [15, 16]. In this regard, the topic of scientific research is relevant.

The purpose of the study was to determine the influence of meteorological conditions of the region on the duration of the growing season and the production process of domestic and foreign soybean selection.

MATERIAL AND METHODS

The research was carried out in 2021–2023 at the experimental field of the Bryansk State Agricultural University (Bryansk region). The object of the study were 18 soybean varieties of domestic and foreign selection, included in the Register of Breeding Achievements allowed for use of different ripeness groups.

According to FAO classification on the basis of the growing season length, soybean varieties are divided into ultra-early ripening (000) – 75–80 days, very early ripening (00) – 81–90, early ripening (0) – 91–110, early maturing (medium early ripening) (I) – 111–120, medium maturing (II) – 121–130, medium-late – 131–150, late maturing – 151–160, very late maturing – 151–170, exceptionally late maturing – more than 170 days³.

Soils of the experimental plot are gray forest medium loamy well-cultivated, humus content 3.66–3.79%, mobile forms of phosphorus –

300–302 mg/kg of soil, exchangeable potassium – 261–268 mg/kg, pH = 5.5–5.7.

Agrotechnics of soybean cultivation is generally accepted for the region. Comparable varieties were sown on equally cultivated plots. The arrangement of the plots is systematic, the repetition is threefold. The record area of one plot (one variety) is 20 m². Sowing date - the first ten-day period of May, seeding rate - 800 thousand germinated seeds/ha. During the soybean vegetation, phenological surveys and observations were conducted according to the methodology of G.S. Posypanov⁴.

Seed yields were calculated on a field-by-field basis by the method of continuous harvesting. Total nitrogen was determined by the Kjeldahl titrometric method in accordance with GOST 13496.4-2019, the coefficient of 6.25 was used for conversion to crude protein. When determining fat, the extraction method was used (GOST 10857-64). The analyses were performed in the testing laboratory of the Center for Collective Use of Scientific Equipment of the Bryansk State Agrarian University. Statistical processing of the experimental data was carried out according to the method of B.A. Dospekhov⁵.

RESULTS AND DISCUSSION

In the years of research, weather conditions of the growing season of soybean did not differ radically from the average climatic norm. The sum of active temperatures, an indicator characterizing the amount of heat required for soybean growth and development, was sufficient to produce mature seeds (see Fig. 1).

The sum of active air temperatures for May–September 2021 amounted to 2278.5 °C, which is 286.3 °C below the mean annual index. In 2022 its value was also below the norm by 508.3 °C, 2023 by the indicator of the sum of active temperatures was the closest to the climatic

³Korsakov N.I. Soybean (systematics and bases of breeding): Extended abstract of Doctor's thesis in Biology. Leningrad: VIR, 1973, 32 p.

⁴Posypanov G.S. Methods of studying biological fixation of air nitrogen: reference manual. Moscow: Agropromizdat, 1991, 299 p.

⁵Dospekhov B.A. Methodology of field experiment: (with the basics of statistical processing of research results): textbook for university students in agronomic specialties; 6th ed. Moscow: Alliance, 2011, 350 p.

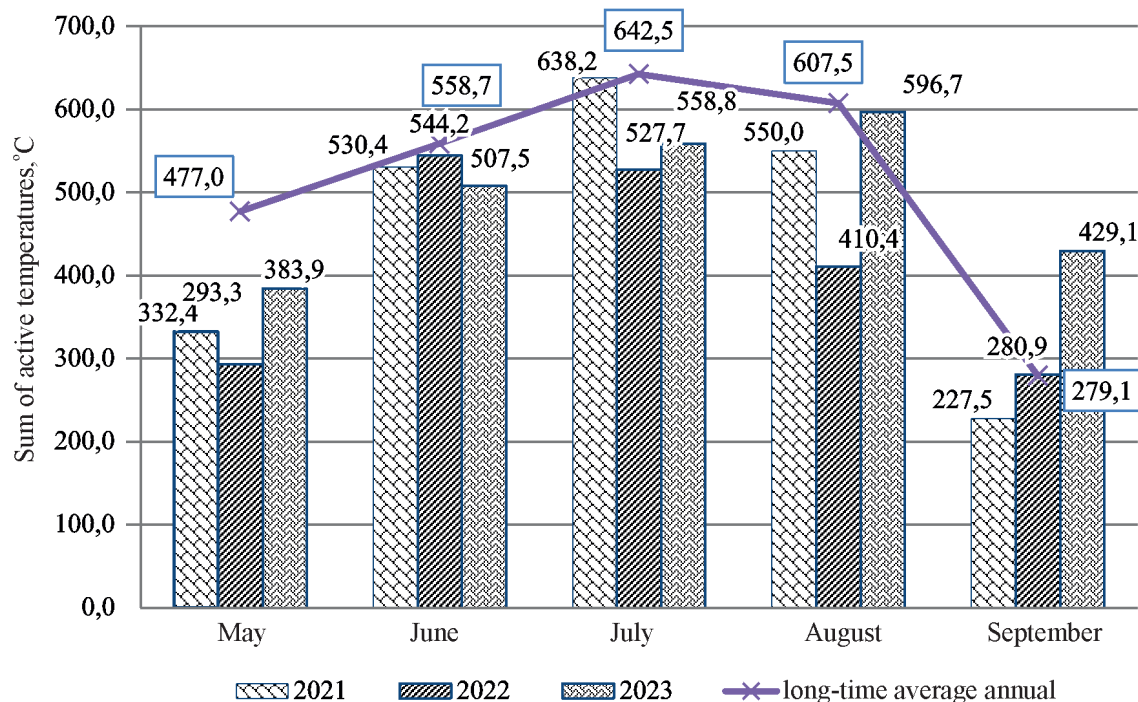


Рис. 1. Сумма активных температур в вегетационный период сои

Fig. 1. Sum of active temperatures in soybean growing season

norm and amounted to 2476.0 °C with the norm of 2564.8 °C. Thus, the sums of active temperatures were sufficient for ontogenesis of the studied soybean varieties, as this indicator has a direct impact on its cultivation in the conditions of the region. According to the results of long-term observations, the amount of precipitation during soybean growing season amounted to 312 mm. In 2022 and 2023 they occurred within the norm, while in 2021 May, July, August were rainy, the total amount of precipitation was 2 times higher than the norm. In 2022, the optimal amount of precipitation was in August in the phase of the beginning of seed ripening. Their distribution in 2023 was more uniform, except for August (42.0 mm with a norm of 64.0 mm). Precipitation of stormy character was recorded in the second ten-day period of May, June and in the third ten-day period of July.

Temperature conditions of the growing season of soybean in the years of the experiment were on average slightly higher than the climatic norm: in 2021 by 3.0 °C, in 2022 by 2.2 and in 2023 by 0.5 °C. The average daily temperature in May amounted to 14.5 °C. Summer

months remained warm during the study period, but in the first ten-day period of September air temperature decreased by 0.6°C compared to the norm. In the II and III ten-day periods of September, in the presence of precipitation, the average air temperature increased to 14.4 and 15.0 °C, respectively. This made it possible to get mature soybean seeds and harvest them at the optimal time.

The hydrothermal coefficient of the growing season in 2021–2023 had differences in comparison with the mean annual values. For soybean yield formation it was more favorable in 2022 – 2.0, in 2023 – 1.3, with more precipitation in September 2021 and 2022, which slightly increased the seed maturation phase (see Fig. 2).

One of the most important indicators of high yield of soybean seeds in the conditions of the Bryansk region is the duration of its vegetation. The vegetation period is one of the main traits that takes into account the suitability of a variety for maturation in certain soil and climatic conditions. Differences in weather conditions had a significant impact on the duration of the growing season of soybean, so its duration in

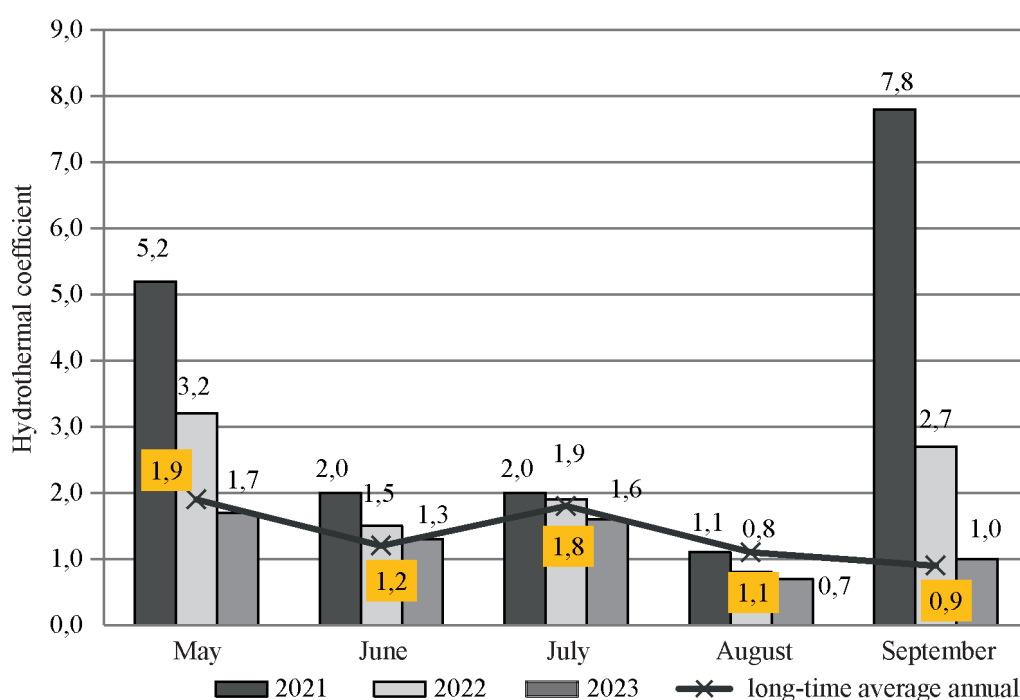


Рис. 2. Гидротермический коэффициент в вегетационный период сои

Fig. 2. Hydrothermal coefficient in soybean growing season

the same variety could vary up to several days. According to the duration of the growing season in the conditions of the south-west of the Non-Chernozem zone of Russia, the studied varieties were divided into three groups of ripeness: (0) early ripening – Vita, Lira, Leader 10, Amadea, Lisbon, Vera; early-maturing (I) –

Protina, Volma, Kora, Zusha, Mezenka, Osmon, Sultana; medium-maturing (II) – Sculptor, Pripyat, Puma, Sirelia, Ros (see Table 1).

Soybean varieties differed in vegetation duration. On average, the period of sprouting - maturation of seeds of the early maturing group was 100–112 days. The earliest of them was the Vita

Табл. 1. Продолжительность вегетационного периода сои

Table 1. Soybean growing season duration

Variety	Originator	Vegetation period, days			
		2021	2022	2023	Average value
1	2	3	4	5	6
<i>Fast-ripening</i>					
Vita	FSBSI FSC VNIIMK	101	100	103	101
Lira	FSBSI FSC VNIIMK	104	103	105	104
Leader 10	ACT	107	110	106	108
Amadea	SAATZUCHT DONAU GMBH & CO KG	109	106	112	109
Lisbon	AGRELIANT GENETICS INC	109	110	109	109
Vera	OOO “SPA Soya-Center”	111	110	110	110
LSD ₀₅		4,43	4,86	4,18	
<i>Early-maturing</i>					
Protina	SOCIETE RAGT 2N S.A.S.	110	110	112	111
Volma	OOO “Soya-Sever Co”	112	114	111	112
Kora	FSBSI FSC VNIIMK	112	112	113	112
Zusha	SSI VNIIZBK	113	113	114	113

Окончание табл. 1

1	2	3	4	5	6
Mezenka	SSI VNIIZBK	114	113	116	114
Osmon	SSI VNIIZBK	115	115	118	116
Sultana	SOCIETE RAGT 2N S.A.S.	118	118	116	117
LSD ₀₅		3,25	3,80	3,14	
<i>Medium-maturing</i>					
Skulptor	NORDDEUTSCHE PFLANZENZUCHT HANS-GEORG LEMBKE KG	121	120	123	121
Pripyat	ООО “Soya-Sever Co“	122	124	121	122
Puma	FSBSI FSC VNIIMK	120	120	125	122
Sirelia	SOCIETE RAGT 2N S.A.S.	126	127	128	127
Ros	ООО “Soya-Sever Co“	128	128	130	129
LSD ₀₅		5,49	5,82	5,13	

variety with semideterminant type of growth (vegetation period 101 days, $V = 5.305\%$), created at the V.S. Pustovoit All-Russian Research Institute of Oil crops. Four genotypes of domestic selection were classified as early maturing varieties in the region with a vegetation period of 111–120 days: Kora (112 days), Zusha (113), Mezenka (114), Osmon (116 days), as well as three varieties of foreign selection: Belarusian Volma (112 days) and French Protina (111), Sultana (117 days). It should be noted that when calculating the coefficient of variation, very low variability was shown by the genotypes in all three ripeness groups ($V = 1.4–5.6\%$). The longest growing season was in medium maturing indeterminate varieties of French and Belarusian selection Sirelia and Ros (127–129 days on average). Individual elements of the yield structure of soybean plants in the years of the experiment are presented in Table 2.

Taking into account the prevailing meteorological conditions in the crops, changes in plant height by varieties and years were observed. Weather conditions at this time were contrasting. As the vegetation period increased, an increase in plant height was observed in most varieties. This pattern was maintained during the period of the experiment. On average, the height of soybean plants of early maturing varieties was 75.8 cm. In the early maturing group, Protina, Kora, Zusha and Sultana varieties had the same average plant height of 79 cm. The total for the group was 77.3 cm. The medium maturing ones had an average plant height of 83.0 cm.

The Ros' variety created by “Soya-North Co.” stood out from the group with a vegetation period of 121–130 days with a vegetation period of 128 days. In general, the plant height of the varieties classified by us in the group of medium-maturing varieties varied from 68 to 121 cm. The average height of the group was 83 cm.

Distance to the lower first bean in soybean is an important trait on which quality seed harvesting depends. During 3 years of research four genotypes (22%) with lower lower bean attachment were identified: Vera (9.3 cm), Kora (9.9), Pripyat (9.6), Sirelia (9.7 cm); 11 varieties (61%) with medium attachment: Vita (13.8 cm), Lyra (10.1), Leader 10 (10.6), Amadea (10.3), Lisbon (12.7), Volma (10.8), Zusha (10.1), Osmon (11.7), Sultana (11.0), Sculptor (10.1), Puma (11.3 cm) and three varieties (17%) with higher distance to the lower beans: Protina (14.1 cm), Mezenka (14.7), Ros (14.8 cm).

The mass of 1000 seeds is one of the main elements of soybean yield structure, on which plant productivity depends. On average for the years of study of the varieties according to this indicator the following should be emphasized: Vita (158 g), Lisbon (162), Vera (158), Sultana (176), Sirelia (158), Ros (177 g). The minimum value of 1000 seeds weight was the Osmon variety – 127 g. In general, the hydrothermal regime during the period of research had a favorable effect on the phases of soybean growth and development, including the phases of bobo formation and seed ripening.

Табл. 2. Количественные и качественные показатели сои (среднее за 2021–2023 гг.)

Table 2. Quantitative and qualitative indicators of soy (average for 2021–2023)

Variety	Plant height, cm	Distance to lower bean, cm	Weight of 1000 seeds, g	Yield, c/ha	Crude protein, %	Crude fat, %
<i>Fast-ripening</i>						
Vita	83	13,8	158	21,4	31,90	19,33
Lira	76	10,1	141	17,2	29,73	19,79
Leader 10	74	10,6	146	20,1	29,65	21,15
Amadea	78	10,3	152	16,3	32,29	19,71
Lisbon	69	12,7	162	22,1	30,84	20,29
Vera	75	9,3	158	21,6	35,34	20,54
LSD ₀₅	3,0	1,6	7,5	1,9	2,9	1,2
<i>Early-maturing</i>						
Protina	79	14,1	137	18,9	33,67	17,57
Volma	68	10,8	129	17,7	35,60	20,73
Kora	79	9,9	150	18,3	34,07	20,25
Zusha	79	10,1	148	22,8	34,59	22,45
Mezenka	80	14,7	138	20,0	35,95	23,72
Osmon	77	11,7	127	19,7	35,75	20,48
Sultana	79	11,0	176	20,7	38,27	22,36
LSD ₀₅	3,4	2,0	7,1	2,0	3,2	1,8
<i>Medium-maturing</i>						
Skulptor	80	10,1	146	22,2	33,90	23,18
Pripyat	76	9,6	150	22,2	36,17	21,98
Puma	70	11,3	146	19,9	36,66	20,67
Sirelia	68	9,7	158	18,5	39,05	20,89
Ros	121	14,8	177	25,3	31,24	23,78
LSD ₀₅	3,8	1,3	7,6	2,1	3,6	2,1

The main property of varieties is yield, as it is the result of manifestation of their biological traits and properties in specific soil and climatic conditions. The maximum seed yield of the studied varieties was obtained in 2023, which is associated with an increase in the sum of active temperatures compared to the previous years. On average for the period of research, the yield varied from 16 (Amadea) to 25.3 c/ha

(Ros). As for the average yield between the ripeness groups, its value in early maturing and early maturing varieties did not differ practically: 19.78 c/ha (early-maturing) and 19.73 c/ha (early-ripening). The medium-ripening samples have higher yields because the growing season is longer. The soybean plant spends more time on the formation of leaf apparatus, laying of generative organs and seed formation. As a result, there is a higher number of beans on the plant, seeds in the bean (productivity) and higher seed collection per unit area (yield). It can be concluded that medium-maturing soybean varieties are more productive under optimal hydrothermal conditions of the region. On average for the years of study, the varieties with the highest seed yield were identified: Ros (25.3 c/ha), Zusha (22.8), Sculptor (22.2), Pripyat (22.2), Lisbon (22.1 c/ha).

Qualitative indicators along with productivity determine the economic value of varieties. The results of analyses for crude protein and crude fat content in soybean seeds are presented in Table 2.

On average for the years of research, high crude protein content was observed in domestic varieties Puma (36.66%), Mezenka (35.95), Osmon (35.75), Vera (35.34%). Among the foreign samples, two French Sirelia (39.05%), Sultana (38.27) and Belarusian yielding variety Pripyat (36.17%) stood out in terms of protein content.

Crude fat content in seeds varied both by year and by variety. Its content was highest in all the varieties in 2021, when precipitation at the beginning of soybean vegetation was almost twice as much as in 2022 and 2023. Fat content in 2022 for varieties of all ripeness groups exceeded the values of 2023 by 0.80–0.85%.

On average over the years of study, the maximum value of fat was observed in the following genotypes: Ros (23.78%), Mezenka (23.72), Sculptor (23.18), Zusha (22.45), Sultana (22.36%).

It should be noted that in soybean varieties of the Krasnodar region Vita, Lira, Kora, Puma and the Belarusian selection varieties Volma, Pripyat and Ros with increasing vegetation pe-

riod increased the content of crude protein and crude fat.

CONCLUSIONS

1. According to the duration of the vegetation period in the conditions of the region, the varieties are divided into three groups of ripeness: early-maturing - Vita, Lira, Leader 10, Amadea, Lisbon, Vera; early-ripening – Protina, Volma, Kora, Zusha, Mezenka, Osmon, Sultana; medium-maturing – Sculptor, Pripyat, Puma, Sirelia, Ros.

2. On average by ripeness groups, plant height increased with increasing vegetation period: early-maturing – 75,8 cm, early-ripening – 77,3, medium-maturing – 83,0 cm.

3. Four varieties (22%) with low first bean attachment were identified: Vera, Kora, Pripyat, Sirelia, 11 varieties (61%) with medium: Vita, Lira, Leader 10, Amadea, Lisbon, Volma, Zusha, Osmon, Sultana, Sculptor, Puma, three varieties (17%) with high distance to the lower beans: Protina, Mezenka, Ros.

4. varieties with larger plump seeds were selected: Sultana (176 g), Ros (177), Lisbon (162), Vita (158), Vera (158), Sirelia (158 g).

5. Varieties with the highest seed yields were identified: Ros (25.3 c/ha), Zusha (22.8), Sculptor (22.2), Pripyat (22.2), Lisbon (22.1 c/ha).

6. In soil and climatic conditions of the region, high crude protein content was formed by the varieties of domestic selection: Puma (36.66%), Mezenka (35.95), Osmon (35.75), Vera (35.34%). Among the foreign samples, French varieties Sirelia (39.05%), Sultana (38.27), Belarusian variety Pripyat (36.17%) stood out in terms of protein content.

7. Crude fat content in seeds varied both by year and by variety. Its content was highest in all the varieties in 2021, when precipitation at the beginning of soybean vegetation was almost 2 times more than in 2022 and 2023. The maximum value of fat was observed in the following genotypes: Ros (23.78%), Mezenka (23.72), Sculptor (23.18), Zusha (22.45), Sultana (22.36%).

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Сорта льна-долгунца отечественной селекции в условиях Томской области

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Представлены результаты изучения 20 образцов культурного льна (*Linum usitatissimum* L.) Федерального научного центра лубяных культур в 2021–2023 гг. Полевые исследования проводились в подтаежной зоне Томской области. Природно-климатические условия соответствовали требованиям возделывания льна-долгунца. В результате проведенных исследований выявлен ценный и пластичный исходный материал для создания сортов с признаками высокой продуктивности. По общей и технической длине стеблей выделились сорта псковской селекции Антей, Восход, Норд, Шанс, тверской (Торжок) – Полет, Универсал, смоленской – Феникс, Импульс и стандарт Памяти Крепкова. Длина стеблей общая достигала 90 см и выше, техническая составляла более 80 см. Лидерами по содержанию волокна в технической части стеблей стали сорта тверской селекции (Торжок): Тонус, Визит, псковской – Квартет, Орион, Пересвет – 40% и выше. Наивысшее значение по признаку мыклость отмечено у сорта Восход (681,0) и Пересвет (652,6). По признаку линейная плотность стебля сорта между собой различались незначительно, у большинства сортов значения находились в пределах 5,0–6,0 мг/см. Также изучено влияние фактора «Год включения в Госреестр СД РФ». Наибольшее влияние фактор оказал на признак содержание волокна. Сорта с более ранними сроками включения в Госреестр показывали невысокий выход волокна. Сорта льна российской селекции признаны перспективными и включены в селекционный процесс в качестве отцовских и материнских родительских форм при гибридизации.

Ключевые слова: лен-долгунец (*Linum usitatissimum* L. f. *elongata*), селекция, коллекция, сорта, продуктивность, волокно, семена, мыклость

Fiber flax varieties of domestic selection under conditions of the Tomsk region

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The results of the study of 20 samples of cultivated flax (*Linum usitatissimum* L.) of the Federal Scientific Center of Bast Crops in 2021–2023 are presented. The field studies were conducted in the sub-taiga zone of the Tomsk region. Natural and climatic conditions corresponded to the requirements of fiber flax cultivation. As a result of the conducted research, valuable and flexible source material for the creation of varieties with high productivity traits has been identified. The varieties of the Pskov selection – Antey, Voskhod, Nord, Chance, Tver (Torzhok) selection – Polet, Universal, Smolensk selection – Phoenix, Impulse and standard Pamyati Krepkova – stood out in terms of total and technical length of the stems. The total stem length reached 90 cm and above, the technical stem length was more than 80 cm. The leaders in terms of fiber content in the technical part of the stems were varieties of the Tver selection (Torzhok): Tonus, Visit, Pskov varieties – Kvartet, Orion, Peresvet – 40% and

higher. The highest value for the characteristic of stem slenderness (the ratio between technical length and stem thickness) was observed in the varieties Voskhod (681.0) and Peresvet (652.6). In terms of linear stem density, the varieties differed insignificantly among themselves, with most varieties having values in the range of 5.0–6.0 mg/cm. The influence of the factor "The year of inclusion in the State Register of BA of the Russian Federation" was also studied. The factor had the greatest influence on the fiber content trait. Varieties with earlier dates of inclusion in the State Register showed low fiber yield. Russian flax varieties are recognized as promising and are included in the breeding process as male and female seed parents during hybridization.

Keywords: fiber flax (*Linum usitatissimum* L. f. *elongata*), breeding, collection, varieties, productivity, fiber, seeds, stem slenderness

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Conflict of interest

The authors declare no conflict of interest.

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INTRODUCTION

The value of fiber flax is due to the variety of its applications [1]. Linen fiber is used to produce fabrics for various purposes: for clothing, household and technical, furniture and decorative, industrial, as well as special purpose fabrics (medical and defense industry). In EU countries and China 30 – 50% of linen fabrics production are textile fabrics for clothing, in Russia production of technical fabrics is about 50%¹ [1, 2].

The technical part of the stem, the section from the hypocotyl to the beginning of the inflorescence, from which long fibers are obtained, is of industrial interest² [3]. One of the main features determining the technological value of flax straw in processing is the fiber yield [4].

Over the years, breeders have been improving the fiber flax crop. The new breeding varieties developed by various scientific institutions are almost twice as high in fiber content as the first varieties, which used thick flax as the source material³ [5]. Modern varieties are taller, have higher deseeded flax and flax seed yields [5].

It should be noted that with a high yield potential of flax products, new breeding varieties are less adapted to soil and climatic conditions of the area of cultivation. This is especially true if the regions are highly differentiated in terms of heat and moisture availability [5]. Climate change is occurring, so previously developed varieties may decrease in quantity and quality and become less adaptive to growing conditions and pathogens [5, 6]. For example, the climate in the entire subtaiga of the West Siberian Plain of

¹Grishina E., Gelman D., Belopukhov S., Starosvetsky D., Groysman A., Ein-Eli Y. Improvement of aluminum–air battery performances by the application of flax straw extract // *ChemSusChem*, 2016, vol. 9, N 16, pp. 2103–2111. DOI: 10.1002/cssc.201600298.

²Korepanova E.V., Goreeva V.N., Maslova M.P. Comparative evaluation of flax varieties in the conditions of the Middle Urals // *Vestnik of Ulyanovsk State Agricultural Academy*, 2012, N 4 (20), pp. 9–14.

³Krepkov A.P. Selection of fiber flax in Siberia. Tomsk: Tomsk University, 2000, 186 p.

the period from 1936 to 2015 changed towards warming [7]. Therefore, the search and enrichment of initial breeding material with increased fiber quality indicators, resistance to biotic and abiotic environmental factors remains relevant.

The purpose of the research is to study the responsiveness of fiber flax varieties of different origin to soil and meteorological conditions of the sub-taiga zone of the Tomsk region for further involvement in the breeding process for the formation of stable high-yielding varieties.

MATERIAL AND METHODS

The material for the study was 20 samples of cultivated flax (*Linum usitatissimum* L.) of the Federal Research Center for Bast Fiber Crops: 8 high-fiber varieties of fiber flax of the Pskov selection, 9 – Tver (Torzhok), 3 – Smolensk (see Table 1)⁴. Standards for productivity and early maturity of varieties – Pamyati Krepkova (Krepkov settlement) and Tomsky 16. Standards for fiber quality – Svetoch variety of the All-Russian Research Institute of Flax (VNIIL) – now the Federal Research Center for Bast Fiber Crops (FRCBFC) – and 2 samples of the Orshansky 2 variety of the Belarusian selection, the first sample was cultivated in the conditions of the Tomsk region for more than 15 years, the second sample was received from the collection of the FRCBFC in 2021.

The collection nursery is one of the main sources for the creation of the source material. Since 2022, the variety Pamyati Krepkova has been used as a standard for comparison in nurseries due to the fact that the FSBI “Gos-sortkomissiya” for the West Siberian region switched to using it.

Field studies were conducted from 2021 to 2023 in the Bogashevsky subdivision of the SibNIISKHiT – Branch of the SFSCA RAS located in the sub-taiga zone of the Tomsk district of the Tomsk region.

The Tomsk region is located in the taiga zone of the southeastern part of the West Siberian lowland, the climate of the territory is continental-cyclic [7]. In the subtaiga, the frost-free period has an average duration of 115 days, the sum of average daily temperatures above 10 °C is 1700 °C; precipitation during the growing season is 200–220 mm which is about half of the annual norm. According to agroclimatic zoning, the study area belongs to the 5th agroclimatic zone and is characterized as moderately warm and moderately humidified; the hydrothermal coefficient of T.K. Selyaninov (HTC) varies from 1.1 to 1.6⁵ [7]. In some years, despite the location of the territory in the zone of excessive moisture, droughts and dry winds may occur. In general, agroclimatic resources of heat and moisture are close to the optimal conditions, fully meet the needs for the cultivation of fiber flax crop.

The varieties were studied for the following traits:

- total stem length of fiber flax, cm;
- technical stem length of fiber flax, cm;
- stem diameter, mm;
- straw mass of the technical part of the stem, mg;
- fiber weight of the technical part of the stem, mg;
- fiber content in the technical part of the stem, %;
- stem slenderness – the ratio of technical length and stem thickness, mm/cm;
- linear stem density – the ratio of the mass of the technical part of the straw stem to its technical length, mg/cm;
- total number of bolls, pcs.;
- number of seeds from one plant, pcs.;
- number of seeds per one boll, pcs;
- weight of one seed, mg.

The normality of the distribution of traits was tested using the Kolmogorov-Smirnov test. To compare the morphological features with nor-

⁴The State Register of Breeding Achievements Approved for Use (plant varieties): [//gossortrf.ru/wpcontent/uploads/2022/06/Register%20of%20admission%202022.pdf](https://gossortrf.ru/wpcontent/uploads/2022/06/Register%20of%20admission%202022.pdf) Accessed on 18.11.2023.

⁵Azmuka T.I. Climate Resources. Natural resources of the Tomsk region. Tomsk: Tomsk University Publishing House, 1991, pp. 83-103.

Табл. 1. Характеристика сортов льна-долгунца в Государственном реестре селекционных достижений, допущенных к использованию
Table 1. Characteristics of fiber flax varieties in the State Register of Breeding Achievements allowed for use

Variety	Year of inclusion in the State Register of BA RF	Region of coverage	Maturity group
<i>Pskov (SD Pskov NIISKh of the Federal Research Center for Bast Crops)</i>			
Antei	2003	North-Western, Volgo-Vyatsky	Medium-maturing
Voskhod	2000	Volgo-Vyatsky	Early-maturing
Dobrynya	2011	North-Western, Volgo-Vyatsky	»
Kvartet	2017	North-Western	»
Nord	2009	North-Western, Volgo-Vyatsky	»
Orion	2007	» »	Medium-maturing
Peresvet	2015	North-Western, Volgo-Vyatsky	Early-maturing
Chance	2022	North-Western, Central, Volgo-Vyatsky	»
<i>Torzhok (SD Institute of Flax of the Federal Research Center for Bast Crops)</i>			
Alexandrit	2013	North-Western	Medium-maturing
Vizit	2018	North-Western, Central	»
Diplomat	2012	North-Western	Late maturing
Nadezhda	2018	»	Medium-maturing
Polet	2019	»	»
Sursky	2015	»	»
Tonus	2016	»	»
Universal	2017	North-Western, Central, Volgo-Vyatsky	»
Caesar	2017	North-Western, Central	»
<i>Smolensk (SD Smolensk NIISKh of the Federal Research Center for Bast Crops)</i>			
Impulse	2002	Central	Medium-maturing
Leader	2005	North-Western, Central, West Siberian	Early-maturing
Phoenix	2018	North-Western, Central	Late maturing
<i>Tomsk (SibNIISKHiT – Branch of SFSCA RAS)</i>			
Pamyati Krepkova	2012	West Siberian	Early-maturing
Tomsky 16	1990	»	»
<i>Fiber Quality Standards (FRC FC)</i>			
Svetoch	1936	VNIIL	Medium-maturing
Orshansky 2	1971	BelNIIZ	»

mal distribution, one-factor analysis of variance and the Newman-Keuls test were used. The Kruskal-Wallis test and the Dunn test were used to compare the morphological features with the distribution different from the normal distribution. Pearson's ("traits with normal distribution") and Spearman's ("traits with distribution

other than normal") criteria were used to study the correlation relationship. One-factor analysis of variance was used to identify the share of influence of the factor "Year of inclusion in the State Register of Breeding Achievements of the Russian Federation".

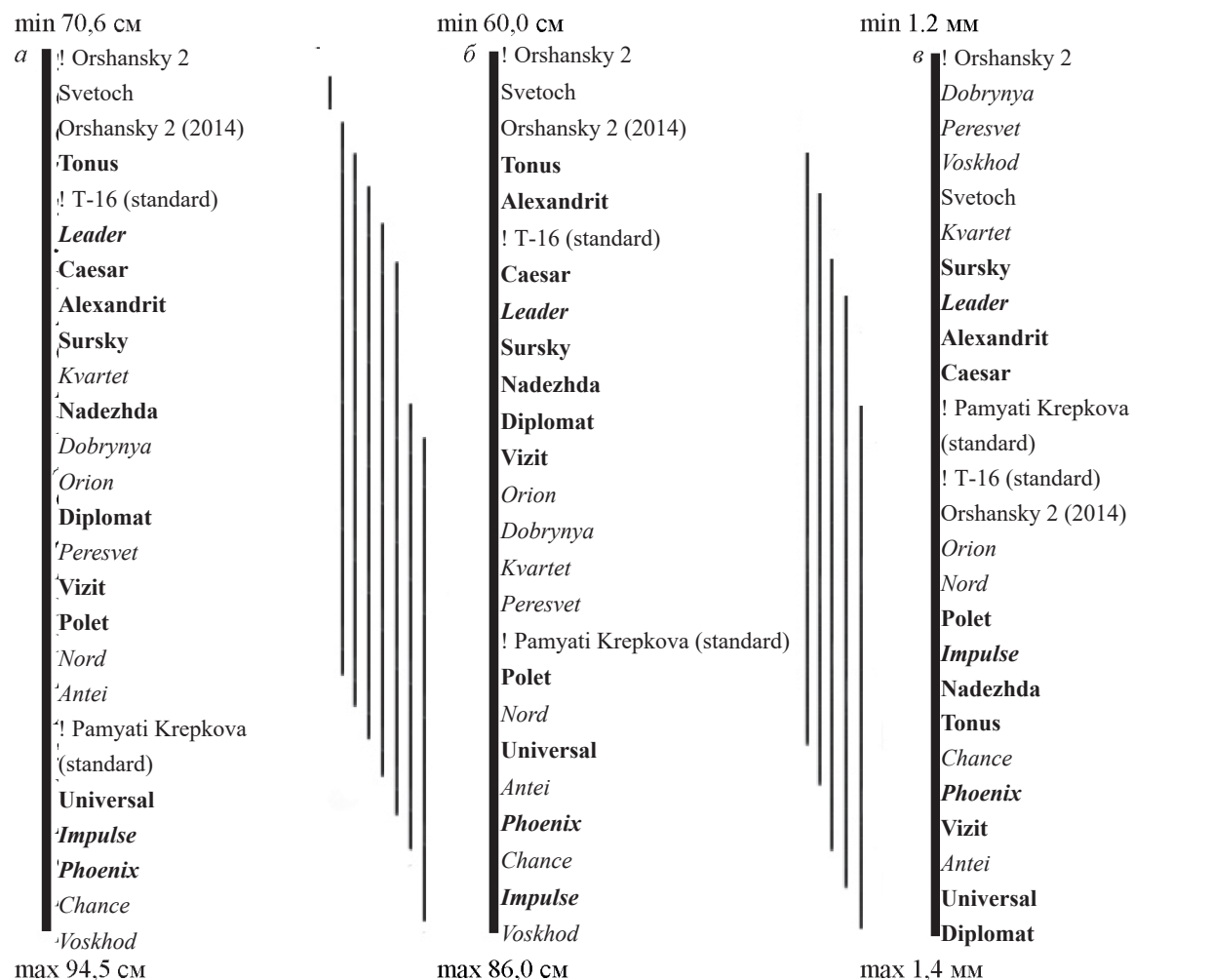


Рис. 1. Гомогенные группы, рассчитанные с помощью теста Ньюмена–Кейлса ($p < 0,05$) для морфологических признаков сортов льна-долгунца разного происхождения: обычный шрифт со знаком ! – Томск, полужирный – Торжок, курсивный – Псков, полужирный курсив – Смоленск и обычный – ФНЦ ЛК. Сорта ранжировались в порядке от минимального до максимального значения признака. Линии соединяют сорта без значимых различий в значениях признаков:

a – общая длина стебля льна-долгунца; *b* – техническая длина стебля льна-долгунца; *c* – диаметр

Fig. 1. Homogeneous groups calculated using the Newman-Keuls test ($p < 0.05$) for morphological traits of fiber flax varieties of different origins: regular lettering with ! sign – Tomsk, bold lettering – Torzhok, italic lettering – Pskov, bold and italic lettering – Smolensk and regular lettering – FSC BC. The varieties were ranked in order from the minimum to the maximum value of the trait. Lines connect the varieties without significant differences in trait values:

a – total stem length of fiber flax; *b* – technical stem length of fiber flax; *c* – diameter

RESULTS AND DISCUSSION

The traits that largely determine fiber yield are the total and technical length of fiber flax stem. According to these traits, the maximum indicators were recorded in the variety Voskhod (see Fig. 1). Eight varieties (Polet, Nord, Antei, P. Krepkova, Universal, Impulse, Phoenix and Chance) also registered high values. In all these

varieties, the total stem length exceeded 90 cm, the technical stem length was more than 80 cm. The lowest values for the two lengths were found in the varieties Orshansky 2 of the Tomsk reproduction and Svetoch. On average for three years, the total stem length of these two varieties did not exceed 80 cm, the technical stem length did not exceed 70 cm. At the same time,

in all three years, the varieties Orshansky 2 of the Tomsk reproduction and Svetoch had only single specimens with total stem length of more than 90 cm and technical stem length of more than 80 cm. The varieties differed slightly in stem diameter. Only the variety Orshansky 2 of the Tomsk reproduction had a diameter of 1.2 mm, while the other varieties had a diameter of 1.3–1.4 mm.

There was a strong diversity between the varieties in straw weight and fiber weight (see Fig. 2). The variety Antei exceeded the variety Orshansky 2 of the Tomsk reproduction 1.8 times in straw weight and 2.3 times in fiber weight. But in terms of fiber content Antei did not show the highest values. The five varieties Tonus, Quartet, Orion, Visit and Peresvet were the best in fiber content. The fiber content of these varieties was 40% and higher. Also, the Peresvet variety was the leader in the characteristic of stem slenderness with a value of 652.6. The highest value for stem slenderness trait was observed in the variety Voskhod (681.0). In terms of linear stem density, the varieties differed slightly among themselves, most varieties had values in the range of 5.0–6.0 mg/cm.

The greater number of bolls, hence, the greater number of seeds was observed in the variety Orshansky 2 of the Tomsk reproduction (see Fig. 3). At the same time, this variety showed average results in terms of seeds per capsule. Although the Kvartet variety formed the least number of bolls compared to other varieties, it was the leading variety in terms of the number of seeds in one boll; the seeds were rather heavy (4.7 mg) compared to most of the studied varieties. Seeds with heavy weight were observed only in three varieties: Phoenix (4.8 mg), Nadezhda (4.8 mg) and Diplomat (4.9 mg).

The correlation matrix shows that fiber content and stem slenderness, which characterize fiber productivity, are negatively correlated with the traits characterizing seed productivity (see

Table 2). This is also evident from Figs. 1–3; varieties with high fiber content and high stem slenderness often had a low number of bolls and, consequently, few seeds. A strong negative correlation can be observed between stem slenderness and diameter, i.e. the varieties Dobrynya, Peresvet and Voskhod with thinner stems had a higher value of stem slenderness. A rather high negative correlation is observed between stem slenderness and linear stem density. Thus, varieties with a high value of stem slenderness (Voskhod, Dobrynya and Peresvet) had a stem with a small linear density.

The analysis of variance showed that the factor “Year of inclusion in the State Register of Breeding Achievements of the Russian Federation” had a different impact on the studied traits (see Fig. 4). The factor had the greatest influence on the fiber content trait. The varieties with earlier dates of inclusion in the State Register showed a low fiber yield.

The main purpose of the fiber flax crop is to obtain the fibers formed in its stems. The fibers contain 20–30% of fibrous substances⁶ (see footnote 2) [3]. Of all the varieties studied in our work, only two had fiber yields below 30%. Five varieties had a fiber content of 40% or more. Some of the varieties considered in our work were also studied by other authors in their regions, and the differences in fiber content by region were not significant [4, 8]. It has been repeatedly proved that the yield of almost any crop is determined by 20–25% by variety. The role of variety is especially great where soil and climatic conditions are extreme for crops [9]. Small differences in traits of the same varieties in different regions of cultivation can be considered as an indirect indicator of ecological plasticity of a variety and the possibility of its use in breeding programs.

One of the significant traits characterizing fiber yield and quality is stem slenderness⁷. As noted by V.P. Ponazhev and E.G. Vinogradova [10], modern varieties of fiber flax showed a

⁶Romzhina T.A. National collection of Russian flax as a source of resistance to unfavorable agro-climatic environmental factors // Achievements of Science and Technology of AIC, 2003, N 11, pp. 17–18.

⁷Brach N.B., Sharov I.Ya., Pavlov A.V., Porokhovina E.A. Diversity of flax traits associated with fiber formation and the influence of growing conditions on their manifestation // Ecological Genetics, 2010, vol. 8, N 1, pp. 25–35.

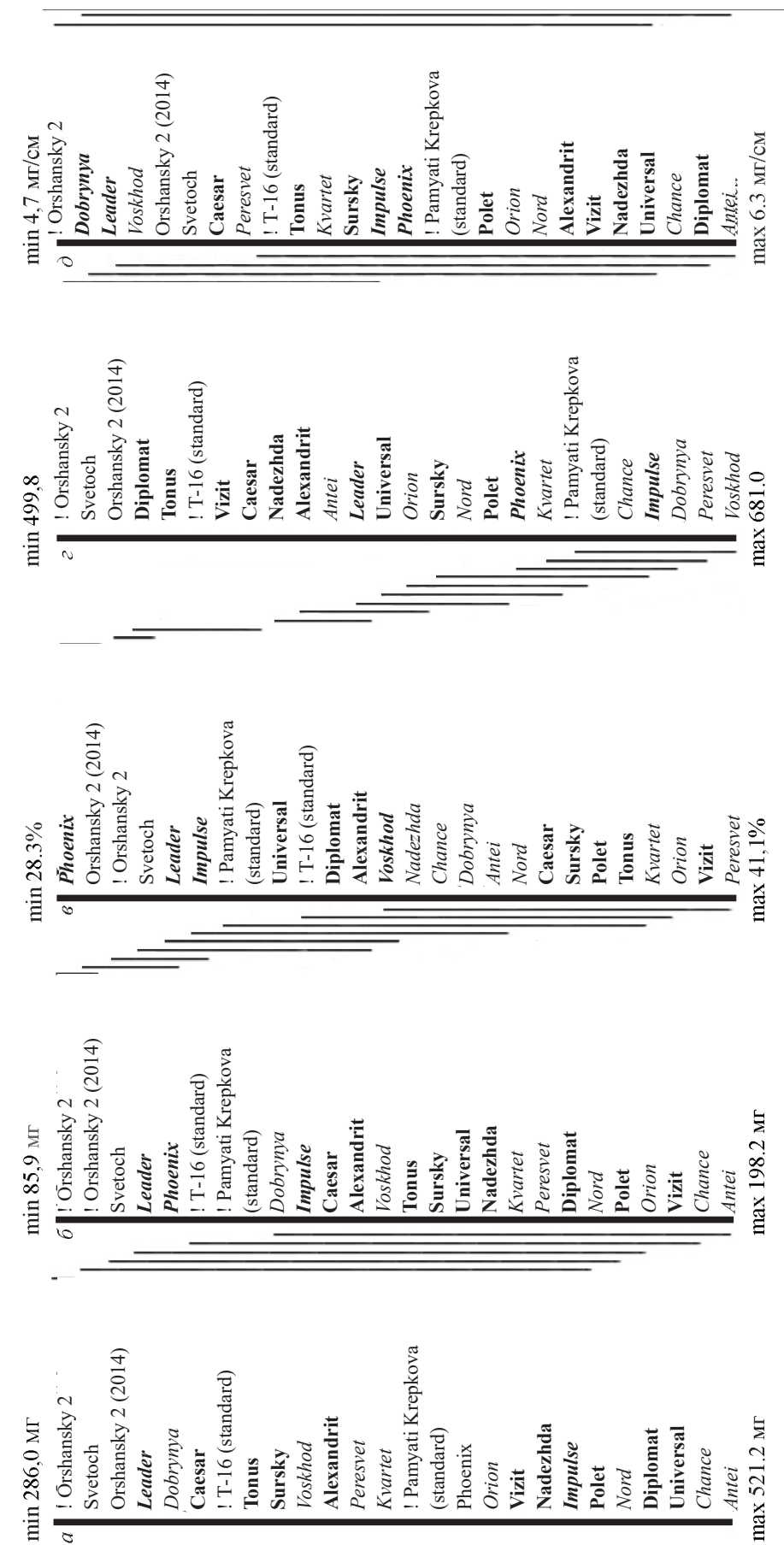


Рис. 2. Гомогенные группы, рассчитанные с помощью теста Ньюмена – Кейлса ($p < 0,05$) для признаков, характеризующих волокнистую продуктивность сортов льна-долгунца разного происхождения: обычный прифт со знаком ! – Томск, полужирный – Торжок, курсивный – Псков, полужирный курсив – Смоленск и обычный – ФНЦ ЛК. Сорта ранжировались в порядке от минимального до максимального значения признака. Линии соединяют сорта без значимых различий в значениях признаков:

а – масса соломы; б – масса волокна; в – содержание волокна; г – масса соломы; δ – мыклость; ε – линейная плотность стебля

Fig. 2. Homogeneous groups calculated using the Newman-Keuls test ($p < 0.05$) for the traits characterizing fiber productivity of fiber flax varieties of different origins, regular lettering with ! sign – Tomsk, bold lettering – Torzhok, italic lettering – Pskov, bold and italic lettering – Smolensk and regular lettering – FSC BC. The varieties were ranked in order from the minimum to the maximum value of the trait. Lines connect varieties without significant differences in the values of the following traits:

а – straw weight; б – fiber weight; в – fiber content; г – stem slenderness; δ – linear stem density

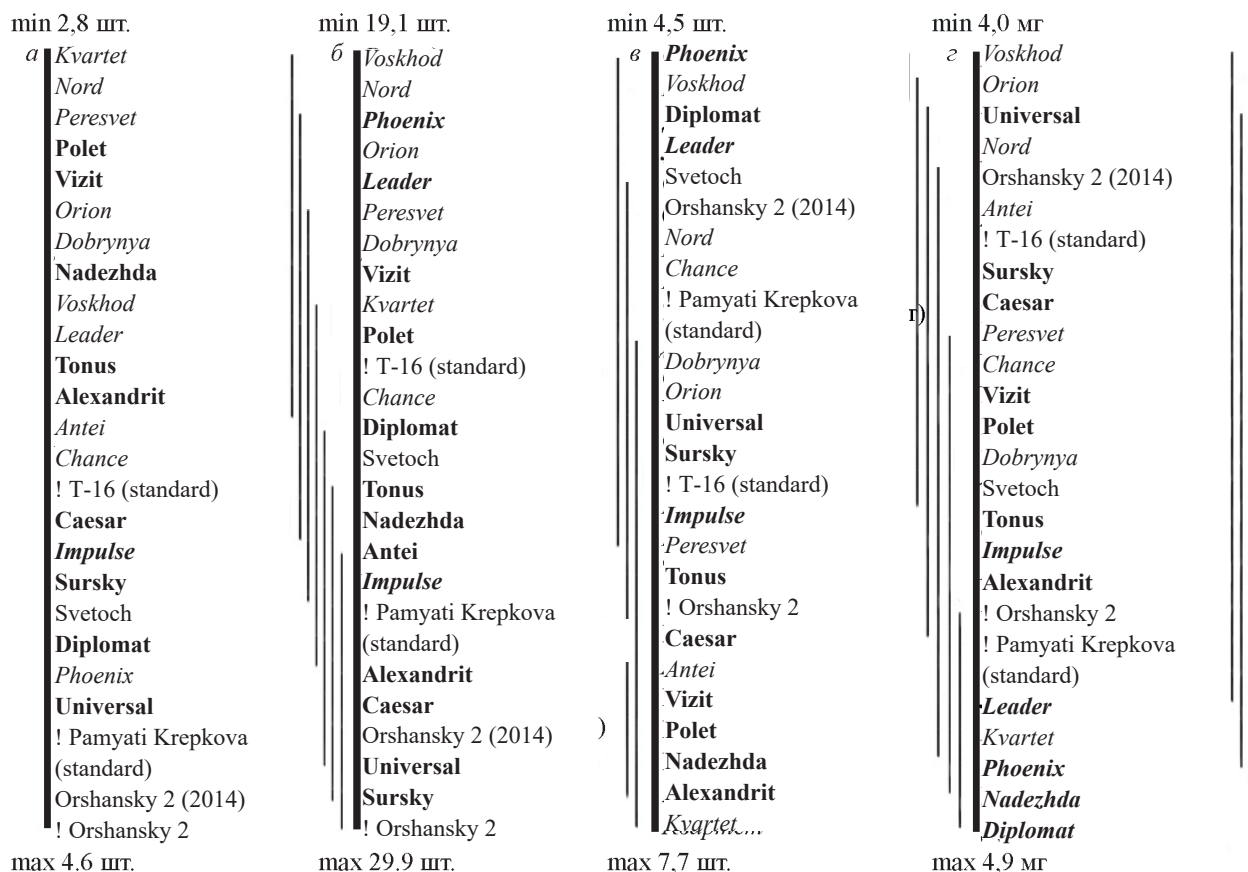


Рис. 3. Гомогенные группы для признаков, характеризующих семенную продуктивность сортов льна-долгунца разного происхождения, обычный шрифт со знаком ! – Томск, полужирный – Торжок, курсивный – Псков, полужирный курсив – Смоленск и обычный – ФНЦ ЛК. Сорта ранжировались в порядке от минимального до максимального значения признака. Линии соединяют сорта без значимых различий в значениях признаков, рассчитанные с помощью теста Данн ($p < 0,05$):

a – общее число коробочек; *б* – число семян; *в* – число семян на одну коробочку, и теста Ньюмена – Кейлса ($p < 0,05$); *з* – масса одного семени

Fig. 3. Homogeneous groups for the traits characterizing seed productivity of fiber flax varieties of different origins, regular lettering with ! sign – Tomsk, bold lettering – Torzhok, italic lettering – Pskov, bold and italic lettering – Smolensk and regular lettering – FSC BC. The varieties were ranked in order from the minimum to the maximum value of the trait. Lines connect varieties without significant differences in trait values calculated using Dunn's test ($p < 0.05$):

a – total number of the bolls; *б* – number of seeds; *в* – number of seeds per 1 boll, and Newman-Keuls test ($p < 0.05$); *з* – weight of 1 seed

decrease in stem slenderness from 620–650 to 420–450 units. However, in our work, the varieties bred among the first ones showed lower stem slenderness values. This is probably due to the fact that the main direction in flax breeding work is the creation of early maturing high-yielding varieties. With such selection, only early-flowering plants were included in further work, and strong selective pressure occurred, which in the end led to the varieties becoming typical semi fiber flax varieties (see

footnote 3). At the same time, the development of new varieties is mainly aimed at increasing the index of stem slenderness [11, 12], so the year of variety development did not have a strong effect on this trait, which was shown by the analysis of variance.

The number of bolls was positively correlated with the diameter and weight of both straw and fiber. At the same time, the number of bolls was negatively correlated with fiber yield and stem slenderness. This may be due to the fact

Табл. 2. Корреляционная матрица по признакам, характеризующим морфологию растения, волокнистую и семенную продуктивность

Table 2. Correlation matrix for the traits characterizing plant morphology, fiber and seed productivity

Trait	Flax stem length total length	Technical stem length	Diameter	Straw weight	Fiber weight	Fiber content	Stem slenderness	Linear stem density	Total number of bolls	Number of seeds	Number of seeds per boll
Technical stem length	0.88										
Diameter	0.27	0.02									
Straw weight	0.61	0.41	0.79								
Fiber weight	0.61	0.46	0.68	0.93							
Fiber content	0.09	0.21	-0.25	-0.09	0.26						
Stem slenderness	0.35	0.59	-0.76	-0.36	-0.26	0.33					
Linear stem density	0.28	-0.01	0.86	0.89	0.79	-0.20	-0.66				
Total number of bolls	0.22	0.00	0.71	0.65	0.51	-0.35	-0.61	0.73			
Number of seeds	-0.04	-0.19	0.62	0.49	0.40	-0.25	-0.67	0.64	0.77		
Number of seeds per boll	-0.28	-0.24	0.09	-0.01	0.03	0.06	-0.25	0.09	-0.03	0.54	
Weight of 1 seed	-0.18	-0.23	0.09	0.14	0.12	-0.06	-0.22	0.25	0.65	0.18	0.15

Note. Statistically significant correlation at $p < 0.05$ is highlighted in semi-bold.

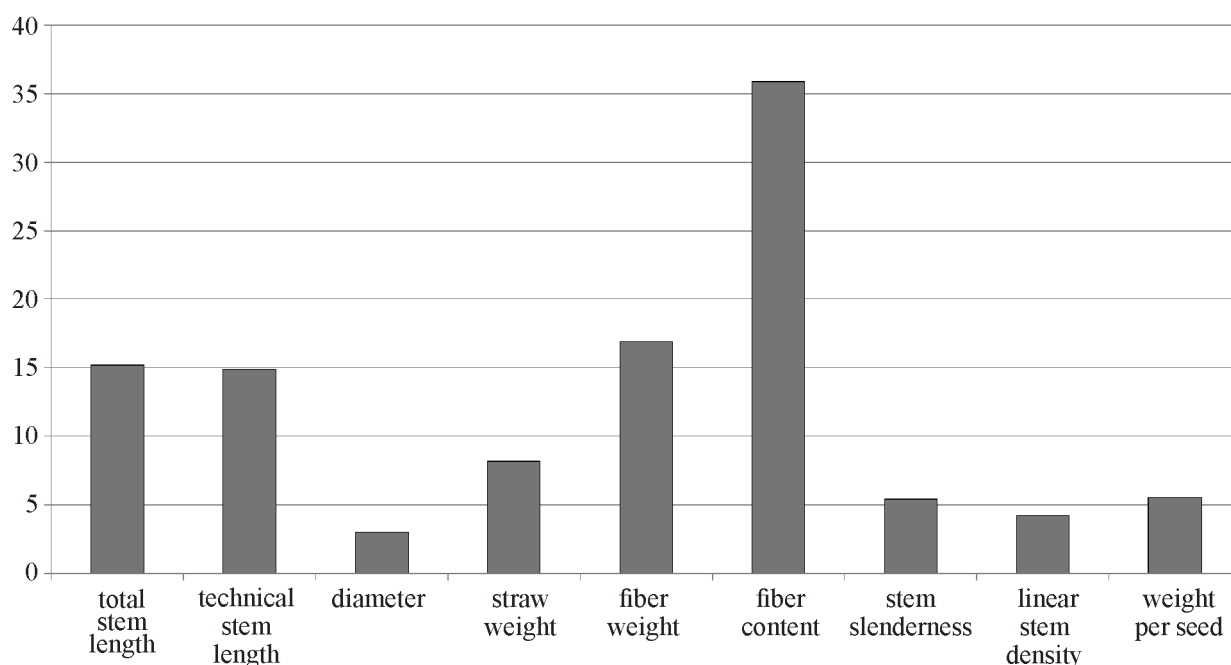


Рис. 4. Влияние фактора «Год включения в Госреестр СД РФ» на признаки, характеризующие морфологию растения, волокнистую и семенную продуктивность и имеющие нормальное распределение. Уровень значимости по всем признакам $p < 0,05$

Fig. 4. Influence of the factor "Year of inclusion in the State Register of BA of the Russian Federation" on the traits characterizing plant morphology, fiber and seed productivity and having normal distribution. Significance level for all traits is $p < 0.05$

that a thicker and heavier stem is needed for boll formation to hold the bolls and keep the plants from lodging. In contrast, the values of stem slenderness were higher in thinner and longer stems [6]. Also, stem slenderness was negatively correlated with linear stem density, which had a strong positive correlation with the number of bolls and seeds. Fiber with low density is considered to be of the highest quality⁸ (see footnote 7). Consequently, the lower the straw density, the lower the final fiber density will be. It turns out that the varieties with high fiber quality have strongly reduced seed production characteristics. The problem of incompatibility of high fiber quality and seed productivity was also noted by other authors [13–15].

CONCLUSION

As a result of the research, valuable and plastic source material for the development of the varieties with high productivity traits was identified. The varieties of the Pskov selection – Antei, Voskhod, Nord, Chance, Tver (Torzhok) – Polet, Universal, Smolensk – Phoenix, Impulse and the standard Pamyati Krepkova were distinguished by total and technical stem length. The total length of the stems reached 90 cm and higher, the technical length was more than 80 cm. The leaders in terms of fiber content in the technical part of stems were varieties of the Tver selection (Torzhok) Tonus, Visit, Pskov – Kvartet, Orion, Peresvet – 40% and higher. The highest value for the characteristic of stem slenderness was observed in the varieties Voskhod (681.0) and Peresvet (652.6). In terms of linear stem density, the varieties differed insignificantly among themselves, most varieties had values within the range of 5.0–6.0 mg/cm. The linear stem density of the Voskhod, Peresvet and Dobrynya varieties was one of the lowest, which, together with a high stem slenderness index, may indicate high quality fiber. Russian flax varieties are recognized as promising and are included in the breeding process as male and female seed parents in hybridization.

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Анализ гибридных популяций картофеля в условиях Магаданской области

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Приоритетным направлением в селекции картофеля в Магаданской области, учитывая короткий период вегетации и дефицит тепла, является создание преимущественно раннеспелых сортов. В статье представлены результаты оценки селекционных образцов картофеля по продуктивности и скороспелости. За два года исследовано около 3 тыс. образцов 67 гибридных комбинаций. Исследования проводили в 2022 и 2023 гг. на опытном поле Магаданского научно-исследовательского института сельского хозяйства на пойменных дерново-аллювиальных галечниково-супесчаных почвах. В питомнике сеянцев изучено более 2 тыс. образцов, представленных 25 гибридными комбинациями. Выделены гибридные комбинации, характеризующиеся высокой частотой отбора перспективных форм: Арктика × Эльбеда, Удача × Беллароза, Кроне × Беллароза, Чароит × Беллароза, Кроне × Лабадия, Арктика × Гала. В данных гибридных комбинациях отобрано в виде клонов от 7,6 до 17,9% образцов от общего количества высаженных в поле сеянцев. В питомнике гибридов 1-го года отобраны образцы с высокими показателями продуктивности. Максимальная масса клубней одного растения отмечена в популяциях Коломба × Крепыш (2010 г), Удача × Беллароза (1820), Арктика × Эльбеда (1825), Чароит × Беллароза (1800 г). В питомнике гибридов 2-го года по показателям урожайности и хозяйственно ценным признакам выделены гибриды с продуктивностью, превышающей 1000 г/куст: Коломба × Крепыш (2700 г/куст), Удача × Беллароза (1950), Арктика × Крепыш (1670 г/куст). Частота отбора продуктивных клонов здесь превысила 50%. Данные гибридные комбинации рекомендуются для селекционных исследований в условиях Магаданской области.

Ключевые слова: картофель, селекционные питомники, перспективные сеянцы, гибриды, Магаданская область

Analysis of hybrid potato populations in the conditions of the Magadan region

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The priority direction in potato breeding in the Magadan region, given the short growing season and heat shortage, is the creation of predominantly early-ripening potato varieties. The article presents the results of the evaluation of potato breeding samples in terms of productivity and ripeness. Over two years, about three thousand samples of 67 hybrid combinations have been studied. The research was carried out in 2022–2023 on the experimental field of the Magadan Scientific Research Institute of Agriculture on floodplain, sod-alluvial, pebble-sandy loam soils. More than two thousand samples represented by 25 hybrid combinations were studied in the nursery of seedlings. Hybrid combinations characterized by a high frequency of selection of promising forms are identified, such as Arctica × Elbeida, Udacha × Bellarosa, Krone × Bellarosa, Charoite × Bellarosa, Krone × Labadia, Arctica × Gala. In these hybrid combinations, from 7.6 to 17.9% of the samples from the total number of the seedlings planted in the field were selected as clones. The samples with high productivity indicators were selected in the nursery of hybrids of the 1st year. The maximum weight of tubers of one plant was noted in the populations of Columba × Krepysch – 2010, Udacha × Bellarosa – 1820, Arctica ×

Elbeida – 1825, Charoite × Bellarosa – 1800. In the nursery of hybrids of the 2nd year, hybrids with productivity exceeding 1000 g/bush, such as Columba × Krepysh (2700 g/bush), Udacha × Bellarosa (1950 g/bush), Arctica × Krepysh (1670 g/bush), were identified in terms of yield and economically valuable characteristics. The frequency of selection of productive clones here exceeded 50%. These hybrid combinations are recommended for breeding research in the conditions of the Magadan region.

Keywords: potatoes, breeding nurseries, promising seedlings, hybrids, Magadan region

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Conflict of interest

The author declares no conflict of interest.

INTRODUCTION

In our country, potato is one of the socially important crops, because it is an indispensable product in the diet of every person [1]. Among tuber and root crops, it is the first in terms of cultivation. The nutritional importance of potatoes is largely due to the high content of carbohydrates, a significant amount of ascorbic acid, anthocyanins, good digestibility of proteins, potassium, calcium and magnesium salts [2].

Potato plays a significant role in ensuring food security of the country. At the same time, the efficiency of potato production by 70–80% depends on the varietal component. In this regard, the actual task of potato breeders is to breed new varieties of different maturity groups and directions of use, which should have high adaptability to the conditions of cultivation [3].

One of the main and low-cost factors to increase the yields is the use of new varieties. Variety change allows selecting varieties that are best adapted to the soil and climatic conditions of the region, and provide growth in such important parameters as productivity, yield quality, resistance to diseases and pests, consumer properties of products [4].

Variety determines yield and product quality, it is the basis of cultivation technology, which is aimed at the realization of genetic possibilities of the crop, economic efficiency of production. A variety is a commercial product that brings a traditional product to the market in general, but

has certain consumer properties and parameters (in potato growing it is starch, alcohol, dextrins) [5].

Creation of new potato varieties possessing certain economically valuable traits is currently a priority task of domestic breeding, for which the acceleration of the breeding process and increasing its efficiency are important. To solve this problem, it is necessary to identify new sources of valuable traits for the most important directions of breeding. Modern varieties should combine such properties as high productivity, suitability for processing, high culinary and technological qualities, resistance to the most harmful and widespread diseases [6].

One of the most important achievements of modern potato breeding is the development of the varieties possessing the whole complex of traits, including the combination of high productivity with resistance to diseases and pests. Breeding practice shows that more resistant forms should be selected during hybridization, which transfer their resistance well to the progeny obtained as a result of self-pollination and crosses with these forms.

Important for breeding work is the use of parent seeds with a whole complex of economically valuable traits. An important characteristic of varieties is their suitability for use as female and male forms in obtaining hybrid progeny [7].

The selection of parental pairs in potato breeding is considered a key problem. The fertility of the original parental forms is a funda-

mental trait that determines the success of hybridization [8].

Breeding of high-yielding varieties adapted to the negative impact of the environment involves the study, selection and isolation of genetic sources with the best consumer qualities for their inclusion in practical breeding in the given directions. In the difficult natural and climatic conditions of the Far Eastern region of the Russian Federation, there is a need for comprehensive study of the source material for the creation of modern competitive varieties with ontogenetic adaptation, capable of adapting to external conditions [9].

When selecting pairs for hybridization, breeders use different approaches and methods, including selection of parental pairs based on ecological and geographical features, differences in productivity parameters, duration of vegetation phases or unequal resistance to diseases and pests, as well as on the results of evaluation of combinatory ability of parental forms [10].

The breeding work efficiency is decisively determined by the ecological adaptability of the initial variety or population. The worldwide regularity is confirmed that the local breeding varieties are the most appropriate to climatic conditions of the region and technological capabilities of producers, they are more resistant to local races and strains of phytopathogens. In this regard, the issues of creating new varieties with high adaptive potential to local agro-ecological conditions and combining high productivity, high field resistance to diseases and early accumulation of marketable yield are becoming relevant [11].

Agricultural production in the Magadan region is associated with a number of critical factors that cannot be controlled. First of all, it is heat deficit and a short vegetation period. The key factor affecting potato productivity is the heat factor [12]. All this implies the cultivation of predominantly early maturing potato varieties in this area.

In potato production in the northern regions of Russia it is necessary to use the varieties of early maturity group, adapted to soil and climat-

ic conditions, with high yield, nutritional value, and resistance to major phytopathogens [13].

Providing the region with its own agricultural products is an urgent and crucial task. In this case, the costs of transportation of potatoes and risks of losses during its transportation are significantly reduced. The gross yield can be increased by introducing new varieties and using advanced cultivation technologies that take into account the specific features of a particular region.

The purpose of the research is to analyze new hybrid combinations of potato in different breeding nurseries for the subsequent identification of promising hybrids in the conditions of the Magadan region.

For the first time in the Magadan region breeding research on the development and introduction of new highly adaptive potato varieties into production was carried out from the seedling stage.

MATERIAL AND METHODS

The studies were conducted in 2022 and 2023 in the area of the Ola settlement, on field No. 16. Soils of the site are floodplain sod-alluvial pebble-sandy loam, predominantly medium acidic (pH of salt extract 4.60–5.22). The content of basic nutrition elements is at the average level: ammonia nitrogen – 0,54–0,79 mg/100 g of soil, nitrate nitrogen – 0,65–0,96 mg/100 g of soil, potassium – 8,13–18,36 mg/100 g of soil. The phosphorus content is quite high (93.0–148.5 mg/100 g of soil), but under conditions of high soil acidity and its low biological activity, phosphorus is in a low-available state for plants, so liming of soils was required.

The macrorelief is without peculiarities, the plots are characterized by good levelness. Two-field crop rotation was used: annual grasses – potatoes.

In the III ten-day period of May, moldboard plowing to a depth of 18–20 cm with simultaneous harrowing with a MTZ-80 tractor (plow PLN-4-35) was carried out. Cutting of furrows with row spacing of 70 cm was carried out by the KRN-4,2 cultivator. Planting was carried

out in pre-cut furrows on the scheme of 30×70 cm to a depth of 5–6 cm manually. Cultivation was carried out in the phase of full sprouts, 14 days later hilling was carried out with a tractor MTZ-80 with a cultivator KRN-4.2. Mineral fertilizers ($N_{60}P_{60}K_{60}$) were applied manually locally at planting and before hilling under a bush. Treatment with herbicides Lazurit (active ingredient – metribuzin in concentration of 700 g/kg) and Otlichnik (active ingredient – chisalofof-P-ethyl in concentration of 51.6 g/l) was carried out. In the nursery of seedlings, a three-fold treatment with IntaVir (active substance – cypermethrin at a concentration of 37.5 g/kg) was carried out against the larvae of burying beetle.

Methodological guidelines on potato breeding process technology 2006¹, methodology of field surveys and postharvest quality control of seed potatoes², modern potato storage technologies³ were used in the research work. Laying of experiments was carried out in accordance with the methodology of field experiment of B.A. Dospekhov⁴. The methodology of agrotechnical experiments, registration, observations and analyses on potatoes of 2019 was also used⁵.

Botanical potato seeds were sown in pre-prepared boxes on May 10-15 on the scheme 1×3 cm. Temperature regime of 16–18°C was maintained until the emergence of the seedlings. Since the phase of mass sprouts, seedlings were grown in a greenhouse at a daytime temperature of 14–16 °C, night temperature – 10–12 °C. Care of the seedlings consisted in weeding and watering. Two-fold fertilization with mineral fertilizer solution in the dose $N_{60}P_{60}K_{60}$ was carried out. Visual assessment of potato plants in terms of field resistance to diseases was carried out on 9-point scale (see footnote 2) every ten days starting from the moment of appearance of

the first signs of diseases.

The tubers were planted in the nursery of the preliminary test on two-row plots on the scheme 30×70 cm in threefold repetition, the plot area 12.6 m² (60 tubers per plot). In the main test nursery – on two-row plots on the scheme 30×70 cm in threefold repetition, the plot area 12.6 m² (60 tubers per plot).

Weather conditions of the growing season 2022 significantly differed from the mean annual values both in temperature and moisture conditions. May was almost 1°C warmer than usual, which contributed to faster thawing of soils. Precipitation was three times more than the multiyear average (see Table 1).

The beginning of June was warm and favorable for agrotechnical works on potato planting, the soil at the depth of the plowing horizon warmed up to 5–8 °C.

Temperature and humidity regime of July – August favored the formation of a good crop, but abundant precipitation in the III ten-day period of August hampered harvesting operations, as potatoes were very wet and strongly saturated with moisture, which increased natural loss during the treatment period due to moisture loss and tuber respiration intensity.

The beginning of the vegetation period in 2023 was characterized by a lower temperature regime compared to the mean annual values. Spring was cold and prolonged. There was practically no precipitation during the potato sprouting period (1.2 mm fell in June, which is almost 28 times less than the average annual values) (see Table 2).

The air temperature in July-August exceeded the average values by 1–3°C. There was enough moisture during the period of tuber formation and growth. All this contributed to a good accumulation of yield. Heavy precipitation in late

¹Methodological instructions on the technology of potato breeding process / compiled by E.A. Simakov. Moscow, 2006, 70 p.

²Methods of field surveys and post-harvest quality control of seed potatoes: methodical instructions. Moscow, 2005, 112 p.

³Modern potato storage technologies: practical recommendations. Moscow, 2004, 56 p. (Library “In Aid to the Consultant”).

⁴Dospekhov B.A. Methodology of field experiment (with the basics of statistical processing of research results). Moscow: Agropromizdat, 1985, 351 p.

⁵Methods of conducting agrotechnical experiments, records, observations and analyses on potatoes: method. instructions. Moscow, 2019, 120 p.

August, although complicated the harvesting process, but did not significantly affect the storability of tubers, but led to their severe cracking in some hybrids. In general, the growing season was favorable for growth and development of plants and formation of high tuber yields.

Breeding nurseries

1. Seedling nursery: Crone × Bellarosa, Terra × Bellarosa, Betina × Bellarosa, Charoit × Bellarosa, Labadia × Ricarda, Crone × Labadia, Jewel × Labadia, Meteor × Gala, Florice × Gala, Betina × Gala, Ricarda × Gala, Baltikrose × Gala, Osiris × Gala.

2. Nursery of 1st year hybrids: Arctica × Hardy, Columba × Hardy, Luck × Bellarosa, Arctica × Bellarosa, Arctica × Gala, Crone × Bellaro-

sa, Meteor × Gala, Crone × Labadia, Arctica × Elbeida, Charoit × Bellarosa, Bettina × Gala.

3. Nursery of 2nd year hybrids: Bellarosa × Kiwi – 2 hybrids, Bellarosa × Dubrava – 5 hybrids, Zlatka × Bellarosa – 5 hybrids, Krepysch × Russian Souvenir – 3 hybrids, Batya × Labadia – 2 hybrids, Favorite × Innovator – 1 hybrid, Favorite × Labadia – 1 hybrid, Gulliver × Mirage – 1 hybrid. Kolymsky variety – early-maturing standard, Sante – middle-early standard.

4. Preliminary hybrid testing nursery: 1-4/20 (Bellarosa × Kiwi), 2-4/20 (Bellarosa × Kiwi), 25-4/19 (Bellarosa × Dubrava), 30-1/20 (Zlatka × Bellarosa), 30-2/20 (Zlatka × Bellarosa), 30-3/20 (Zlatka × Bellarosa), 30-4/20 (Zlatka ×

Табл. 1. Метеорологические данные за 2022 г.
Table 1. Meteorological data for 2022

Month	Air temperature, °C			
	ten-day average			monthly average
	I	II	III	
May	0,9 (1,1)	3,0 (2,5)	4,2 (4,1)	3,7 (2,6)
June	7,0 (6,2)	6,1 (7,8)	6,9 (10,0)	6,6 (8,0)
July	13,9 (11,4)	14,5 (12,4)	14,0 (12,8)	14,1 (13,2)
August	13,6 (13,2)	14,5 (12,9)	12,8 (11,4)	13,6 (12,5)

The sum of active temperatures above 5 °C
during the growing season – 1343 (1327) °C

Month	Total precipitation, mm			
	ten-day average			per month
	I	II	III	
May	– (–)	– (–)	– (–)	56,5 (22,0)
June	9,2 (10,0)	20,1 (14,0)	4,5 (17,0)	33,8 (34,0)
July	1,5 (14,0)	0,8 (22,0)	34,0 (25,0)	36,3 (61,0)
August	7,1 (27,0)	46,2 (24,0)	81,2 (30,0)	134,5 (81,0)

Total precipitation for the growing season –
204,6 (176,0) mm
HTC (above 10 °C) – 2,0

Табл. 2. Метеорологические данные за 2023 г.
Table 2. Meteorological data for 2023

Month	Air temperature, °C			
	ten-day average			per month
	I	II	III	
May	–1,0 (1,1)	2,3 (2,5)	5,5 (4,1)	2,4 (2,6)
June	8,7 (6,2)	7,6 (7,8)	12,3 (10,0)	9,5 (8,0)
July	14,8 (11,4)	13,9 (12,4)	14,5 (12,8)	14,4 (13,2)
August	14,5 (13,2)	13,6 (12,9)	12,9 (11,4)	13,6 (12,5)

The sum of active temperatures above 5 °C
during the growing season – 1349 (1327) °C

Month	Total precipitation, mm			
	ten-day average			per month
	I	II	III	
May	0,0 (6,0)	26,0 (7,0)	7,0 (9,0)	33,0 (22,0)
June	0,4 (10,0)	0,5 (14,0)	0,3 (17,0)	1,2 (34,0)
July	28,5 (14,0)	3,8 (22,0)	57,8 (25,0)	90,1 (61,0)
August	4,5 (27,0)	6,0 (24,0)	44,5 (30,0)	55,0 (81,0)

Total precipitation for the growing season –
179,3 (176,0) mm
HTC (above 10 °C) – 1,7

Note. In Tables 1 and 2, the mean annual value of the indicators is given in brackets.

Bellarosa), 2-1/20 (Krepysch × Russian Souvenir), 2-2/20 (Krepysch × Russian Souvenir), 3-2/20 (Batyа × Labadia). Kolymsky variety – early-maturing standard, Sante – middle-early standard.

5. Basic hybrid testing nursery: 18-3/18 (Al-louette × Innovator), 14-8/18 (Kumach × Labadia), 11-4/18 (2479) (Favorite × Labadia), 25-2/19 (Bellarosa × Dubrava), 3-3/19 (BP 808 × Signal), 28-1/19 (Labadia × Kiwi), 22-4/19 (Bellarosa × Kiwi), Seedling 15-562 and Seedling 3-4/19 (BP 808 × Signal). Kolymsky variety – early-maturing standard, Sante – middle-early standard.

The initial breeding material (hybrid botanical seeds) was obtained by hybridization. This stage is conducted by the staff of the Russian Potato Research Center named after A.G. Lorkh according to the concluded contract. At the second stage of our research, we used the method of clonal selection.

RESULTS AND DISCUSSION

Seedling nursery

The nursery provides for the production of the breeding material of the first tuberous generation. In 2022, more than one and a half thousand samples of 12 hybrid combinations were studied in the nursery of seedlings.

Planting of the seedlings was carried out on June 20–29 at seedling height of 8–12 cm with simultaneous abundant watering. During planting, plants were rejected for signs of stunting or negative morphological features. During the vegetation period, the plants were watered four times and fertilized before hilling at a dose of $N_{60}H_{60}K_{60}$. No diseases were observed during the growing period of the seedlings.

Visually better development and good plant alignment were observed in the combinations with early maturing varieties Gala and Bellarosa: Arctica × Gala, Meteor × Gala, Bettina × Gala, Krone × Bellarosa and Charoit × Bellarosa. At the same time, very strong cleavage was observed in the population 29-3/02. The source material was obtained by hybridization and self-pollination of the Kolymsky variety.

Plants here differed significantly in height, developmental power, and color of flowers in the flowering phase.

Mass development of any diseases was not observed in the mentioned year. Affection was low, mainly insignificant lesions of *Alternaria* and single cases of black leg (mainly in populations 29-3/02 (seeds from self-pollination), Kolomba × Krepysch, Arctica × Bellarosa). No signs of late blight were recorded in the nursery. Among pests, a large number of burying beetle larvae was recorded, against which appropriate treatments were carried out.

During harvesting, the main rejection was carried out on the basis of morphological features associated with the unwholesome appearance of tubers, the presence of cracks and splits. The greatest number of such samples was observed in the populations Meteor × Gala, Krone × Labadia and Bettina × Gala. Tuber rejection due to late maturity was predominant in the populations Arctica × Bellarosa (19.8%) and Arctica × Krepysch (24.3% of late maturing samples).

At harvest time, there was strong variation in shape, coloration, number of tubers per nest box and tuber size in the Udacha × Bellarosa, Krone × Bellarosa and Gala × Labadia populations.

Analysis of the samples selected for further study shows that the highest frequency of selection is characterized by hybrid populations represented by the varieties Arctica, Bellarosa, and Krone: Arctica × Elbeida (52.3% of the hybrids planted in the field were selected), Udacha × Bellarosa (35.0), Krone × Bellarosa (36.0), Charoit × Bellarosa (36.4), Krone × Labadia (34.8), and Arctica × Gala (32.7%).

Phytopathological conditions for late blight in 2022 were favorable and the hybrids showed high resistance in the year of the trial.

In 2023, 832 seedlings of 13 hybrid combinations were planted in the field. All combinations are represented by ultra-early, early, medium-maturing and middle-early varieties.

The maximum number of samples in the form of clones could be selected in hybrid combinations represented by the variety Bellarosa. The combination of the early variety Bellarosa with

the middle-early variety Krone was particularly successful here. In this population, the proportion of the selected clones amounted to 17.9%. In the combinations of Bellarosa with ultra-early and very early varieties Terra and Charoit, the selection rate, although much lower, was also high: Terra × Bellarosa – 7.6%, Charoit × Bellarosa – 8.9%. This is due to the large number of tubers with ugly shape or cracks and splits.

High rates of selection of promising clones were also noted in the combinations with the early maturing variety Gala, especially in such combinations as Meteor × Gala (16.7%), Ricarda × Gala (13.9% of the number of planted in the field).

1st year clone nursery

In 2023, 12 hybrid combinations were studied in the nursery of clones of the 1st year. The clones differed in tuber size, which was reflected in the productivity indices that reached the maximum in the following populations: Kolomba × Krepysch (very early × early) – up to 2010 g / bush, Udacha × Bellarosa (early maturing × early) – 1820, Arctica × Elbeida (middle-early × early) – 1825, Charoit × Bellarosa (ultra-early × early) – 1800 g. All selected combinations are represented by early and very early varieties.

2nd year clone nursery

In 2022, 20 hybrids of eight hybrid combinations were tested in the nursery. The first sprouts appeared on the 22–29th day after planting, mass sprouts – 5–7 days after the beginning of sprouting. The budding phase was the earliest in the hybrids of Zlatka × Bellarosa population – two weeks after mass sprouting, 7–9 days later – in the hybrids Favorit × Labadia and Gulliver × Mirage. Flowering was uneven and delayed. In the hybrids of Bellarosa × Kiwi and Bellarosa × Dubrava populations, flowering intensity was weak, while the mass flowering phase was not observed in most hybrids. Hybrids of Zlatka × Bellarosa, Batya × Labadia and Favorite × Labadia populations were distinguished by powerful development. Maximum productivity of the hybrids (more than 600 g / bush) was observed

in the combinations Bellarosa × Kiwi and Bellarosa × Dubrava, Zlatka × Bellarosa.

In 2023, 64 hybrids of 12 hybrid combinations were studied in the nursery. The condition of the plantings during the growing season was good, the total haulm score of most hybrids was maximally high and was within 6-7 points. The combination Kolomba × Krepysch stood out in terms of yield and economically valuable traits, where a sample with a maximum weight of 2700 g/bush was obtained. A high frequency of selection of productive clones (83.3%) was also noted here. Hybrids of the combinations Udacha × Bellarosa (maximum tuber weight of one plant here was 1940 g), Arctica × Krepysch (1670), Meteor × Gala (1380), and Arctica × Gala (1380 g) are also characterized by high productivity per plant.

Preliminary trial nursery

In 2023, most hybrids were characterized by good initial development and capacity. Nevertheless, by these indicators they were not ahead of the released standard varieties Kolymsky and Sante. The hybrids bloomed abundantly and formed berries. The exception is both hybrids of the Bellarosa × Kiwi population, whose flowering was weak, hybrid 1-4/20 (Bellarosa × Kiwi) had no flowering at all.

Digging for early maturity, conducted on the 60th day from planting, allowed to select the samples capable of forming a high early yield. Most hybrids were tentatively categorized as early hybrids based on the ratio of haulm weight to tuber weight. However, none of the hybrids formed an early yield higher than the standard early variety Kolymsky, although tuber marketability was high – from 86.2 to 97.4% (see Table 3).

Yield evaluation based on the results of the nursery harvest showed that none of the hybrids formed a tuber yield at least at the level of the standard varieties. On average, the yield of the hybrids under study was 1.5-2.0 times lower than that of the standard varieties of the corresponding ripeness group.

The main indicators of consumer demand for potatoes are their taste qualities. The con-

ducted research (evaluation on a scale from 1 to 9 points) showed that none of the hybrids surpassed the released variety Kolymsky, developed at the Magadan Research Institute of Agriculture, in terms of taste qualities. Only hybrid 3-2/20 (Batya × Labadia) was at the level of the released standards in terms of taste qualities (see Table 3).

Basic trial nursery

In 2023, the initial development of all hybrids was good. The first friendly seedlings appeared 16–19 days after planting, and only hybrid 3-3/19 (BP 808 × Signal) was lagging behind in development. In terms of overall planting evaluation, all hybrids were at or slightly above the level of standard varieties. Abundant friendly flowering was observed only in the standard varieties and hybrids Seedling 15-562 and Seedling 3-4/19 (BP 808 × Signal). Flowering of the hybrids 11-4/18 (2479) (Favorite × Labadia), 25-2/19 (Bellarosa × Dubrava), 3-3/19 (BP 808 × Signal) was very weak (see Table 4).

Digging for early maturity was carried out on the 60th day from planting. According to the ratio of tuber weight to haulm weight, most hybrids showed themselves as medium-ripening. In terms of early yield, most of them did not

exceed the yield of the standard medium-ripening variety, although they formed a tuber weight of more than 20.0 t/ha. Insignificant excess (by 3 kg) of early yield compared to the standard was observed only in hybrid 28 1/19 (Labadia × Kiwi) (see Table 4).

None of the hybrids surpassed the standard varieties in terms of final yield. The lag was significant, despite the very high tuber marketability, exceeding 96% in most hybrids. In addition, hybrids 25-2/19 (Bellarosa × Dubrava) and 28-1/19 (Labadia × Kiwi) had a high number of cracked and split tubers. In this regard, none of the hybrids should be further investigated as significantly inferior in yield to the standard released varieties (see Table 4).

CONCLUSION

The conducted research allowed identifying hybrid combinations in the seedling nursery characterized by a high frequency of selection of the promising samples: Arctica × Elbeida, Uдача × Bellarosa, Krone × Bellarosa, Charoit × Bellarosa, Krone × Labadia, Arctica × Gala.

The nursery of the 1st year hybrids received samples with high productivity reaching the maximum in the representatives of hybrid

Табл. 3. Урожайность и товарность гибридов в питомнике предварительного испытания (2023 г.)

Table 3. Productivity and marketability of the hybrids in a preliminary test nursery (2023)

Selection number	Hybrid combination	Digging for early maturity		Yield, t/ha	Deviation from the standard, t/ha		Flavor rating, score
		Early yield, t/ha	Marketability, %		Kolymsky	Sante	
1-4/20	Bellarosa × Kiwi	20,7	95,4	21,5	–41,4	–34,3	1
2-4/20		25,2	87,3	27,1	–35,8	–28,7	3
25-4/19	Bellarosa × Dubrava	24,0	97,4	21,3	–41,6	–34,5	3
30-1/20	Zlatka × Bellarosa	22,3	86,5	29,7	–33,2	–26,1	5
30-2/20		28,3	95,3	34,2	–28,7	–21,6	3
30-3/20		33,0	90,7	39,1	–23,8	–16,7	1
30-4/20		23,1	86,8	27,5	–35,4	–28,3	3
2-1/20	Krepysh × Russian Souvenir	19,5	86,2	27,1	–35,8	–28,7	–
2-2/20		27,3	89,2	25,9	–37,0	–29,9	–
3-2/20	Batya × Labadia	29,5	87,8	33,7	–29,2	–22,1	7
Kolymsky (standard)		49,3	99,0	62,9	0	7,1	8
Sante (standard)		29,3	98,0	55,8	–7,1	0	7
LSD ₀₅				35,2			

combinations Kolomba × Krepysh (2010 g), Udacha × Bellarosa (1820), Arktika × Elbeida (1825), Charoit × Bellarosa (1800 g).

In the nursery of the 2nd year clones in 2022, hybrids of the combinations Zlatka × Bellarosa, Bellarosa × Kiwi and Bellarosa × Dubrava were marked for high productivity. In 2023, hybrids of the combinations Kolomba × Krepysh, where a sample with a maximum productivity of 2700 g / bush, Udacha × Bellarosa (1940 g / bush) and Arctica × Krepysh (1670 g / bush) were selected for yield and economically valuable traits.

The samples selected in the nurseries of the hybrids of the 1st and 2nd years can become the basis for new high-yielding varieties, maximally adapted to the severe natural and climatic conditions of the Magadan region, capable of forming a high tuber yield in early terms and provide the population of the region with self-produced products.

In the nurseries of the preliminary and main trial it was not possible to identify any promising hybrids, which could significantly exceed the performance of the standard varieties in terms of their economically valuable traits.

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Табл. 4. Урожайность и товарность гибридов в питомнике основного испытания (2023 г.)

Table 4. Productivity and marketability of the hybrids in the main test nursery (2023)

Selection number	Hybrid combination	Digging for early maturity		Yield, t/ha	Marketability, %	Deviation from the standard, t/ha	
		Early yield, t/ha	Marketability, %			Kolymsky	Sante
18-3/18	Allouette × Innovator	19,2	93,0	21,5	94,6	–41,4	–34,3
14-8/18	Kumach × Labadia	7,3	73,7	27,1	75,7	–35,8	–28,7
11-4/18 (2479)	Favorite × Labadia	20,0	88,3	21,2	88,3	–41,7	–34,6
25-2/19	Bellarosa × Dubrava	23,4	97,4	29,7	99,4	–33,2	–26,1
3-3/19	BP 808 × Signal	27,1	83,3	34,2	93,3	–28,7	–21,6
28-1/19	Labadia × Kiwi	29,6	92,4	39,1	96,4	–23,8	–16,7
22-4/19	Bellarosa × Kiwi	23,9	94,4	27,5	96,4	–35,4	–28,3
15-562	Seedling	20,0	96,8	27,1	96,8	–35,8	–28,7
3-4/19	Seedling (BP 808 × Signal)	21,0	98,0	25,9	98,0	–37,0	–29,9
Kolymsky (standard)		49,3	99,0	62,9	99,2	–	–
Sante (standard)		29,3	95,2	55,8	95,8	–	–
LSD ₀₅				35,0			

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Распространение вредителей *Robinia pseudoacacia* на юге Дальнего Востока России

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В последние годы одной из проблем, связанных с интродуцированными видами древесных растений, является проникновение в их вторичные ареалы свойственных им вредителей и болезней. Таким инвайдером в России, в том числе на Дальнем Востоке, является *Robinia pseudoacacia* L. Для оценки распространения вредителей этого вида на территории юга Дальнего Востока и оценки наносимого ими вреда необходим мониторинг насаждений растений в населенных пунктах региона. В статье приводятся данные по распространению вредителей *R. pseudoacacia* – *Euura tibialis* (Newmann, 1837) (Hymenoptera: Tenthredinidae) и *Obolodiplosis robiniae* (Hald., 1847) (Diptera: Cecidomyiidae) в Приморском крае. Обследования посадок *R. pseudoacacia* показывают, что *E. tibialis* встречается в 9 из 24 населенных пунктов. На каждом экземпляре растения в той или иной степени поврежденными оказались примерно 2–3%, на некоторых – до 4%, листовых пластинок. Самой северной точкой распространения вредителя является г. Лучегорск, южной – пгт. Славянка. Наиболее поражены г. Уссурийск, с. Синий Гай. Такой вредитель, как *O. robiniae*, встречается во всех 24 обследованных населенных пунктах. Самой северной точкой его распространения является г. Лучегорск, южной – пгт. Хасан. Наиболее поражены данным вредителем г. Артем, г. Большой Камень, пгт. Хороль, с. Тавричанка. Необходим дальнейший мониторинг насаждений *R. pseudoacacia* в Приморском крае с целью определения распространения его вредителей и оценки наносимого ими вреда.

Ключевые слова: Приморский край, *Robinia pseudoacacia*, вредители, *Euura tibialis*, *Obolodiplosis robiniae*

Distribution of *Robinia pseudoacacia* pests in the south of the Russian Far East

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In recent years, one of the problems associated with introduced woody plant species has been the invasion of pests and diseases into their secondary habitats. Such an invader in Russia, including the Far East, is *Robinia pseudoacacia* L. In order to assess the distribution of pests of this species in the south of the Far East and to evaluate the damage caused by them, monitoring of plantations in populated areas of the region is necessary. The article provides data on the distribution of pests *R. pseudoacacia* – *Euura tibialis* (Newmann, 1837) (Hymenoptera: Tenthredinidae), *Obolodiplosis robiniae* (Hald., 1847) (Diptera: Cecidomyiidae) in the Primorsky Territory. Studies of the *R. pseudoacacia* plantings show that *E. tibialis* occurs in 9 of 24 localities. On each plant specimen, approximately 2–3%, in some cases up to 4%, of the leaf plates were damaged to a greater or lesser extent. The northernmost point of the

pest distribution is the town of Luchegorsk, the southern point is the Slavyanka settlement. The most affected are the city of Ussuriysk and the village Sinij Gay. A pest such as *O. robiniae* is found in all the 24 surveyed settlements. The northernmost point of its distribution is the city of Luchegorsk, the southernmost point is the Hassan settlement. The most affected by this pest is the town of Artem, the town of Bolshoi Kamen, Khorol settlement, Tavrichanka village. Further monitoring of *R. pseudoacacia* plantations in the Primorsky Territory is necessary in order to determine the distribution of its pests and assess the damage they cause.

Keywords: Primorsky Territory, *Robinia pseudoacacia*, pests, *Euura tibialis*, *Obolodiplosis robiniae*

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Conflict of interest

The author declares no conflict of interest.

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INTRODUCTION

Both native and introduced species of woody plants are widely used in landscape design.

One of the problems associated with introduced plants is the penetration of dangerous pests and diseases into their secondary habitats. As a result, such plants reduce or lose their functions when used in agriculture, forestry and landscaping. In addition, there is a possibility of transition of these pests to native related plants.

To protect introduced plantings, it is necessary to carry out prospecting works aimed at identifying alien pests, determining the state of their populations, studying the peculiarities of their biology and distribution within the new region [1].

One of the actively used introduced species in landscape design is *Robinia pseudoacacia* L., false acacia (Fabaceae Lindl., family Legumes) – a fast-growing tree of the flora of Northern America naturalized in many regions of our planet [2–6].

Among the economically valuable properties of *R. pseudoacacia* are honey-bearing and ornamentality [7]. Its wood is used [8]; it is

strong, gives a lot of heat and is resistant to rot and insect damage. The plant is used to create protective forest belts [9, 10], and in Japan it is planted to prevent erosion and afforestation of riverine areas. In addition, the species is used for reclamation of rock dumps in places of mining, optimization of plantations of various types in arid areas [11]. It also has limited food and medicinal value [12].

R. pseudoacacia is associated with a complex of specialized phytophages, which often penetrate into the territory of the secondary range of the plant [13] and also become invasive [14].

This is also observed in the south of the Russian Far East, where *R. pseudoacacia* has been used in landscape design since the beginning of the last century. Thus, in 2005, in four settlements of the Primorsky Territory a new phytophage *Obolodiplosis robiniae* (Hald., 1847) (Diptera: Cecidomyiidae), a white-acacia leaf gall, which is already widespread in the neighboring states of the Russian Far East, was found on *R. pseudoacacia*.

In 2019, an alien phytophage *R. pseudoacacia* – North American species *Euura tibialis*

(Newmann, 1837) (Hymenoptera: Tenthredinidae) in the territory of the arboretum of the Mountain-Taiga Station – Branch of the Federal Scientific Center of the East Asia Terrestrial Biodiversity of the Far Eastern Branch of the Russian Academy of Sciences (FSC Biodiversity of the Far Eastern Branch of the Russian Academy of Sciences) was registered for the first time in the Primorsky Territory [15].

In 2022, a phylophagous pest new to Russia, the North American mining moth, was discovered at the Mountain Taiga Station, Branch of the Federal Scientific Center of the East Asia Terrestrial Biodiversity of the Far Eastern Branch of the Russian Academy of Sciences *Chrysaster ostensackenella* (Fitch, 1859) (Lepidoptera: Gracillariidae) [16].

In connection with a fairly wide use of *R. pseudoacacia* in landscaping of the settlements of the Primorsky Territory, further spread of its phytophages is possible.

Therefore, in order to assess the distribution of *R. pseudoacacia* pests in the south of the Far East and to evaluate the damage caused by them, monitoring of plantations in other populated areas of the region is necessary.

The purpose of the study was to describe the current expansion of the pests of *R. pseudoacacia* – *E. tibialis* and *O. robiniae* – in the Primorsky Territory and to assess their harmfulness for the region.

MATERIAL AND METHODS

Studies were conducted in June - October 2021–2023 by route method. Plantings of *R. pseudoacacia* were studied in 24 settlements of the Primorsky Territory which belong to 15 administrative districts. In each locality, 10–20 plant specimens were visually inspected for the presence of phytophagous pests or damage caused by them. Leaves damaged by phytophages were collected in zip-lock polyethylene bags for further analysis in laboratory conditions.

To detect *E. tibialis* in different locations in the Primorsky Territory, visual inspection of *R. pseudoacacia* leaves was performed, dam-

age and feeding insects were recorded, and the number of damaged leaf plates was counted.

Collection of leaf plates with larvae feeding on them was carried out during summer from July to September. In order to hatch adults, plates with false caterpillars were placed in Petri dishes and kept in the laboratory at room temperature. In 2–3 weeks after the beginning of pupation, live adults appeared from pupae, their length reaching 7 mm.

The presence of *O. robiniae* was recorded by visual inspection of *R. pseudoacacia* crowns. The formed galls were examined in the laboratory. The curled edges of the gall were unfolded and the number of larvae or pupae and their sizes were noted.

Photographs of the studied pests and the damage caused by them were taken with a Sony cyber-shot camera using a MBS-9 microscope.

RESULTS AND DISCUSSION

Studies have shown the presence of *E. tibialis* (see Fig. 1, 2) in nine localities of the Primorsky Territory (see Fig. 3): Luchegorsk settlement – Pozharsky district, 46°27' N, 134°17' E, Ussuriysk – 3°48' N, 131°57' E, Arsenyev – 44°10' N, 133°16' E., Partizansk – 43°08' N, 133°08' E, Khorol settlement – Khorol district, 44°25'30 "N, 132°04'30"E, Slavyanka settlement – Khasansky district, 42°51' N, 131°23' E, Gorno-Taezhnoye – Ussuriyskiy Municipal District, 43°42'00 "N, 132°09'00 "E, Synyi Gai - Chernigovsky district, 44°27'29" N, 132°35'28" E., Razdolnoye – Nadezhdinsky District, 43°32'00" N.

A small degree of damage to leaf plates of *R. pseudoacacia* by the phytophage *E. tibialis* was observed. In each plant specimen, biting marks were recorded in about 2–3%, and in some localities – in 4%, of the leaf plates (leaflets). One, less often two young false caterpillars 1–3 mm long were usually observed on one leaf plate. They were localized more often closer to the center of the leaf plate (see Fig. 2). Larva pseudocaterpillars of older ages are often found on leaflets singly and reach 8 mm in length. Adult larva pseudocaterpillars often nibble

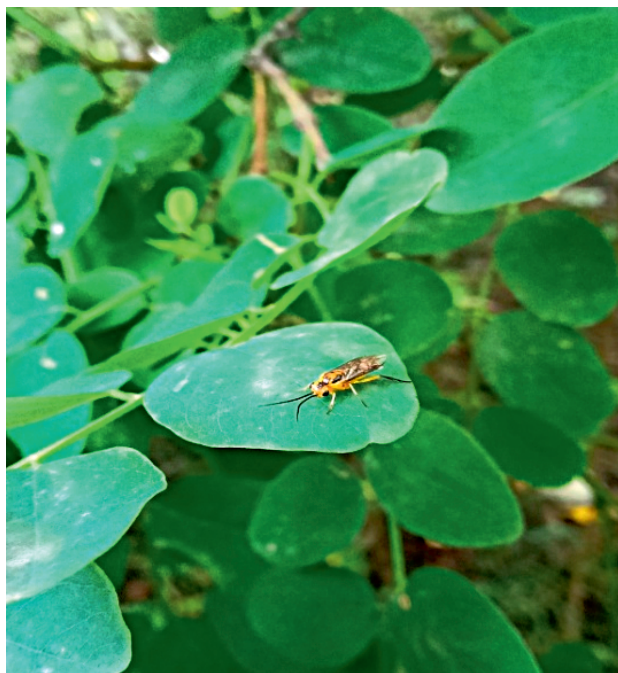


Рис. 1. Имаго *Euura tibialis* (Newmann, 1837)
Fig. 1. Imago of *Euura tibialis* (Newmann, 1837)



Рис. 2. Ложногусеница *Euura tibialis* (Newmann, 1837)
Fig. 2. Larva pseudocaterpillar of *Euura tibialis* (Newmann, 1837)

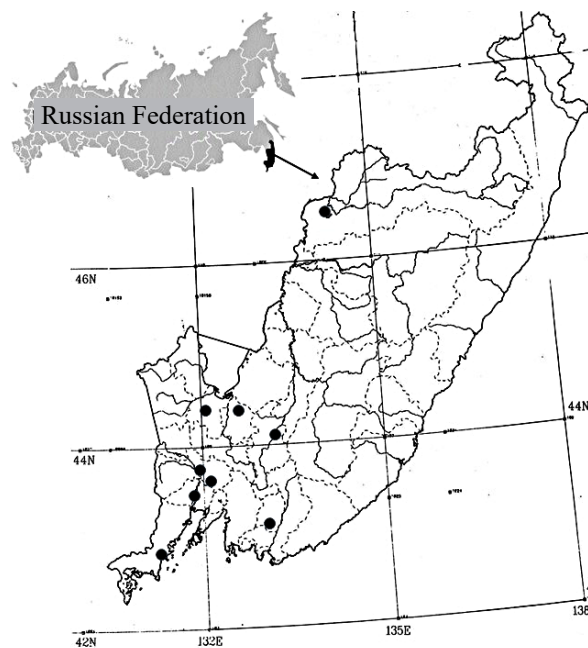


Рис. 3. Распространение *Euura tibialis* (Newmann, 1837) в Приморском крае

Fig. 3. Distribution of *Euura tibialis* (Newmann, 1837) in the Primorsky Territory

leaflets almost to the petiole or up to 2/3 of the leaflet. The most affected by this pest are plantations of *R. pseudoacacia* in Ussuriysk city, village of Siny Gai. It should be noted that, in general, there is no decrease in the ornamentalty of plants. The damage caused is insignificant and does not affect the condition of the trees. No visible weakening of the trees was noted.

The northernmost point of distribution of the phytophagous *E. tibialis* is Luchegorsk settlement, the southern point is Slavyanka settlement.

Studies on the distribution of *O. robiniea* have shown that the invasive pest is observed in 24 settlements of the Primorsky Territory (see Fig. 4): Spassk-Dal'ny – 44°36' N, 132°49' E, Cherngovka village – Chernigovsky district, 44°20' N, 132°34' E, Sibirtsevo settlement – Chernigovsky district, 44°12'05" N, 132°26'40" E, Khasan settlement – Khasansky district, 42°25'42" N, 130°38'44" E, Bamburovo – Khasansky district, 42°55'42" N, 131°19'35" E, Luchegorsk settlement, Lesozavodsk – 45°28'N, 133°24'E, Razdolnoye settlement – Nadezhdinsky district, 43°32'00 "N, 131°53'50 "E, Arte-



Рис. 4. Встречаемость *Obolodiplosis robiniae* (Hald., 1847) (Diptera: Cecidomyiidae) в Приморском крае

Fig. 4. Occurrence of *Obolodiplosis robiniae* (Hald., 1847) (Diptera: Cecidomyiidae) in the Primorsky Territory

movsky settlement – Artemovsky Municipal District, 43°22'45" N, 132°17'20" E, Zavodskoy settlement – Artemovsky Municipal District, 43°27'35 "N, 132°17'00 "E, Gorno-Taezhnoye, Arsenyev, Tavrichanka village – Nadezhedinsky district, 43°19'40 "N, 131°51'35 "E, Syny Gai village, Dmytrievka village – Chernigovsky district, 44°23' 49" N, 132°39' 08" E, Novodevitsa village – Khorolsky district, 44°17'04" N, 132°15'36" E, Khorol settlement, Nakhodka – 42°49' N, 132°53' E, Bolshoy Kamen – 43°07' N, 132°21' E, Shkotovo settlement – Shkotovsky district, 43°19' N, 132°21' E, Kamen-Rybolov village – Khankaysky district, 44°44'24 "N, 132°02'32 'E, Dushkino village – Nakhodka district, 42°55'34 'N, 132°41'47 "E, Zolotaya Dolina village - Partizansky District, 42°56'05" N, 133°06'55" E, Partizansk – 43°08'N, 133°08'E, Ussuriysk, 3°48'N, 131°57'E.

During visual inspection, galls formed by *O. robiniea* were detected on young leaves of the lower and middle parts of *R. pseudoacacia* crowns. Up to 4 galls may occur on a single

leaf, but 1-2 galls were most commonly observed (see Figure 5). Observations showed that during larval development the lateral edges of leaf plates of the plant are twisted. Young galls have light green coloration of their walls, then as the larva grows, the gall expands and acquires yellowish color. Once development is complete and the gall has emerged, the galls turn brownish in color and shrivel up. Gall formation leads to damage of leaf plates of the plant and some reduction of its ornamental value.

During the summer period, whitish-matt, almost transparent spindle-shaped larvae and red-brown pupae of *O. robiniea* were found in the galls. Our observations showed that they may contain from 1 to 4 live larvae of different stages, their sizes varying from 1 to 6 mm. The adult size of the gall imago is about 8 mm.

Analysis of insect distribution in the crown of *R. pseudoacacia* showed that insects most

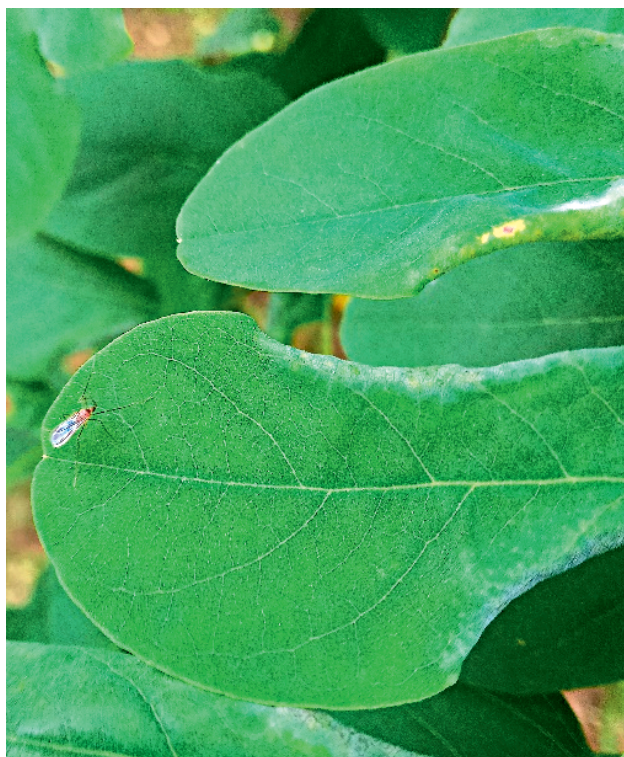


Рис. 5. Имаго *Obolodiplosis robiniae* (Hald., 1847) (Diptera: Cecidomyiidae) и образуемые ею галлы на листочках *Robinia pseudoacacia* (справа)

Fig. 5. Imago of *Obolodiplosis robiniae* (Hald., 1847) (Diptera: Cecidomyiidae) and galls formed by it on the leaves of *Robinia pseudoacacia* (on the right)

often infest leaves on the lower shoots of the plants. Galls are also found on coppice shoots. The plants were most affected in Artem, Bolshoi Kamen, Khorol settlement, Tavrichanka village, Novodevitsa village. The northernmost point of *O. robiniae* distribution is Luchegorsk and the southern point is Khasan settlement. Despite the fact that damage to leaflets by galls has so far resulted in a slight decrease in the ornamental quality of *R. pseudoacacia* plants, further spread of this phytophage may increase the damage caused by it.

CONCLUSION

Pests of *R. pseudoacacia* such as *E. tibialis* and *O. robiniae* are found in the Primorsky Territory. *E. tibialis* was registered in nine settlements, *O. robiniae* in all investigated settlements. The northernmost point of distribution of the phytophagous *E. tibialis* is Luchegorsk settlement and the southern one is Slavyanka settlement, while the phytophagous *O. robiniae* – respectively Luchegorsk – Khasan settlement.

At present, these pests do not cause significant damage to the ornamental quality of *R. pseudoacacia* damaging only a small part of leaflets. No noticeable weakening of plants is noted.

However, due to climate change and the active use of *R. pseudoacacia* in landscape design in the south of the Russian Far East, further monitoring of plantations of this plant in the Primorsky Territory is necessary to establish the intensity of its pest distribution and assess the degree of their harmfulness.

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Исследование протяженных гомозиготных районов хромосом у кур породы итальянская куропатчатая

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Селекция и сопутствующий ей инбридинг составляют основу разведения различных пород кур. С появлением современных молекулярных методов оценки инбридинга стало возможным идентифицировать гены и их функции в гомозиготных районах (РОН) хромосом кур. В настоящем исследовании осуществлен полногеномный анализ гомозиготных районов хромосом у кур породы итальянская куропатчатая с применением SNP чипа Illumina Chicken 60K SNP iSelect BeadChip. В ходе исследования в хромосомах кур выявлено в среднем 177 ± 5 РОН-последовательностей на одну птицу, при этом средний коэффициент инбридинга составил $0,30 \pm 0,01$. Было установлено, что в геноме кур преобладают короткие РОН-последовательности (0,25–2 м.п.н.). РОН-последовательности длиной более 8 м.п.н., свидетельствующие о недавнем инбридинге, составляют не более 2,2%. Определено, что в целом РОН-последовательности плотнее распределены в микрохромосомах кур, исключение составляет хромосома 16, не имеющая РОН-последовательностей. Этот факт обусловлен гетерозиготностью аллелей генов, ответственных за иммунитет и расположенных в микрохромосоме 16. В хромосомах 1, 5 и 14 обнаружены РОН-островки. Гены в РОН-островках ответственны за выклевание перьев (ген *DMD*), состояние иммунитета (гены *TAB3*, *EIF2S3*), массу тела (ген *IL1RAPL1*), pH мяса (гены *EIF2S3*, *APOO*, *KLHL15*), яйценоскость (ген *APOO*), усвоение кормов (ген *SATI*), агрессивность петухов (ген *SLITRK6*), транспорт внутриклеточных компонентов в развивающихся нейронах и защиту гетерохроматина в ядрах клеток нейронов (ген *NDE1*), адаптацию кур к тропическим условиям обитания (ген *CDIN1*). Таким образом, РОН-анализ позволил выделить гены, потенциально селектированные в результате разведения кур породы итальянская куропатчатая.

Ключевые слова: полногеномный анализ, однонуклеотидный полиморфизм, инбридинг, РОН, РОН-островки, куры

Study of extended homozygous chromosome regions in Italian partridge breed of chickens

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Selection and accompanying inbreeding are the basis for breeding chicken breeds. With the advent of modern molecular methods for assessing inbreeding, it has become possible to iden-

tify genes and their functions in the homozygous regions (ROH) of chicken chromosomes. In this study, a genome-wide analysis of homozygous regions of chromosomes in Italian partridge chickens was carried out using an SNP chip Illumina Chicken 60KSNPiSelectBead-Chipchip. An average of 177 ± 5 ROH-sequences per chicken were identified in the chicken chromosomes, and the average inbreeding coefficient was 0.30 ± 0.01 . It was determined that the chicken genome is dominated by short ROH-sequences of 0.25–2 Mbp. ROH-sequences longer than 8 Mbp indicating recent inbreeding account for no more than 2.2%. It was found that, in general, ROH-sequences are more densely distributed in chicken microchromosomes, with the exception of chromosome 16, which does not have ROH-sequences. This fact is due to the heterozygosity of the alleles of the genes responsible for immunity, located in microchromosome 16. ROH-islands were found in the chicken chromosomes 1, 5, and 14. The genes in ROH-islands are responsible for feather pecking in chickens (*DMD* gene), immune status (*TAB3*, *EIF2S3* genes), body weight (*IL1RAPL1* gene), pH of meat (*EIF2S3*, *APOO*, *KLHL15* genes), egg production (*APOO* gene), feed uptake (*SAT1* gene), aggressiveness of roosters (*SLITRK6* gene), transport of intracellular components in developing neurons and protection of heterochromatin in the cell nuclei of neurons (*NDE1* gene), adaptation of chickens to tropical living conditions (*CDIN1* gene). Thus, ROH analysis allowed us to identify genes potentially selectable as a result of breeding Italian partridge breed chickens.

Keywords: genome – wide analysis, single nucleotide polymorphism, inbreeding, ROH, ROH-islands, chickens

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Conflict of interest

The author declares no conflict of interest.

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INTRODUCTION

The existing variety of chicken breeds in the world is a consequence of domestication of birds from both India and South-East Asia. Therefore, chickens can be considered as a promising subject for genetic research. When breeds of chickens were developed, selection was used, inevitably leading to inbreeding. With the advent of modern molecular methods of animal genome analysis, a more accurate assessment of inbreeding has become possible. Inbreeding leads to the emergence of homozygous regions in chromosomes, which are called “regions of

high homozygosity” (runs of homozygosity, ROH).

In the present study, a full genomic analysis of Italian partridge (IP) chickens was used using single nucleotide polymorphism (SNP) Illumina Chicken 60K SNP iSelect BeadChip, which allows genotyping of the chicken genome by 60 thousand SNPs. Software detectRUNS was used to identify homozygous SNP sequences of the chicken genome [1].

It should be noted that two approaches are used in animal genome scanning: sequential and frame scanning. It has been shown that sequen-

tial scanning allows to detect ROH-sequences more completely [2]. Therefore, this method of genome scanning was used in the present study. In animals, ROH-analysis is widely used in the assessment of inbreeding. As a result of numerous studies, a phenomenon called ROH islands has been discovered. They are formed from the same ROH-sequences found in many animals of the analyzed population. It is assumed that ROH islands are formed due to intensive inbreeding¹. Thus, genes in ROH-islands are the target of inbreeding, and by analyzing their functions, it is possible to estimate the direction of selection when breeding a chicken breed.

Objectives of the study:

- 1) identify ROH-sequences in the chromosomes of chickens of the IP breed;
- 2) determine their number, length and distribution in the chromosomes;
- 3) estimate the inbreeding coefficient based on the ROH data;
- 4) detect ROH islands in chicken chromosomes;
- 5) determine gene functions in ROH islands.

MATERIAL AND METHODS

Italian partridge hen is a breed of egg-type hens, originated from aboriginal Italian breeds. Representatives of this breed are of medium size, characterized by brown coat, wide, long and deep body. Egg production of the birds for 52–56 weeks of life is 162–185 eggs. Egg mass of 52-week-old hens is 56–62 g. Live weight of hens is 1,8–2,5 kg, roosters – 2,3–3,0 kg.

For the study, 19 chickens were randomly selected from the population in the genetic collection of rare and endangered breeds of chickens (All-Russian Research Institute of Genetics and Breeding of Farm Animals). Only autosomes were used in the study. Genotyping quality control was performed using PLINK 1.9² software.

In the first quality control step, SNPs with a quality score (QS) less than 0.7 were removed. Then, no more than 5% of non-genotyped SNPs were left in the SNPs-data of the animals, and SNPs with minor allele frequency (MAF) less than 0.01 were removed. As a result of quality control, 53,780 SNPs were obtained.

Sequential ROH-scanning of the chicken genome was performed according to the following parameters:

- 1) sequential runs on autosomes with the use of 20 SNP;
- 2) the minimum size of ROH-sequences is assumed to be 250 bp (thousands of nucleotide pairs);
- 3) the maximum distance between ROH-sequences is assumed to be 1 Mb;
- 4) heterozygous SNPs in ROH sequences are prohibited.

The detectRUNS program allows the detection of ROH islands. When scanning ROH islands, heterozygous SNPs in them were prohibited. In the detected ROH islands, identical ROH sequences were found in at least 89% of hens.

Chromosome rank was calculated using the following formula:

$$\text{chromosome rank } i = \frac{\text{ROH number in chromosome } i}{\text{sum of all ROHs}} \bigg/ \frac{\text{chromosome } i \text{ length}}{\text{sum of the lengths of 28 chromosomes}}.$$

The inbreeding coefficient according to ROH data was calculated by the formula

$$F_{\text{ROH}} = L_{\text{ROH}} / L_{\text{genome}},$$

where L_{ROH} – total length of ROH-sequences in the genome of each hen; L_{genome} – cumulative length of chicken autosomes covered by SNPs.

Genes located in ROH islands were identified using the Ensembl BioMart database [3]. The functions of genes in ROH islands were determined based on the materials of scientific

¹Peripolli E., Munari D.P., Silva M.V.G.B., Lima A.L.F., Irgang R., Baldi F. Runs of homozygosity: current knowledge and applications in livestock // *Animal Genetics*, 2016, vol. 48, N 3, pp. 255–271.

²Purcell S., Neale B., Todd-Brown K., Thomas L., Ferreira M.A.R., Brender D., Maller J., Sklar P., de Bakker P.I.W., Daly M.J., Sham P.C. PLINK: A tool set for whole-genome association and population-based linkage analyses // *American Journal of Human Genetics*, 2007, vol. 81, pp. 559–575.

ic articles submitted to PubMed³ and Google Academy⁴.

RESULTS AND DISCUSSION

General characterization of ROH sequences. As a result of ROH-scanning of the genome of IP chickens, an average of 177 ± 5 ROH-sequences were detected. Figure 1 shows the distribution of the ratio of the number of ROH sequences in a chicken to their total length. The figure shows a shift in the number of chickens with this indicator to higher values of ROH-sequence lengths, which indicates the predominance of an increased number of ROH-sequences in the genome of many chickens compared to other individuals. Table 1 shows data on the quantitative distribution of ROH sequences depending on their length. Short sequences with lengths from 0.25 to 2 m.bp (million nucleotide

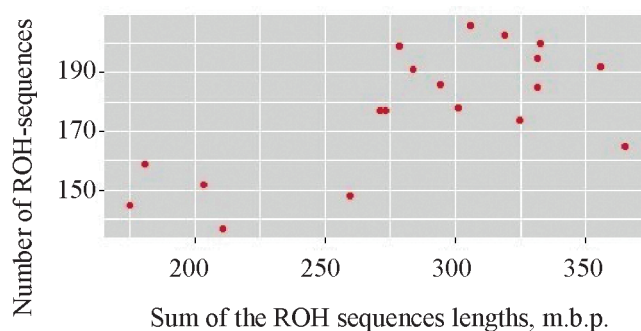


Рис. 1. Распределение кур породы ИК по соотношению суммарной длины и числу ROH-последовательностей

Fig. 1. Distribution of IP breed of chickens by the ratio of total length and number of ROH-sequences

Табл. 1. Число ROH-последовательностей и их доля в пяти классах длин у кур породы ИК
Table 1. Number of ROH-sequences and their proportion in five length classes in chickens of the IP breed

Length class, m. b.p.	Number of ROH sequences	Share of ROH sequences, %
0,25–2	2633	0,781
2–4	440	0,131
4–8	223	0,066
8–16	59	0,018
> 16	14	0,004

pairs) predominate, and long sequences (more than 16 m.bp) are extremely rare. This distribution is due to recombination of long homozygous sequences resulting in their shortening.

Table 2 presents chromosome ranks that characterize the density of the ROH-sequences distribution in chromosomes. There is a tendency to a denser distribution of ROH-sequences in chromosomes of intermediate size, starting from chromosome 10, and in microchromosomes. It is known that the recombination frequency in microchromosomes is 2.8 times higher than in macrochromosomes⁵, which should lead to the gradual fragmentation of ROH-sequences into the shorter ones. Thus, the increased frequency of recombination in microchromosomes should lead to their greater quantitative occupancy than in macrochromosomes. Special attention should be paid to chromosome 16, in which ROH-sequences are absent. This chromosome contains

Табл. 2. Ранг хромосом кур породы ИК

Table 2. Chromosome rank of the IP breed chickens

Rank	3,459	2,987	2,937	2,751	2,471	2,236	2,074	2,014	1,901	1,883
Chromosome	25	23	22	27	28	17	24	14	18	21
Rank	1,878	1,809	1,668	1,620	1,484	1,454	1,416	1,400	1,229	1,181
Chromosome	19	20	11	15	12	26	9	10	6	13
Rank	1,154	1,115	1,041	0,882	0,880	0,879	0,800			
Chromosome	7	8	5	1	2	4	3	16*		

*In chromosome 16, ROH sequences are absent.

³<https://pubmed.ncbi.nlm.nih.gov/>

⁴<https://scholar.google.com/>

⁵Megens H.J., Crooijmans R.P., Bastiaansen J.W., Hindrik H.H.D., Coster A., Jalving R., Vereijken A., Silva P., Muir W.M., Cheng H.H., Hanotte O., Groenen M.A.M. Comparison of linkage disequilibrium and haplotype diversity on macro- and microchromosomes in chicken // BMC Genetics, 2009, vol. 10, Art. 86.

genes responsible for immunity, including the histocompatibility complex⁶. The alleles of these genes tend to be heterozygous. Perhaps, this fact explains the absence of ROH-sequences in this chromosome. The distribution of chromosome ranks is normal (Shapiro-Wilk normality test at $p = 0,05$ confirms the normality of distribution). However, chromosome 25 differs from the mean chromosome rank value by 2.4 standard deviations and can be considered as a pop-out value. Thus, in general, ROH sequences in the chromosomes of the chickens of the IP breed tend to be more densely distributed in microchromosomes.

The average inbreeding coefficient in chickens calculated on the basis of ROH data was 0.30 ± 0.01 (maximum value – 0.39, minimum – 0.19). Visually, the distribution of chickens according to the value of inbreeding coefficient is presented in Fig. 2. It shows the predominance of chickens with inbreeding coefficient of 0.27–0.35. Thus, there is a rather high inbreeding in the population of IP chickens due to the breeding of this breed of chickens.

Gene function in ROH islands. Three ROH islands were detected in chromosome 1. The first one is located in the area of 115442689 and 117794006 bp, found in 89% of chickens. It contains three genes. The dystrophin gene (DMD) is associated with feather pecking [4]. Its functions are related to the immune system, circadian rhythm and food seeking behavior [5]. The second gene, TGF-beta-activated kinase (TAB3), is one of the genes responsible for immunity to Salmonella and Campylobacter [5]. The third gene interleukin 1 receptor auxiliary protein, similar to IL1RAPL1 in local Chinese chicken breeds, is associated with chicken weight [6].

The second ROH island in the region of 118294809 and 118993016 bp is found in 89% of chickens and includes several genes. The gene is a subunit of the zinc finger protein

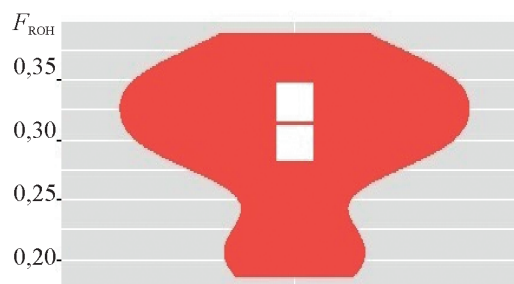


Рис. 2. Распределение плотности коэффициента инбридинга кур породы ИК

Ширина изображения на рисунке вдоль оси x соответствует частоте встречаемости данного значения F_{ROH}

Fig. 2. Distribution of the inbreeding coefficient density of chickens of the IP breed

The image width along the X-axis in the picture corresponds to the frequency of occurrence of a given F_{ROH} value

(ZFX) is a transcription activator [7]. Together with other genes, ZFX modulates the growth of stem cells – precursors of chronic myeloleukemia in humans [8]. Replication of the NDV virus that causes Newcastle disease depends on the virus protein translation apparatus. The eukaryotic translation initiation factor gamma subunit 2 (EIF2S3) gene, located in this ROH island, is the candidate gene for controlling viral replication. The study by A.P. Del Vesco et al. [9] found that the expression of the genes dependent on the EIF2S3 gene may contribute to differential resistance to NDV, as well as to the understanding of the interaction between protein synthesis shutdown and virus control in chickens. In Leghorn chickens, the EIF2S3, apolipoprotein (APOO) and Kelch-like protein 15 (KLHL15) genes located in this ROH island are candidate genes involved in meat pH formation⁷. The APOO gene was also associated with egg production of hens [10, 11].

Other genes from this ROH locus are spermidine/spermine N1 acetyltransferase 1 (SAT1), in meat-type chickens involved in feed digestion⁸, and the acyl-CoA thio esterase 9 (ACOT9) gene

⁶Miller M.M., Taylor R.L. Brief review of the chicken Major Histocompatibility Complex: the genes, their distribution on chromosome 16, and their contributions to disease existence // Poultry Science, 2016, vol. 95, N 2, pp. 375–392.

⁷Li X., Liu X., Nadaf J., Bihan-Duval E.L., Berri C., Dunn I., Talbot R., De Koning D.J. Using targeted resequencing for identification of candidate genes and SNPs for a QTL affecting the pH value of chicken meat // G3: Genes, Genomes, Genetics, 2015, vol. 5, N 10, pp. 2085–2089.

affecting the pH of the breast muscle of chickens⁹.

The third ROH island in the region of 149990492 and 150459263 bp is found in 94% of chickens. The *SLITRK6* gene is located in this region. It is known to be associated with a genetic nervous disorder called Tourette's syndrome. Its differential expression in the brain cortex of Luxi fighting roosters has been found, which may be responsible for their aggressiveness [12].

In chromosome 5 in the region of 31004853 and 31434045 bp, there is a ROH island, which is found in 94% of chickens. It contains a nuclease interacting nuclease 1 (*CDINI*). This gene has been associated with the adaptation of chickens to tropical habitats [13].

The SNP in chromosome 14 (GGalu-GA102488) is homozygous in 89% of chickens. It is located in the *NDEI* gene, which encodes a scaffold protein important for brain development. The key role of this gene in the protection of heterochromatin in the nuclei of neuronal cells has been established [14]. Nde1 protein belongs to highly conserved proteins that play an important role in dynein-controlled transport of intracellular components in growing neurons [15].

CONCLUSION

Thus, an average of 177 ± 5 ROH-sequences were detected in chickens of the IP breed. Sequences with the length of 0.25–2 m.bp. ROH-sequences with the length of more than 8 m.bp., indicating recent inbreeding, are rare (their share is 2.2%). In general, the density of ROH-sequences is higher in chicken microchromosomes.

ROH-sequences are distributed unevenly in chromosomes. ROH-sequences are absent in chromosome 16, which may indicate increased heterozygosity of gene alleles in it. The average inbreeding coefficient in chickens was found to be 0.30 ± 0.01 . ROH islands were found in

chromosomes 1, 5 and 14. They contain the genes responsible for immunity and behavior (*DMD*), immunity to Salmonella and Campylobacter (*TAB3*), resistance to Newcastle disease (*EIF2S3*), egg production (*APOO*), feed digestion (*SATI*), aggressiveness of Luxi roosters (*SLITRK6*), adaptation of chickens to tropical habitats (*CDINI*), and transport of intracellular components in growing brain neurons (*NDEI*).

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⁸Lee J., Karnuah A.B., Rekaya R., Anthony N.B., Samuel E.A. Transcriptomic analysis to elucidate the molecular mechanisms that underlie feed efficiency in meat-type chickens // Molecular Genetics and Genomics. 2015. Vol. 290. P. 1673–1682.

⁹Nadaf J., Berri C., Dunn I., Godet E., Bihan-Duva E.L., De Koning D.J. An Expression QTL of closely linked candidate genes affects pH of meat in chickens // Genetics. 2014. Vol. 196. N 3. P. 867–874.

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Микробиологическое и генетическое типирование атипичных микобактерий, выявленных на территории Новосибирской области

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Для изоляции возбудителя туберкулеза, микробиологического и генетического типирования выделенных культур атипичных микобактерий исследованы 219 проб биологического материала животных и 54 пробы объектов внешней среды с территории хозяйств Новосибирской области, благополучных по туберкулезу крупного рогатого скота. Микробиологическая диагностика включала культуральный метод, биохимические тесты и постановку биологической пробы. При обработке биоматериала животных выделено 50 культур, из объектов внешней среды – 20. Выделенные культуры на основе их культурально-морфологических свойств и бактериоскопии отнесены к микобактериям. По биохимическим характеристикам из 70 изученных культур 27 изолятов (38,6%) принадлежали к атипичным микобактериям различных видов. Из них 26 культур (96,3%) отнесены к III группе, 1 культура (3,7%) – к IV группе согласно классификации Раньона. Осуществлена постановка биологической пробы инфицированием нелинейных белых мышей суспензиями 27 идентифицированных культур атипичных микобактерий. При вскрытии и патолого-анатомическом изучении лабораторных животных характерные для туберкулеза изменения во внутренних органах не обнаружены, что подтверждает принадлежность исследуемых культур к атипичным микобактериям. В результате молекулярной систематизации изолированных культур установлено наличие *Mycobacterium avium* (20 культур, 74%), *M. nonchromogenicum* (5 культур, 18,5%), *M. intracellulare* (1 культура, 3,7%) и *M. fortuitum* (1 культура, 3,7%). Таким образом, по итогам комплексного изучения 70 культур атипичных микобактерий, изолированных из биоматериала животных и объектов внешней среды с территории хозяйств Новосибирской области, благополучных по туберкулезу крупного рогатого скота, выявили 27 изолятов, принадлежащих к атипичным микобактериям III и IV групп согласно классификации Раньона. На основе типирования установлено, что ведущую роль среди идентифицированных патогенов занимают атипичные микобактерии III группы, в частности *M. avium*. Этиологию неспецифических туберкулиновых реакций в благополучных по туберкулезу стадах крупного рогатого скота можно объяснить изоляцией из объектов внешней среды и персистированием в организме здоровых животных атипичных микобактерий туберкулеза III и IV групп согласно классификации Раньона.

Ключевые слова: туберкулез, микобактерии, микробиологическая характеристика, молекулярно-биологическое типирование

Microbiological and genetic typing of atypical mycobacteria identified in the Novosibirsk region

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219 samples of biological material from animals and 54 samples of environmental objects from farms in the Novosibirsk region, which are free from bovine tuberculosis, were examined for isolation of the tuberculosis pathogen, microbiological and genetic typing of isolated cultures of atypical mycobacteria. Microbiologic diagnosis included culture method, biochemical tests and biological

assay. During the treatment of animal biomaterial 50 cultures were isolated, and 20 cultures were isolated from the environmental objects. The isolated cultures were classified as mycobacteria on the basis of their culture and morphological properties and bacterioscopy. According to biochemical characteristics, out of 70 cultures studied, 27 isolates (38.6%) belonged to atypical mycobacteria of different species. Of these, 26 cultures (96.3%) were categorized as Group III and 1 culture (3.7%) as Group IV according to Runyon's classification. Next, a biological assay was performed by infecting nonlinear white mice with suspensions of 27 identified cultures of atypical mycobacteria. At autopsy and pathological-anatomical study of laboratory animals, changes in internal organs characteristic for tuberculosis were not found, which confirms that the cultures under study belong to atypical mycobacteria. Molecular systematization of the isolated cultures revealed the presence of *Mycobacterium avium* (20 cultures, 74%), *M. nonchromogenicum* (5 cultures, 18.5%), *M. intracellulare* (1 culture, 3.7%) and *M. fortuitum* (1 culture, 3.7%). Thus, based on the results of a comprehensive study of 70 cultures of atypical mycobacteria isolated from animal biomaterial and environmental objects from the territory of farms in the Novosibirsk region, free from bovine tuberculosis, 27 isolates belonging to atypical mycobacteria of groups III and IV were identified according to Runyon's classification. On the basis of typing, it was found that the leading role among the identified pathogens is occupied by atypical mycobacteria of group III, in particular *M. avium*. The etiology of nonspecific tuberculin reactions in tuberculosis-free herds of cattle can be explained by the isolation of atypical *Mycobacterium tuberculosis* groups III and IV according to Runyon classification from environmental objects and their persistence in the organism of healthy animals.

Keywords: tuberculosis, mycobacteria, microbiological characteristics, molecular biological typing

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Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

The genus *Mycobacterium* contains 259 species and 24 established subspecies, including both atypical (including saprophytes) and expressed pathogens [1, 2]. Some of them (e.g., *M. bovis* and *M. tuberculosis*) are considered to be the most significant and widespread pathogens causing tuberculosis in cattle and humans in veterinary practice. However, it has been established that certain species of atypical mycobacteria can cause mycobacterial infections in laboratory and farm animals. In addition, they pose one of the major problems in conducting lifetime and postmortem diagnosis of tuberculosis in herds when examined by tuberculin (intradermal) sampling.

Atypical mycobacteria are more than 20 species of acid-fast bacteria widely distributed in

the environment that are not part of the *M. tuberculosis* complex but are opportunistic pathogens for domestic and wild animals [3]. Because of their ecological nature, atypical mycobacteria are widespread throughout the world and have been isolated from a variety of sources, including water, feed, soil and dust. In some cases, usually associated with immunosuppressive processes, they can infect animals and humans and act as opportunistic microorganisms. Atypical mycobacteria are highly adaptive and can remain viable in environmental objects for long periods of time, even under unfavorable conditions, resulting from a combination of several biological features related to their exceptional hydrophobic and lipid-rich impermeable cell wall, biofilm phenotype, and widespread symbiosis with protozoa. The basic metabolism of

this mycobacterial species allows them to adapt to changing conditions, making them less susceptible to TB drugs and disinfectants, as well as to anaerobiosis, starvation, low pH, and high temperatures [4].

Animals infected with atypical mycobacteria often have nonspecific tuberculin reactions because such saprophytic mycobacteria cause immune reorganization of the organism. In addition, pronounced single macroscopic lesions found in the internal organs of animals are sometimes indistinguishable from the changes caused by *M. bovis* and, in many cases, *M. tuberculosis*. As a consequence, in veterinary practice, atypical mycobacteria complicate the diagnosis of tuberculosis during intradermal testing in cattle, can cause misinterpretation of the test results, which leads to economic losses due to unjustified slaughter of tuberculin-responsive animals. The initial lack of scientific knowledge about the clinical and epizootic significance of atypical mycobacteria led to their disregarding for many years, even when describing cases of granulomatous lesions in the internal organs of animals. Therefore, information on infections caused by atypical mycobacteria (mycobacteriosis) in animals is currently of great importance, as it is associated with a wide range of diseases and false positive tuberculin reactions [4]. At the same time, active surveillance for the detection of atypical mycobacteria is not always foreseen and is much less mandatory in the control of farm animal health. In some cases, this leads to premature slaughter of healthy productive livestock, thus causing significant economic damage, which is associated with the loss of litter, milk, meat and other agricultural products [5–10].

The main methods to confirm the presence of *Mycobacterium tuberculosis* in internal organs and lymph nodes of animals are standard lab-

oratory tests: bacterioscopy, culture, biochemical and biological tests for pathogen isolation and identification. A number of methodological problems, including the long incubation time of mycobacteria, require the development of more sensitive, reliable and rapid methods, such as molecular genetic studies, which should be used in the comprehensive diagnosis of tuberculosis and contribute to the effective detection of mycobacteria. [11, 12].

The purpose of the study is complex microbiological and genetic identification of atypical mycobacteria isolated from biological material of the animals and environmental objects on the territory of different districts of the Novosibirsk region.

MATERIAL AND METHODS

Microbiological studies of animal biomaterial and environmental samples from various sources were conducted in the laboratory of tuberculosis of farm animals of the Institute of Experimental Veterinary Science of Siberia and the Far East (IEVSS&FE SFSCA RAS) by culture method, biochemical tests and biological assay.

The culture method consisted of pre-sowing treatment of biomaterial according to the method of A.P. Alikieva and sowing of the obtained sediment on the Lowenstein-Jensen and Finn II egg nutrient media, direct microscopy of the smears from isolated cultures stained by Ziel-Nielsen staining according to GOST 26072-89 (ST SEV 3457-81)^{1, 2}. Biochemical tests included determination of the presence of colony growth of atypical cultures at 22; 37 and 42 °C, formation or absence of pigment, resistance of the cultures to sodium salicylic acid and 5% NaCl, hydrolysis of tween 80, nitrate reduction, determination of arylsulfatase and amidase activity^{3, 4} [13]. Differentiation of the cultures by

¹GOST 26072-89 (ST SEV 3457-81). Agricultural animals and poultry. Methods of laboratory diagnostics of tuberculosis. Moscow: Publishing house of standards, 1989, 14 p.

²Laboratory diagnosis of tuberculosis: method. recommendations / compiled by: B.Y. Khaykin, N.M. Kolychev, N.S. Boganets, L.M. Karimova. Omsk, 1988, 68 p.

³Methodical instructions for conducting studies in mycobacteriosis of animals. Moscow: Publishing house VIEV, 2012, 85 p.

⁴Zykov M.P., Ilyina T.B. Potentially pathogenic mycobacteria and laboratory diagnosis of mycobacterioses. Moscow: Medicine, 1978, 161 p.

cultural, morphological and biochemical properties was carried out according to “Bergey's Bacterial Identifier” (2000) and GOST 27318-87 (ST SEV 5627-86)⁵. The biological method of research was carried out by infecting non-linear white mice (average weight 23 g) with suspensions of the studied mycobacteria containing 1 mg of bacterial mass of the pathogen cultures dissolved in 1 ml of physiological solution. Suspensions were administered intraperitoneally by 1 ml. Laboratory animals were euthanized after 30 days with autopsy and determination of pathological and anatomical changes in internal organs. Experiments on experimental animals were performed in accordance with the “Guidelines for Laboratory Animals and Alternative Models in Biomedical Technologies”⁶ and “Directive 2010/63/EU of the European Parliament and of the Council of the European Union on the protection of animals used for scientific purposes”⁷.

Molecular biological identification of field isolates of atypical mycobacteria obtained from the Laboratory of Tuberculosis of Farm Animals of the IEVSS&FE SFSCA RAS was carried out in the bacteriological laboratory of the FSBI “Novosibirsk Research Institute of Tuberculosis” of the Ministry of Health of Russia: mass spectrometrically – on a Microflex MALDI-TOF device (Bruker, Germany), molecularly and genetically – by hybridization method on a microchip test-system MIKO-BIOCHIP (Engelhardt Institute of Molecular Biology of the Russian Academy of Sciences).

RESULTS AND DISCUSSION

Laboratory studies were conducted in 2021–2024. Animal biomaterial and environmental samples for isolation and identification of mycobacteria were taken from the territory of bovine tuberculosis-free farms in the Ordynsky,

Karasuksky, Krasnozersky, Kochkovsky, Dovolensky, Zdvinsky and Vengerovsky districts of the Novosibirsk Region.

A total of 219 samples of biomaterial (lymph nodes of cattle and pigs, lungs and sections of small intestine of cattle, internal organs of pigeons from livestock farms) were examined. From the total number of these samples 50 cultures were isolated. 20 cultures were isolated during processing of 54 environmental samples (water from various sources, manure, soil from pastures and grazing areas, fodder (silage, straw and haylage)).

Direct bacterioscopy of smears of the identified cultures, stained by Ziel-Nielsen staining, showed the presence of thickened short red acid-fast granular bacilli, indicating that they belonged to *Mycobacterium tuberculosis*. Out of 70 mycobacteria obtained, 27 cultures (38.6%) were attributed to atypical mycobacteria of different species on the basis of culture-morphological and biochemical properties. At the same time, 26 cultures (96.3%) out of 27 had the following general characteristics: the beginning of growth from biomaterial (lymph nodes of cattle and pigs, lungs and sections of small intestine of cattle) on the 14–19th day; medium-sized colonies of mucous and rough consistency (S and R shapes) of light beige color, merged with each other; absence of pigment formation.

Colonies grew at 22 and 37 °C, while growth was absent or weak at 42 °C. The cultures were resistant to Na salicylate and unstable to 5% NaCl. Hydrolysis of Tween 80 was observed on day 9–11. Arylsulfatase activity of the isolated colonies was weak to positive. Amidase activity is positive, nitrate reduction varies from negative to weakly expressed. The obtained results indicate that these cultures belong to atypical mycobacteria of group III according to Runyon's classification.

During the study of 1 culture (3.7%) of

⁵GOST 27318-87 (ST SEV 5627-86). Agricultural animals. Methods of identification of atypical mycobacteria. Moscow: Publishing House of Standards, 1987, 16 p.

⁶Manual on laboratory animals and alternative models in biomedical technologies: textbook / edited by N.N. Karkishchenko, S.V. Grachev. Moscow, 2010, 358 p.

⁷Directive 2010/63/EU of the European Parliament and of the Council of the European Union on the protection of animals used for scientific purposes. St. Petersburg, 2012, 50 p.

27 nontuberculous mycobacteria, its primary growth from biomaterial (internal organs of pigeons from the territory of the farms) was recorded on the 30th day in the form of small colonies of mucous consistency (S form) of beige color, separate from each other and merged with each other in the form of a solid plaque with the formation of pigment in the dark. At 22 and 37 °C, abundant growth of colonies was observed; at 42 °C, the growth was scanty. The culture is resistant to Na salicylate and 5% NaCl. Hydrolysis of Tween 80 on day 10. Arylsulfatase, amidase activity and nitrate reduction were positive. Identification features of this culture indicate that it belongs to group IV of atypical mycobacteria according to the Runyon classification.

After the biological test on nonlinear white mice with inoculation of suspensions of the studied cultures, pathologoanatomical examination of the laboratory animals revealed a slight enlargement of the lungs, liver and spleen with the presence of single purulent foci in the liver and spleen.

Molecular biological identification of 27 cultures of atypical mycobacteria revealed the predominance of *M. avium* - 20 cultures, 74.0% of the total number of the studied isolates. Such species of atypical mycobacteria as *M. nonchromogenicum* (5 cultures, 18.5%), *M. intracellulare* (1 culture, 3.7%) and *M. fortuitum* (1 culture, 3.7%) were also identified (see the Figure). The distribution of typical species of atypical mycobacteria on the territory of bovine tuberculosis-free farms in different districts of the Novosibirsk Region is presented in the table below.

CONCLUSION

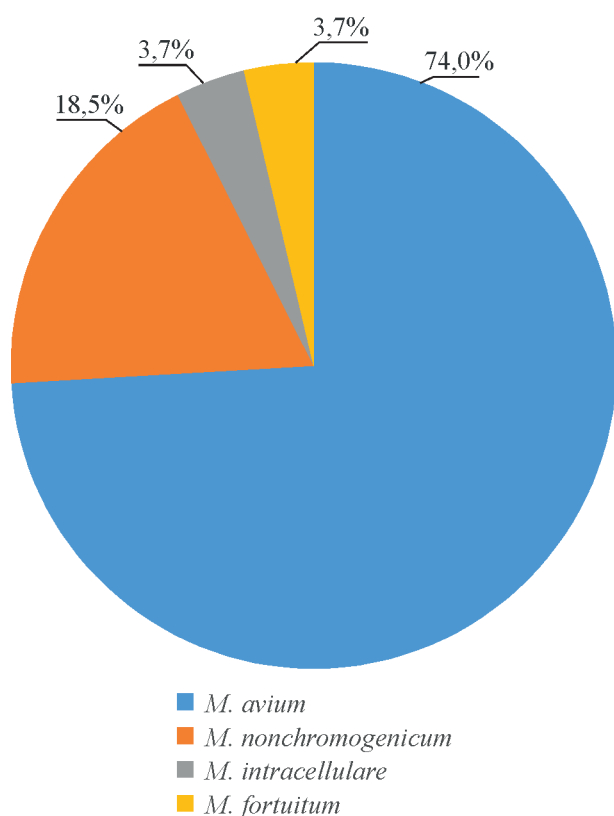
Cultural and morphological methods of investigation of 70 field cultures isolated from 219 samples of animal biomaterial and 54 samples of environmental objects on the territory of bovine tuberculosis-free districts of the Novosibirsk Region revealed their identity with *Mycobacterium tuberculosis*.

Biochemical tests showed that 27 cultures (38.6%) belonged to atypical mycobacteria of groups III (26 cultures, 96.3%) and IV (1 culture, 3.7%) according to the Runyon classification. The biological test with infection of nonlinear white mice with cultures of atypical mycobacteria and the subsequent pathologoanatomical study of internal organs of laboratory animals confirmed that these cultures belonged to atypical mycobacteria.

Molecular-biological typing made it possible to carry out their most detailed identification and to distinguish among the identified cultures such mycobacterial species as *M. avium*, *M. nonchromogenicum*, *M. intracellulare* and *M. fortuitum*. The leading role of *M. avium* (74%), belonging to group III according to the Runyon classification, was established. Based on the conducted scientific studies, it is possible to explain the etiology of nonspecific tuberculin reactions in bovine herds free from tuberculosis by isolation from environmental objects and persistence in the body of healthy animals of atypical *Mycobacterium tuberculosis* of groups III and IV according to Runyon's classification.

Распространение атипичных микобактерий на территории районов Новосибирской области
Distribution of atypical mycobacteria in various areas of the Novosibirsk region

District	Species			
	<i>M. avium</i>	<i>M. nonchromogenicum</i>	<i>M. intracellulare</i>	<i>M. fortuitum</i>
Ordynsky	8	1	1	–
Karasuksky	4	–	–	–
Krasnozersky	2	–	–	1
Vengerovsky	1	–	–	–
Zdvinsky	–	1	–	–
Kochkovsky	1	2	–	–
Dovolensky	1	1	–	–



Видовой состав атипичных микобактерий, выделенных на территории Новосибирской области

Species composition of atypical mycobacteria isolated in the Novosibirsk region

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Многомерный анализ морфологической изменчивости исходного стада внутривидового типа сарбоянского карпа (*Cyprinus carpio* L.)

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Представлен анализ морфологической изменчивости исходного стада внутривидового типа сарбоянский карп (*Cyprinus carpio* L.) методом главных компонент. Исследования проведены в 2022, 2023 гг. в Новосибирской области. Стадо сарбоянского карпа (самцы и самки) из рыбного хозяйства изучено по восьми бонитировочным промерам: массе тела, абсолютной длине тела, длине тела без хвостового плавника, наибольшей высоте, ширине и обхвату. Проведен сравнительный анализ особенностей телосложения сарбоянского карпа, принадлежащего к четырём гаплотипам (H1, H15, H16, H17). Морфометрические признаки сарбоянского карпа обработаны при помощи метода главных компонент. Установлено, что половой диморфизм отмечен по признаку общих размеров: самки имеют более крупные размеры, чем самцы. В изучаемом стаде рыб установлена тенденция к различию между гаплотипами H1 и H16. Особи в гаплотипе H1 относительно более толстотелые и короткие по сравнению с H16. В структуре данных имеется группа рыб с неизвестными гаплотипами, все они демонстрируют сдвиг в направлении третьей компоненты относительно H1, т.е. имеют более высокую спину и меньшую толщину тела. Гаплотипических различий не выявлено в компоненте, показывающей очевидную обратную зависимость признака длины головы, длины тела и абсолютной длины рыбы. Многомерный анализ морфологической изменчивости также показал, что распределение особей в трехмерном пространстве PC2 – PC3 – PC4, свободном от размерно-возрастной изменчивости, позволяет предварительно отобрать для дальнейшего воспроизводства рыб с требуемыми пропорциями морфологических признаков.

Ключевые слова: сарбоянский карп, гаплотипы, бонитировочные промеры, метод главных компонент

Multivariate analysis of morphological variability of the initial stock intrabreed type of Sarboyan carp (*Cyprinus Carpio* L.)

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The analysis of morphological variability of the initial stock within the breed type Sarboyan carp (*Cyprinus carpio* L.) by the principal component method is presented. The research was conducted in 2022, 2023 in the Novosibirsk region. The Sarboyan carp stock (males and females) from the fish breeding farm was studied according to eight valuation measurements: body weight, absolute body length, body length without tail fin, maximum height, width and girth. A comparative analysis of the body features of the Sarboyan carp belonging to four haplotypes (H1, H15, H16, H17) was carried out. The morphometric features of the Sarboyan carp were processed using principal component method. It was found that sexual dimorphism was noted on the basis of total size: females have larger sizes than males. In the fish stock under study, a trend towards the difference between H1 and H16 haplotypes was established. The individuals in the H1 haplotype are relatively thicker and shorter

compared to H16. There is a group of fish with unknown haplotypes in the data structure, all of which show a shift towards the third component relative to H1, i.e. they have a higher back and smaller body thickness. No haplotypic differences were found in the component showing an apparent inverse relationship between head length trait, body length and absolute fish length. Multivariate analysis of morphological variability also showed that distribution of the individuals in the three-dimensional space PC2-PC3-PC4, free from size-age variability, allows pre-selection of fish with the required proportions of morphological features for further reproduction.

Keywords: Sarboyan carp, haplotypes, bonification measurements, principal component method

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Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

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INTRODUCTION

In Russia, the main object of pond fish farming is carp (*Cyprinus carpio* L.) [1, 2]. Currently, there are more than 50 different breeds, forms and varieties of carp, each of which has different characteristics, such as productivity, size, weight and scale covering [3, 4]. The most common carp breeds in commercial fish farming in the Novosibirsk region are the Sarboyan and the Altai mirror carp breeds [5].

The Sarboyan breed was created by a complex crossing of unbred mirror carps with the Amur carp and the Ropshinsky carp by V.A. Korovin and A.S. Zybin¹. This breed is bred specifically for harsh climatic conditions of Siberia. It is characterized by increased fecundity, cold tolerance, including the ability to feed and reproduce at low temperatures. Depending on the proportion of blood on the Amur carp, there were three zonal types within the breed: Omsk, northern and steppe². From 1990 to 2005 carps of the steppe and Omsk types disappeared. The

descendants of the northern type of the Sarboyan carp are preserved in the Moshkovsky district of the Novosibirsk region in the fish farm “ECO-PARK” [6].

One of the most common methods of multivariate statistical analysis is the method of principal components [7]. This method allows reducing the number of correlated variables in the statistical matrix and reducing losses from the obtained information [8]. Recently, this method has been widely used in monitoring studies in agriculture, including fish farming [9–15].

The purpose of the study was to analyze the morphological variability of the initial herd of the inbreed type Sarboyan carp (*Cyprinus carpio* L.) using the principal component method.

MATERIAL AND METHODS

The object of the study were females and males of the Sarboyan carp of the fish farm ООО “ECO-PARK”, Moshkovsky District, No-

¹Author's certificate No. 4317. Sarboyan carp / V.A. Korovin, A.S. Zybin; applicant SibNIPTIZh SB VASKhNIL; applied 18.01.1985; published 25.03.1987; entered in the State Register of Breeding Achievements Allowed for Use. Animal Breeds (2001) under No. 9357412 in 1993.

²Korovin V.A. Breeding methods and current state of the Sarboyan carp breed // Fish breeding. Moscow: Agropromizdat, 1989, pp. 195-210.

vosibirsk Region. Biological material for the study was collected while alive. A fragment of the dorsal fin measuring 15-20 mm was cut off and fixed in 96% ethyl alcohol at the sites of the material collection. The studied individuals were chipped.

The morphological analysis was carried out according to the method of I.F. Pravdin (1966)³ using the scheme of measurements of carp fishes by L.S. Berg (1948)⁴. The following measurements were chosen for selection: fish weight (Q), body length (l), absolute body length (L), head length (C), back height (H), girth (V) and body thickness (B).

The initial data were processed using the statistical packages PAST⁵, Jacobi4 [12], Microsoft Office Excel 2007 and the statistical programming language of the data analysis environment RStudio (1.2.5033).

Morphometric features of the Sarboyan carp were processed using the principal component analysis (PCA)⁶ method. This method solves the following problem: to find the direction along which the maximum dispersion of the object “cloud” projection is achieved. The principal component method searches for the entire set of directions that preserves information about the cloud and has one additional property: if the directions are ordered by the magnitude of variability, the total variance of any number of the first components is maximized. The main components do not correlate with each other by construction, so the variability of any of the components does not manifest itself in the rest. From the geometrical point of view, the transition to new features means only a rotation of the whole “cloud” in space without changing the distances and mutual location of the objects, so the information is neither added nor disappeared. Each new feature is a linear combination of the initial

ones. The opposite is also true: each old feature is a linear combination of the new ones, which emphasizes the preservation of the original information during these transformations.

In the case of morphometric traits, the “cloud” of objects, as a rule, has an ellipse-like shape, and the first component always represents the total dimensions, since almost all or even all traits give a contribution of the same sign, often close in magnitude⁷. However, since it involves many traits, these “new” dimensions are defined more reliably and universally than if only one of them, such as body length, were used. In the second and subsequent components, significant in terms of dispersion, the contributions of the traits reflect proportions (or in other terminology - indices), which do not depend on the size-age component of the traits, since this variability has already been “taken over” by the first main component. Given that the first component “removes” the size variability, and the main contribution to the second and subsequent components is made by the traits on which selection was made, it is reasonable to believe that the variability in these components reflects the differences between individuals, largely due to hereditary factors, i.e., differences in the genetic programs of development of the individuals (see footnote 6).

RESULTS AND DISCUSSION

Previously, we investigated phylogenetic relationships between the modern breeds, subspecies, and species of the genus *Cyprinus* by the method of constructing a median haplotype network based on the nucleotide sequences of the COX1 mtDNA gene [6]. It is shown that the herd of Sarboyan carp bred in the Moshkovsky district in the farm of OOO “ECO-PARK” contains four haplotypes (H1, H15, H16, H17).

³Pravdin I.F. Guide to the study of fish. Moscow: Pischepromizdat, 1966, 365 p.

⁴Berg L.S. Fish of fresh waters of the USSR and the neighboring countries. Part 1, MOSCOW: AS SSSR, 1948, 467 p.

⁵Hammer O., Harper D., Ryan P. PAST: Paleontological Statistics Software Package for Education and Data Analysis // Palaeontologia Electronica, 2001, vol. 4, pp. 1–9.

⁶Pearson K. On lines and planes of closest fit to systems of points in space // The London, Edinburgh and Dublin Philosophical Magazine and Journal of Science, 1901, vol. 2, N 11, pp. 559–572. DOI: 10.1080/14786440109462720.

⁷Polunin D., Shtaijer I., Efimov V. JACOBI4 software for multivariate analysis of biological data // BiOrxiv, 2019, p. 803684. DOI: 10.1101/803684.

Haplotypes H1 and H16 are the most numerous in the studied herd of fish. It should be noted that this study of morphometric variability did not include all individuals from the above-mentioned work, but only 56 exemplars.

We measured exterior parameters of the Sarboyan carp in sexually mature individuals in haplotypes. Average values of exterior parameters of sexually mature individuals of different haplotypes are given in Table 1.

Individuals of haplotype H1 outperformed the individuals of other haplotypes in body weight, absolute length, body length, body thickness, and head length.

The component analysis of morphological variability showed the following results. The first four main components include 96.14% of the total variance of morphometric traits of the sample, so their consideration can be just enough.

The maximum dispersion (75.16%) corresponds to the first principal component (PC1). It is formed by positive contributions of all morphometric traits and reflects the size-age variability of the Sarboyan carp sample. Fig. 1, *a* shows that the total size of individuals increases in accordance with age, the maximum dispersion on this component is observed in 7-year-old individuals. Sexual dimorphism was noted in terms of total size: females have larger sizes than males (see Fig. 1, *б*). At the same time, no differences in total size were observed among the individuals of different haplotypic groups (see Fig. 1, *в*).

The second principal component, free of size-age variability, accounts for 9.02% of the total

Табл. 2. Коэффициенты корреляции ($\times 1000$) главных компонент (PC) с морфометрическими признаками сарбянского карпа

Table 2. Correlation coefficients ($\times 1000$) of the main components (PC) with morphometric features of the Sarboyan carp

Trait	PC1	PC2	PC3	PC4
Fish weight, g	971	94	-29	-82
Absolute fish length, cm	931	-244	-66	-235
Body length, cm	929	-246	-66	-250
Head length, cm	789	-395	-204	424
Back depth, cm	822	104	479	100
Thickness, cm	730	530	-412	46
Body girth, cm	869	234	250	93
λ	75,16	9,02	7,33	4,64
Σ	75,16	84,18	91,5	96,14

Note. PC1-PC7 - numbers of the components; λ – share of of the total dispersion attributable to each component, %; Σ – total accumulated dispersion of the components, %.

variance. It reflects an increase in fish thickness associated with a decrease in head (C), body (l) and absolute length (L). At PC2 > 0, the study sample consists of relatively thicker and shorter specimens compared to relatively longer and narrower specimens at PC2 < 0 (similar body types are observed in humans: hypersthénics and asthenics). There is a trend towards a difference between H1 and H16 haplotypes on this trait. H1 are relatively thicker and shorter than H16 (see Fig. 1, *в*).

Табл. 1. Экстерьерные показатели сарбянского карпа разных гаплотипов

Table 1. Exterior indicators of the Sarboyan carp of different haplotypes

Haplotype	Average values of individuals by haplotype						
	<i>Q</i>	<i>L</i>	<i>l</i>	<i>C</i>	<i>H</i>	<i>B</i>	<i>V</i>
H1	5410 $\pm$ 161,5	68,6 $\pm$ 0,8	59,04 $\pm$ 1,37	13,3 $\pm$ 0,71	17,7 $\pm$ 0,17	11 $\pm$ 0,17	46,9 $\pm$ 0,5
H15	4000	59	51,5	11,5	16,5	10	42
H16	4823,1 $\pm$ 259,7	66,2 $\pm$ 1,41	56,8 $\pm$ 1,2	12,8 $\pm$ 0,36	17,8 $\pm$ 0,39	10,2 $\pm$ 0,3	46 $\pm$ 1,09
H17	4000	61	53	11,5	15,5	10	41,5

Note. In haplotypes H15 and H17, the mean and error of the mean have not been calculated because they include only one individual each.

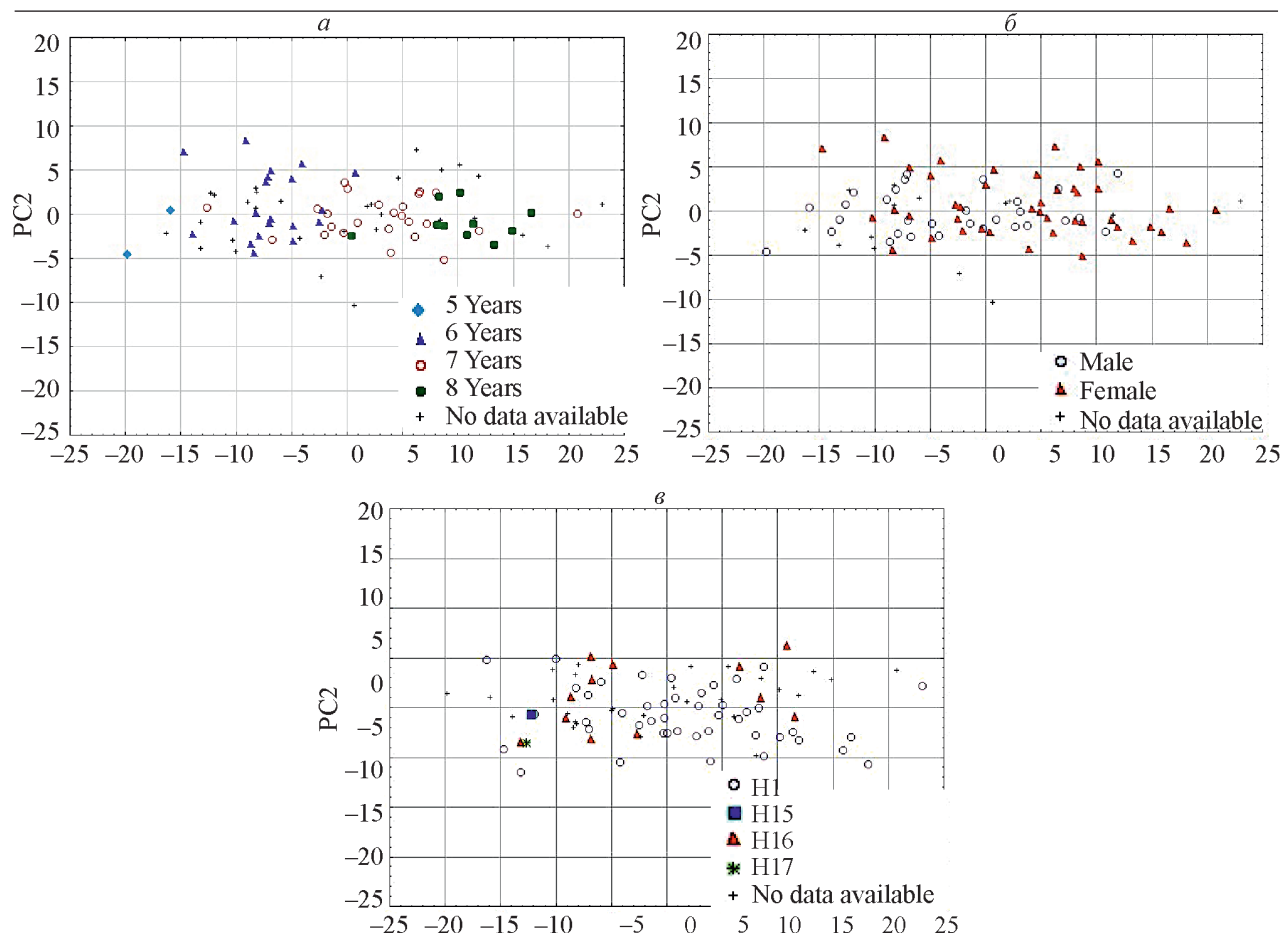


Рис. 1. Распределение особей сарбянского карпа на плоскости компонент PC – PC2:

а – в направлении PC1 проявляется изменчивость размеров в зависимости от возраста особей; б – в направлении PC1 проявляется изменчивость размеров в связи с полом; в – в направлении PC1 не проявляется изменчивости размеров особей разных гаплотипических групп; в направлении PC2 намечается тенденция расхождения между гаплотипами H1 и H16; $p = 0,051$

Fig. 1. Distribution of the Sarboyan carp individuals on the plane of PC1 – PC2 components:

а – in the direction of PC1, size variability is manifested depending on the age of the individuals; б – in the direction of PC1, size variability is manifested due to the gender; в – in the direction of PC1, there is no variability in the size of the individuals of different haplotypic groups; in the direction of PC2, there is a tendency for divergence between haplotypes H1 and H16; $p = 0,051$

The third principal component includes 7.33% of the total variance of the traits and characterizes the direction of morphological variability of the individuals associated with the opposite behavior of back height and fish thickness: individuals with a deep-bodied back have a relatively smaller body thickness and vice versa (see Fig. 2). Based on the available data, no differences between the haplotypes for this component were found. However, it draws attention to the fact that in the data structure there is a significant group of individuals with unknown haplotypes and all of them demonstrate a shift in the direction of the third component relative

to H1, i.e., they have a deeper back and smaller body thickness. It is possible that adding information on this group will reveal the differences between the haplotypes in these proportions.

The fourth principal component, the last of the considered ones (4.64% of the total variance), demonstrates an obvious inverse relationship between the head length and body length traits and the absolute length of the fish. No haplotypic differences in this component were revealed.

Distribution of individuals in the three-dimensional space PC2 – PC3 – PC4, free from size-age variability (PC1), allows to pre-select

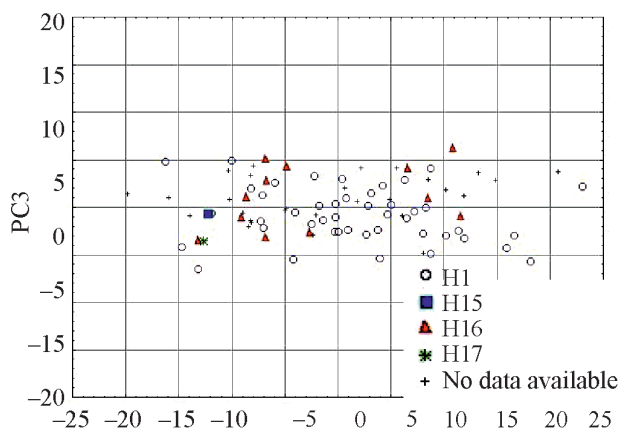


Рис. 2. Распределение особей сарбоанского карпа на плоскости компонент PC1 – PC3

Fig. 2. Distribution of the Sarboyan carp individuals on the plane of PC1 – PC3 components

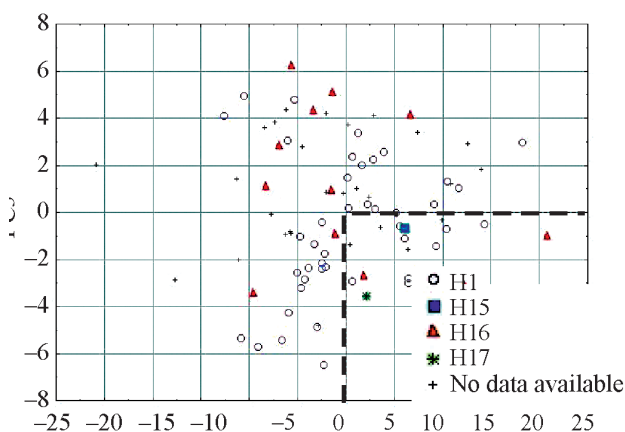


Рис. 3. Распределение особей сарбоанского карпа на плоскости компонент PC2 – PC3. Наиболее перспективными для отбора являются особи, имеющие наибольшие значения по PC2 и наименьшие по PC3 (выделено штрихом)

Fig. 3. Distribution of the Sarboyan carp individuals on the plane of PC2 – PC3 components. The most promising individuals for selection are those with the highest PC2 values and the lowest PC3 values (highlighted by dashed lines)

for further reproduction of fish with the required proportions of morphological features (see Fig. 3). This method has long been known and is called selection index (or breeder's index). For its more reasonable use, it is necessary to know the heritability of the breeding-important traits, which is the direction of further research.

CONCLUSIONS

1. As a result of the study of morphological traits of the Sarboyan carp in the Moshkovsky district of the Novosibirsk region, it was noted that the total size of the individuals increases in accordance with age, the maximum variance in this component is observed in 7-year-old individuals. Sexual dimorphism is observed in terms of total size: females are larger in size than the male individuals.

2. The studied sample consists of relatively thicker and shorter specimens compared to relatively longer and narrower specimens at PC2 < 0. According to this trait, there is a tendency for a difference between H1 and H16 haplotypes. H1 are relatively thicker and shorter compared to H16.

3. The individuals with a deep-bodied back have a relatively smaller body thickness and vice versa. Differences between haplotypes, based on the available data, were not revealed. However, there is a group of individuals with unknown haplotypes in the data structure and all of them show a shift in the direction of the third component relative to H1, i.e., they have a deeper back and a smaller body thickness.

4. No haplotypic differences were revealed in the component that reflects an obvious inverse relationship between the trait of head length, body length and absolute length of fish.

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Особенности живой массы молодняка цигайской породы в период подсоса в связи со сроками суягности овцематок

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В статье изучена сопряженность длительности суягности овцематок цигайской породы с особенностями роста и развития молодняка овец в период подсоса. Для анализа выбраны даты осеменений и окотов для расчета длительности суягности маток и показатели живой массы молодняка при рождении и при отъеме с последующим расчетом корреляционных связей между этими признаками. Средняя длительность суягности овцематок составляет $157,76 \pm 0,61$ сут ($C_v = 7,6\%$). Ярочки-единцы линии № 01684 при отъеме по живой массе на 6,9% ($p \leq 0,001$), по среднесуточным приростам на 6,0% ($p \leq 0,001$) превышают средние показатели по выборке. Баранчики-единцы линии № 80077 имеют достоверное преимущество по живой массе при отъеме на 9,1% ($p \leq 0,01$), а по среднесуточным приростам – на 11,8% ($p \leq 0,05$). Баранчики-единцы линий № 01684 и 66796 при пониженной живой массе при рождении более интенсивно растут: достоверное преимущество по показателям живой массы при отъеме и среднесуточному приросту соответственно на 12,1% ($p \leq 0,001$) и 9,6% ($p \leq 0,01$) выше в сравнении со средними значениями по выборке. Двойневые ярочки линии № 80077, при меньшей живой массе при рождении на 0,2% и повышенной массе при рождении на 0,4%, разница которой также не является достоверной, имеют достоверное преимущество по среднесуточному приросту в сравнении со средним – на 9,1% ($p \leq 0,001$), в то время как баранчики-двойни не имеют достоверной разницы по показателям периода подсоса. Молочность отрицательно сопряжена с длительностью суягности маток и положительно – с живой массой при отъеме у ягнят. Для закладки линии на повышенное многоплодие следует отбирать в ремонтное стадо ярочек из двойневых помётов в линии № 80077. Повышенную живую массу молодняка из одиночных помётов формирует родительское поголовье линий № 01684, 20832, 65204 и 80077. Преимущество баранчиков-двоен по живой массе над средними значениями не доказано.

Ключевые слова: цигайская порода, суягности овцематок, ярочки, баранчики, живая масса, корреляция

Live weight peculiarities of the Tsigai breed young sheep during the suckling period in connection with the terms of sheep ewes' gestation

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The correlation of the Tsigai breed ewes' gestation period with the patterns of growth and development of the sheep growing stock during the suckling period was explored in the article. The dates of inseminations and calvings were selected for analysis to calculate the duration of ewes' gestation and indicators of live weight of young animals at birth and at weaning with subsequent calculation of correlations between these traits. The average duration of the ewes' gestation period is 157.76 ± 0.61 days ($C_v = 7.6\%$). The single-born ewe lambs of the No. 01684 line were higher in live weight by 6.9% ($p \leq 0.001$), and higher in average daily gain by 6.0% ($p \leq 0.001$) than the sample averages at weaning. The single-born ram lambs the No. 80077 line have a significant advantage in terms of live weight at weaning by 9.1% ($p \leq 0.01$), and in terms of average daily gains by 11.8% ($p \leq 0.05$). Single-born ram lambs of the No. 01684 and No. 66796 lines with a reduced live weight at birth grow more intensively: a significant advantage in terms of live weight at weaning and average daily growth, respectively, is 12.1% ($p \leq 0.001$) and 9.6% ($p \leq 0.01$) higher in comparison with the average sample values. Twin ewe lambs of the No. 80077 line with a lower live weight at birth by 0.2% and an increased weight at

birth by 0.4, the difference of which is also not reliable, nevertheless have a significant advantage in average daily growth compared to the average – by 9.1% ($p \leq 0.001$), while the twin ram lambs have no significant difference in the indicators of the suckling period. Milkiness is negatively associated with the duration of pregnancy of ewes and positively with the lambs live weight at weaning period. In order to establish a line for increased multiplicity, it is necessary to select ewe lambs to be used in the replacement stock from twin litters in the line No. 80077. The increased live weight of young animals from single litters is formed by the parent livestock of No. 01684, 20832, 65204 and 80077 lines. The advantage of twin ram lambs in terms of live weight over the average values has not been proven.

Keywords: Tsigai breed, ewes' gestation period, ewe lambs, ram lambs, live weight, correlation

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Conflict of interest

The author declares no conflict of interest.

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INTRODUCTION

At present, sheep of the Tsigai breed remain a planned breed in the breeding sector of the Republic of Crimea. Animals with a strong constitution, increased live weight and early maturity combine also good adaptability to the extreme conditions of the Steppe Crimea [1].

It should be noted that the Tsigai breed is still widespread on the Eurasian continent [2–7]. The expediency of saving the genetic resource of the Tsigai breed has been proved, since such a unique genotype is resistant to extreme environmental conditions [8]. This work, in addition, is actualized by modern challenges in the light of import substitution – the need to orient sub-branches of the agricultural sector of our country in the direction of food independence [9].

Optimal growth and development of young sheep is an important link in breeding, because selection is, in fact, a purposeful search for parents with the best offspring [10]. In all branches

of livestock breeding, the evaluation of parental stock by progeny occupies a significant part of work in the course of breeding activities¹ [11–13]. The expediency is dictated by the addition of selection of producers by the progeny phenotype, which increases the efficiency of selection several times [14], therefore reproduction occupies a large part of the breeding work with the herd: it is important to get at least one lamb a year from a ewe mother [15], and the optimal development of young stock in the early period of ontogenesis will allow forming a highly productive herd [16].

The gestation of the ewe lamb is one of the most important production cycles for the formation of the healthy young [13]. This period is relatively short (about 150 days), and litter sizes usually consist of one, and rarely two lambs, so the profitability of a sheep breeding enterprise is closely related to the reproductive efficiency [17].

¹Kononova L.V., Vasilev E.A., Rachkov I.G., Plotnikov S.N. Genealogical lines of breeding mares as biological resources of a thoroughbred horse breed bred in the Stavropol Krai // IOP Conference Series: Earth and Environmental Science, Zernograd, Rostov Region, August 27–28, 2020. Zernograd, Rostov Region, 2021, p. 012101. DOI 10.1088/1755-1315/659/1/012101.

Reproduction rates are related to the overall productivity of the herd², so the importance of assessing the reproduction rates and productivity of sheep in the complex is relevant at all stages of improvement of certain breeds and intra-breed types [18].

The purpose of the study is to investigate the relationship between pregnancy rate and the growth and development of young animals during the suckling period to form an optimal level of reproduction of the Tsigai sheep.

MATERIAL AND METHODS

The work was carried out in 2015 in the breeding plant of the State Unitary Enterprise “Chernomorskoye” of the Republic of Crimea. Objects of research were ewe lambs and young cattle of the Crimean type Tsigai breed of the following breeding lines: № 1128, 65204, 80077, 20832, 66796, 01684, 82104 and 884. Material of the research: indicators of live weight of young animals at birth and at weaning at the age of 4.5-5.0 months; duration of gestation of ewe lambs in order to study the conjugation of this indicator with indicators of growth and development of young animals. Age of ewes – second and older lambing time.

Calculation of the pregnancy duration was carried out according to the presence of the records in the primary documents by calculating the difference in days between the dates of mating and calving. Young animals were weighed at birth and at the time of weaning (4.5–5.0 months) on area scales with an accuracy of 0.1 kg. Calculation of average daily gain is described by Y.A. Kolosov et al. [19]. Processing of statistical parameters was carried out according to the work “Evaluation and use of selection-genetic parameters in sheep breeding” [20].

RESULTS AND DISCUSSION

In the breeding nucleus of the Tsigai breed the following features of the formation of preg-

nancy depending on the sex of the lamb and the multiple fertility of the uterus were revealed.

In single ewes the average pregnancy duration varies from 156,8 to 158,9 days (see the figure, *a*); in single rams – from 156,8 to 159,0 days (see the figure, *б*). In twin fetus the pregnancy duration is formed in the following way: ewe lambs – from 159,5 to 162,3 days (see the figure, *в*) – with insignificant increase in pregnancy duration in comparison with single fetus-analogues, rams – from 155,7 to 158,6 days (see the figure, *г*) – with some reduction in comparison with single fetus-analogues.

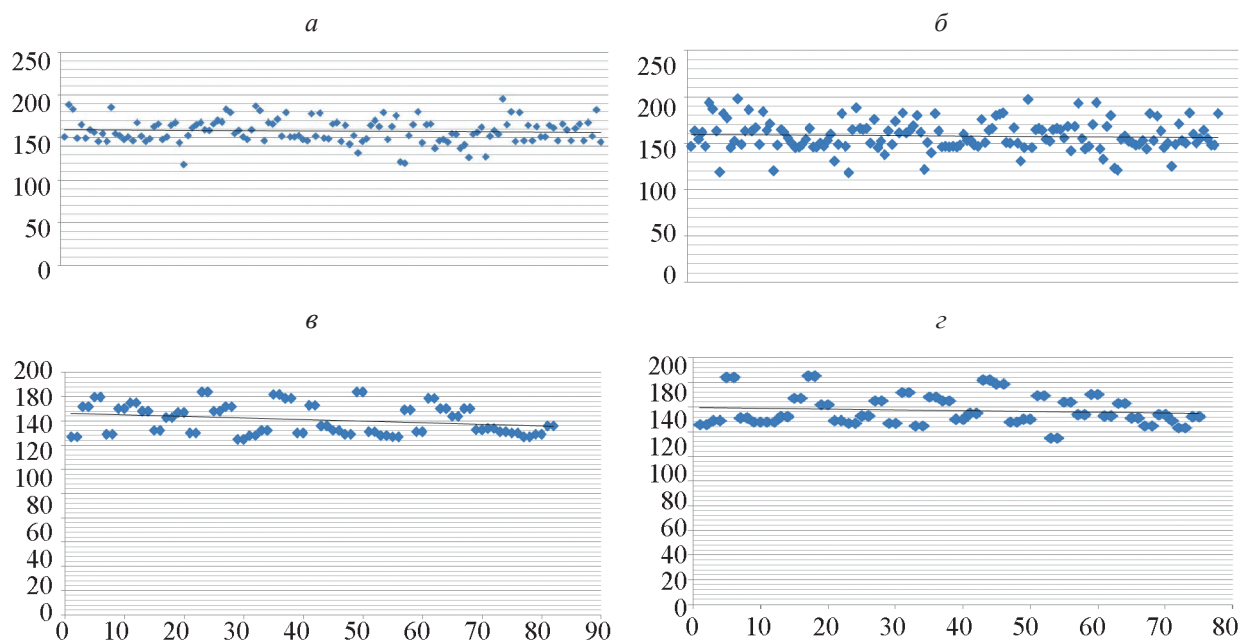
The increase or decrease in the duration of pregnancy of ewe lambs carrying twin fetuses is probably due to the fact that carrying twins or triplets requires more energy to support fetal growth than in ewe lambs carrying a single fetus³, hence the conflicting data were reported.

In the literature available to us, another factor affecting the organism of the ewe-mother during the pregnancy period is the increase in the concentration of L-homoarginine, the cumulation of which increases in twin mothers ten times, affecting the period of pregnancy, which allows to compensate for the increased load on the body of the uterus when increasing multiple births. L-homoarginine is a product of catabolism of L-arginine. Its role in the course of cardiovascular, hepatic and neurological functions, as well as in the regulation of glucose metabolism and hormonal status of ewe lambs at any multiple birth, forming healthy, normal young (see footnote 4) has been proved. In our studies, both at birth and in the further period of development, the twin youngsters are somewhat behind their single counterparts. This fact practically does not affect the survival rate, because the average level of this indicator of the whole studied group of sucking lambs during the period of keeping with mothers amounted to 93.5%.

Table 1 shows the growth and development of single ewes from birth to weaning.

²Corner R.A., Kenyon P.R., Stafford K.J., West D.M., Morris S.T., Oliver M.H. The effects of pasture availability for twin- and triplet-bearing ewes in mid and late pregnancy on ewe and lamb behaviour 12 to 24 h after birth // *Animal*, 2010, vol. 4, N 1, pp. 108–115. DOI: 10.1017/S1751731109990899.

³Hou Y., Hu Sh., Jia S., Nawaratna G., Che D., Wang F., Bazer F.W., Wu G. Whole-body synthesis of L-homoarginine in pigs and rats supplemented with L-arginine // *Amino Acids*, 2016, vol. 48, pp. 993–1001. DOI:10.1007/s00726-015-2145-4.



Длительность суягности овцематок:

a – ярочки-единцы; *б* – баранчики-единцы; *в* – ярочки-двойни; *г* – баранчики-двойни

Ewes' gestation duration:

a – single-born ewe lambs; *б* – single-born ram lambs; *в* – twin ewe lambs; *г* – twin ram lambs

The highest live weight at birth was 3.6 kg (3.6 kg) in lambs of lines No. 82104, 01684, 1128, 66796 and 20832: in comparison with the data of line No. 65204, the difference is highly reliable ($p \leq 0.001$). At weaning, the advantage is preserved in the ewes of the line No. 01684 (by 11.5%, $p \leq 0.001$) in comparison with the lowest data in the ewes of the line No. 80077.

Above the average values (30.7 kg), the advantage is maintained only in the ewes of lines No. 66796 and 20832, but the difference with the ewes with the lowest values is not reliable. A significant advantage in average daily gain remains only in the ewes of the line No. 01684: compared to the lowest values with the ewes of the line No. 80077, this difference is 12.3% (p

Табл. 1. Особенности развития ярок-единцов и молочность маток

Table 1. Peculiarities of the development of single-born ewe lambs and ewe milkness

Line number	<i>n</i>	Live weight of young animals, kg		Average daily weight gain, g	Milk yield of females, kg
		at birth	at weaning		
80077	18	3,5 ± 0,07	29,4 ± 0,77	171,8 ± 5,64	19,2 ± 0,55
884	16	3,4 ± 0,05	30,3 ± 0,85	182,3 ± 8,22	19,9 ± 0,61
82104	20	3,6 ± 0,05***	30,7 ± 0,37	182,9 ± 3,92	20,1 ± 0,25
01684	13	3,6 ± 0,05***	32,8 ± 0,51***	193,0 ± 2,50***	21,6 ± 0,36***
1128	14	3,6 ± 0,07***	30,2 ± 0,55	182,8 ± 5,95	19,7 ± 0,39
66796	12	3,6 ± 0,05***	31,2 ± 0,92	180,6 ± 9,73	20,4 ± 0,67
20832	8	3,6 ± 0,06***	31,0 ± 1,15	177,8 ± 8,37	20,3 ± 0,82
65204	27	3,39 ± 0,03	30,86 ± 0,57	186,56 ± 3,53	20,4 ± 0,40
Average value for females with single ewes	128	3,52 ± 0,02	30,68 ± 0,25	182,11 ± 2,03	20,1 ± 0,17

Hereinafter in the tables – reliability of the difference: * $p \leq 0,05$; ** $p \leq 0,01$; *** $p \leq 0,001$.

≤ 0.001). When comparing the difference with the sample average, only lines № 82104 and 01684 are characterized by reliable advantages: the difference in live weight differs from the sample average by 3.1% ($p \leq 0.05$) and 2.8% ($p \leq 0.05$), respectively. However, the reliable advantage is preserved only in the ewes of the line No. 01684 in the later period: at weaning this difference is 6.9% ($p \leq 0.001$), in terms of average daily gain of 6.0% ($p \leq 0.001$). The ewes of the line No. 65204 have a significant decrease in birth weight compared to the average values: the difference is 3.7% ($p \leq 0.001$). Milk yield of females of the line No. 01684 significantly exceeds the average value by 7.5% ($p \leq 0.001$).

Table 2 shows the data on growth and development of single rams. Comparison was made with the sample average. The lambs of line No. 80077 have a significant advantage in live weight at weaning compared to the sample average by 9.1% ($p \leq 0.01$), in average daily gain by 11.8% ($p \leq 0.05$). The sample of rams of the line No. 01684 significantly decreases from the average values: at birth by 3.0 ($p \leq 0.01$), at weaning age by 3.2% ($p \leq 0.05$). The rams of the line No. 66796 significantly have lower sample values in live weight at birth by 6.3% ($p \leq 0.01$); the reliable advantage is also preserved in live weight at weaning and average daily gain by 12.1% ($p \leq 0.001$) and 9.6% ($p \leq 0.01$), respectively. Milk yield of females of the

line No. 80077 prevails over the average value by 10.0% ($p \leq 0.01$). However, reliable lines for this trait were also noted: No. 01684 and 66796, respectively, lower values by 3.2% ($p \leq 0.05$) and 12.8% ($p \leq 0.001$).

The peculiarities of early ontogenesis of twin ewes are presented in Table 3. Ewes of the line No. 80077, with lower unreliable live birth weight by 0.2% and increased birth weight by 0.4, the difference of which is also not reliable, nevertheless have a reliable advantage in average daily gain compared to the sample average of 9.1% ($p \leq 0.001$). Only in ewes of the line No. 66796 the value of average daily gain was significantly lower than the average data for the sample by 15.0% ($p \leq 0.001$). In terms of milk production, line No. 80077 had an advantage over the average value by 9.04% ($p \leq 0.01$).

According to the growth and development data during early ontogenesis, twin rams have no significant difference compared to the sample average. Tendentially, rams of the line No. 884 have an advantage, and at birth young lambs of the line No. 82104 (see Table 4). In terms of milk yield, due to the low number of rams in the sample, no significant advantages from the average value were observed, only significantly lower was observed in the lines No. 80077 (by 9.5%, $p \leq 0.01$), 82104 (by 8.6%, $p \leq 0.01$) and 01684 (by 16.8%, $p \leq 0.001$).

Табл. 2. Особенности развития баранчиков-единцов и молочность маток

Table 2. Peculiarities of the development of single-born ram lambs and ewe milkness

Line number	<i>n</i>	Live weight of the born young, kg		Average daily weight gain, g	Milk yield of females, kg
		at birth	at weaning		
80077	13	3,9 ± 0,11	38,8 ± 1,18*	236,3 ± 10,58*	25,8 ± 0,81**
884	17	3,6 ± 0,04	34,2 ± 0,55	210,0 ± 5,99	22,7 ± 0,41
82104	18	3,9 ± 0,04	34,3 ± 0,67	198,3 ± 6,37	22,5 ± 0,49
01684	21	3,7 ± 0,04	34,4 ± 0,45	208,6 ± 4,20	22,7 ± 0,31
1128	14	3,8 ± 0,08	36,6 ± 0,79	207,3 ± 6,02	24,3 ± 0,53
66796	9	3,6 ± 0,09	31,2 ± 0,90	191,1 ± 8,73	20,5 ± 0,63
20832	16	4,1 ± 0,08	35,1 ± 1,11	206,4 ± 7,13	23,0 ± 0,78
65204	40	3,92 ± 0,04	36,39 ± 0,56	216,02 ± 3,26	24,1 ± 0,39
Average value for females with single rams	148	3,84 ± 0,02 ^{1; 2}	35,53 ± 0,29 ^{1; 2}	211,36 ± 2,07	23,47 ± 0,2 ^{1; 2}

Note. Reliable advantage of the mean over the lines: ¹ № 01684; ² № 66796.

Табл. 3. Особенности развития ярок-двоен и молочность маток

Table 3. Peculiarities of the development of twin ewe lambs and ewe milkness

Line number	n	Live weight of the born young, kg		Average daily weight gain, g	Milk yield of females, kg
		at birth	at weaning		
80077	8	3,3 ± 0,04	29,4 ± 0,81	186,5 ± 4,35***	20,9 ± 0,55***
884	3	3,3 ± 0,08	28,0 ± 1,92	153,9 ± 7,00	18,3 ± 1,37
82104	17	3,3 ± 0,03	28,4 ± 0,60	170,2 ± 4,27	18,6 ± 0,46
01684	5	3,2 ± 0,02	29,2 ± 1,18	169,4 ± 3,81	19,2 ± 0,87
1128	5	3,4 ± 0,08	28,0 ± 0,89	165,6 ± 3,21	18,2 ± 0,62
66796	3	3,3 ± 0,05	27,7 ± 1,41	145,2 ± 6,23	18,1 ± 1,03
20832	4	3,4 ± 0,09	31,5 ± 1,13	178,6 ± 10,01	20,4 ± 0,48
65204	19	3,36 ± 0,03	30,00 ± 0,48	171,59 ± 3,52	19,74 ± 0,35
Average value for females with twin ewes	64	3,33 ± 0,02	29,25 ± 0,31	170,88 ± 1,97 ¹	19,2 ± 0,31

¹ Reliable advantage of the mean over the line No. 66796.

Thus, the largest single ewes are born in line No. 01684, which retain an advantage over their peers during the whole period of keeping on suckling with mothers; no such advantage was observed in twin ewes. Single rams of the line No. 01684, on the contrary, have lower data on live weight from the average values, and the advantage is characterized by young stock of the line No. 80077; this trait is also connected with increased milk production of mothers of this line. Also, the increased milk production is characterized by mothers of the line No. 80077. Twin rams with increased live weight are born

from the mothers of lines No. 884 and 82104.

Table 5 shows the correlation between the duration of pregnancy in mothers and live weight of the progeny during the suckling period.

In single ewes, duration of pregnancy was not correlated with milk yield and live weight at birth and weaning; however, a strong positive correlation was observed between live weight at birth and weaning (0.571 ± 0.073 , $p \leq 0.001$) and a medium one between milk yield and live weight at weaning (0.228 ± 0.087 , $p \leq 0.001$).

The duration of pregnancy during the suckling period was negatively weakly associated

Табл. 4. Особенности развития баранчиков-двоен и молочность маток

Table 4. Peculiarities of the development of twin ram lambs and ewe milkness

Line number	n	Live weight of the born young, kg		Average daily weight gain, g	Milk yield of females, kg
		at birth	at weaning		
80077	6	3,4 ± 0,06	30,2 ± 1,00	184,1 ± 3,79	19,8 ± 0,72
884	7	3,6 ± 0,09	35,0 ± 1,76	190,2 ± 6,80	23,2 ± 1,24
82104	8	3,5 ± 0,02	30,5 ± 0,84	176,9 ± 5,54	20,0 ± 0,63
01684	3	3,4 ± 0,04	28,0 ± 0,38	174,2 ± 7,04	18,2 ± 0,31
1128	1	3,3	30,0	157,0	19,8
66796	3	3,4 ± 0,05	32,7 ± 1,80	169,5 ± 6,19	21,7 ± 1,31
20832	10	3,4 ± 0,02	33,2 ± 0,70	175,6 ± 4,09	22,1 ± 0,52
65204	17	3,48 ± 0,03	33,06 ± 0,80	189,73 ± 4,83	21,9 ± 0,58
Average value for females with twin rams	55	3,46 ± 0,02	32,30 ± 0,44	182,56 ± 2,25	21,9 ± 0,41 ^{1; 2; 3}

Note. Advantage of the mean over the lines: 1No. 80077 ($p \leq 0,01$); 2No. 82104 ($p \leq 0,01$); 3No. 01684 ($p \leq 0,001$).

Табл. 5. Сопряженность между показателями живой массы в период подсоса и молочностью овцематок цигайской породы

Table 5. Correlation between the live weight during the suckling period and the milk yield of the Tsigai breed ewe lambs

Coupling index	Period	Pregnancy duration	Live weight of young animals	
			at birth	at weaning
Single ewes				
Live weight of young animals	At birth	−0,090 ± 0,089	0,571 ± 0,073***	0,228 ± 0,087***
	At weaning	−0,003 ± 0,089		
Milkiness		−0,071 ± 0,089	−0,090 ± 0,089	
Single rams				
Live weight of young animals	At birth	−0,100 ± 0,082	0,744 ± 0,055***	0,998 ± 0,005***
	At weaning	−0,220 ± 0,080*		
Milkiness		−0,227 ± 0,080**	0,705 ± 0,059***	
Twin ewes				
Live weight of young animals	At birth	−0,208 ± 0,127	0,420 ± 0,118***	0,983 ± 0,024***
	At weaning	−0,206 ± 0,127		
Milkiness		−0,200 ± 0,128	−0,208 ± 0,127	
Twin rams				
Live weight of young animals	At birth	−0,066 ± 0,135	0,457 ± 0,120***	0,685 ± 0,098***
	At weaning	−0,394 ± 0,124***		
Milkiness		−0,314 ± 0,128**	0,161 ± 0,133	

with live weight in single rams during the weaning period (-0.220 ± 0.080 , $p \leq 0.05$). Milk yield of mothers was negatively related to duration of pregnancy (-0.227 ± 0.080 , $p \leq 0.01$). Live weight at birth and at weaning had a positive strong correlation (0.744 ± 0.055 , $p \leq 0.001$), and live weight was positively related to milk yield ($p \leq 0.001$) at both ages (0.705 ± 0.05 at birth and 0.998 ± 0.005 at weaning).

In twin ewes, live weight at birth and at weaning is significantly and positively correlated (0.420 ± 0.118 , $p \leq 0.001$) and live weight at weaning is conditioned by the milk yield of the mothers (0.983 ± 0.024 , $p \leq 0.001$).

In twin rams, there was a negative significant relationship between the duration of their mothers' pregnancy duration and live weight at weaning (-0.394 ± 0.124 , $p \leq 0.001$) and milk yield (-0.314 ± 0.128 , $p \leq 0.01$). Probably, this pattern is caused by some decrease in the period of their mothers' pregnancy, while this factor did not affect the further development of this group of animals and their safety during the suckling period, while the pattern of twin ewes was pre-

served: live weight at birth and weaning (0.457 ± 0.120 , $p \leq 0.001$) and live weight at weaning and milk yield of their mothers. (0.685 ± 0.098 , $p \leq 0.001$).

Thus, in our studies, milk yield is inversely related to the duration of pregnancy, but positively affects live weight at weaning of young animals.

CONCLUSION

According to the results of the analysis of the obtained data, the Crimean type of the Tsigai sheep is adapted to the difficult climatic conditions of the steppe Crimea, which indicates a low level of lamb waste during the suckling period. In the percentage ratio of singles to twins, the Tsigai breed mothers reproduce in the following ratio: out of 160 heads of mothers who gave birth to ewes, 32 heads had twins (20% of the herd); out of 176 head of mothers that gave birth to rams, only 15,6% of this herd gave birth to twins. In general, in the studied sample, this ratio is as follows: for one female lambd with a

single lamb, there are 0.18 females lambd with twin lambs. The average duration of pregnancy with single ewes is 157.83 ± 1.02 days, with single rams – 157.88 ± 1.07 days, with twin ewes – 160.58 ± 1.50 days and with twin rams – 154.29 ± 1.38 days. Thus, the average duration of pregnancy is 157.76 ± 0.61 days for the Tsigai breed females ($C_v = 7,6\%$).

For further laying of lines selected for increased multiple fertility, it is necessary to select in the replacement stock the ewes from twin litters in line No. 80077, because in this line twin ewes exceed the average values of average daily gain during the whole period of keeping with mothers by 9.1% ($p \leq 0.001$) in comparison with the sample average; increased live weight of young animals from single litters is formed by parental stock of lines No. 01684, reproducing ewes with increased live weight by 2.8–6.9% ($p \leq 0.05 \dots p \leq 0,001$) during the whole period of keeping with mothers and rams from the lines No. 20832, 65204 and 80077, the advantage of which over the average values is 3,1–12,1% ($p \leq 0,05 \dots p \leq 0,001$). Milkiness was found to be negatively related to the duration of pregnancy and positively related to live weight at weaning in all groups of lambs.

The advantage of twin rams from the average values is not proved, therefore it is not reasonable to carry out breeding for selection of replacement young rams from twin litters for the formation of line founders with increased multiple fertility, these observations should be expanded with the involvement of a larger array of indicators.

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Селекционно-генетические параметры овец агинской породы зугалайского типа

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Представлены результаты изучения селекционируемых признаков, экстерьерно-конституциональных особенностей полугрубошерстных овец агинской породы зугалайского типа. Приведены данные корреляционно-регрессионного, дисперсионного анализа, по результатам которых спроектированы модели парной и многофакторной регрессии. Наибольшей вариабельностью у изучаемых овец отличаются масса тела (6,4–12,6%), длина пуха (19,3–19,7%) и ости (13,1–16,9%) и обхват пясти (9,1%). По индексам телосложения бараны выделяются большей длинноногостью, лучшим развитием груди, более крепким костяком, овцематки – более растянутым, сбитым и массивным телом с лучше развитой задней частью. Корреляционный анализ селекционируемых признаков с экстерьерными статями свидетельствует, что живая масса и настриг шерсти у баранов имеет более тесную сопряженность с линейными промерами в сравнении с овцематками. Как у самцов, так и у самок живая масса сильнее коррелирует с шириной в маклоках, настриг шерсти – с шириной в маклоках у баранов, у овцематок связь была слабой или практически отсутствовала. Коэффициент линейной регрессии свидетельствует, что прирост живой массы и настрига шерсти у баранов прогнозируется при увеличении на единицу измерения промера ширины в маклоках (4,37 абс. прироста; $r = 0,824$; $p < 0,001$ и 0,13 абс. прироста; $r = 0,792$; $p < 0,001$). Коэффициент детерминации показал, что у баранов изменения живой массы и настрига шерсти на 67,9 и 62,8% обусловлены шириной в маклоках, влияние остальных факторов – 32,1 и 37,2% соответственно. В моделях многофакторной регрессии изменения массы тела и настрига шерсти у баранов на 90,3 и 78,0% объясняются воздействием комплекса линейных промеров, у овцематок – на 25,7 и 17,5% соответственно, оставшаяся доля отводится на влияние других факторов соответственно.

Ключевые слова: овцы, агинская порода, зугалайский тип, селекционно-генетические параметры, живая масса, настриг шерсти, корреляция, регрессия, дисперсия

Selection and genetic parameters of sheep of the Aginskaya breed of the Zugalay type

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The results of the study of selectable traits, exterior-constitutional features of medium wool sheep of the Aginskaya breed of the Zugalay type are presented. The data of correlation-regression, variance analysis are given, according to the results of which paired and multifactor regression models have been designed. Body weight (6.4–12.6%), down length (19.3–19.7%) and awn length (13.1–16.9%) and cannon bone girth (9.1%) are characterized by the greatest variability in the studied sheep. In terms of physique indices, rams are distinguished by longer legs, better breast development, stronger bones, ewe lambs are distinguished by a more stretched, bunched and massive body with a better developed hind part. Correlation analysis of the breeding traits with external body parts indicates that live weight and wool clip in rams has a closer correlation with linear measurements in comparison with ewe lambs. In both males and females, live weight was more strongly correlated with the width in the dippers, wool clip – with the width at hips in rams, in ewe lambs the relationship was weak or practically absent. Linear regression coefficients indicate that live weight and wool clip gain in

rams are predicted by an increase per unit in hip width (4.37 abs. gain; $r = 0.824$; $p < 0.001$ and 0.13 abs. gain; $r = 0.792$; $p < 0.001$). The coefficient of determination showed that in rams the changes in live weight and wool clip by 67.9 and 62.8% were explained by the width at hips, the influence of other factors – 32.1 and 37.2%, respectively. In multifactor regression models, 90.3 and 78.0% of changes in body weight and wool clip in rams are explained by the influence of a complex of linear measurements, in ewe lambs – by 25.7 and 17.5%, respectively, the remaining share is attributed to the influence of other factors, respectively.

Keywords: sheep, Aginskaya breed, Zugalay type, selection and genetic parameters, live weight, wool clip, correlation, regression, dispersion

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Конфликт интересов

Автор заявляет об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

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INTRODUCTION

The basis of the process in the creation of new selection forms and improvement of breeds is the restructuring of the correlation systems. In this regard, in pedigree sheep-breeding the result of selection depends largely on the complex of selectable traits and the nature of their interrelationships, and accurate evaluation and skillful use of these systems are crucial in breeding [1].

Knowledge of breeding-genetic parameters of animals and their competent use will allow breeders to more effectively select promising individuals of desirable type in selection work. In addition, they should be the basis for scientifically based methods of planning breeding work and forecasting the level of productivity of the progeny of selected animals [2].

In modern conditions it is required to use new parameters of exterior, more accurately characterizing the value of the breed and deter-

mining its variability in conditions of high phenotypic homogeneity¹ for selection of animals to improve their productive qualities.

A.Yu. Krivoruchko and colleagues (2021), applying the method of principal component analysis for lifetime estimation of meat productivity of sheep of the Dzhalgin Merino breed, suggest using measurements of shoulder, lower arm and thigh circumference, and for sheep of the North Caucasian breed – thickness of thigh muscle and fat, lower arm circumference, which have shown high significance [3, 4].

Live weight and exterior-constitutional characteristics are the most important selection parameters for improving the productive qualities of farm animals [5, 6]. Body weight of animals, unlike linear measurements, which are not significantly affected by paratypical factors, depends to a greater extent on feeding and housing conditions. In this regard, selection on live weight is more effective not directly but in correlation with morphometric parameters [7].

¹Scholz A.M., Bünger L., Kongsro J., Baulain U., Mitchell A.D. Non-invasive methods for the determination of body and carcass composition in livestock: dual-energy X-ray absorptiometry, computed tomography, magnetic resonance imaging and ultrasound: invited review // *Animal*, 2015, vol. 9, Is. 7, pp. 1250–1264. DOI: 10.1017/s1751731115000336.

However, correlation does not show the amount of change in one trait when changing the other by one unit. In this regard, in order to analyze the results of selection, to predict the development of one trait when selecting for another, it is necessary to determine regression indices, which allow predicting the increase or decrease of the evaluated trait when others change by a certain amount within the studied animal populations².

The method of correlation-regression analysis is an accessible way to build regression models for predicting productive qualities of farm animals and can be used in the development of the selection programs with different breeds.

The purpose of the research is to study selection and genetic parameters of medium-wool breed of sheep of the Aginskaya breed of the Zugalay type.

MATERIAL AND METHODS

The studies were carried out in 2022, 2023. Full-aged medium-wool breed rams (♂) and ewe lambs (♀) of the Aginskaya breed of the Zugalay type (AGZ) of the pedigree breeding unit OOO “Gerel” of the Mogoytuisky district of the Transbaikal Territory served as the research material.

Live weight of the experimental animals was determined by individual weighing on electronic scales with an accuracy of 0.05 kg, wool clip – individually during shearing of sheep.

Measurement of the main linear measurements of the body height at the withers (HW), chest girth (CG) and heel girth (HG), chest width (ChW) and depth (ChD), height at hips (HH), oblique body length (OBL), oblique quarters length (OQL) were carried out according to generally accepted methods. On the basis of the obtained results, the following body build indices were calculated: long-leggedness (LLN), lengthiness (L), chest (Ch), pelvis-chest (P-Ch), blockiness (Bl), massiveness (M), quarters development (QD) and boniness (Bn).

The digital material was processed biometri-

cally according to the methods of E.K. Merkurieva (1970) and N.A. Plokhinskii (1980), as well as by means of the methods of variation statistics according to Student using a personal computer, Microsoft Excel program of the “Data Analysis” package using built-in functions of descriptive statistics, correlation, regression, straight-line regression equations and PAST version 3.25 within the following significance levels: ¹ – $p < 0,05$; ² – $p < 0,01$; ³ – $p < 0,001$.

RESULTS AND DISCUSSION

Table 1 shows data on live weight, wool shearing and linear measurements of medium-wool breed AGZ sheep.

The presented results indicate that in the population of medium-wool breed AGZ sheep in rams the selection on live weight, length of down and awn is the most effective, in ewes – on length of down and awn, as the coefficients of variation for these traits have the highest variability. In addition, the obtained data indicate that in selection work with rams it is necessary to pay attention to such features as width of the quarters at hips and cannon bone girth, in ewes – on wool clips and cannon bone girth.

Table 2 shows the results of calculation of body build indices of medium-wool breed AGZ sheep.

The analysis of body build indices of medium-wool breed AGZ sheep indicates that medium-wool breed sheep have proportionally developed physique. At the same time, males are characterized by longer legs, better chest development in width and depth, stronger bones, while females are characterized by more stretched, bunched and massive body with better developed hindquarters.

The highest coefficient of variation in both males and females was observed in the bone structure index, which, as well as the cannon bone girth, indicates the possibility of selection on this index.

Fig. 1 shows the correlation of live weight with wool clip and length, as well as with linear

² Kolosov Yu.A., Zasedchuk I.V. Correlation variability and inheritability of economically useful traits in young sheep of the Salskaya breed // Don Agrarian Science Bulletin, 2011, N 4 (16), pp. 64–67.

Табл. 1. Живая масса, настриг, длина шерсти и промеры тела овец АГЗ

Table 1. Live weight, clipping, wool length and body measurements of the AGZ sheep

Indicator	Group			
	♂, n = 31		♀, n = 69	
	$\bar{X} \pm S_x$	$C_v, \%$	$\bar{X} \pm S_x$	$C_v, \%$
LW, kg	73,3 ± 9,20	12,6	56,6 ± 3,64	6,4
WC, kg	3,6 ± 0,28	7,8	2,8 ± 0,28	9,9
Linear measurements, cm:				
DL	8,0 ± 2,23	19,3	6,7 ± 1,33	19,7
AL	19,3 ± 2,52	13,1	17,8 ± 3,01	16,9
HW	69,1 ± 4,22	6,1	65,5 ± 2,50	3,8
OBL	78,1 ± 3,73	4,8	75,2 ± 2,84	3,8
OQL	24,6 ± 1,63	6,6	24,1 ± 0,96	4,0
ChG	93,4 ± 6,66	7,1	90,9 ± 4,12	4,5
ChD	33,5 ± 2,76	8,2	32,3 ± 1,49	4,6
ChW	19,2 ± 1,54	8,0	18,3 ± 1,21	6,6
WH	18,7 ± 1,74	9,3	18,8 ± 1,17	6,2
CBG	8,7 ± 0,79	9,1	8,0 ± 0,73	9,1

Табл. 2. Индексы телосложения овец АГЗ, %

Table 2. Body indices of the AGZ sheep, %

Indicator	Group			
	♂, n = 31		♀, n = 69	
	$\bar{X} \pm S_x$	$C_v, \%$	$\bar{X} \pm S_x$	$C_v, \%$
LLG	51,7 ± 2,95	5,7	50,6 ± 2,27	4,5
L	113,3 ± 5,32	4,7	114,9 ± 4,85	4,2
Ch	57,7 ± 5,00	8,7	56,6 ± 3,99	7,1
P-Ch	102,9 ± 7,00	6,8	97,5 ± 6,98	7,2
Bl	119,6 ± 6,27	5,2	121,0 ± 5,49	4,5
M	135,1 ± 9,43	7,0	138,9 ± 6,76	4,9
QD	31,5 ± 1,54	4,9	32,1 ± 1,51	4,7
Bn	12,6 ± 1,16	9,2	12,2 ± 1,12	9,2

body measurements.

In medium-wool breed males pairwise conjugation of traits is stronger than in females. At the same time, the closest positive correlation of live weight at a high level of reliability was established with wool clip ($r = 0,929, p < 0,001$) and external body parts ($r = 0,702-0,824, p < 0,001$), except for oblique hindquarters length ($r = 0.610, p < 0.001$) and cannon bone girth ($r = 0.486, p < 0.01$), and down and awn length ($r = 0.001$ and $r = 0.137$), between which moderate, weak and no relationship was found, respectively. Low levels of conjugation between

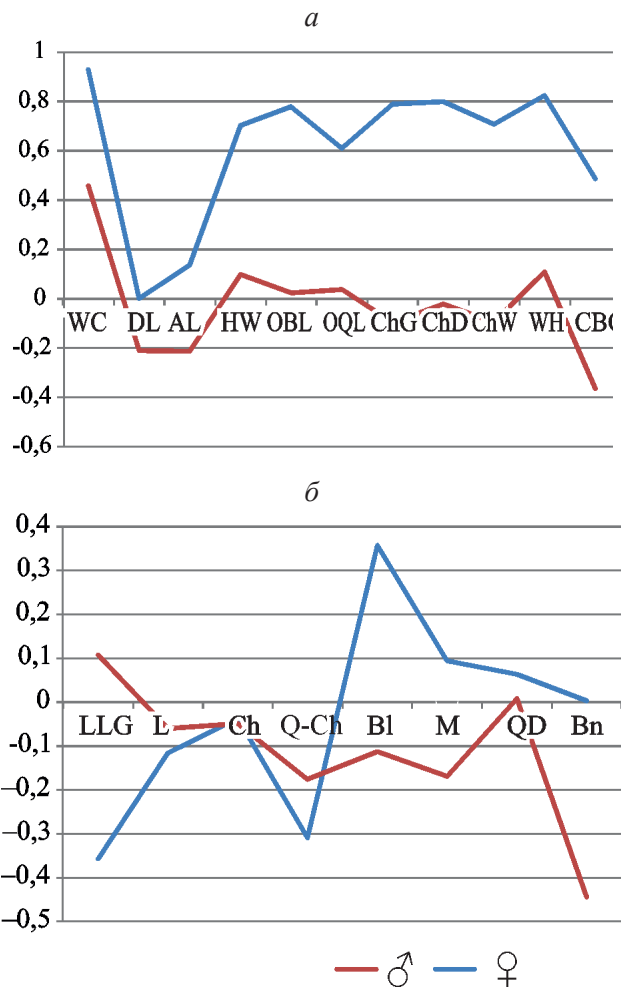


Рис. 1. Корреляция живой массы у овец АГЗ (♂, n = 31; ♀, n = 69):

a – с настригом, длиной шерсти и промерами тела; б – с индексами телосложения

Fig. 1. Correlation of live weight in the AGZ sheep (♂, n = 31; ♀, n = 69):

a – with clipping, coat length and body measurements; б – with body indexes

live weight and down and awn length, similar to ours, were found in coarse-wool sheep of Brlik type of the Edilbaev breed [8].

In sheep females of both positive and negative orientation the correlation of live weight with the studied parameters was in the range from $r = -0,365$ to $r = +0,459$. The closest positive correlation, similar to rams, of live weight with wool clip should be noted ($r = +0,459$, $p < 0,001$, the nature of the relationship is weak). It is necessary to note a closer negative conjugation with the cannon bone girth ($r = -0,365$, $p < 0,001$). A weak or practically absent positive and negative correlation was revealed with the other traits.

A strong correlation between live weight and hip width in Cornigliese sheep, similar to our results, was observed in the work [9].

Close correlation of body weight with oblique body length has been revealed in North Caucasian meat-wool sheep [10], in Qatar sheep and crossbred sheep breeds – with chest girth [11, 12], in Corriedale sheep – with abdominal girth [13], in aboriginal breeds of Saudi Arabia – with height at hips [14], in Ethiopian mountain sheep – with height at the withers³.

The analysis of the correlation between live weight and body build indices in medium-wool breed AGZ sheep indicates the ambiguity of the results obtained. Thus, in rams it varied from $r = -0,353$ (with LLN index, $p < 0,05$) to $r = +0,357$ (with Bl index, $p < 0,01$), in ewes - from $r = -0,444$ (with Bn index, $p < 0,001$) to $r = +0,107$ (with LLN index).

In general, in AGZ sheep, with the exception of the massiveness index, live weight has a weak and practically absent correlation with all body build indices of different orientation.

Fig. 2 shows the results of studying the correlative relationship of wool clip with the length of down, awns and linear body measurements.

The analysis of the presented data indicates that wool clip, as well as live weight in medium-wool breed AGZ males, is in a closer rela-

tionship with the studied traits than in females. Thus, they showed positive conjugation of moderate and strong relationship of wool clip with all linear measurements of the body ($r = 0,562-0,792$, $p < 0,001$), except for the cannon bone girth ($r = 0,479$, $p < 0,01$, the nature of the relationship is weak) and weak relationship with the length of down ($r = 0,221$) and awn ($r = 0,365$, $p < 0,01$). Similar results were obtained in coarse-wool sheep of the Saryarka fat

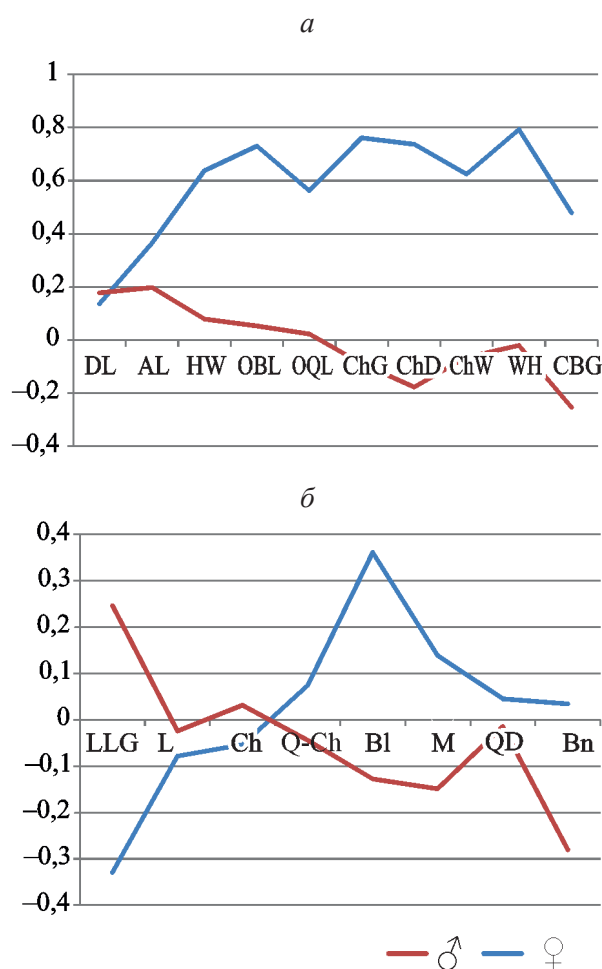


Рис. 2. Корреляция настрига шерсти у овец АГЗ (♂, $n = 31$; ♀, $n = 69$):

a – с длиной пуха и ости, промерами тела;

б – с индексами телосложения

Fig. 2. Correlation of wool clipping in the AGZ sheep (♂, $n = 31$; ♀, $n = 69$): *a* – with the length of down and spine, body measurements; *б* – with body indexes

³Tesfay H.H., Banerjee A.K., Mummed Y.Y. Live body weight and linear body measurements of indigenous sheep population in their production system for developing suitable selection criteria in Central Zone of Tigray, Northern Ethiopia // African Journal of Agricultural Research, 2017, vol. 12, pp. 1087–1095.

tailed breed, and in sheep of the Edilbaev breed of different genotypes^{4,5}.

The closest relationship was found with width at hips ($r = 0.792, p < 0.001$), chest girth ($r = 0.761, p < 0.001$), chest depth ($r = 0.737, p < 0.001$) and oblique body length ($r = 0.730, p < 0.001$).

In AGZ sheep females, practically absent positive and negative correlation of wool clip with all traits was revealed ($r = -0.254... +0.198$). It should be noted that wool clip, as well as live weight in females negatively correlates with the metacarpal girth ($r = -0.254, p < 0.05$).

When constructing the graph of pair correlation relationship of wool clip with body build indices in AGZ sheep, a similar regularity with the graph obtained when studying the conjugation of live weight with the studied traits was revealed. In males it was from $r = -0.330$ (with LLN index) to $r = +0.361$ (with B1 index), in females – from $r = -0.281$ (with Bn index, $r < 0.05$) to $r = +0.246$ (with LLN index, $r < 0.05$).

In general, in AGZ sheep, wool clip has a weak and practically absent correlation with all body build indices of different directions.

Low variability of linear measurements and high correlation with live weight allow using dimensions of exterior body parts for predicting productive and breeding qualities of cattle⁶.

Table 3 shows the regression coefficients of live weight with exterior body parts of AGZ rams.

Regression coefficients were calculated for the traits having strong interrelation with live weight and wool clip ($r > 0.7$), for sheep females all exterior body parts were excluded from further study due to practically absent and weak interrelation of traits.

The calculated coefficients of paired linear regression between live weight and linear measurements in AGZ rams indicate that with the increase of exterior body parts per unit of absolute growth we can predict an increase in live weight by 1.53–4.37 of their absolute gains.

Табл. 3. Коэффициенты регрессии живой массы баранов АГЗ (♂, $n = 31$)

Table 3. Regression coefficients of live weight of the AGZ rams (♂, $n = 31$)

Model	Predictor	Coefficient	SE	$t_{\text{стат}}$	$P_{\text{знач}}$	r
1	Constant	-8,4	10,48	-0,80	0,428	0,824 ³
	WH	4,37	0,56	7,83	0,000**	
2	Constant	-15,9	12,53	-1,27	0,214	0,799 ³
	ChD	2,67	0,37	7,15	0,000**	
3	Constant	-28,5	14,77	-1,93	0,064	0,789 ³
	ChG	1,09	0,16	6,91	0,000**	
4	Constant	-77,0	22,46	-3,43	0,002	0,779 ³
	OBL	1,92	0,29	6,70	0,000**	
5	Constant	-8,0	15,14	-0,53	0,602	0,707 ³
	ChD	4,24	0,79	5,39	0,000**	
6	Constant	-32,4	19,97	-1,62	0,115	0,702 ³
	HW	1,53	0,29	5,31	0,000**	

Note. Here and in Table 4: SE – standard error, $t_{\text{стат}}$ – t -statistics, $P_{\text{знач}}$ – statistical significance of the regression coefficients, r – correlation coefficient; ** – statistically significant; ³ – $p < 0.001$.

⁴Adylkanova Sh.R. Genetic parameters of the selectable traits of the Saryarka coarse-wool fat-tailed sheep breed // Agrarian science, 2010, N 7, pp. 27–28.

⁵Traisov B.B., Esengaliyev K.G., Davletova A.M. Conjugacy of the breeding traits in the Edilbayev breed ewe lambs // Sheep, goats, wool business, 2013, N 3, pp. 16–17.

⁶Gerasimov N.P., Kayumov F.G., Tretyakova R.F., Ryabov N.I. Formation of the exterior of steers of different genotypes in the relationship with the level of feeding // Animal Husbandry and Fodder Production, 2018, vol. 101, N 2, pp. 17–24.

Assessment of significance of regression coefficients P_{value} indicates a high level of validity and reliability of the obtained results and excludes randomness in our study (at a significance level of 0.05).

The highest live weight gain in AGZ males is expected when the absolute increase in width per unit of absolute gain in the hips is increased – model 1 (4,37 abs. gain; $r = 0,824$; $p < 0,001$).

Table 4 shows the wool clip regression coefficients with exterior body parts of AGZ rams.

The results of the regression analysis presented in Table 4 indicate that wool clip, as well as live weight, is most closely correlated with the width at hips – model 1 ($p < 0,001$). At increase of the specified external body part per unit of absolute growth it is possible to predict increase of the analyzed sign on 0,13 of its abs. gains ($r = 0,792$; $p < 0,001$).

The adequacy of the obtained regression coefficients of wool clip in terms of linear measurements of rams is confirmed by the significance of P_{value} at the significance level of 0,05.

Studies have shown that in the Malya sheep breed, the greatest increase in body weight is provided by the increase in cannon bone girth⁷, the Cornigliese breed – breast girth [9], the Corriedale breed – belly girth [13], the Kashmir Merino breed – height at the withers [15].

The models of multiple and pair regression equations can be used in predicting the live weight, as well as in the selection of medi-

um-wool breed AGZ sheep in the breeding process (see Table 5).

The correlation and regression analysis of live weight on exterior body parts of the AGZ allowed compiling 13 regression models: six multiple and six pairwise regression models for rams and one multiple regression model for ewe lambs.

Table 5 shows four of the six compiled multiple regression models were of good quality, two models were of acceptable quality ($R_{qv} = 0.792$ and $R_{qv} = 0.793$ at $p < 0.001$), and one of the six paired regression models was of reasonable quality. The remaining five paired regression equations had worse quality, with correlation and determination coefficients lower than model 5 (predictor – width at hips).

The obtained equations of multifactor regression indicate that the resultant factor “live weight” in medium-wool breed of the AGZ sheep using all linear measurements has positive and negative interaction (model 1). In models 2– 4 of multifactor regression, the equations differ only by positive interaction. Minus in front of the regression coefficient for linear measurements indicates their negative influence on the resultant factor.

The variance analysis of the regression equations by F -criterion testifies to their statistical significance and indicates the reliability of the regression equations for both rams and ewe lambs ($F_{est} > F_{crit}$ at the significance level of 0.05).

Табл. 4. Коэффициенты регрессии настрига шерсти баранов АГЗ (♂, $n = 31$)

Table 4. Regression coefficients of wool clipping from the AGZ rams (♂, $n = 31$)

Model	Predictor	Coefficient	SE	t_{stat}	P_{value}	r
1	Constant	1,2	0,35	3,45	0,002**	0,792 ³
	WH	0,13	0,02	6,99	0,000**	
2	Constant	0,6	0,48	1,24	0,224	0,761 ³
	ChG	0,03	0,01	6,30	0,000**	
3	Constant	1,1	0,43	2,50	0,018	0,737 ³
	ChD	0,08	0,01	5,86	0,000**	
4	Constant	–0,7	0,76	–0,94	0,354	0,730 ³
	OBL	0,06	0,01	5,74	0,000**	

⁷Çilek S., Petkova M. Phenotypic correlations between some body measurements and prediction of body weight of Malya sheep //Bulgarian Journal of Agricultural Science, 2016, vol. 22 (Suppl. 1), pp. 99–105.

Табл. 5. Уравнения множественной и парной регрессии живой массы овец АГЗ
Table 5. Equations of multiple and pair regression of live weight of the AGZ sheep

Mod- el	Equation	<i>R</i>	$F_{est} - F_{crit}$	R_{qv}
$\sigma, n = 31$				
1	$LW = -88,4 + 0,43 HW + 0,44 OBL - 0,03 OQL - 0,02 ChG + 0,99 ChD + 1,98 ChW + 0,41 WH + 2,56 CBG$	0,950 ³	24,4 > 2,42**	0,903 ³
2	$LW = -74,0 + 0,52 HW + 0,23 OBL + 0,25 ChG + 0,83 ChD + 1,19 ChW + 1,04 WH$	0,940 ³	30,5 > 2,51**	0,884 ³
3	$LW = -64,8 + 0,52 OBL + 0,39 ChG + 1,13 ChD + 1,22 WH$	0,921 ³	35,1 > 2,76**	0,849 ³
4	$LW = -44,4 + 0,48 ChG + 1,25 ChD + 1,68 WH$	0,911 ³	44,3 > 2,96**	0,831 ³
5	$LW = -8,4 + 4,37 WH$	0,824 ³	61,4 > 4,18**	0,679 ³
$\phi, n = 69$				
6	$LW = 50,9 + 0,41 HW - 0,01 OBL + 0,40 OQL - 0,04 ChG - 0,23 ChD - 0,63 ChD + 0,66 WH - 2,41 CBG$	0,507 ³	2,6 > 2,01**	0,257 ¹

Note. *R* – multiple correlation coefficient; *F* – Fisher's criterion (estimated, critical),
 R_{qv} – coefficient of determination (0,8–1,0 – model of good quality, 0,5–0,8 – acceptable and 0,0–0,5 – poor);
** – the regression equation is statistically significant; ¹ – $p < 0,05$; ³ – $p < 0,001$.

The value of the coefficient of determination in AGZ sheep increases with the addition of independent factors to the equation, its highest value was obtained in model 1 for all linear measurements.

Model 6 of multiple regression of live weight in ewe lambs, despite the revealed statistical significance, is characterized by poor quality.

The values of determination coefficients for multiple equations show that in rams the change in live weight by 83.1–90.3% can be predicted by their linear body measurements in various combinations. Evaluation of pairwise regression equations revealed that body weight of males was more influenced by the effect of the width at hips by 67.9% ($p < 0,001$, $SE = 5,303$, model 5 of reasonable quality).

Similar results have been obtained in the studies [9, 13, 15, 16].

The models of multiple and pair regression equations can be used in predicting live weight, as well as in selecting medium-wool breed AGZ sheep in the breeding process (see Table 6).

On the basis of correlation-regression analysis of wool clip by linear measurements of rams seven equations of pair, seven – multiple regressions and one – multiple regression for ewe lambs were compiled.

Table 6 presents three models characterized by the best values of coefficients of multiple and pair correlation and determination. Like body weight, wool cut in medium-wool breed AGZ sheep has both positive and negative interactions with linear body measurements, which were observed for the models that used all independent variables.

In the regression equations, strong and moderate multiple correlation was established at a high level of reliability ($R > 0.5-0.7$, $p < 0.001$), in ewe lambs the multiple correlation had a weak character of connection.

At estimation of regression models of wool clip in terms of exterior body parts on adequacy their statistical significance for rams ($F_{est} > F_{crit}$ at the significance level of 0,05) was found, for ewe lambs the equation of multiple regression was insignificant ($F_{est} < F_{crit}$ at the significance level of 0,05) and of poor quality ($R_{qv} < 0,5$).

The coefficients of determination show that all the designed multivariate regression models are characterized by acceptable quality, while of the seven paired regression models only four were of acceptable quality ($R_{qv} > 0.5$) and three were of poor quality ($R_{qv} < 0.5$, predictors – HW, ChD, OQL).

Табл. 6. Уравнения множественной и парной регрессии настрига шерсти овец АГЗ
Table 6. Equations of multiple and paired regression of wool shearing from the AGZ sheep

Model	Equation	<i>R</i>	$F_{est} - F_{crit}$	R_{qv}
$\sigma, n = 31$				
1	WC = -0,6 + 0,01 HW + 0,01 OBL - 0,001 OQL + 0,01 ChG + 0,02 ChD + 0,02 ChW + 0,04 WH + 0,04 CBG	0,883 ³	9,7 > 2,40**	0,780 ³
2	WC = 1,2 + 0,13 WH	0,792 ³	48,9 > 4,18**	0,628 ³
$\varphi, n = 69$				
3	WC = 2,3 + 0,03 HW + 0,01 OBL + 0,03 OQL + 0,01 ChG - 0,06 ChD - 0,04 ChW + 0,004 WH - 0,13 CBG	0,419 ³	1,6 < 2,10*	0,175

Note. *R* – multiple correlation coefficient; *F* – Fisher's criterion (estimated, critical), R_{qv} – coefficient of determination (0,5–0,8 – model of acceptable quality and 0,0–0,5 – of poor quality); * – the regression equation is statistically insignificant ** – the regression equation is statistically significant; ³ – $p < 0,001$.

As a result, it has been found that the change in wool clip in medium-wool breed AGZ sheep can be predicted with greater accuracy (by 78.0%) by the complex of linear measurements of the body, and with less accuracy (by 62.8%) by the predictor of width at hips.

CONCLUSION

The use of correlation-regression analysis allows understanding the nature of variability of the selected traits and contributes to obtaining reliable results for their further effective use in the breeding process in medium-wool sheep breeding in the Transbaikal region.

The revealed correlation-regression interrelations indicate the importance of the studied factors in the formation of the breeding traits of productivity of medium-wool AGZ sheep which are largely conditioned by their exterior-constitutional characteristics. The exterior characteristics of sheep, which are the basis of the designed models, will allow predicting the productivity of animals both in terms of body weight and wool clip, as well as selecting sheep corresponding to the desirable type.

The reliability and significance of the forecast is higher with a greater choice of factors, as indicated by the obtained coefficients of multiple correlation, determination and Fisher's criteria at a high level of confidence.

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Факторы зимнего передвижения влаги в пахотных почвах Ишимской степи

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На основе материалов многолетних полевых наблюдений в южных районах Омской области определено, какие факторы влияют на зимнее передвижение влаги в пахотных почвах Ишимской степи. Глубиной проникновения температуры 0 °С обусловлены нижняя граница и вертикальная мощность слоя намерзания влаги. Расстояние между его нижним краем и глубиной проникновения 0 °С составляет 20–40 см. Глубина проникновения 0 °С зависит от температуры воздуха и мощности снежного покрова и достигает на изучаемой территории 170–240 см. С гранулометрическим составом связаны формы доминирующей в почве влаги. В тяжелосуглинистых высокоилюистых почвенно-грунтовых толщах Ишимской степи преобладает пленочная влага. Содержание капиллярно-подпертной и свободной гравитационной воды не превышает 6% от объема почв при полной влагоемкости, чем обусловлен малый объем намерзания влаги (до 50 мм). Термоградиентная миграция влаги полевыми методами определяется в высокоувлажненных почвенно-грунтовых толщах. Высокая влажность почв и пород Ишимской степи связана с их гранулометрическим составом и близким залеганием грунтовых вод. Если во II декаде октября грунтовые воды фиксируют на глубине менее 3 м, слой намерзания влаги в конце марта отмечается в промежутке глубин от 40–80 до 160–200 см, объем криогенной аккумуляции при этом составляет 30–50 мм, в том числе в верхнем метровом слое – 10–25 мм. Если осенью грунтовые воды обнаруживают на глубине более 3 м, слой намерзания фиксируют на отметках от 80 до 160–200 см, прибавка влаги в нем составляет 15–30 мм, в слое 0–100 см влагосодержание не изменяется. Роль криогенной аккумуляции в восполнении влаги после вегетационного дефицита в корнеобитаемом слое по яровым зерновым культурам незначительна. Этот процесс оказывает большое влияние на формирование условий анаэробизации и развитие современного гидроморфизма в нижних горизонтах почв и подпочвенной толще.

Ключевые слова: глубина проникновения 0 °С, гранулометрический состав, влажность почв, уровень грунтовых вод, корнеобитаемый слой, криогенная аккумуляция влаги

Factors of winter moisture movement in arable soils of the Ishim steppe

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Based on the materials of long-term field observations in the southern regions of the Omsk region, the influence of the main factors on the winter movement of moisture in arable soils of the Ishim steppe was traced. The penetration depth of 0 °C determines the lower boundary and vertical thickness of the moisture freezing layer. The distance between its lower edge and the penetration depth of 0 °C is 20–40 cm. The penetration depth of 0 °C is predetermined

by the air temperature and the thickness of the snow cover and reaches 170–240 cm. The forms of moisture dominant in the soil are associated with the granulometric composition. Film moisture prevails in the heavy loamy, highly silty soil-ground strata of the Ishim steppe. The content of capillary-backed and free gravitational water does not exceed 6% of the soil volume at full moisture capacity, which determines the small volume of moisture freezing (up to 50 mm). Thermogradient migration of moisture is determined by field methods in highly moistened soil-ground strata. High humidity of the soils and rocks of the Ishim steppe is associated with their granulometric composition and the close occurrence of groundwater. If in the second ten days of October groundwater is recorded at a depth of less than 3 m, the layer of moisture freezing at the end of March is noted in the depth range between 40–80 and 160–200 cm, the volume of cryogenic accumulation is 30–50 mm, including in the upper meter layer – 10–25 mm. If groundwater is detected at a depth of more than 3 m in the autumn, the freezing layer is fixed at 80 to 160–200 cm, the moisture gain in it is 15–30 mm, in the 0–100 cm layer the moisture content does not change. The role of cryogenic accumulation in replenishing the post-vegetation moisture deficit in the root layer of spring grains is modest. This process is significant for the formation of conditions for anaerobiosis and the development of modern hydromorphism in the lower soil horizons and in the subsoil strata.

Keywords: penetration depth 0 °C, granulometric composition, soil moisture, groundwater level, root layer, cryogenic moisture accumulation

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Автор заявляет об отсутствии конфликта интересов.

Conflict of interest

The author declares no conflict of interest.

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INTRODUCTION

The Ishim steppe (Ishim-Irtysh steppe interfluvium) is an important agrarian region of Siberia [1, 2]. At the same time, this territory is characterized by the presence of the factors that complicate obtaining high stable yields of agricultural crops. One of such factors is the limited resources of soil and atmospheric moisture. On this basis, monitoring of moisture reserves and establishing ways to optimize them in arable soils of the region is of transcendent importance [3, 4].

Siberian steppe soils in the cold season of the year are deeply and permanently frozen to negative temperatures, which causes the movement and accumulation of soil moisture in the

seasonally frozen layer. In summer, soils warm up, which predetermines the migration of soil moisture in the opposite direction. Therefore, seasonal moisture movements are an important element of the water regime of Siberian steppe soils, and redistributed moisture is a significant component of their water balance [5, 6]. At the same time, thermogradient migration of moisture occurs in the soils [7].

The relevance of the problem of moisture movement in Siberian steppe soils is emphasized by long-term fluctuations in the natural and climatic conditions of the region [8–11], under the influence of which the indicators of seasonal migration of soil moisture can change. It is still unclear how such dynamics affects the

parameters of soil moisture movement, especially in winter time. To forecast the characteristics of moisture migration under the influence of dynamic environmental factors and for economic assessment of the changing size of cryogenic moisture accumulation, it is necessary to identify the main factors of its winter movement and to establish quantitative dependencies of soil moisture movement parameters on these factors. At the same time, generalized data on the impact of natural factors on moisture redistribution in soils of Ishim steppe during the cold season are absent.

The purpose of the study is to establish the influence of certain natural factors on winter moisture movement in arable soils of the Ishim steppe.

MATERIAL AND METHODS

In the course of the study, the data of field work in the eastern part of the Ishim-Irtysh steppe interfluvium, on the territory of the Russo-Polyansky and, partly, Novovarshevsky municipal districts of the Omsk region were generalized.

The relief of the Ishim steppe is represented by a lowland (with absolute heights of 110–135 m) weakly articulated plain, within which there are micro depressions (up to 1 m deep, up to 100 m in diameter) and large depressions (up to 5–6 km in diameter, up to 20 m deep). The earth sur-

face is covered by middle and upper quaternary cover sediments up to 10 m thick.

The annual air temperature is 2.2 °C (based on the observations of the Russkaya Polyana weather station of the Ob-Irtysh Department of Hydrometeorology and Environmental Monitoring, located 5 km north of the reference transects). The average July temperature reaches 20 °C. The area is characterized by a long (130–140 days) winter. The average temperature in January is 17.2 °C. During the year 360 mm of precipitation falls on average [12, 13]. Heat resources are sufficient for evaporation of 500–700 mm of water [14]. The hydrographic network of the area is represented by shallow lakes.

Within the arable lands (plowing of the territory at present reaches 85–95%) dark dispersed carbonate gypsum-containing saline agroze- ms developed on plateau areas are spatially dominant. Dark clayey-illuvial quasi-gleyey agroze- ms are recorded in micro depressions. In large hollows, dark dispersed carbonate gypsum-containing saline quasi-gleyey agroze- ms are developed [15]. All soils and subsoil rocks are characterized by heavy loamy granulometric composition with high (up to 45%) content of silt fraction. Spring grain crops prevail on arable land.

Field observations were carried out in 1986-1990 and 2002-2022 on the reference soil tran-

Опорные почвенные разрезы и их местоположение
Supporting soil sections and their location

Section	Geographic coordinates	Absolute height, m	Terrain	Soil
1	53°43'47.14" N 74°03'35.59" E	111	Site of the first terrace above flood-plain of the mesocotyl basin	Dispersed carbonate saline quasi-gleyey agrozem
2	53°43'47.16" N 74°03'35.57" E	112	Site of the second terrace above flood-plain of the mesocotyl basin	Dispersed carbonate agrozem
4	53°43'50.26" N 74°03'45.49" E	110	Slope of the first terrace above flood-plain of the mesocotyl basin	Dispersed carbonate saline quasi-gleyey agrozem
7	53°43'12.52" N 73°57'01.65" E	121	Flat interfluvium, microhill	Dispersed carbonate agrozem
8	53°43'22.83" N 73°57'03.42" E	120	Flat interfluvium, microdepression	Clay-illuvial quasi-gleyey agrozem

sects located within the arable land (see the table). The volume of frozen moisture and the location of its seasonal accumulation layer were established by comparing moisture profiles constructed from observation materials in the II-III ten-day periods of October and in the III ten-day period of March. Samples for construction of moisture profiles were taken in the process of manual drilling to the depth of groundwater table and processed by the thermostat-weight method. In the drilled wells the groundwater level was revealed in parallel by measuring the depth of their occurrence. Snow cover thickness and moisture reserves in it were determined during snow survey in the third ten-day period of March, when maximum snow cover thickness is observed in the Ishim steppe. The temperature of the edaphonic-earth cover was measured with fume thermometers in the depth range of 20–320 cm in parallel with soil sampling for humidity.

RESULTS AND DISCUSSION

It was found that in the lower part of the Ishim steppe soil profiles and in the subsoil stratum the moisture content increases at the end of the winter season compared to the autumn months. The layer of moisture intention in spring grain crops is observed at depths from 40–80 to 160–200 cm, i.e. below the root-habitat layer dried up to wilting moisture and below. Moisture gain in the layer of winter accumulation varies from 10 to 50 mm, while in the upper meter layer of the soils the gain can reach 25 mm. Humidity of the rooting layer and rock strata below the seasonally freezing layer practically does not change during winter. Groundwater level, which is fixed in the second ten-day period of October at depths from 200 to 450 cm, decreases by the third ten-day period of March by 30–90 cm.

To explain the material presented, it is necessary to consider the factors determining winter moisture movement in soils.

The most important factor determining the winter migration of soil moisture is the depth of penetration of 0 °C temperature into eda-

phonic-earth cover. It predetermines the position of the lower boundary and the thickness of the cryogenic moisture accumulation layer. The depth of penetration of 0 °C depends on air temperature and snow cover thickness. At the same snow cover thickness, the depth of 0 °C penetration depends on the air temperature: the lower it is, the greater the depth. For example, in transect 4 in seasons with the same snow cover thickness (26 cm in the third ten-day period of March), the 0 °C penetration depth was 180 (at an air temperature of 13.1 °C) and 200 cm (at a temperature of 14.1 °C). In section 2, at a snow cover thickness of 16 cm and at an air temperature of 14.1 °C, the penetration depth of 0 °C was 240 cm, and at a temperature of 10.4 °C – 210 cm.

Snow cover prevents soil freezing. Thus, during the season with a temperature of 14.1 °C, a snow cover with a thickness of 42 cm caused penetration of 0 °C into the soil of transect 7 to a depth of 190 cm, which is 50 cm less than in transect 2 with a snow cover of 15 cm (penetration depth of 240 cm). During a particular cold season, the penetration depth of 0 °C depends on the snow cover thickness: the greater the thickness, the shallower the penetration depth is.

Thus, due to different air temperatures and unequal snow cover thickness, the depth of penetration of 0 °C into the soil of the same section differs from year to year. However, 0 °C in the third ten-day period of March is always observed in the highly moistened stratum under the layer of summer desiccation. For example, in the soil of transect 2 during three consecutive winter seasons, 0 °C was recorded at depths of 180, 240, and 210 cm. In accordance with the depth of penetration of 0 °C, the position of the layer of seasonal moisture freezing (at 80–160, 80–200 and 90–170 cm) and the addition of moisture in it (29, 42 and 34 mm) change. The distance between the depth of penetration of 0 °C in the III ten-day period of March and the lower boundary of the layer of moisture intention is 20–40 cm. Thus, the greater the depth of penetration of 0 °C, the greater is the vertical

thickness of the freezing layer and the greater is the volume of moisture freezing in it.

The most important factor determining winter movement of soil moisture is the granulometric composition of soils and parent rocks. The granulometric composition determines the predominant forms of moisture in soils and, consequently, the volume of mobile water and conditions of its movement. In the edaphonic-earth cover of the Ishim steppe due to heavy loamy high-silt granulometric composition, film-sticky and sorption-closed moisture dominates; capillary-supported and free gravitational water contains no more than 4–6% of the soil volume with moisture at the level of full water capacity. The small content of capillary and gravitational water causes relatively low values of winter moisture migration in the soils of the Ishim steppe – up to 50 mm. At the same time, winter moisture gain in the 0–100 cm layer of hydromorphic soils of the Barabinsk Plain reaches 80–100 mm.

Another factor important for seasonal moisture migration is high moisture content of the edaphonic-earth cover (80% of the lowest water content (LWC) and higher). Moisture migration is manifested at such high moisture content. Significant moisture content of soils and rocks is predetermined by the granulometric composition and high position of groundwater (lying at a depth of 200–450 cm) due to their anthropogenic rise in the second half of the twentieth century.

Moisture accumulation in the seasonally frozen layer does not cause drying of subpermafrost strata; moisture withdrawal from them is compensated by capillary moisture inflow from groundwater, causing their lowering. If groundwater in October is observed at the depths from 200 to 450 cm, the moisture gain in the freezing layer in the soils of the Ishim steppe is proportional to the groundwater level drop during October–March (see the figure).

Thus, within the Ishim steppe, the most important factors predetermining the volume of cryogenic moisture accumulation in the seasonally freezing layer are the position of groundwa-

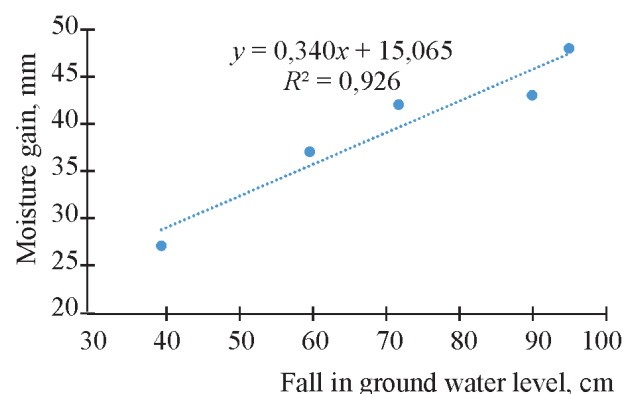
ter close to the earth's surface and the associated high initial humidity of the seasonally freezing strata. A similar situation is observed in heavy loamy soils of the Barabinsk Plain, as well as in sandy loam soils of the Kulunda Plain.

To predict the parameters of winter moisture movement in the edaphonic-earth cover of the Ishim steppe, it is possible to be guided by the autumn depth of groundwater table and dynamics of its level during October–March. Summer and then autumn position of groundwater level on arable land for spring cereals depends on the sum of atmospheric precipitation of the previous winter season. For 2009–2022 the following proportionality between the sum of winter precipitation (x , mm) and groundwater table depth (y , mm) was obtained, for example, for the reference transect 7:

$$y = -0,0125x + 4,6362$$

at reliability of approximation $R^2 = 0,8327$.

If in the second and third ten-day periods of October ground waters are observed at the depths of more than 3 m, then in the soil profiles of spring grain crops the layer of summer drying is fixed up to the depth of 80 cm. Therefore, the layer of moisture intrusion in March is traced from the depth of 80 cm; its vertical thickness may exceed 100 cm. The groundwater table drop by March is 30–70 cm; the volume of



Пропорциональность между падением уровня грунтовых вод в течение октября – марта и прибавкой влаги в слое намерзания (2017–2018 гг.)

Proportionality between groundwater level drop during October – March and moisture gain in the freezing over layer (2017–2018)

moisture accumulation in the seasonally freezing layer reaches 15–30 mm; in the upper meter layer the moisture increase during winter is unlikely to occur.

At groundwater position in the middle of October at the depths of less than 3 m, the thickness of summer evapodesic drying layer will be less than 80 cm. For example, at groundwater table 290 cm the layer thickness will reach 70 cm, at 210 cm – 40 cm, etc. In such cases (for the same crops of spring cereals), the lower boundary of the summer evapodrying layer is marked at different levels (from 40 to 80 cm), so the layer of moisture intrusion can be different in thickness at the same depth of penetration of 0 °C into the edaphonic-earth cover. Moisture content in the seasonally frozen layer increases by 30–50 mm, including by 10–25 mm in the upper meter layer. A more accurate answer regarding the volume of frozen moisture can be obtained in the third ten-day period of March not only by comparing layer-by-layer moisture reserves in the edaphonic-earth cover, but also on the basis of groundwater level decrease during October–March, which is 40–90 cm. When the level drops by 40 cm, the moisture gain in the freezing layer reaches 25–30 mm, when the level drops by 90 cm, the gain will increase to 50 mm.

As a result, the moisture content in the freezing layer may exceed the water table. If in autumn groundwater is observed at the depths of more than 3 m, in spring and early summer, due to soil warming, a part of the moisture frozen above the level of the lowest water content flows to deeper layers; a part in the form of capillary-suspended moisture remains in place, thus creating conditions for anaerobiosis and development of modern subsurface hydromorphism. If in autumn groundwater is located above 3 m, due to freezing, moisture content can exceed the lowest water content level in the lower part of the 0–100 cm layer. However, in spring and early summer time moisture content reduction to the optimal level at the depth of 60–100 cm, as a rule, does not occur due to the close position of mineralized groundwater (occurring at the depth of 150–250 cm). Due to high humidity and close

position of mineralized groundwater in the layer of 60–100 cm aeration porosity often falls to critical values (less than 10%), there is a high concentration of easily soluble compounds (up to 1% and higher). These factors predetermine unfavorable conditions for the development of root systems of spring grain crops, create conditions for the emergence of anaerobiosis and manifestations of hydromorphism.

Thus, at present, in the Ishim steppe, when spring grain crops dominate in the crop structure, moisture freezing in the seasonally freezing layer of the edaphonic-earth cover is rather a negative factor complicating the development of root systems of spring grain crops at close groundwater table (at a depth of less than 3 m in the autumn period).

CONCLUSION

As a result of the analysis, the influence of three main factors on winter moisture movement in seasonally frozen soils of the research area has been traced out.

The vertical thickness and position of the lower boundary of the moisture intrusion layer are predetermined by the penetration depth of 0 °C. The penetration depth of 0 °C is determined by the air temperature of winter months and snow cover thickness and reaches 170–240 cm.

Forms of dominant soil moisture are related to the granulometric composition of soils and rocks. In heavy loamy high silty strata of the Ishim steppe film moisture prevails. Capillary and free gravitational water in microporous strata contains no more than 4–6% of the soil volume with moisture at the level of full water holding capacity. Therefore, the size of cryogenic water accumulation in the seasonally freezing layer of the Ishim steppe is generally smaller than in sandy loam and loamy soils of Kulunda and Baraba.

Moisture movement is characteristic of highly moistened horizons. High autumn moisture content of the edaphonic-earth cover under the rooting layer of spring cereals dried up to wilting moisture and below is connected with their granulometric composition and with close oc-

currence of groundwater. The volume of freezing moisture and location of cryogenic accumulation layer in the edaphonic-earth cover are predicted by autumn groundwater position.

Moisture freezing during winter is not important in replenishing the moisture deficit in the root-inhabited layer of soils in spring grain crops. However, its role in creating conditions of anaerobiosis and development of hydromorphism in the lower part of soils and in the sub-soil stratum remains noticeable.

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К 85-летию Виталия Алексеевича Бекенёва



Главному научному сотруднику лаборатории разведения свиней Сибирского научно-исследовательского и проектно-технологического института животноводства СФНЦА РАН, доктору сельскохозяйственных наук, профессору, заслуженному деятелю науки РФ Виталию Алексеевичу Бекенёву 23 августа исполнилось 85 лет.

Виталий Алексеевич родился в 1939 г. в д. Дельгей Олёкминского района Якутской АССР в крестьянской семье.

После окончания средней школы в 1957 г. поступил на зоотехническое отделение сельскохозяйственного факультета Якутского государственного университета. В 1960 г. был направлен для продолжения учебы и подготовки преподавательских кадров для ЯГУ на зоотехнический факультет Московской ветеринарной академии, которую окончил в 1962 г., получив специальность «ученый зоотехник». С 1962 по 1963 г. Виталий Алексеевич работал на производстве зоотехником, заведующим птицефермой совхоза «Хатасский» Якутской АССР. В 1963 г. поступил в аспирантуру Сибирского научно-исследовательского института животноводства. Научным руководителем его был директор института член-корреспондент ВАСХНИЛ М.О. Симон. Кандидатскую диссертацию «Влияние адаптивных свойств на проявление эффекта гетерозиса при скрещивании свиней» Виталий Алексеевич защитил в 1968 г. на объединенном ученом совете по биологическим наукам в Институте цитологии и генетики СО РАН СССР по специальности «генетика».

С 1967 г. Виталий Алексеевич работал в СибНИИЖе сначала старшим, затем ведущим научным сотрудником, заведующим сектором, отделом технологии производства свинины, с 1989 по 2014 г. – отделом разведения и генетики сельскохозяйственных животных, с 2015 г. по настоящее время – главным научным сотрудником, заведующим лабораторией разведения свиней. Работает в институте без перерыва 60 лет.

После организации Сибирского отделения ВАСХНИЛ был первым председателем Совета молодых ученых, членом Совета молодых ученых при ЦК ВЛКСМ.

В 1990 г. Виталий Алексеевич защитил во Всероссийском научно-исследовательском институте генетики и разведения сельскохозяйственных животных докторскую диссертацию «Совершенствование генетического потенциала и адаптации свиней в условиях интенсификации отрасли» по специальности 06.02.01 «Разведение, селекция и воспроизводство сельскохозяйственных животных».

В.А. Бекенёв – специалист в области разведения, селекции и генетики сельскохозяйственных животных, технологии производства продуктов животноводства, автор 283 научных работ, из них 12 рекомендаций, 8 монографий и 14 авторских свидетельств и патентов, в том числе 3 – на селекционные достижения. Им опубликованы монографии «Селекция свиней», «Животноводство в крестьянском хозяйстве», «Технология разведения и содержания свиней», «Генетические методы в селекции свиней», «Вездесущие свободные радикалы в здоровье, репродукции, животноводческой продукции».

В системе цитирования Web of Science и Scopus опубликовано 24 статьи, в журналах США, КНР, ОАЭ, Швейцарии, Индии, Румынии – 11 статей.

Основные научные результаты В.А. Бекенёва: разработаны рекомендации по улучшению мясных качеств свиней путем промышленного скрещивания с породами мясного направления продуктивности; предложена новая гипотеза объяснения явления гетерозиса; усовершенствованы существующие и созданы новые способы улучшения адаптации животных и стрессоустойчивости в условиях интенсивных технологий промышленных комплексов; разработаны новые дозы ультрафиолетового облучения свиней в условиях промышленной технологии, позволяющие улучшать плодовитость свиноматок, жизнеспособность и интенсивность роста приплода; впервые обнаружены резкие отличия некоторых пород по уровню свободнорадикального окисления их тканей, связанные с различным содержанием жира в тушах и жирных кислот и холестерина – во внутримышечном жире и сале; показано ухудшение качества мясных продуктов при наличии в структуре большого количества полиненасыщенных жирных кислот, особенно линолевой и липопротеинов низкой плотности, которыми богата свинина некоторых импортных пород; выявлено, что такие антиоксиданты, как каталаза и тиоловые соединения, содержащиеся в крови хряков и свиноматок, способны противодействовать разрушающему воздействию активных форм кислорода при оплодотворении, влиять на плодовитость, массу гнезда при опоросе; впервые экспериментальным путем получено доказательство, что свиной жир, содержащий больше насыщенных жирных кислот, но меньше полиненасыщенных жирных кислот, особенно линолевой жирной кислоты и холестерина, положительно влияет на продуктивность и сердечно-сосудистую систему, снижает атерогенный индекс; его предложения включены в информационно-технический справочник по наилучшим доступным технологиям ИТС 41–2023 «Интенсивное разведение свиней».

Виталий Алексеевич участвует в подготовке кадров высшей квалификации, неоднократно был председателем ГАК в НГАУ, подготовил девять кандидатов наук и два доктора наук. Неоднократно был членом советов по защите докторских и кандидатских диссертаций, является научным экспертом РАН. В течение нескольких лет был членом научно-технического совета при отделении животноводства и ветеринарии Россельхозакадемии.

С сообщениями о результатах своих научных работ В.А. Бекенёв выступал на многих все-союзных, а также международных конференциях, в том числе в Северо-Восточном сельскохозяйственном университете Китая, в Пенсильванском и Мичиганском университетах США.

В 1989 г. В.А. Бекенёву присвоено звание «Заслуженный деятель науки РФ». Номинировался кандидатом в члены-корреспонденты РАН по Отделению сельскохозяйственных наук.

Награжден золотой медалью «Лауреат ВВЦ» РФ, медалями им. И.И. Синягина, «40 лет СО Россельхозакадемии 1969–2009», «80 лет Новосибирской области», «Заслуженный ветеран СО РАН».

Коллектив СибНИПТИЖа СФНЦА РАН поздравляет Виталия Алексеевича с юбилеем и желает крепкого здоровья, благополучия, новых успехов в профессиональной деятельности и многих лет интересной работы.

AUTHOR GUIDELINES

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

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

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

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

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

RECOMMENDATIONS TO THE AUTHOR BEFORE SUBMITTING AN ARTICLE

Submission of an article to the journal “Siberian Herald of Agricultural Science” implies that:

an article has not been published before in any other journal;
an article is not subject to review in any other journal;
all co-authors agree with the publication of the current version of the article.

Before submitting an article, it is necessary to make sure that the file (files) contains all the information required in Russian and English, tables and figures provide the source of the information presented, all references are written correctly.

PROCEDURE FOR SENDING MANUSCRIPTS OF ARTICLES

1 Submission of the article is carried out through the electronic editorial board on the journal's website <https://sibvest.elpub.ru/jour/index>. After preliminary registration of the author, choose the option "Send a manuscript" in the upper right corner of the page. Then download the manuscript (in *.doc or *.docx format) and the accompanying documents. When you have finished uploading, be sure to select the option "Send a Letter", in which case the editorial board will be automatically notified of the receipt of the new manuscript.

Accompanying documents to the manuscript of an article:

- a scanned copy of a letter from the organization confirming authorship and permission to publish (sample cover letter);
- a scanned copy of the author's note in the form provided (sample author's note), in which consent must be expressed for the open publication of the article in the printed version of the journal and its electronic copy in the Internet;
- a scanned copy of the manuscript with the authors' signatures. The author, by signing the manuscript and sending it to the editorial office, thereby transfers the copyright for the publication of this article to SFSCA RAS;
- author questionnaires in Russian and English (sample author questionnaire);
- a scanned copy of your post-graduate school transcript (for full-time postgraduate students).

2. All manuscripts received by the editorial board are registered via the electronic editorial system. The author's personal account shows the current status of the manuscript.

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

ARTICLE DESIGN PROCEDURE

The text of the manuscript is printed in Times New Roman font, type size 14 with 1.5 spacing, all margins 2.0 cm, page numbering at the bottom. The size of a manuscript should not exceed 15 pages (including tables, illustrations and bibliography); the articles placed in the sections "From dissertations" and "Brief reports" should not exceed 7 pages.

Article design structure:

UDC

2. Title of an article in Russian and English (no more than 70 characters).

3. Surnames and initials of the authors, full official name of the scientific institution where the research was conducted in Russian and English.

If authors from different institutions took part in the preparation of the article, it is necessary to indicate the affiliation of each author to a particular institution using the superscript index.

4. Abstract in Russian and English. The size of the abstract should not be less than 200-250 words. The abstract is a brief and consistent presentation of the material of the article on the main sections and should reflect the main content, follow the logic of the presentation of the material and description of the results in the article with the provision of specific data. The abstract should not include the newly introduced terms, abbreviations (with the exception of common knowledge), references to the literature. The abstract should not emphasize the novelty, relevance and personal contribution of the author; the place of research should be indicated to the district (region), specific organizations should not be mentioned.

5. Keywords in Russian and English. There should be up to 5–7 words by the topic of the article. It is desirable that the keywords support the abstract and the title of the article.

6. Information on the conflict of interests or its absence. The author should notify the editor on the real or potential conflict of interests by including the information in the appropriate section of the article. If there is no conflict of interests, the author should also inform the editor about it.

Example wording: "The author declares no conflict of interest".

7. Acknowledgements in Russian and English. This section lists all sources of funding for the study, as well as acknowledgements to people who contributed to the article but are not the authors.

8. The main body of the article. When presenting original experimental data, it is recommended to use subheadings:

INTRODUCTION (problem statement, goal and tasks of the study)

MATERIAL AND METHODS (conditions, methods (methodology) of research, object description, place and time of research)

RESULTS AND DISCUSSION

CONCLUSION

REFERENCES. The number of sources must be at least 15. The list of references includes only peer-reviewed sources: articles from scientific journals and monographs. Self-citation of no more than 10% of the total number. The bibliography list should be designed as a general list in the order of mention in the text, it is desirable to refer to sources 2-3 years old. The rules for the list of references are in accordance with GOST R 7.05-2008 (requirements and rules for compiling a bibliographical reference). In the text the reference to the source is marked by a serial number in square brackets, for example [1]. Literature in the list is given in the languages in which it was published. In the bibliographic description of the publication, it is necessary to include all authors, without abbreviating them by one, three, etc. It is unacceptable to abbreviate the names of articles, journals, publishing houses.

1. If it is necessary to refer to abstracts, dissertations, collections of articles, textbooks, recommendations, manuals, GOSTs, information from websites, statistical reports, articles in socio-political newspapers, etc., such information should be placed in a footnote at the end of the page. Footnotes are numbered in Arabic numerals and placed page by page through continuous page numbering.

Attention! Theoretical, review and problem articles can have any structure, but must contain an abstract, keywords, list of references.

EXAMPLE OF REFERENCES in Russian and English and FOOTNOTES

REFERENCES (in Russian):

Monograph

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

Part of a book

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

Periodical publication

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

REFERENCES (in English):

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

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

Example: Author A.A., Author B.B., Author C.C. Title of article.

Transliteration of the authors. English title of the article.

Zaglavie jurnala = Title of Journal, 2012, vol. 10, no. 2, pp. 49–54.

Transliteration of the source = English name of the source

Monograph

Klimova E.V. *Field crops of Zabaikalya*. Chita, Poisk Publ., 2001, 392 p. (In Russian).

Part of a book

Kholmov V.G. Minimum tillage of coulisse-strip fallow for spring wheat with intensification of arable agriculture in southern forest-steppe of Western Siberia. *Resource-saving tillage systems*, Moscow, Agropromizdat Publ., 1990, pp. 230–235. (In Russian).

Periodical publication

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FOOTNOTES:

Quoted text,

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

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Chu T., Starek M.J., Brewer M.J., Murray S.C., Pruter L.S. Assessing lodging severity over an experimental maize (*Zea mays* L.) field using UAS images // Remote Sensing. 2017. Vol. 9. P. 923. DOI: 10.3390/rs9090923.

The DOI of the article should be checked on the website <http://search.crossref.org/> or <https://www.citethisforme.com>. To do this, enter the title of the article in English in the search bar.

FIGURES, GRAPHS, TABLES, SCREENSHOTS, PHOTOGRAPHS AND FORMULAS

The figures must be of good quality, suitable for printing. All figures must have captions. The caption must be translated into English. Figures should be numbered in Arabic numerals according to the order in the text. If there is only one figure in the text, it is not numbered. References to figures should be formatted as follows: “Fig. 3 indicates that ...” or “It is indicated that ... (see Fig. 3)”. The caption under the figure includes a figure number and its title. “Figure 2. Description of vital processes.” The translation of the figure caption should be placed after the figure caption in Russian.

Tables should be of good quality, suitable for printing. Tables suitable for editing are preferred, not scanned or as figures. All tables should have headings. The title of the table should be translated into English. Tables should be num-

bered in Arabic numerals according to the order in the text. If there is only one table in the text, it is not numbered. References to tables should be formatted as follows: "Table 3 states that ..." or "It is stated that ... (see Table 3)". The title of the table includes a table number and its title: "Table 2. Description of Vital Processes." The translation of the table title should be placed after the table title in Russian.

Photos, screenshots must be uploaded separately as files of the following format*.jpeg files (*.doc and *.docx if the image has additional marks). The resolution of the image should be >300 dpi. The image files should be given a name corresponding to the figure number in the text. In the description of the file a caption should be given separately, which should correspond to the name of the picture placed in the text.

Graphs, charts, histograms, etc. should be attached as a separate file in Microsoft Excel program.

Attention should be paid to the spelling of formulas in the article. All formulas must be editable, i.e. it must be possible to make changes to them. To avoid confusion, it is necessary to write Greek (α , β , π , etc.), Russian (A, a, B, b, etc.) letters and numbers in straight font, Latin letters in italics (*W*, *Z*, *m*, *n*, etc.). Mathematical signs and symbols should also be written in straight font. It is necessary to clearly indicate upper and lower superscript characters (W_1 , F_1 , etc.).

INTERACTION BETWEEN THE JOURNAL AND THE AUTHOR

The Editorial Board asks the authors to be guided by the above stated rules when preparing the article.

All the articles submitted to "Siberian Herald of Agricultural Science" go through preliminary check for compliance with formal requirements. At this stage the Editorial Board reserves the right to:

- accept the article for review;
- return the article to the author (authors) for revision with a request to correct the mistakes or add the missing data;
- return the article which is designed not according to the journal's requirements to the author (authors) without consideration;
- reject the article due to its inconsistency to the journal's goals, lack of originality and little scientific significance.

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

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

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

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

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

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

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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:

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

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

ACTIONS OF THE EDITORIAL BOARD IN CASE OF PLAGIARISM AND DATA FALSIFICATION DETECTION

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

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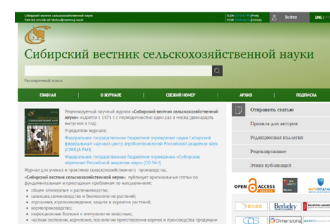
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