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

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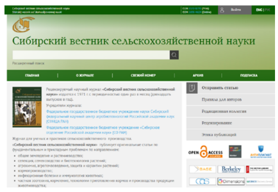

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Совершенствование элементов технологии клонального микроразмножения малины разного типа плодоношения

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Представлены результаты исследований по клональному микроразмножению 17 сортов малины алтайской и европейской селекции. В последнее время исследователи уделяют внимание созданию универсальной питательной среды, которая в равной степени подходила бы для любого сорта определенного вида растений. Особенно это важно при массовом клональном микроразмножении в производственных питомниках. Проведена оценка регенерационного потенциала сортов малины разного типа плодоношения на каждом этапе размножения. На этапе собственно микроразмножения выявлено, что среда Драйвера и Куниюки в нашей модификации превосходила среду Мурасиге и Скуга по длине побегов и составила в среднем 9,0 мм для сортов обычного типа и 12,3 мм для ремонтантных. Это позволило исключить дополнительный этап элонгации микропобегов. Также на новой среде улучшился внешний вид микропобегов. Установлено, что для малины независимо от ее типа оптимальные концентрации регуляторов роста лежат в следующем диапазоне: цитокинин 6-бензиламинопурин (БАП) 2,5–3,5 мкМ совместно с ауксином ß-индолилмасляной кислотой (ИМК) 0,5–0,7 мкМ. На этапе ризогенеза лучшие результаты показала среда Драйвера и Куниюки с пониженным в 2 раза содержанием всех основных компонентов и с добавлением 2,0 мкМ ИМК при длительности пассажа 21 день. После этого все микрочеренки с корнями и без корней проходили этап адаптации – доращивания в нейтральных субстратах в течение 56 дней в условиях *ex vitro* вегетационной комнаты. В большинстве случаев не отмечено статистически достоверных различий по длине и количеству листьев независимо от наличия или отсутствия корней на начальной стадии адаптации. К концу этого этапа получено 100% адаптированных растений малины обычного типа плодоношения и 98% – ремонтантного.

Ключевые слова: малина, клональное микроразмножение, *in vitro*, ризогенез, адаптация, *ex vitro*, доращивание

Improvement of the clonal micro-propagation technology elements for raspberries of various fruiting types

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The results of research on clonal micropropagation of 17 raspberry varieties of the Altai and European selection are presented. Recently, researchers have been focusing on creating a universal nutrient medium that would be equally suitable for any variety of a particular plant species. This is especially important for mass clonal micropropagation in production nurseries. The regeneration potential of the raspberry varieties of different types of fruiting at each stage of reproduction has been assessed. At the stage of actual micropropagation, it was found that Driver and Kuniyuki medium in our modification was superior to the Murashige and Skoog medium in terms of the shoot length and averaged 9.0 mm for common type varieties and 12.3 mm for remontant varieties. This made it possible to eliminate the additional stage of elongation of the microshoots. Also, the appearance of microshoots improved on the new medium. It was found that for raspberry, regardless of its type, the optimal concentrations of the growth regulators lie in the following range: cytokinin 6-benzylaminopurine (BAP) 2.5–3.5 μM together with auxin ß-indolyl butyric acid (IBA) 0.5–0.7 μM. At the stage of rhizogenesis, the best results were shown by the Driver and Kuniyuki medium with 2-fold reduced content of all main components and with the addition of 2.0 μM IBA at the passage duration of 21 days. After that, all microcuttings with and without roots underwent the adaptation stage – growth completion in neutral substrates for 56 days under *ex vitro* conditions in a vegetation room. In most cases, there were no statistically significant differences in the length and number of leaves regardless of the presence or absence of roots at the initial stage of adaptation. By the end of this stage, 100% of the adapted raspberry plants of the usual type of fruiting and 98% of the remontant type were obtained.

Keywords: raspberry, micropropagation, *in vitro*, rhizogenesis, adaptation, *ex vitro*, completion of growing

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INTRODUCTION

The conditions of Western Siberia with sharply continental climate are more favorable for growing berry crops than fruit crops. Raspberry is of considerable food and medicinal interest among berry crops. The Lisavenko Scientific-Research Institute of Horticulture for Siberia (SRIHS), which is a department of the Federal Altai Scientific Centre of Agro-Biotechnologies, has been engaged in raspberry breeding since the 30s of the XX century up to the present time. 34 raspberry varieties have been created, mainly based on the species of common raspberry (*Rubus idaeus* L.) and its hybrids, adapted to growth and fruiting in the harsh climatic conditions of Siberia. At present, despite the high demand among the population, the production of planting material of new local and introduced raspberry varieties is experiencing certain difficulties. This is due to many reasons of economic and social nature, as well as increased requirements to the quality of the planting material, including the absence of pathogens in it [1].

In vitro clonal micropropagation with the development of specific protocols for specific varieties guarantees the production of healthy planting material of horticultural crops corresponding to the highest quality categories [2]. It is important for industrial clonal micropropagation laboratories to use universal technologies and protocols suitable for varieties of different types and origins. As a rule, researchers create clonal micropropagation protocols for raspberries of only one type of fruiting [3, 4], much less often they work with the varieties of both types [5]. At present, there has been a significant increase in the interest in remontant type raspberries[1], large-fruited varieties of raspberries, blackberries and raspberry-blackberry hybrids of foreign selection among the institutions of various forms of ownership and amateur gardeners, which requires increasing the efficiency of their cloning [6–8].

The purpose of the research is to improve the elements of the technology of clonal micro-propagation of the ordinary and remontant fruit-bearing varieties.

The objectives of the study were to optimize the:

– mineral and hormonal composition of the nutrient medium and the duration of subcultivation at the stage of actual micropropagation;

– hormonal composition of the nutrient medium and the duration of subcultivation at the stage of rhizogenesis;

– *ex vitro* adaptation phase.

MATERIAL AND METHODS

The work was carried out over a period of 4 years (2019-2022) in the Biotechnology and Cytology Laboratory of the SRIHS department using the generally accepted methods [2, 3].

The objects of research - 12 varieties of raspberries of the usual type of fruiting (Aurora, Aquarelle, Barnaulskaya, Dobraya, Zatonskaya, Zorenka Altaya, Illusion, Cassiopeia, Kolokolchik, Credo, Meteor, Trojana) and five remontant varieties (Atlant, Bryanskoye divo, Heracles, Oranzhevoe chudo, Penguin).

Murashige and Skoog medium (MS)[4] and Driver and Kuniyuki medium (DKW)[5] were used as the mineral basis of the nutrient medium, which has not yet found widespread use for fruit and berry crops, except for individual examples of their use for clonal micropropagation of stone fruit crops [9] and for raspberry [5]. At the rhizogenesis stage, modified DKW medium with half concentration of the main components was used. Growth regulators (GRs) were added to the media: in the experiments at the actual micropropagation stage – 6-benzylaminopurine (BAP) 1.5–7.0 μM with indolyl-3-butyric acid (IBA) 0.14–1.4 μM; at the rhizogenesis stage – IBA 2.0–4.0 and α-naphthylacetic acid (NAA) 0.4–0.8 μM; the variant without GRs was used as a control [10, 11]. Cultivation conditions were as described in the methods (see footnotes 2, 3). The experiment scheme was as follows: three explants per each repetition, five repetitions per each variant. The results were obtained for one subcultivation.

At the stage of adaptation of microplants to *ex vitro* conditions, a neutral soil mixture of river sand and vermiculite in the ratio of 3 : 1, sterilized in an autoclave for 1 h at 2 atm, was used. The plants were planted one by one in a 200 ml container. The containers were covered with a transparent hood for the first 14 days. The adaptation period lasted 56 days, during which the following scheme of mineral fertilization was applied every 14 days: KH_2PO_4 solution (3.5 g/l, pH = 6.0); mineral salt solution according to DKW prescription (pH = 6.0); salt solution 1/2 DKW (pH = 6.0). Fourteen days after the last feeding (on the 56th day), the survival ability and the shoot length were recorded.

RESULTS AND DISCUSSION

To date, the methods of clonal micropropagation have been developed for more than 2400 plant species, however, the optimization of *in vitro* culture conditions is required for each species and even varieties (see footnotes 4, 5). The main way to optimize the mineral composition of the nutrient media for berry crops is to vary the content of individual elements – calcium,

[1]*Kazakov I.V., Sidelnikov A.I., Stepanov V.V.* Remontant raspberry in Russia. Chelyabinsk: House of Press, 2010, 136 p.

[2]*Solovykh N.V.* The use of biotechnological methods in work with berry crops: method. recommendations. Michurinsk: Publishing house of Michurinsk SAU, I.V. Michurin All-Russian Research Institute of Fruit Crop Genetics and Breeding, 2009, 47 p.

[3]*Dunaeva S.E., Pendinen G.I., Antonova O.Yu. et al*. Preservation of vegetatively propagated crops *in vitro* and cryo-collections: method. instructions. St. Petersburg, 2011, 64 p.

[4]*Muratova S.A., Solovykh N.V., Terekhova V.I.* Induction of morphogenesis from isolated somatic tissues of plants. Michurinsk: MSAU, 2011, 107 p.

[5]*Hunkova Ju., Libiakova G., Gajdosova A*. Shoot proliferation ability of selected cultivars of Rubus spp. as influenced by genotype and cytokinin concentration // Journal of Central European Agriculture, 2016, N. 17, pp. 379–390. DOI: 10.5513/JCEA01/17.2.1718.

magnesium, phosphorus[6], forms of nitrogen (ammonium or nitrate)[7].

At the stage of actual micropropagation, DKW medium was found to be superior to the MS medium in terms of average shoot length in the variant with 1.5 µM BAP and 0.3 µM IBA by 55% (see the Table). Significant differences in the effect of the mineral composition on the reproduction factor were not found, which was also noted in their experiments by researchers from Romania [5].

DKW medium was superior to the MS in terms of qualitative indicators of explants appearance: visually, the shoots had large leaves of saturated green color, which probably indicates the normal course of physiological processes in the plant and enhanced photosynthetic activity due to the balanced mineral composition of the DKW medium (see Fig. 1).

Рис. 1. Микропобеги малины сорта Акварель на среде DKW (слева) и на среде MS (справа) с БАП 1,5 + ИМК 0,3 мкМ

Fig. 1. Microshoots of the raspberry cultivar Aquarelle on the DKW medium (left) and on the MS medium (right) with 1.5 µM BAP + 0.3 µM IBA

In addition to macro- and microelements of the nutrient medium, exogenous growth regulators, their type, concentration and ratio have an undeniable influence on the processes of proliferation and regeneration in *in vitro* tissue culture [3-5]. As a result of the experiment, it was found that for raspberry, regardless of the type of fruiting, the optimal growth regulator concentrations lie in the range of 2.5 – 3.5 µM BAP together with 0.5 – 0.7 µM IBA, which is consistent with the results of other researchers. On this medium, the multiplication rate varied from 5.5 to 8.0 units/explant in common raspberry varieties and from 7.0 to 8.5 units/explant in remontant varieties. The length of microshoots in the common type varieties was 9.0 ± 0.5 mm, in the remontant varieties – 12.3 ± 1.6 mm, which makes

Влияние минеральной основы питательной среды и концентрации регуляторов роста на развитие эксплантов малины

The influence of the mineral base of the nutrient medium and the concentration of growth regulators on the development of raspberry explants

Growth regulators, µM		Number of shoots, pcs.		Average shoot length, mm	
BAP	IBA	MS	DKW	MS	DKW
0,7	0,14	2,8 ± 0,6	2,6 ± 0,9	8,1 ± 1,3	10,8 ± 2,5
1,5	0,30	3,3 ± 0,8	4,8 ± 1,2	7,4 ± 1,5	11,5 ± 2,4
2,0	0,40	3,7 ± 0,9	3,9 ± 1,1	6,6 ± 1,4	9,4 ± 2,5
3,5	0,70	4,6 ± 1,2	4,9 ± 1,1	6,7 ± 1,6	10,0 ± 1,9
5,0	1,00	4,0 ± 1,0	5,3 ± 1,7	6,5 ± 1,3	9,5 ± 2,0
7,0	1,40	3,3 ± 1,0	4,2 ± 1,0	5,0 ± 1,5	8,3 ± 1,8

Note. 10 varieties of raspberries were used – Aquarelle, Atlant, Barnaulskaya, Hercules, Dobraya, Zorenka Altaya, Kolokolchik, Credo, Penguin, Bryanskoye divo.

[6]*Poothong S., Reed B.M.* Increased $CaCl_2$, $MgSO_4$ and KH_2PO_4 improve the growth of micropropagated red raspberries // In Vitro Cellular & Developmental Biology – Plant, 2015, vol. 51, pp. 648–658. DOI: 10.1007/s11627-015-9720-y.

[7]*Poothong S., Reed B.M.* Optimizing shoot culture for Rubus germplasm: the effects of NH_4^+, NO_3^- and total nitrogen // In Vitro Cellular & Developmental Biology – Plant, 2016, vol. 52, pp. 265–275. DOI: 10.1007/s11627-016-9750-0.

them suitable for rooting without the elongation stage (see Fig. 2).

Many researchers note that raspberry explants after the stage of actual propagation have very short shoots, which complicates their further rooting. Therefore, they suggest additional cultivation to elongate the shoots (elongation stage) and then root them, or combining the elongation and rhizogenesis stages [4].

The effect of subcultivation duration (45 and 60 days) on the reproduction factor and the length of microshoots was studied in our research. It was found that the period of 60 days gives the best results, while other researchers found that the passage duration varied only from 30 to 45 days [3, 13].

Microcuttings suitable for rooting were transferred to the auxin-supplemented media. At this stage, varietal specificity was manifested. The difference in response to auxins was particularly pronounced between ordinary and remontant raspberries. Raspberry varieties of the ordinary type had good rhizogenesis indicators; by the 21st day of cultivation, on average, 50% of the total number of microcuttings were already rooted. Remontant varieties reacted very weakly to auxins and by the 21st day only 7.8% of microcuttings were rooted. Further cultivation on the medium with auxins (31 days) slightly increased the number of microcuttings with roots, but no statistically significant difference (at the significance level of $p = 0.05$) was found. At the stage of rhizogenesis, the best results were shown by the medium with the addition of 2.0 μM IBA (see Fig. 3).

As a rule, researchers use for adaptation only rooted microplants or microcuttings immediately after the micropropagation stage without rhizogenesis *in vitro* [12-14]. In our experiments, all regenerant plants (with and without roots) underwent the adaptation stage in the soil substrate to evaluate the aftereffect of auxins at the *in vitro* rooting stage.

According to the requirement of GOST R 54051-2010, the duration of the adaptation stage is at least 30 days, and then the plants are further grown in greenhouse conditions. We combined the stage of adaptation and completing of growing into one stage, holding it in the vegetation room. The auxin aftereffect at the adaptation and completing of growing stage was not established for any of the rhizogenesis media variants. Regenerant plants, planted for adaptation with and without roots did not have statistically significant differences in the shoot length after completion of further growing in most varieties. No significant differences were observed in the number of leaves per shoot. Differences in the shoot length were observed only in some varieties (Barnaulskaya, Kolokolchik, Credo, Atlant, Heracles, Penguin), which is probably due to their genotypic features (see Fig. 4).

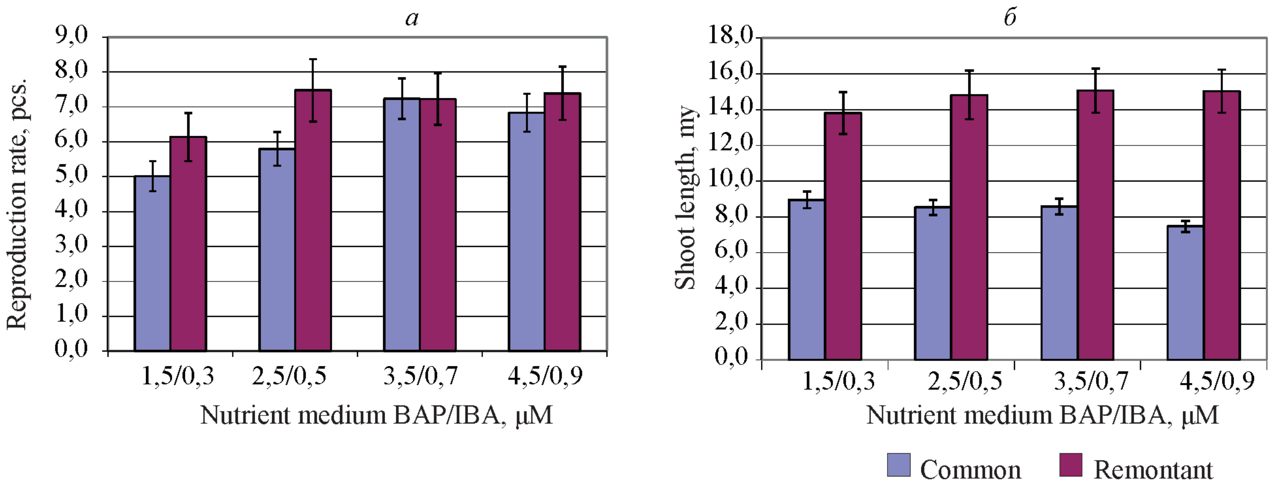

Рис. 2. Влияние регуляторов роста на коэффициент размножения (*а*) и длину побегов (*б*) малины разного типа плодоношения

Fig. 2. Effect of growth regulators on the reproduction rate (*а*) and shoot length (*б*) of raspberries of different fruiting types

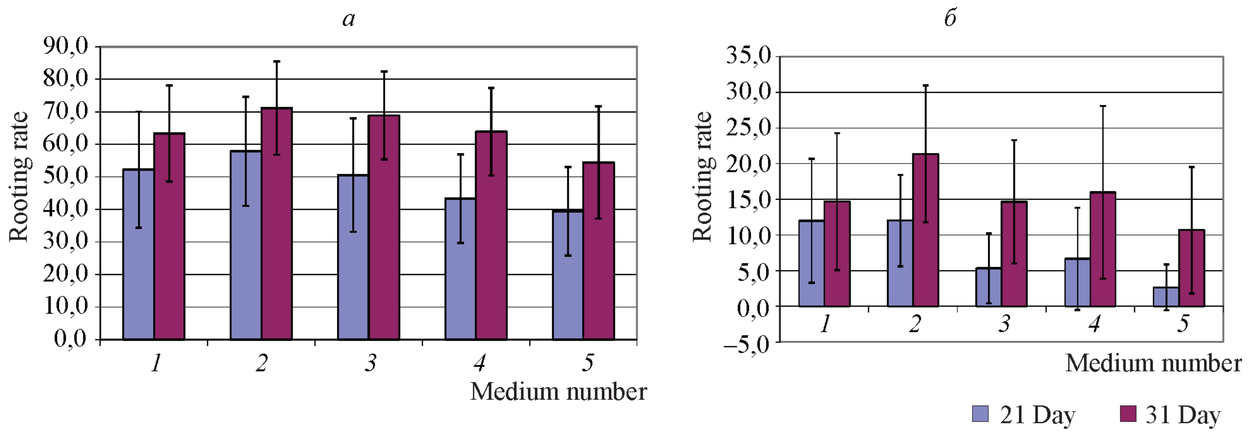

Рис. 3. Укоренение сортов малины на разных питательных средах на 21-й и 31-й день культивирования: *а* – обычные сорта; *б* – ремонтантные:
1 – без регуляторов роста; *2* – ИМК 2,0; *3* – ИМК 2,0 + НУК 0,4; *4* – ИМК 4,0; *5* – ИМК 4,0 + НУК 0,8 мкМ

Fig. 3. Rooting of raspberry varieties on different nutrient media on the 21st and 31st day of cultivation: *a* - conventional varieties; *б* - remontant varieties:
1 – without growth regulators; *2* – IBA 2.0; *3* – IBA 2.0+NAA 0.4; *4* – IBA 4.0; *5* – IBA 4.0+NAA 0.8 μM

The obtained plants of all the studied varieties on the 30th day and further exceeded the requirements of GOST R 54051-2010[8] for planting material of this category. By the end of this stage, plants with a closed root system were suitable for planting in the open ground. The yield of plants was 100% for conventional varieties and 98% for remontant varieties.

CONCLUSIONS

1. For the stage of micropropagation of ordinary and remontant type raspberries, it is optimal to use the medium with mineral composition according to DKW prescription at the concentration of growth regulators in the range of 2.5–3.5 μM BAP together with 0.5-0.7 μM IBA and the duration of subcultivation of 60 days.

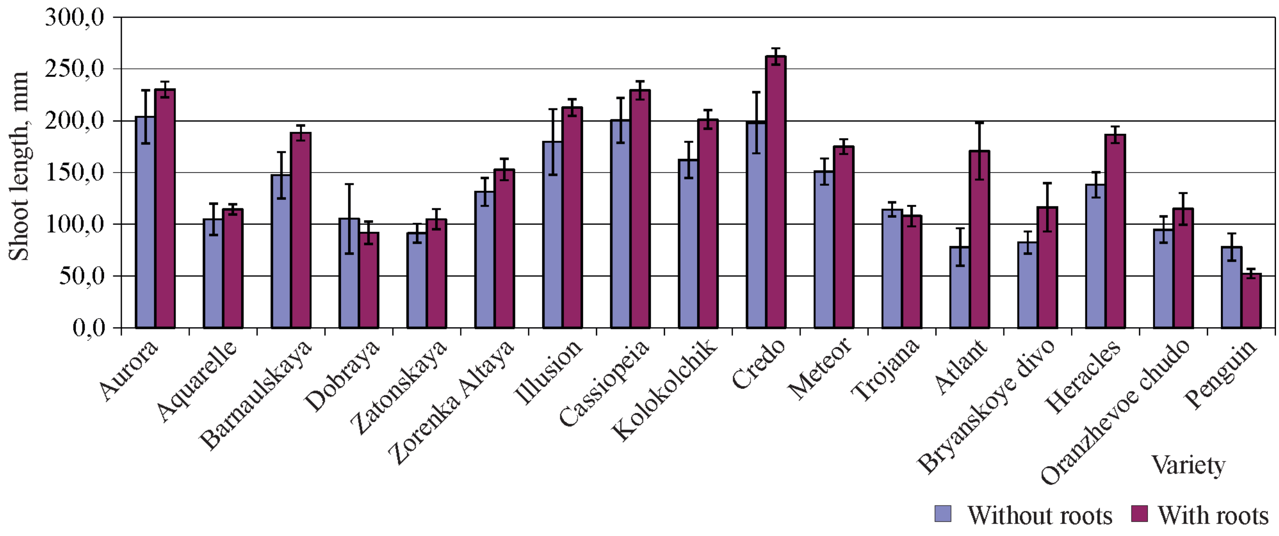

Рис. 4. Длина побегов растений малины после адаптации к условиям *ex vitro* на 56-й день

Fig. 4. The length of raspberry shoots after 56 days of adaptation to *ex vitro* conditions

[8]GOST R 54051-2010. Fruit and berry crops. Sterile crops and adapted microplants. Technical conditions. M.: Standardinform, 2011,12 p.

2. DKW nutrient medium with a half concentration of the main components with the addition of 2.0 μM IBA is optimal for the rhizogenesis stage. It was found that the processes of root formation induction in the studied varieties are completed in the period up to the 21st day, further cultivation on the medium with growth regulators is inexpedient. In this regard, the cultivation period at the rhizogenesis stage is 21 days.

3. At the stage of *ex vitro* adaptation it was found that microshoots with and without roots are equally suitable for planting for adaptation, as microshoots planted for adaptation without roots form them in the substrate, and later after the period of completion of growing do not differ from the plants planted with roots.

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Перспективные гибриды картофеля в Сибири

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Представлены результаты изучения гибридов картофеля в питомниках предварительного и конкурсного сортоиспытания. Исследования проведены в 2018–2022 гг. в Красноярском крае в зернопаропропашном севообороте. Почва опытного участка представлена черноземом выщелоченным, мало- и среднемощным тяжелосуглинистого гранулометрического состава. Закладка опытов, учет урожая и обработка данных проведены согласно общепринятым рекомендациям по работе с культурой. На основе гидротермического коэффициента Селянинова погодные условия вегетационных периодов лет исследований можно охарактеризовать как слабо засушливые. В 2019 и 2021 гг. ГТК составил 1,1, в 2020, 2022 гг. – 1,3. По результатам предварительного сортоиспытания линии А-114, А-326, А-529, А-635а превышали или были на уровне стандартного сорта Красноярский ранний по количеству товарных клубней и урожайности. За 4 года исследований в питомнике конкурсного сортоиспытания изучаемые селекционные линии в среднем сформировали урожайность на уровне или выше стандартных сортов. По элементам структуры урожая в конкурсном сортоиспытании линии А-114, А-529 значительно превышали стандартный сорт по товарности, а также имели меньшее число и массу нетоварных клубней. По результатам оценки в 2019–2021 гг. химического состава клубней для диетического и функционального питания предлагаются линии с низким содержанием крахмала (до 14%): А-114 (12,2%), А-672[a] (9,9), А-635[a] (12,7%). На основании изучения в 2019–2022 гг. линии А-114 в конкурсном испытании, предварительном и производственном размножении, экологической оценки в Госсорткомиссию переданы заявочные материалы на допуск к использованию и охрану нового сорта картофеля Акрукс.

Ключевые слова: картофель, селекция, гибриды, урожайность, содержание крахмала

Promising potato hybrids in Siberia

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The results of studying potato hybrids in the nurseries of preliminary and competitive variety trials are presented. The research was conducted in 2018–2022 in the Krasnoyarsk Territory in grain and fallow crop rotation. The soil of the experimental plot is represented by leached chernozem, low- and medium-moist heavy loam of granulometric composition. Experiment design, yield recording and data processing were carried out in accordance with the generally accepted recommendations for work with the crop. Based on the Selyaninov hydrothermal coefficient, the weather conditions of the vegetation periods of the years of research can be characterized as slightly arid. The HTC was 1.1 in 2019 and 2021, in 2020, 2022 – 1,3. According to the results of the preliminary variety trials, lines A-114, A-326, A-529, A-635a exceeded or were at the level of the standard variety Krasnoyarsky Ranniy by the number of marketable tubers and yield. During 4 years of research in the nursery of competitive varietal trial, the studied breeding lines on average formed yields at the level or higher than the standard varieties. According to the elements of the yield structure in the competitive variety trial lines A-114, A-529 significantly exceeded the standard variety in marketability, as well as had a smaller number and weight of unmarketable tubers. Based on the results of the evaluation in 2019–2021 of the chemical composition of tubers for dietary and functional food, lines with low starch content (up to 14%) are proposed: A-114 (12.2%), A-672[a] (9.9), A-635[a] (12.7%). Based on the study in 2019–2022 of the line A-114 in competitive trials, preliminary and production multiplication, ecological assessment, application materials for admission to use and protection of the new potato variety Akrux were submitted to the State Variety Commission.

Keywords: potatoes, breeding, hybrids, yield, starch content

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INTRODUCTION

Creation of varieties with high yields and good adaptability to the conditions of cultivation, giving the opportunity to spread in different regions of our country – is currently an urgent task in potato breeding. New varieties should have high resistance to late blight, scab, viruses, bacterial diseases, be characterized by good marketable appearance, high taste and safety. The set of cultivated potato varieties is limited in the Krasnoyarsk forest-steppe due to the short frost-free period, low temperatures at the beginning and end of the growing season, early summer droughts. Not all modern varieties combine in their genotype features that make them suitable for cultivation in the region, the need for new potato varieties remains quite high. Breeding for variety adaptability to the conditions of the region is one of the most effective methods to overcome the negative factors[1] [1–10].

The purpose of the research is to identify promising potato lines for state variety testing.

MATERIAL AND METHODS

The research was conducted in 2018-2022 on the basis of the educational and research complex "Borsky" of the Krasnoyarsk State Agrarian University, located in Sukhobuzimsky district, Borsk settlement, 50 km north of the regional center. The experimental fields are located in the closed forest-steppe part of the Krasnoyarsk forest-steppe. The plot for the field experiments is represented by leached chernozem, low- and medium-moist heavy loam of heavy granulometric composition, formed on yellow-brown clay. Soil-agrochemical survey of the site before potato planting showed that the arable layer of chernozem (0-20 cm) was characterized by high humus content (6.3% according to the Tyurin method), very high sum of exchangeable bases (42.5 mmol/100 g), slightly alkaline reaction of soil solution pHn_2o (7.3). The soil was characterized by low nitrate nitrogen (4.68 mg/kg) and ammonium nitrogen (4.54 mg/kg), high mobile phosphorus (269.2 mg/kg), and very high exchangeable potassium (174.4 mg/kg) according to the Chirikov method.

Multiyear value of the Selyaninov HTC in the Sukhobuzimsky district is 1.0. Weather conditions in the years of research based on the HTC data were slightly dry. In 2019 and 2021 the HTC amounted to 1.1, in 2020, 2022 – 1.3, which corresponded to the optimal conditions for heat and moisture availability during the period of the studies.

Potatoes were placed in a four-field grain and fallow crop rotation. Starting from the first tuber generation and until the completion of the breeding process, the samples were grown in the field,

[1]*Adamova A.I., Rodkina O.I.* Effectiveness of evaluation and selection of improved lines for seed production of new and promising potato varieties // Potato breeding. Scientific works, Minsk, 2000, N 10, pp. 208-214.

using the methods and techniques characteristic of the crop technology in production[2, 3]. The first generation was grown with spaced planting (50 cm distance between the clones) to facilitate observation and selection of elite plants. In the second-year hybrid nursery, the selected lines were planted in single-row plots, and standard varieties were used for comparison, placed at 20 sample intervals. The best forms at the next stage were planted in the nursery of the preliminary study in single row plots with repetitions. In the future, the selected lines were transferred to the nursery of competitive trial.

In the preliminary and competitive trial nurseries, planting was carried out with a selection potato planting machine according to the scheme 90 × 40 cm. Full-volume ridges were formed with the AVR Kolnag ridging milling machine. The yield was measured by a combined method. Plots were dug with a two-row mounted selection potato raiser with subsequent manual selection of the tubers. The yield structure was analyzed by counting the number of marketable and non-marketable tubers from the plot, tubers up to 40 g[4] were classified as non-marketable tubers. Experimental data processing was carried out using the program Statistica 13,3[5].

RESULTS AND DISCUSSION

For 23 combinations, 1983 single-tuber hybrids were planted. The initial number of hybrid combinations/tubers was 23/1983.

Lines/hybrid combinations studied in the nurseries:

– second-year hybrid nursery – 633/23;
– preliminary variety trial – 77/20;
– competitive variety trial – 26/11.

The planting was carried out manually on May 28, 2016 in a half ridge formed by a GF-4 milling machine on a 90 × 50 cm pattern. The standard variety Krasnoyarsky Ranniy (maturity group 03) was placed in front of each hybrid combination. Samples of single-tuber hybrids were evaluated for a set of the following traits: resistance to late blight, leaf curling, early blight, compact arrangement of the tubers in the cluster, attractive appearance of the tubers, absence of sprouting, total productivity of the bush, and tuber uniformity. 633 elite plants were selected from the studied breeding material.

In the second-year nursery, the maximum number of the lines was planted by the combination Vasilek × Krepysh (49 families), the minimum – by the combination 117-2 × Irbitsky

Табл. 1. Элементы структуры продуктивности и урожайность картофеля в предварительном испытании в 2018 г.

Table 1. Elements of the productivity structure and potato yield in the preliminary trial in 2018

Sample	Number of tubers in a clone		Average weight of a marketable tuber, g	Marketable yield, kg/m^2	Significance of differences in marketable yield
	marketable	non-marketable			
Krasnoyarsky Ranniy	5,0	3,1	89	2,31	Standard
a-114	6,4	1,2	105	3,10	p = 0,05*
a-529	4,8	0,9	126	3,17	p = 0,00
Tuleevsky	4,1	1,6	131	2,87	Standard
a-326	6,1	1,6	92	3,00	p = 0,72
a-635a	4,8	0,5	135	3,62	p = 0,03

*p = 0,05 – significant differences are highlighted by two-sample t-test, significance level $p < 0,05$.

[2]Methodology of state variety testing of agricultural crops. Potatoes, vegetable and melon crops. Moscow, 2015, Issue 4, 61 p.

[3]*Kiru S.D., Kostina L.I., Truskinov E.V., Zoteeva N.M. et al.* Methodical guidelines for the maintenance and study of the world potato collection. Moscow: SRC VIR named after N.I. Vavilov, 2010, 29 p.

[4]Methodological guidelines for ecological variety testing of potatoes. VASKHNIL, Research Institute of Potato Farming. Moscow, 1982, 16 p.

[5]*Khizhnyak S.V., Puchkova E.P.* Mathematical methods in agroecology and biology. Krasnoyarsk: Publishing house of the Krasnoyarsk State Agrarian University, 2019, 240 p.

(2 families). In the preliminary trial nursery 77 lines of 20 hybrid combinations were planted; the largest number of them (nine) was planted by the hybrid combination Tabor × Kiwi. In the competitive variety trial, 26 lines of 11 hybrid combinations were planted; the maximum number (five) was the combination Irbitsky × Ausonia.

In terms of the number of marketable tubers in the preliminary variety trial, lines A-114, A-326, A-529, and A-635a exceeded or were at the level of the standard varieties (see Table 1).

In terms of marketable tuber weight, the following lines had a reliable advantage over the Krasnoyarsky Ranniy variety (89 g) A-114 – 106 г (p = 0,028), A-529 – 126 г (p = 0,00).

Based on the results of a four-year study, promising lines of different target utilization were isolated from the competitive trial nursery (see Table 2).

On average over the 4 years of study, the breeding lines generated yields at or above the standard varieties.

According to the elements of the yield structure in the competitive variety trial, lines A-114, A-529 significantly exceeded the standard variety in marketability, and also had a lower number and weight of unmarketable tubers, respectively. Line A-326 exceeded the standard Tuleevsky by the number of the tubers in the clone (see Table 3).

According to the results of the correlation analysis, it was found that the number and weight of marketable tubers in a clone have a positive effect on the marketable yield (see Table 4).

During the research of the studied lines, we found the influence of the genotype, year and

Табл. 2. Средняя товарная урожайность перспективных линий картофеля, кг/м^2

Table 2. Average commodity yield of the promising potato lines, kg/m^2

Sample	Yield					Deviation from the standard
	2019	2020	2021	2022	Average	
Krasnoyarsky Ranniy	3,064	1,763	2,045	3,354	2,691	Standard
A-114	4,020	2,513*	1,981	3,706	3,055	0,364
A-529	3,302	1,963	2,651	3,962	2,969	0,278
Tuleevsky	3,463	1,118	2,352	3,329	2,565	Standard
A-326	4,279	1,590	2,168	2,195	2,558	–0,007
A-635a	2,699	1,308	2,615	2,354	2,244	–0,321

*2,513 – significant differences are highlighted at the level of $p < 0{,}05$.

Табл. 3. Элементы структуры урожайности, среднее за 2019–2022 гг.

Table 3. Elements of the yield structure average for 2019–2022.

Sample	Number of tubers per clone		Tuber weight		Tubers per clone, total	Marketability	Weight of one tuber	
	marketable	non-marketable	marketable	non-marketable			marketable	non-marketable
Krasnoyarsky Ranniy	6,07	2,86	779,75	108,39	8,81	65,50	132,63	37,98
A-114	6,34	1,53*	873,41	53,15*	7,88	80,33*	135,58	35,29
A-529	5,95	1,44*	935,61	59,06*	7,39	79,41*	156,14	32,39
Tuleevsky	5,14	2,27	750,08	86,77	7,41	67,62	146,10	36,67
A-326	6,04	2,68	750,26	99,51	8,72*	69,68	128,32*	33,87
A-635a	4,39	1,38*	637,48	55,66*	5,77*	75,01	148,52	36,91

* Significant differences in mean by t-criterion for independent groups are highlighted.

Табл. 4. Коэффициенты корреляции элементов структуры с урожайностью

Table 4. Correlation coefficients of the structure elements with the yield

Variables	Marketable yield, g/m^2
Number of tubers per clone:	
marketable	0,72*
non-marketable	–0,16*
Tuber weight per clone:	
marketable	0,61*
non-marketable	–0,17*
Tubers per clone, total	0,56*
Marketability	0,52*
Weight of one tuber:	
marketable	0,01
non-marketable	–0,07

* Correlations are significant at the level of $p < 0,05$.

their interaction on the elements of potato productivity (see Table 5). Genotype to a greater extent affects the number of marketable and non-marketable tubers in the clone. The influence of the year conditions is reflected in such indicators as the weight of marketable tuber and marketable yield. To reduce the contribution of the year factor to the yield, further breeding improvement of the crop is required.

On average for 3 years of evaluation of the chemical composition of the tubers for dietary and functional nutrition the lines with low starch content (up to 14%) are offered: A-114 (12,2%), A-672 [a] (9,9) A-635[a] (12,7%) (see the figure). The last line is also characterized by the presence of a continuous intense anthocyanin color of the pulp, resistance to cancer and nematodes.

According to the average results of tuber chemical composition evaluation, line A-326 characterized by high starch content and low content of reducing sugars will be included in the preliminary reproduction nursery.

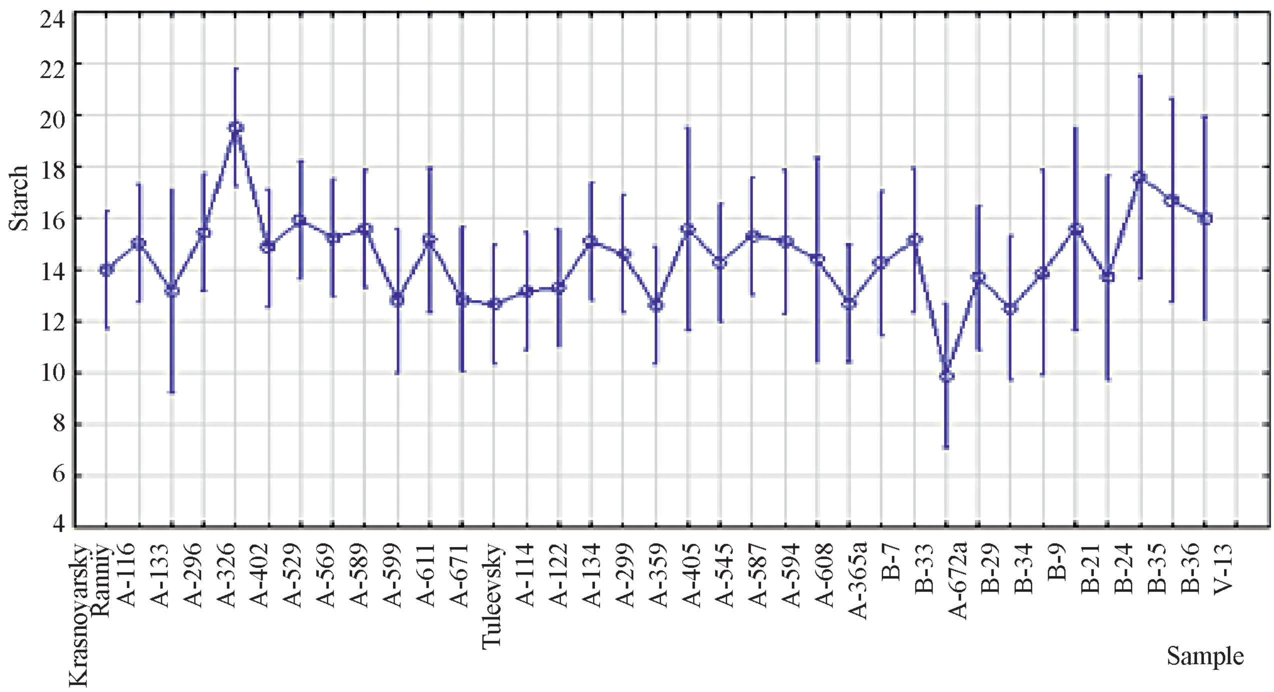
According to the results of evaluation in the competitive trial for 2019-2022, preliminary and production multiplication, ecological evaluation, application materials for admission to use and protection of the new potato variety Akrux, selection No. A-114 were submitted to the State Variety Commission.

A-114 (Irbitsky × Ausonia). The variety of table direction of use, the bush is erect, tall. Flowering is abundant, short-lived, berry formation is rare. The tuber is oblong-oval with red smooth or weakly netted rind, shallow or superficial laying of eyes, yellow flesh. The flavor is good, the digestibility is weak, it does not darken after cooking. Weight of a marketable tuber is 135 g, starch content 13.2%. Marketability at the level of the standard variety Krasnoyarsky Ranniy. The variety is resistant to potato cancer and golden cyst-forming nematode, is weakly affected by scab, rhizoctoniose, tolerant to viruses. According to the results of dynamic tests, the variety is classified in the group of early (early maturing). At harvesting 45 days after full sprouts the marketable yield is 15.5 t/ha with year-to-year fluctuations in the range of 14.4- 28.4 t/ha. At the second record, after 55 days, the yield is 27.8 t/ ha, varies by year from 25.1 to 31.4 t / ha.

Табл. 5. Влияние факторов на элементы продуктивности

Table 5. Influence of factors on the elements of productivity

Элемент продуктивности	Genotype	Year	Interaction
Tubers per clone:			
marketable	35,2	9,7	11,6
non-marketable	21,9	Unreliable	Unreliable
Tuber weight per clone:			
marketable	Unreliable	24	»
non-marketable	14,7	Unreliable	Unreliable
Tubers per clone, total	17	23,5	»
Marketability	12	15,4	22
Marketable tuber weight	Unreliable	31,1	Unreliable
Marketable yield	»	31,1	»



Среднее содержание крахмала в клубнях картофеля
Average starch content in potato tubers

Increase to the standard Krasnoyarsky Ranniy is 1.8 and 3.8 t/ha, respectively, at the first and second registration terms. Marketable yield is 30.6 t/ha, which is 3.7 t/ha higher than the standard.

It has no special requirements to the soil. It is resistant to the action of metribuzin at a dose of up to 750 g/ha in the treatment of the plantings at the height of potato plants 5-10 cm. It develops normally in conditions with heat deficit during the growing season, drought tolerance is average. Overwatering of the soil in the second half of the growing season leads to lenticels growing on the tubers. Shortened dormancy period (90 days) at storage with increased temperature (5-7 ° C) should be attributed to the disadvantages of the variety. However, when maintaining such a temperature before planting short shoots are formed (1-2 cm), resistant to breakage.

Variety value: early formation of marketable products of good quality, attractive appearance of the tubers, resistance to nematodes.

CONCLUSIONS

1. Over the years of research four promising lines were identified from 1983 studied single-tuber hybrids planted in 2016: A-114, A-529, A-326, A-635a. Of these, potato samples A 114 (Irbitsky × Ausonia), A 529 (Irbitsky × Pamyati Osipova) were submitted for state trials in 2022 and 2023, respectively.

2. It was revealed that such elements of the yield structure as the number of marketable tubers in a clone (r = 0.72), the weight of marketable tubers (r = 0.61), the total number of the tubers in a clone (r = 0.56) have a positive correlation relationship with the yield.

3. The number of marketable and non-marketable tubers in a clone has a significant genetic determination. Weather conditions during the growing season have a significant effect on marketable tuber size and yield. Genotype-medium interaction determines the number of marketable tubers in a clone and the marketability of samples.

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Оценка генотипов казахстанско-сибирского питомника (КАСИБ) в условиях Новосибирской области

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В работе представлены результаты оценки устойчивости образцов мягкой пшеницы из питомника КАСИБ-22 к основным патогенам пшеницы. Материалом исследований служили 44 образца пшеницы, полученные из различных регионов России и Казахстана в рамках программы челночной селекции КАСИБ (НПЦЗХ им. А.И. Бараева, Омский ГАУ, ИЦиГ СО РАН, Карабалыкская СХОС, Карагандинская СХОС, Северо-Казахстанская СХОС, ФГБНУ «Омский АНЦ», ВО ГАУ Северного Зауралья, Актюбинская СХОС, Курганский НИИСХ, Павлодарская СХОС, агрокомплекс «Кургансемена», Самарский НИИСХ, Челябинский НИИСХ). В качестве высокопродуктивных и обладающих высокой и средней устойчивостью к бурой ржавчине, мучнистой росе и пыльной головне выделены селекционные линии: Линия Пт-311 (Курганский НИИСХ), Лютесценс 1462, Лютесценс 1486, Линия1616ае14 (Самарский НИИСХ), Лютесценс 1356 (ИЦиГ СО РАН). Урожайность выделившихся образцов в среднем составила 42,1–51,2 ц/га. Генотипы Новосибирская 41, Линия 435/12 и Лютесценс 1364 представляют интерес для селекции на качество. Содержание клейковины у генотипов питомника варьировало от 24,1 (у Линии 23/07 в 2022 г.) до 38,0% (у сорта Астана 2 в 2021 г.), белок варьировал от 13,4 (у сорта Терция в 2022 г.) до 19,5% (у Лютесценс 1364 в 2022 г.). Каждая из выделившихся линий представляет практическую ценность для селекции, и образцы из питомника КАСИБ-22 позволяют расширить генетическое разнообразие яровой мягкой пшеницы за счет отбора наиболее устойчивых форм к местным популяциям возбудителей мучнистой росы, бурой ржавчины и пыльной головне.

Ключевые слова: яровая пшеница, мучнистая роса, бурая ржавчина, пыльная головня, устойчивость

Evaluation of the genotypes of the Kazakh-Siberian nursery (KASIB) in the conditions of the Novosibirsk region

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The paper presents the results of evaluation of the KASIB-22 nursery soft wheat samples resistance to the main wheat pathogens. The research material was 44 wheat samples obtained from different regions of Russia and Kazakhstan within the framework of the KASIB shuttle breeding program (A.I. Barayev Research and Production Centre for Grain Farming, Omsk State Agrarian University, ICiG SB RAS, Karabalyk AES, Karaganda AES, North-Kazakhstan AES, FSBSI "Omsk ASC", HE SAU of the Northern Trans-Urals, Aktyubinsk AES, Kurgan Research Institute of Agriculture, Pavlodar AES, agrokomplex "Kurgansemena", Samara Research Institute of Agriculture, Chelyabinsk Research Institute of Agriculture). The following breeding lines were identified as highly productive and possessing high and medium resistance to brown rust, powdery mildew and loose smut: Line Pt-311 (Kurgan Research Institute of Agriculture), Lutescens 1462, Lutescens 1486, Line1616ae14 (Samara Research Institute of Agriculture), Lutescens 1356 (ICiG SB RAS). The yield of the selected samples averaged 42.1–51.2 c/ha. Genotypes Novosibirskaya 41, Line 435/12 and Lutescens 1364 are of interest for selection for quality. The gluten content of the nursery genotypes ranged from 24.1 (Line 23/07 in 2022) to 38.0% (variety Astana 2 in 2021), protein ranged from 13.4 (variety Tertia in 2022) to 19.5%

(Lutescens 1364 in 2022). Each of the selected lines is of practical value for breeding, and the samples from the KASIB-22 nursery allow to expand the genetic diversity of spring soft wheat by selecting the most resistant forms to local populations of powdery mildew, leaf rust and loose smut pathogens.

Keywords: spring wheat, powdery mildew, leaf rust, loose smut, resistance

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INTRODUCTION

Wheat is one of the most demanded agricultural crops [1 – 3]. World wheat production is currently about 800 million tons [1, 4]. In some countries it is the main food crop - China, India, Russia, USA, Canada, France, Germany, Belarus, etc. [3, 5, 6]. At the moment, there is a huge variety of soft spring wheat varieties, which allows to attract varieties from different countries and different ecological and geographical origin into the breeding programs. The obtained new forms should be used in different soil and climatic conditions.

Despite the continental climate of the forest-steppe of Western Siberia, cultivated varieties of spring wheat have a high content of protein (12 – 17%) and gluten (25 – 32%). Gluten is also characterized by good strength and elasticity, which allows its use as a component of flour mixtures with medium and low quality grain[1].

The Kazakhstan-Siberia Network for Spring Wheat Improvement (KASIB) on the basis of the International CIMMYT Center has been conducting ecological trials and exchange of the breeding material and promising breeding lines in different geographical locations of Russia and Kazakhstan since 1997 [7, 8]. The study is conducted on the main economically valuable traits (yield, vegetation period duration, grain quality, resistance to major diseases of wheat). At the moment 18 scientific institutions from Russia and Kazakhstan are involved in the project.

Creation of selective high-yielding varieties with good grain quality, characterized by high and long-term resistance to a complex of major pathogens, is one of the modern tasks in the breeding of spring soft wheat. Genetic diversity of the breeding forms from KASIB nursery will allow solving this problem, as the more sources are combined in the genotype, the more opportunities to obtain the desired forms. The purpose of the research is to study the genotypes of spring soft wheat from the KASIB-22 nursery as a source material for breeding for the main economically valuable traits (yield, vegetation period duration, grain quality, resistance to major wheat diseases) in the conditions of the forest-steppe of Western Siberia.

MATERIAL AND METHODS

The research was conducted in the forest-steppe conditions of the Novosibirsk region

[1]*Morgounov A., Rosseeva L., Koyshibayev M.* Leaf rust of spring wheat in Northern Kazakhstan and Siberia: incidence, virulence, and breeding for resistance // Australian Journal of Agricultural Research, 2007, vol. 58, pp. 847–853. DOI: 10.1071/AR07086.

on the experimental field of the experimental farm "Elite" of the Siberian Research Institute of Plant Breeding and Selection - branch of the Federal Research Center of the Institute of Cytology and Genetics of the Siberian Branch of the Russian Academy of Sciences (SibNIIRS - branch of the Institute of Cytology and Genetics SB RAS). 44 varieties from Kazakhstan-Siberia nursery in 2021, 2022 were evaluated for duration of the vegetation period, yield, grain quality and resistance to powdery mildew, loose smut and brown rust. In addition to the presented 21 genotypes from Russia and 15 from Kazakhstan, 5 international (Tertia, Pamyati Azieva, Astana 2, Omskaya 35 and Saratovskaya 29) and 3 local standards (Novosibirskaya 41, Novosibirskaya 18 and Sibirskaya 12) were studied in the nursery.

The nursery varieties were divided into groups by duration of the vegetation period: early-maturing and middle-early, mid-ripening, middle-late and late. The degree of powdery mildew damage was determined according to the scale of E.E. Geshele. The degree of soft spring wheat rust damage was assessed using the CIMMYT[2] scale. Loose smut was counted in the phase of earing - flowering. Loose smut prevalence, expressed as a percentage, was determined by the lesion group: single (1 point), weak (2), medium (3), strong (4 points)[3]. Protein and gluten content were analyzed according to GOSTs[4, 5].

The coefficient of variation and the analysis of variance were calculated according to the method of B.A. Dospekhov (1985)[6] using Microsoft Office Excel 2013.

The weather conditions in 2021, 2022 were contrasting, as evidenced by the data of the pogodaiklimat.ru[7]. In 2021, drought was observed at the beginning of the vegetation period, the average monthly temperature reached 15.3°C, which is 4.4°C above the mean annual values. June was characterized as humid – 73.1 mm, which was crucial for crop formation. In July, starting from the second ten-day period there was a deficit of precipitation (4.4 mm). In August, the weather was hot and precipitation was within the norm.

The growing season 2022 was warm and dry. In May, a very severe drought (2.5 mm) was observed. In June, optimal moisture content was observed (58.8 mm). The average temperature for June and July was at par with the mean annual values. But July was classified as dry. August can also be characterized as hot and dry. Only 23 mm of precipitation was recorded during the whole month.

RESULTS AND DISCUSSION

In the KASIB-22 nursery for the years studied, the duration of the growing season varied from 71 (Lutescens 1356 and Lutescens 1364 in 2022) to 94 days (Lutescens 1462 in 2022) (see the Table). Most genotypes in 2021 matured in 80-82 days, in 2022 – 84 days or more (17 specimens). In the conditions of the Novosibirsk Priobie, early maturing and early varieties are of great importance due to climate peculiarities. The shortest growing season was observed in 14 varieties and lines of the nursery. In 2022, genotypes of the local selection Lutescens 1356 and Lutescens 1364 formed the crop in 71 days. However, the group of the middle-late and late varieties was the most numerous, it is represented by Kazakh (7 genotypes), Ural (6 genotypes) Volga (4 genotypes) and West Siberian (4 genotypes) selections. Such varieties and breeding lines as Agronomical 5, Sibirskaya 12, KS 14/09-2, Lutescens 1486, Lutescens 1489 and Line1616ae14 required 90 days or more from sprouting to maturity in 2022.

The works conducted by I.V. Pototskaya, T.V. Nekalo and E.V. Zagoruichenko (2022) on the fields of the Omsk SAU in the condi-

[2]*Koyshybaev M., Muminjanov H.* Methodological guidelines for monitoring of diseases, pests and weeds in cereal crops. Ankara: Food and Agriculture Organization of the United Nations (FAO), 2016, 29 p.

3*Shutko A.P., Tuturzhans L.V.* Phytosanitary diagnostics of plant diseases: textbook. Stavropol: AGRUS, 2018, 111 p.

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Средняя урожайность и вегетационный период сортов и линий из питомника КАСИБ-22
Average yield and growing season of the varieties and lines from the KASIB-22 nursery

Genotype	2021		2022		Vegetation period, days	
	Yield, c/ha	*V*, %	Yield, c/ha	*V*, %	2021	2022
1	2	3	4	5	6	7
Group of middle-early and early varieties						
Astana 2 (standard)	39,5	11,3	28,3	35,4	79	77
Pamyati Azieva (standard)	44,0	20,6	27,7	35,4	78	81
Novosibirskaya 41 (standard)	40,0	19,1	21,5	57,1	80	78
Lutescens 342/08	44,0	1,4	33,1	34,2	79	79
Lutescens 8-12-18	47,8	11,1	17,8	34,9	79	77
Lutescens 2244	35,2	8,2	20,1	37,3	79	77
Line 23/07	43,7	8,5	25,1	13,3	80	77
Lutescens 1356	49,8	8,6	34,3	17,8	79	71
Lutescens 1364	45,9	7,7	25,9	11,8	79	71
Lutescens 82/09-7	48,6	6,1	26,9	30,4	79	78
Yalutorovka	48,2	2,3	30,1	19,6	79	78
GAU-11-2016	42,5	1,8	27,8	19,4	79	79
Agronomical 5	47,3	8,7	33,5	17,9	80	90
Average for the group	45,3	6,4	27,5	23,7	79,2	77,9
$LSD_{0,05}$	2,2	–	1,9	–	0,3	0,8
Group of medium-maturing varieties						
Saratovskaya 29 (standard)	42,0	14,0	27,4	13,8	78	80
Novosibirskaya 18 (standard)	51,4	7,9	32,0	49,9	79	78
Line 198/225-2020	44,4	6,3	30,4	43,9	80	81
Line 205-2020	40,2	3,3	28,3	43,2	81	81
Lutescens 176/09	46,7	7,5	28,4	19,7	83	82
Line 435/12	47,4	11,1	24,7	44,8	80	82
Line Cht-11	49,0	17,3	32,3	31,3	80	81
Line Pt-235	47,6	20,7	30,4	25,6	80	80
Line Pt-311	51,0	4,0	33,7	37,1	80	82
Lutescens 76-17	49,4	8,5	30,5	23,8	80	81
Average for the group	46,9	10,1	29,8	33,3	80,1	80,8
$LSD_{0,05}$	2,2	–	2,5	–	0,6	0,6
Group of middle-late and late varieties						
Tertia (standard)	45,7	5,5	30,1	19,0	80	82
Omskaya 35 (standard)	53,6	9,1	28,6	35,9	83	80
Sibirskaya12 (standard)	50,2	10,9	27,7	55,5	82	90
Dynasty	39,7	10,0	24,3	41,5	80	85
Line 43/94к-07-7	39,5	7,5	35,9	38,1	83	89
Line 2/03-09-3	51,7	7,3	32,6	28,4	84	88
Lutescens 77 201/09	47,9	2,8	28,8	49,8	85	88
Lutescens 30 22/09	42,2	9,4	26,3	35,2	84	89
Lutescens 2219	41,7	2,8	22,7	22,7	80	86

End of the table

1	2	3	4	5	6	7
Lutescens 2223	40,1	6,2	25,0	22,5	84	86
KS 14/09-2	51,5	9,2	29,5	38,7	84	90
KS 60/09-9	51,6	3,5	31,5	22,7	82	87
KS 61/09-4	51,2	6,7	39,7	23,2	84	87
KS 285/12-1586	49,8	13,1	35,6	33,4	85	88
Lutescens 1462	56,7	8,7	45,7	18,8	85	89
Lutescens 1486	52,4	9,7	46,9	23,3	85	94
Lutescens 1489	42,3	13,4	37,5	23,4	82	92
Lutescens 136/10-1	50,8	2,1	29,3	23,2	81	89
Lutescens 71/10-4	51,2	9,9	25,3	25,1	82	89
Chelyabinka	45,5	14,7	36,1	31,0	83	80
Line 1616ae14	53,6	1,5	34,4	27,6	85	90
Average for the group	50,5	8,3	36,2	25,2	83,0	87,52
$LSD_{0,05}$	1,7	–	2,1	–	1,2	1,6

Note. *V* – coefficient of variation.

tions of the southern forest-steppe of the Western Steppe showed that the greatest interest from the set of varieties and lines KASIB-22 as source material for breeding for early maturity are Lutescens 1364, Lutescens 1356 (SibNIIRS - branch of ICIG SB RAS), Line Cht-11, Line Pt-235 (Kurgan Research Institute of Agriculture), Lutescens 76-17 (Omsk SAU), Lutescens 82/09-7 (Omsk ARC), Yalutorovka (SAU of the Northern Trans-Urals)[8], Lutescens 176/09 (A.I. Barayev Research and Production Centre for Grain Farming), Lutescens 176/09 (A.I. Barayev Research and Production Centre for Grain Farming), Lutescens 2244 (Karabalyk AES), Line 198/225-2020 (Aktobe ARD), Lutescens 342/08 (A.I. Barayev Research and Production Centre for Grain Farming), Lutescens 8-12-18 (Karabalyk AES)[9]. The studied varieties of soft spring wheat had a wide range of variability in yield. Insignificant and average yield variation (V = 1.4 – 20.7%) was observed in 2021, while in 2022 the coefficient of variation in yield for most varieties exceeded 20%. The average variation of this trait was observed in only 10 genotypes this year (Line 23/07, Lutescens 1356, Lutescens 1364, Yalutorovka, GAU-11- 2016, Agronomical 5, Saratovskaya 29, Lutescens 176/09, Tertia and Lutescens 1462). In 2022, the presence of early drought and continued precipitation deficit throughout the growing season caused significant yield variation among the nursery varieties and lines.

Under the prevailing conditions of the years under study, KASIB-22 varieties and lines of the set varied in yield from 17.8 (in 2022 for Lutescens 8-12-18) to 56.7 c/ha (in 2021 for Lutescens 1462). In 2021 in the group of middle-early and early among the standards stood out the variety Pamyati Azieva, which yielded 44.0 c/ha. The worst in this group by the yield formation was the standard variety Astana 2 (39.5 c/ ha) and the Lutescens 2244 line (35.2 c/ ha). Significantly higher yields of the standards in the prevailing meteorological conditions were

[8]*Pototskaya I.V., Nekalo T.V.* Breeding evaluation of spring soft wheat varieties of Russian selection of KASIB-22 nursery under the conditions of Western Siberia // Catalog of graduate qualification works FSBEI HE Omsk SAU. Omsk: Omsk State Agrarian University named after P.A. Stolypin, 2022, pp. 70-74.

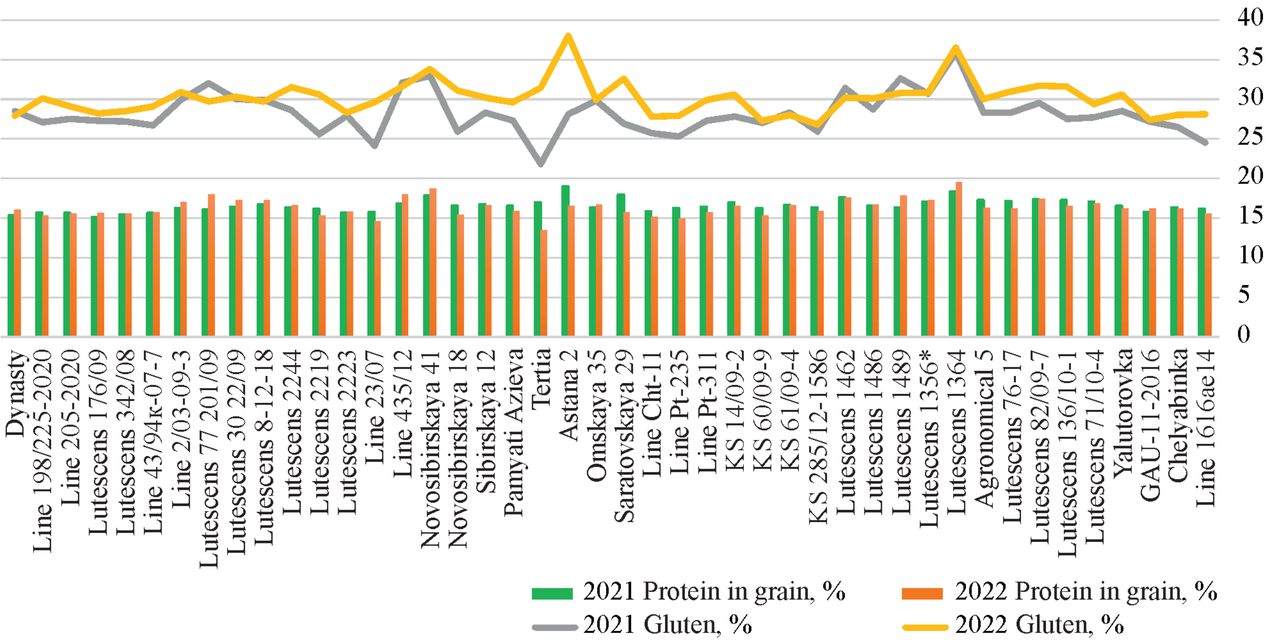
[9]*Pototskaya I.V., Zagoruichenko E.V.* Breeding evaluation of spring soft wheat varieties of Kazakh selection of KASIB-22 nursery under the conditions of the southern forest-steppe of Western Siberia // Catalog of graduate qualification works FSBEI HE Omsk SAU. Omsk: Omsk State Agrarian University named after P.A. Stolypin, 2022, pp. 68-70.

observed in the genotypes Lutescens 8-12-18 (47.8 c/ha), Lutescens 1356 (49.8 c/ha), Lutescens 82/09-7 (48.6 c/ha), Yalutorovka (48.2 c/ha) and Agronomical 5 (47.3 c/ha).

In 2021, the most productive genotypes in the medium maturity group were Line Pt-311 (51.0 c/ha), Line Cht-11 (49.0 c/ha) and Lutescens 76-17 (49.4 c/ha). The weather conditions of vegetation negatively affected the yield of middle-late varieties and lines, 8 genotypes of the ripeness group of middle-late and late had very low yields of 40.1 – 45.7 c/ha. Significant excess of the international standard Omskaya 35 with a yield of 53.6 c/ha was observed only in the breeding line Lutescens 1462 (56.7 c/ha). In this group, 9 genotypes (Line 2/03-09-3, Lutescens 77 201/09, KS 14/09-2, KS 60/09-9, KS 61/09-4, KS 285/12-1586, Lutescens 1462, Lutescens 1486, Lutescens 136/10-1, Line 1616ae14) had a significant yield excess over the local standard Sibirskaya 12 (50.2 kg/ha).

The following varieties stood out in terms of their yields during the 2 years of the study: Lutescens 342/08 (A.I. Barayev Research and Production Centre for Grain Farming), Lutescens 1356 (ICIG SB RAS), Yalutorovka (SAU of the Northern Trans-Urals), Agronomical 5 (Omsk SAU); among medium-ripening varieties: Line 198/255-2020 (Aktyubinsk AES), Lutescens 176/09 (A.I. Barayev Research and Production Centre for Grain Farming), Line Pt-235 (Kurgan Research Institute of Agriculture), Line Pt-311 (Kurgan Research Institute of Agriculture), Line Pt-311 (Kurgan Research Institute of Agriculture), Line Pt-311 (Kurgan Research Institute of Agriculture), Line Pt-235 (Kurgan Research Institute of Agriculture), Line Pt-235 (Kurgan Research Institute of Agriculture), Line Pt-311 (Kurgan Research Institute of Agriculture), Lutescens 76-17 (Omsk SAU); among middle-late and late maturing: Line 2/03-09-3 (Pavlodar AES), KS 60/09-9 KS (Agrocomplex "Kurgansemena"), 61/09-4 (Agrocomplex "Kurgansemena"), KS 285/12-1586 (Agrocomplex "Kurgansemena"), Lutescens 1462 (Samara Research Institute of Agriculture), Lutescens 1486 (Samara Research Institute of Agriculture), Line1616ae14 (Samara Research Institute of Agriculture).

Lutescens 8-12-18 (Karabalyk AES) (see footnote 9), Line Cht-11 (Kurgan Research Institute of Agriculture), Lutescens 1356 (SibNIIRS – branch of ICIG SB RAS) among the



Показатели белка и клейковины сортов и линий питомника КАСИБ-22 (2021, 2022 гг.), %

Protein and gluten indicators of the varieties and lines of the nursery KASIB-22 (2021, 2022), %

early-ripening and middle-early maturing varieties and lines; in the medium-ripening group – Line Pt-311 (Kurgan Research Institute of Agriculture); in the middle-late group – Lutescens 1489 (Samara Research Institute of Agriculture) (see footnote 8) were of interest as sources for selection for yield in the research by I.V. Pototskaya et al. [10] conducted on the same set of the varieties and lines of KASIB-22.

When studying the content of protein and gluten in a set of KASIB-22 nursery genotypes (see the figure), it was revealed that, in general, protein content averaged 16.5%, while gluten content averaged 29.2%. The variation of protein among nursery genotypes was insignificant, averaging 3.2%. Whereas the coefficient of variation of gluten content was in the range of 0.2 –25.5%.

In general, during 2 years of field experiments, the variation in the protein content of the studied samples ranged from 14.6 (Line 23/07 in 2022) to 19.5% (Lutescens 1364 in 2022). The genotypes of the greatest interest in protein content were among early and medium-early genotypes – Novosibirskaya 41 (17.9 in 2021 and 18.7% in 2022), Lutescens 82/09-7 (17.4% in both years of study), Lutescens 1364 (18.4 and 19.5%); among medium-ripening genotypes – Line 435/12 (16.9 and 18.0%); among middle-late and late genotypes – Lutescens 1462 (17.7 and 17.6%).

Gluten content in wheat grain is one of the most important indicators characterizing grain quality [9], but a decrease in grain quality has been noted in recent decades due to the increase in the yield of modern wheat varieties, especially due to the loss of genetic information [10]. Thanks to the study of the varieties and breeding lines of Russia and Kazakhstan, presented in the KASIB-22 nursery, it is possible to identify the sources with high gluten content. As a result of the field experiments it was found that the highest gluten content of the varieties of the nursery was observed in 2021 – Lutescens 2244 (31.5%), Line 435/12 (31.6%), Novosibirskaya 41 (33.8%), Astana 2 (38%), Saratovskaya 29 (32.6%), Lutescens 1364 (36.5%), Lutescens 82/09-7 (31.7%), Lutescens 136/10-1 (31.6%). In 2022, the average gluten content across the nursery was 1.9% lower. The highest gluten content this year was observed in Lutescens 77 201/09 (32.0%), Lutescens 30 22/09 (30.0%), Line 435/12 (32.1%), Novosibirskaya 41 (32.9%), Lutescens 1462 (31.4%), Lutescens 1489 (32.6%), Lutescens 1356 (30.7%), Lutescens 1364 (35.9%). High gluten content as a result of the studies in 2021, 2022 in the conditions of the forest-steppe of the Novosibirsk Priobie was observed in the genotypes Novosibirskaya 41, Line 435/12 and Lutescens 1364.

The results of evaluation of the varieties and lines of the nursery show that the incidence of powdery mildew, brown rust and loose smut depends mainly on the weather conditions. Under favorable conditions, pathogen development increased by 20 – 30%. The spread of wheat diseases has an impact on the formation of the yields [4, 11, 12].

In the Novosibirsk region over the years of study the genotypes Line 198/225- 2020, Lutescens 30 22/09, Lutescens 2244, KS 14/09-2, KS 285/12-1586, Lutescens 1356, Lutescens 1364, Lutescens 136/10-1, GAU-11-2016, Chelyabinka and Line 1616ae14 had a medium degree of brown rust damage (20MR-40MS), while the varieties Line Pt-235, Agronomical 5, Lutescens 71/10-4 were resistant to this pathogen. Whereas the field experiments conducted in Kazakhstan (Gvardeysky village, Kordaysky district, Zhambyl region) showed that the varieties and breeding lines from this set of KASIB-22 are of the greatest interest for resistance to brown rust, such as Dynasty, Line 198/225-2020, Lutescens 30 22/09, Lutescens 2244, Line Pt-235, KS 14/09-2, KS 285/12-1586, Lutescens 1356, Lutescens 1364, Agronomical 5, Lutescens 136/10-1, Lutescens 71/10-4, GAU-11-2016, Chelyabinka and Line 1616ae14 [13]. These genotypes were proposed as donors.

The degree of powdery mildew damage in most varieties and lines in 2021, 2022 was 0 –10% (19 and 18 pieces, respectively) and 20 – 30% (23 and 17 pieces, respectively). The varieties Lutescens 8-12-18, KS 61/09-4, Lutescens 1462, KS 285/12-1586, Lutescens 1486, Lutescens 1489, Line Pt-311, Lutescens 76-17, KS 60/09-9, Lutescens 71/10-4, Lutescens 82/09-7, Lutescens 136/10-1, Line 1616ae14 were characterized as highly resistant to this pathogen. It is worth noting that in 2021, powdery mildew lesion in 60% was recorded in Lutescens 176/09, and in the variety Dynasty – in 40%. In 2022, lesions ≤ 60% were observed in the genotypes Line 198/225-2020, Dynasty, Line 205-2020, Lutescens 176/09, Lutescens 2244, Lutescens 2219, Lutescens 2223, Line 23/07 and Tertia. The highest incidence of loose smut was observed in 2022 among the KASIB-22 varieties and lines. Susceptible to the loose smut pathogen were in 2021 the Line 43/94k-07-7, Line 2/03-09-3, Lutescens 30 22/09, Lutescens 8-12-18, Lutescens 2244, Sibirskaya 12, Agronomical 5, Lutescens 71/10-4 and Line1616ae14. In the second year of the trial, 16 varieties were affected by loose smut.

The conducted correlation analysis showed a significant correlation between the yield and the development of leaf pathogens of spring wheat. The greatest yield losses in 2021 were due to brown rust (r = -0.62) and powdery mildew (r = -0.47), in 2022 - only due to powdery mildew (r = -0.42), correlation with brown rust was weak that year.

CONCLUSION

The breeding lines Line Pt-311 (Kurgan Research Institute of Agriculture), Lutescens 1462, Lutescens 1486, Line1616ae14 (Samara Research Institute of Agriculture), Lutescens 1356 (ICIG SB RAS) are noted as highly productive and having high and medium resistance to brown rust, powdery mildew and loose smut. Varieties Novosibirskaya 41, Line 435/12 and Lutescens 1364 can be recommended in the breeding programs for selection for quality. Each of the selected lines is of practical value for breeding and the samples from the KASIB-22 nursery allow to expand the genetic diversity of spring soft wheat by selecting the most resistant forms to local populations of powdery mildew, brown rust and dusty mildew pathogens.

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Оценка устойчивости к полеганию яровых тритикале на основе изучения физико-механических свойств

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Представлены результаты исследования архитектоники и физико-механических свойств стеблей селекционных форм яровых гексаплоидных тритикале различного эколого-географического происхождения. Объектами исследований служили признаки 19 коллекционных и селекционных образцов из коллекций Всероссийского института генетических ресурсов растений им. Н.И. Вавилова (ВИР) и Сибирского научно-исследовательского института растениеводства и селекции – филиала Федерального исследовательского центра Института цитологии и генетики Сибирского отделения Российской академии наук (СибНИИРС – филиал ИЦиГ СО РАН). Изучение макрометрических параметров выполнялось на 25 репрезентативных экземплярах каждого селекционного образца при достижении ими фазы полной спелости в течение трех лет (2021–2023). Сопротивление стебля изгибу или излому определяли на изготовленном в СибНИИРСе экспериментальном образце, в конструкции которого предусмотрены устойчивая платформа, перекладины для фиксации образца и прорезь для размещения динамометра. Предрасположенность растений тритикале к полеганию оценивалась по совокупности признаков: массы 10-сантиметровой соломины 2-го междоузлия; сопротивлению стебля излому, определяемому по пиковому показанию электронного динамометра; плотности ткани стебля 2-го междоузлия. Изученные образцы существенно различались по данным параметрам и характеризовались различной степенью устойчивости к полеганию. По совокупности прочностных параметров выделены перспективные селекционные образцы, которые могут быть использованы как источники ценных признаков. Применение метода главных компонент позволило выявить маркерный признак «сумма длин 2-го и 3-го междоузлий», который являлся определяющим в обеспечении высокой устойчивости к полеганию у изучаемых образцов. Установлена тесная взаимосвязь признака массы 10-сантиметровой соломины 2-го междоузлия с параметром сопротивления стебля излому. Сопряженность этих характеристик позволит выявить источники ценных признаков и целенаправленно вести селекционный процесс яровых тритикале на устойчивость к полеганию без привлечения короткостебельных форм.

Ключевые слова: яровые гексаплоидные тритикале, стеблевое полегание, архитектоника растений, физико-механические свойства, устойчивость к полеганию

Assessment of the resistance to lodging of spring triticale based on the study of physical and mechanical properties

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The results of the study of architectonics and physical and mechanical properties of the stems of selective forms of spring hexaploid triticale of different ecological and geographical origin are presented. Traits of 19 collection and breeding samples from the collections of the N.I. Vavilov All-Russian Institute of Plant Genetic Resources (VIR) and the Siberian Research Institute of Plant Growing and Selection - branch of the Federal Research Center of the Institute of Cytology and Genetics of the Siberian Branch of the Russian Academy of Sciences (SibNIIRS – branch of the Institute of Cytology and Genetics of the Siberian Branch of the Russian Academy of Sciences) served as research objects. Macrometric parameters were studied on 25 representative specimens of each breeding sample when they reached the phase of full ripeness during three years (2021–2023). The resistance of the stem to bending or fracture was determined on an experimental specimen manufactured at the SibNIIRS with a stable platform, bars for fixing the specimen and a slot for placing a dynamometer. The susceptibility of triticale plants to lodging was evaluated by a set of traits: weight of a 10-cm straw of the 2nd internode; stem resistance to breaking determined by the peak reading of an electronic dynamometer; stem tissue density of the 2nd internode. The studied samples differed significantly in these parameters and were characterized by different degrees of the resistance to lodging. Promising breeding specimens that can be used as sources of valuable traits have been identified based on the totality of the strength parameters. Application of the principal component method allowed to identify the marker trait "sum of lengths of the 2nd and 3rd internodes", which was determinant in providing high lodging resistance in the studied samples. A close relationship between the trait of 10-cm straw mass of the 2nd internode and the parameter of the stem resistance to breakage has been established. The conjugation of these characteristics will make it possible to identify the sources of valuable traits and purposefully carry out the selection process of triticale for resistance to lodging without attracting short-stemmed forms.

Keywords: spring hexaploid triticale, stem lodging, plant architectonics, physical and mechanical properties, resistance to lodging

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INTRODUCTION

Among synthetic allopolyploids, wheat-rye amphidiploids – triticale[1, 2] [1] are of considerable interest for both fundamental research and breeding activities. The successes of the Russian scientists prove the high productivity potential and commercial value of hexaploid level triticale [2]. Every year the State Register of Breeding Achievements[3] is replenished with new varieties characterized by high yield, improved adaptive properties and grain quality. Hexaploid triticale combines many valuable traits: high yield, drought resistance, ability to effectively use soil fertility and nutrient elements of fertilizers, high biological value of grain and its products, formation of significant vegetative mass suitable for use as high-quality green fodder[4] [3]. At present, triticale remains the only spiked cereal crop with

[1]*Grebennikova I.G., Stepochkin P.I.* Optimization of the breeding process of lodging-resistant varieties of spring triticale // E3S-Web of Conferences, 2023, vol. 390, p. 03008. DOI: 10.1051/e3sconf/202339003008.

[2]*Gorbunov V.N., Shevchenko V.E.* Breeding achievements on triticale in scientific centers of Russia and the nearest foreign countries // Achievements of science and technology of AIC, 2015, vol. 29, N 4, pp. 24-27.

[3]The State Register of Breeding Achievements admitted to use. Plant varieties. Moscow: FSBSI "Rosinformagroteh", 2020, vol. 1, 680 p.

[4]Innovative varieties and cultivation technologies of spring triticale: collective monograph. FSBSI ARRIOFP, Vladimir: PresSto; Ivanovo, 2017, 295 p.

a minimal level of plant damage by leaf and viral diseases[5] [4]. In Russia, there is an increasing interest in spring triticale as an emergency crop, which is associated with the changes in climatic conditions in recent years [5, 6].

Insufficient resistance to lodging, which increases in conditions of intensive farming, is considered to be a problem in the improvement of triticale grain varieties. Lodging negatively affects the level and quality of grain yield, often reducing it by 30-50%[6] [7]. Formation of small grains with low 1000-grain weight as a result of disruption of assimilants transportation to the ear is a frequent phenomenon in lodging [8, 9]. In addition, leaves of lodged plants due to conditions of high humidity can become a favorable environment for the spread of diseases that reduce yield and grain quality [10, 11].

In the Siberian region, the most typical is stem lodging of plants, which occurs at the end of milky – beginning of waxy ripeness of seeds due to a large mechanical load of the aboveground mass of the plant on the lower internodes of the stem. According to the majority of the authors, the length, diameter, mass of the 2nd lower internode, and resistance to force load should be considered as the main morphological and biological traits characterizing the stem strength of grain crops [8, 11, 12]. Determination of the secondary so-called marker traits that contribute to the early stages of breeding to increase the efficiency of genotype selection for a set of economically valuable traits is of great importance in the breeding process. Thus, the studies of V.N. Tishchenko [13] showed the possibility of using the trait "culm thickness of the 2nd internode" in selection for productivity in winter wheat.

According to the sources [12, 14], the resistance of cereal crop stems to lodging has a positive correlation with the parameters of the culm wall thickness and plant height, controlled by a complex system of genes and environmental factors. For practical breeding purposes, stem fracture resistance, which reflects the development and architectonics of mechanical elements of stem tissues, can serve as a reliable indicator of stem strength [12, 15]. In the work[7] it is shown that an increase in the culm wall thickness increases the mechanical strength of the stem and resistance to lodging. However, as was shown in the works of P. A. Tsilke[8], plants with a thick stem, as a rule, have reduced productivity of the ear. In Siberia, the problem of lodging resistance of varieties should be solved by polygenic systems controlling the stem length, morphological and anatomical traits that determine its resistance, rather than by dwarfing genes with strong individual effects [16].

The purpose of the research is to study the indicators of varietal features of architectonics and physical and mechanical properties of stems of selective forms of spring triticale and to identify valuable trait sources on their basis.

MATERIAL AND METHODS

Traits of 19 collection and breeding samples of spring hexaploid triticale from the collections of the Federal Research Center "N.I. Vavilov All-Russian Institute of Plant Genetic Resources (VIR) and SibNIIRS – branch of ICIG SB RAS served as research objects: early maturing variety K-3992 (VIR selection); middle-early variety Arsenal (Ukraine); medium-maturing samples Ditr 165, Ditr 168 (SibNIIRS), varieties Kissa half-awned (Mexico), Timur (Krasnodar) and Ukro (Russia, Ukraine); middle-late breeding samples (SibNIIRS): Divergent №19, Divergent № 21, Divergent 6 x A1 № 19, Divergent 6xVrnA1, LMK462/208, O312/29 non/awned, O312/29 awned non/hairy, O312/38, O312/153,

[5]*Kasynkina O. M., Orlova N. S., Kanevskaya I. Yu*. Evaluation of winter triticale varieties for disease resistance // Agrarian Scientific Journal, 2017, N 8, pp. 7-10.

[6]*Medvedev A.M., Medvedeva L.M., Poma N.G., Osipov V.V., Osipova A.A.* Winter and spring triticale in the Russian Federation. Moscow: MosNIISKh, 2017, pp. 154-195.

[7]*Wang D., Ding W., Feng S.* Stem characteristics of different wheat varieties and its relationship with lodging-resistance // The journal of applied ecology, 2016, vol. 27 (5), pp. 1496–1502. DOI: 10.13287/j.1001-9332.201605.039.

[8]*Tsilke R.A.* Genetic bases of selection of soft spring wheat for productivity in Western Siberia: Doctor's thesis in Biology: 03.00.15, Novosibirsk, 1983, 505 p.

SiArs217; middle-late UK 30/33 (SibNIIRS) and late maturing Sirs57 × Ukro (ICIG). The studied breeding forms belong to different ecological and geographical groups, belong to different ripeness groups, are characterized by field resistance to leaf diseases, to loose smut and kernel smut, stem and yellow rust. Previously, the authors evaluated the ecological plasticity and determination of selection index of spring hexaploid triticales [17]. A detailed description and characteristics of the selection material used for food and fodder grain production are given in the paper[9]. The set was studied for three years (2021 – 2023). The variety Timur, zoned in the West Siberian region, was taken as a standard. Planting of spring triticale plants was carried out in the breeding nursery of SibNIIRS – branch of ICIG SB RAS in the open ground by manual method with a seeding rate of 90 seeds per one linear meter. Repetition of the experiment is threefold with full randomization of variants. The methodology of the field experiment corresponds to the methodology adopted in SibNIIRS[10].

To identify the influence of triticale plant structure on lodging resistance, the research was methodologically divided into the following areas: 1) field phenological observations using a unified phenological scale – BBCH code[11]; 2) field visual assessment of plant resistance to lodging using a visual assessment method in field conditions on a 9-point scale[12]; 3) study of the features of stem architectonics; 4) study of the physical and mechanical properties of the stem; 5) determination of the breeding productivity of selection of samples during the period of the study; 6) evaluation of the influence of the elements of architectonics and physical and mechanical properties of the stem on yield and lodging resistance using information technologies.

Analysis of physical and mechanical properties and architectonics of the studied breeding samples was carried out according to the following quantitative traits: stem length, number of internodes, lengths of the 2nd, 3rd and upper internodes (distance from the upper stem node to the base of the ear), outer diameters and thickness of the 2nd and 3rd internodes, inner diameter of the 2nd internode, weight of the culm segment of the 2nd internode, length of the ear awns, field resistance to lodging, stem tissue density, breaking strength of the 2nd internode. The values of the outer diameters and wall thickness of the internodes were measured after leaf removal with an electronic caliper TOPEX 150 mm 31C628/0.02 with an accuracy of hundredths of a millimeter. Numerical signs of the length, density and weight of ears were studied during plant productivity studies.

Stem resistance to bending or fracture was determined on an experimental specimen manufactured in the SibNIIRS, branch of the Institute of Cytology and Genetics of the Siberian Branch of the Russian Academy of Sciences, with a stable platform, bars for fixing the specimen, and a slot for placing a dynamometer. The study of the force load was carried out on the 2nd internode. Deformations during lodging due to the greater load are most often observed in this internode, despite the fact that the third internode has less strength. This fact is confirmed by the works of A.V. Pinkal and V.N. Obraztsov [18, 19].

As noted by the authors[13], fixing the ends of the test specimens with a screw vise led to their deformation and weakening. This circumstance may be the cause of premature rupture of the samples at the vise clamp. There is also a prob-

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[9] *Grebennikova I.G., Stepochkin P.I.* Optimization of the breeding process of lodging-resistant varieties of spring triticale // E3S Web of Conferences (AGRITECH-VIII 2023), 2023, vol. 390 (2), p. 03008. DOI: 10.1051/e3sconf/202339003008.

[10] Methods of state variety testing of agricultural crops. Issue two: cereals, cereals, legumes, corn and forage crops / edited by A.I. Grigoriev, Moscow: Kolos, 1989, 194 p.

[11] *Tottman D.* The Decimal Code for the Growth Stages of Cereals // Annals of Applied Biology, 2008, vol. 110 (2), pp. 441–454. DOI: 10.1111/j.1744-7348.1987.tb03275.x.

[12] *Filatenko A.A., Shitova I.P.* Broad unified CMEA classifier of the genus Triticum, L., 1989, 44 p.

[13] *Baker C., Sterling M., Berry P.* A generalised model of crop lodging // Journal of Theoretical Biology, 2014, vol. 363, pp. 1–12. DOI: 10.1016/j.jtbi.2014.07.032.

lem of slipping of the sample from the clamps. To eliminate the harmful effect of the clamps, the ends of the stem section without rigid fixation were freely placed on the bar. In order to ensure a stable position of the specimen on the installation, it was decided to use 10-cm sections of the middle part of the 2nd internode of the stem. Due to the ellipsoidal shape of the stem cross-section, the position of the stem sections on the platform was oriented in such a way that the load direction was parallel to the minor axis of the stem cross-section. The validity of this approach is confirmed by the studies of C. Baker et al. (see footnote 13). The middle part of the section, horizontally placed on the plant, was the location of the concentrated transverse load applied to the stem by the phenotyping device - electronic dynamometer DACELL DN-FGA-K2/20H (2 kg) / ± 0.2% (Korea). The tests were terminated in case of specimen fracture or reaching the maximum load at which "flow" of the stem tissue occurred. The peak readings of the dynamometer (F, kg) were recorded. Macrometric parameters were studied on 25 representative samples of each selection sample when they reached the phase of full ripeness. The following mathematical methods were used to identify the criteria for evaluating the parameters of the samples for lodging resistance: variation and correlation analyses, principal component method, determination of stem tissue density by cross-sectional area and linear mass of the stem sample. Statistical analysis was performed using Statistica 10 software package.

RESULTS AND DISCUSSION

During the years of research, meteorological conditions did not contribute to active lodging of plants, in connection with which in the phases of tillering and flowering the resistance score was close to the maximum value (9 points). In the phases of waxy ripeness and grain maturation, when the ear had the largest mass, stem bends (at the level of 8 points) in 2021 and 2023 were observed in the following samples O312/29 non/awned and O312/29 awned non/hairy; in 2022 – O312/38, O312/153, O312/29 non/awned and O312/29 awned non/hairy. The use of the visual method, which has a strong dependence on meteorological conditions, allowed to obtain only a general idea of the variety behavior, but excluded the possibility of individual evaluation and selection of plants. In order to identify the individual resistance potential of the studied breeding forms, a detailed biometric analysis of structural elements providing stem strength properties was performed.

According to the VIR[14] classification, the studied samples were grouped by stem length. The greatest stem length during the study period was characterized by the sample O312/29 non/awned (123,55 cm). The lowest indices were possessed by the samples from the dwarf group: Divergent No. 19 – 57.86 cm and Divergent 6 x A1 No. 19 – 57.29 cm. The stem length index of most varieties ranged from 74 to 104 cm (see Table 1).

Analysis of varietal traits revealed differences in the architectonics of the studied accessions. The highly variable traits (Cv > 20%) include: stem length, lengths of the 2nd, 3rd and upper internodes, thickness of the 2nd and 3rd internodes and weight of a 10-cm culm.

The most accomplished culm, i.e. the maximum value of the wall thickness of the 2nd internode, was possessed by the samples Timur, Divergent No. 19 and Divergent 6 x VrnA1 ($Width_{II}$ = 0.72 – 0.74 mm). Samples K-3992 and LMK462/208 were characterized by the highest values of the diameter and weight of the 2nd internode culm (D_{II} = 4.46 – 4.50 mm; M10cm = 0.28 – 0.32 g).

Divergents along with the variety Timur were characterized by the lowest values of the parameters of the lengths of the 2nd (L_{II} = 7.80 – 10.78 cm) and 3rd internode (L_{III} = 10.92 –15.86 cm) and the greatest wall thickness of the 2nd internode ($Width_{II}$ = 0.68 – 0.74 mm). The hy-

[14]Methodical guidelines for the study of the world wheat collection. L.: VIR, 1987, 178 p.

Табл. 1. Макроструктурные признаки стебля и продуктивность колоса селекционных образцов яровой тритикале за период исследования (2021–2023 гг.)

Table 1. Macrostructural traits of the stem and ear productivity of the selective samples of spring triticale during the study period (2021–2023)

№ п/п	Name	L_{Stem}	L_{II}	L_{III}	L_{Top}	D_{II}	D_{III}	$Width_{II}$	$Width_{III}$	M10cm
	Tall-growing (> 120 cm)									
1	OZ12/29 non/awned	123,55	17,30	26,73	44,03	4,42	4,71	0,57	0,51	0,27
	Medium-grown (120–105 cm)									
2	OZ12/29 awned non/hairy	117,27	16,93	22,96	39,89	4,21	4,49	0,56	0,51	0,24
	Low-growing (104–85 cm)									
3	UK 30/33	103,87	14,84	25,90	40,69	4,22	4,40	0,55	0,53	0,22
4	OZ12/153	101,56	15,13	24,03	39,17	4,12	4,29	0,56	0,55	0,21
5	LMK462/208	98,90	13,91	22,54	36,45	4,50	4,77	0,61	0,58	0,28
6	O312/38	98,59	15,11	24,09	39,20	4,14	4,31	0,56	0,58	0,23
7	Ukro	92,37	13,99	25,67	39,51	4,32	4,36	0,55	0,52	0,19
8	Kissa half-awned	87,45	12,87	25,87	38,75	4,33	4,40	0,54	0,53	0,21
9	К-3992	85,22	13,85	25,26	38,82	4,46	4,33	0,55	0,49	0,32
	Semi-dwarf (84–60 cm)									
10	Ditr 165	83,09	14,79	22,23	37,02	3,80	3,54	0,57	0,57	0,19
11	Arsenal	81,56	13,57	20,95	34,53	3,86	3,81	0,56	0,55	0,19
12	SiArs 217	79,35	10,36	17,79	28,15	4,39	4,41	0,63	0,57	0,23
13	Sirs 57 × Ukro	79,06	9,48	16,08	25,56	4,59	4,88	0,59	0,55	0,23
14	Ditr 168	76,17	11,17	20,53	31,70	3,87	4,02	0,59	0,55	0,19
15	Timur	74,33	10,42	18,51	28,93	3,53	3,61	0,72	0,65	0,22
16	Divergent 6xVrnA1	65,83	9,97	15,35	25,32	4,00	4,16	0,72	0,70	0,21
17	Divergent No. 21	62,63	10,78	15,86	26,64	3,95	3,91	0,68	0,65	0,21
	Dwarfs (< 60 cm)									
18	Divergent No.19	57,86	9,73	14,72	24,45	4,06	4,00	0,74	0,71	0,24
19	Divergent 6 x A1 № 19	57,29	7,80	10,92	18,72	3,75	3,63	0,69	0,63	0,23
	C_v	24,79	28,25	27,35	33,17	14,30	16,44	24,08	26,24	52,19

Note. L_{Stem} – stem length, cm; L_{II}, L_{III} and L_{Top} – lengths of the 2nd, 3rd and upper internodes, cm; D_{II} and D_{III} – outer diameters of the 2nd and 3rd internodes, mm; $Width_{II}$ и $Width_{III}$ – widths of the 2nd and 3rd internodes, mm; M10cm – mass of the straw segment of the 2nd internode, g; C_v % – coefficient of variation.

brids with the winter variety Sirs 57 – Sirs 57 × Ukro and SiArs 217 were also characterized by the minimum length of the 2nd internode.

The character of manifestation of the plant productivity structure traits differed significantly depending on the environmental conditions. The minimum indicators were obtained under conditions of prolonged drought 2023. Plants experienced moisture deficit in the phases of booting, flowering, and earing, which determined the reduction of the resulting trait in general (see Fig. 1).

Under drought conditions in 2023, grains were set only in the first and second flowers of the ear (rye type), in favorable (2022) – and in the third and fourth flowers, due to which a more productive ear with increased lakeiness was formed. The maximum ear productivity was observed in favorable climatic conditions in 2022. The highest value of the trait was observed in the samples Sirs 57 × Ukro (6.35 g), O312/29 non/awned (5.26 g), Kissa half-awned and LMK462/208 (4.98) and O312/29 awned non/hairy (4.91 g).

The susceptibility of triticale plants to lodging was evaluated by a set of traits of 10-cm culm weight (*M*10cm), stem break resistance (*F*) and density of the 2nd internode tissue (ρ). The studied samples differed significantly by these parameters, which indicates their inherent different degree of resistance to lodging (see Fig. 2).

It was found that at the same culm diameter the plants differed by the value of load resistance - the peak value of dynamometer readings (*F*, kg), which characterizes the yield strength of the sample tissue at stem fracture or irreversible deformation. Samples O312/29 non/awned (*F* = 2.99 kg), LMK462/208 (*F* = 2.84 kg), O312/29 awned non/hairy (*F* = 2.68 kg), SiArs217 (*F* = 2.60 kg), Timur (*F* = 2.52 kg), Sirs 57 × Ukro (*F* = 2.48 kg) were characterized by the highest values of the fracture strength parameter. Early maturing low-growing variety K-3992 had the highest tissue density parameter.

Functionally related morphological and physical-mechanical traits that ensure productivity and plant resistance to lodging should be considered in an integrated manner. Pearson correlation coefficients were used to detect and describe statistical dependence.

The dependence of the stem length trait had a strong degree of expression with the trait length of the upper internode (*r* = 0.85*). Moderate correlation dependence was observed with the following traits: length of the 2nd internode (*r* = 0.66*), length of the 3rd internode (*r* = 0.59*); sum of the lengths of the 2nd and 3rd internodes (*r* = 0.65*), internal diameter of the 2nd internode (*r* = 0.44*) and number of spikelets in the ear (*r* = 0.45*). The correlation between the stem length and the spikelet length traits was weak (*r* = 0.25*).

The correlation analysis showed a positive relationship between the ear productivity and ear length (*r* = 0.6*). This is explained by the fact that longer ears produce more spikelets (*r* = 0.48*) and more grains. The ear productivity trait had a positive, moderate to strong correlation with the following traits: outer diameters of the 2nd and 3rd internodes (*r* = 0.63* and *r* = 0.67*, respectively), culm length of the 2nd internode (*r* = 0.73*) and the breaking strength value (*r* = 0.66*). The most stable correlation of culm resistance to breakage was shown with

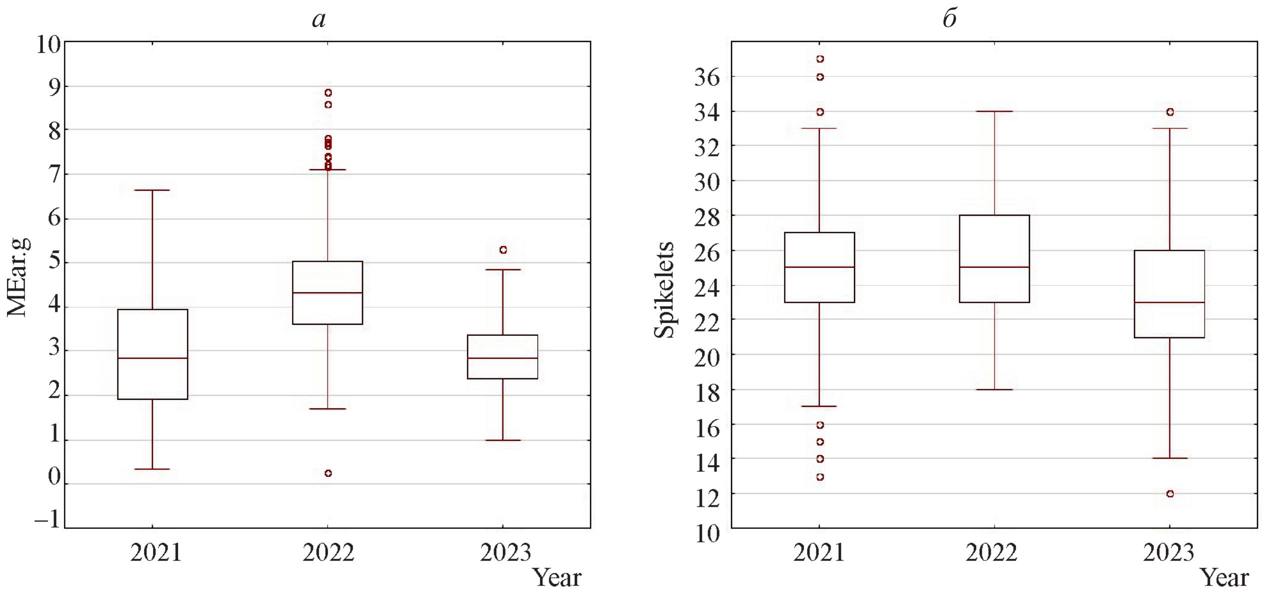

Рис. 1. Диаграммы размаха значений признаков по годам:
а – масса колоса, г; *б* – число колосков в колосе, шт. □ – 25–75%, ⌶ – размах без выбросов, ○ – выбросы – медиана
Fig. 1. Diagrams of the range of trait values by years:
a – ear weight, g; *б* – number of spikelets per ear, pcs. □ – 25–75%, ⌶ – range without outliers, ○ – outliers – median

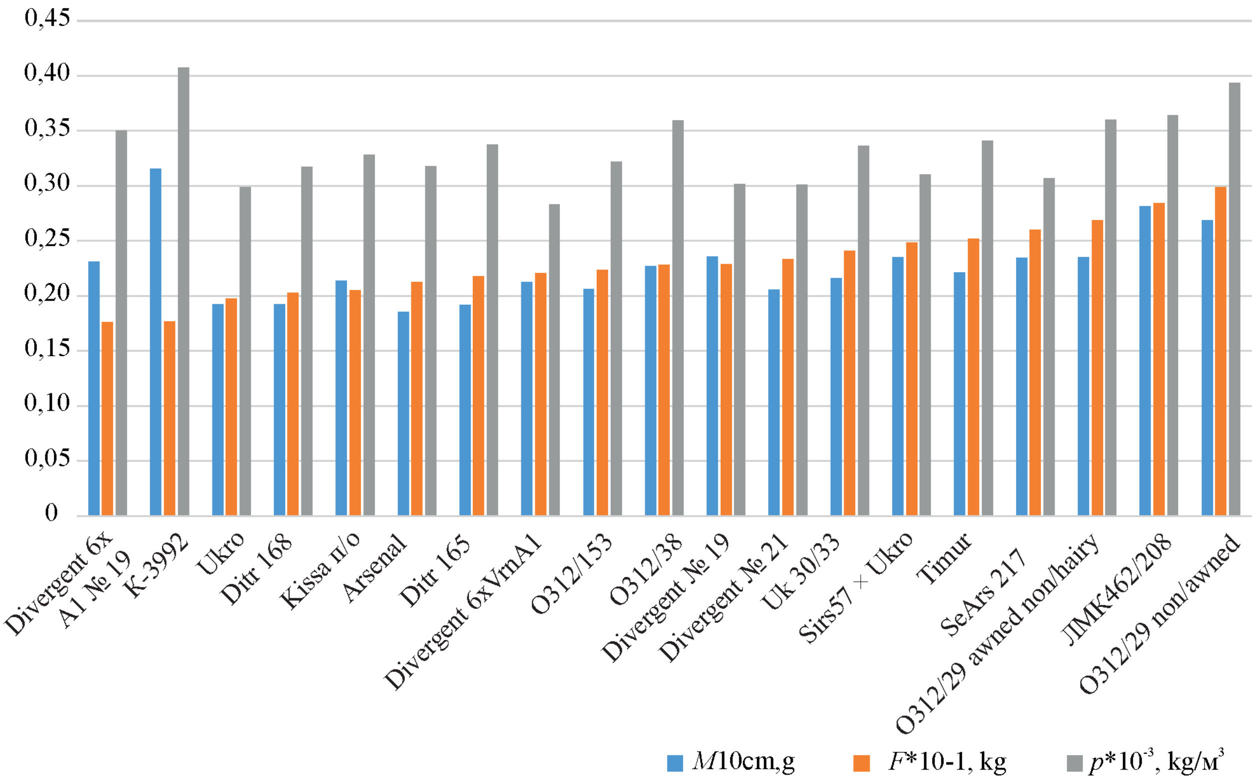

Рис. 2. Прочностные характеристики образцов в фазе полной спелости
Fig. 2. Strength characteristics of the samples in the full ripeness phase

the thickness of the 2nd and 3rd internodes (r = 0.72* and r = 0.63*, respectively) and the culm weight of the 2nd internode (r = 0.86*). The conducted correlation analysis revealed the presence of direct and inverse relationships describing different degrees of conjugation between morphological, physical and mechanical traits and productivity of the studied samples.

The method of principal components was used to describe the studied multivariate data, which have not always explicit relationships, as well as analyze and visualize them. The calculation of principal components was reduced to the replacement of the original interrelated variables by a set of uncorrelated parameters, calculation of eigenvectors and eigenvalues of the covariance matrix of the original data.

As a result of the analysis, it was found that the variability of quantitative traits is determined by four main components, which are linear combinations of initial factors and determine the total variance by 70.3% in the aggregate. In this case, the first – by 28.3%, the second – by 23.8%, the third – by 9.8%, the fourth – by 8.3%.

The use of the principal component method allowed reducing the dimensionality of the data, estimating their variability and eliminating multicollinearity. The observations were differentiated using the "Power" parameter, which shows how well the trait is represented in the principal components in the measurement range from 0 to 1 (see Table 2). Variables with the lowest power have low significance for ranking the results of the observations by principal components. The leading role belongs to the trait " the sum of lengths of the 2nd and 3rd internodes", which is determinant in providing higher resistance to lodging in the studied samples. It follows that selection of plants according to the minimum value of the trait " the sum of lengths of the 2nd and 3rd internodes" and their use as sources of this trait can lead to increased resistance to lodging in the breeding process.

According to the data of the load matrix, a graph was constructed to show the relationships between the factors and the contributions of factors to each principal component (see Fig. 3). The axes of the graph are the first and second components with the highest variability (28.30 and 23.86%, respectively). The influencing factors are designated by their ordinal numbers (see Table 2), and the ellipses highlight the formed groups of interrelated features.

The analysis of the graph of loads allowed to reveal the structures of mutual relations between the variables. Thus, two large clusters of correlating features were identified: 1) L_{II}, L_{III}, L_{II}+L_{III}, L_{Top}, L_{Stem}; 2) d_{II}, D_{II}, D_{III}, L_{Ear}, Spikelets, M_{Ear}. The farther the points on the graph are located from the origin of coordinates, the higher the contribution of the variable to the formation of the principal component. A close relationship between the secondary trait of 10-cm culm mass (M10cm) and the parameter of stem resistance to breakage (F) was also found. The conjugation of these characteristics and consideration of the mutual influence of the traits will allow direct selection of genotypes with increased resistance to lodging at early stages of breeding.

CONCLUSION

Табл. 2. Значимость исследуемых признаков в главных компонентах

Table 2. Significance of the studied features in principal components

Variable	Variable number	Capacity	Significance
L_{II}+L_{III}	8	0,899	1
L_{top}	9	0,889	2
D_{II}	11	0,871	3
L_{III}	7	0,850	4
L_{Stem}	4	0,817	5
D_{II}	22	0,787	6
Internode	5	0,764	7
D_{III}	12	0,760	8
L_{II}	6	0,718	9
F	16	0,709	10
$Width_{II}$	13	0,678	11
LEar	17	0,654	12
Spikelets	18	0,653	13
M10cm	15	0,644	14
EarDensity	19	0,643	15
L_{Top}/L_{Srem}	10	0,640	16
MEar	21	0,565	17
$Width_{III}$	14	0,450	18
ρ	23	0,366	19

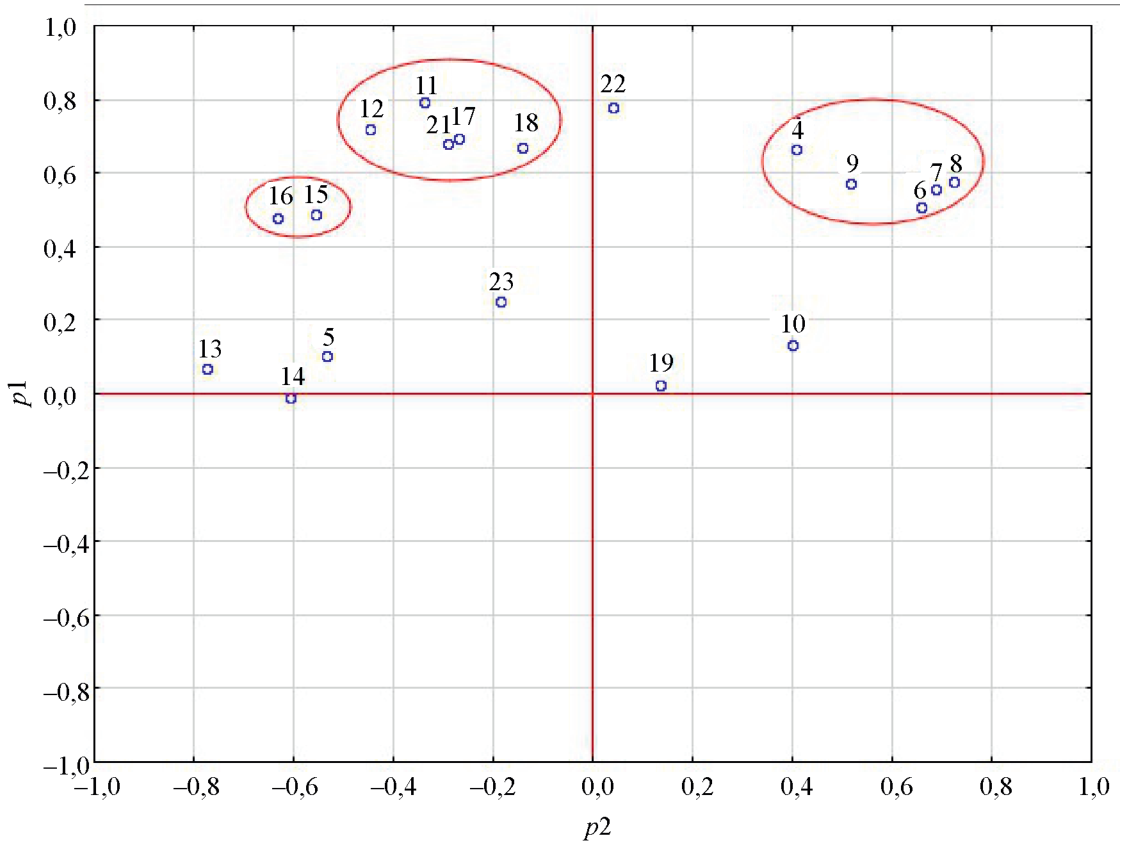

Рис. 3. График взаимосвязи между факторами по первой и второй компоненте

Fig. 3. Graph of the relationship between the factors for the first and second component

Compared to labor-intensive methods of studying the anatomical structure of stem tissue and visual field evaluation, which does not always allow determining the level of processability under unregulated environmental conditions, the applied methodology for assessing stability by tissue density and resistance of stem sections of the 2nd internode to fracture is simple. It was reliable and showed high efficiency during the study period.

According to the results of principal component analysis, the trait " the sum of lengths of the 2nd and 3rd internodes", which is a determinant in providing higher lodging resistance in the studied samples, was identified. A close relationship between the secondary trait "weight of a 10-cm culm" and the parameter of stem resistance to breakage was established.

Among the studied breeding forms, promising specimens were identified according to the totality of the strength parameters, which can be used as sources of valuable traits at the early stages of selection for lodging resistance without involving short-stemmed forms.

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Сравнительная оценка перспективных линий озимой мягкой пшеницы в условиях юга Ростовской области

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Представлен анализ изменчивости линий озимой мягкой пшеницы по количественным признакам. Исследования проведены в 2020–2023 гг. в Ростовской области. В качестве объекта исследований были взяты семь линий озимой мягкой пшеницы конкурсного сортоиспытания. Сорт Ермак использовали в качестве стандарта. Урожайность линий за годы исследования в среднем варьировала от 9,78 до 10,12 т/га при средней по опыту 9,76 т/га. Высота растений составила от 85,0 до 115,0 см. Все изучаемые линии по массе 1000 зерен относились к мелко- и среднезерным (32,9–45,9 г). В среднем за годы изучения минимальную массу 1000 зерен сформировала линия 1638/19 (34,6 г), максимальную – 1361/19 (43,5 г). По показателю даты колошения линии имели разную группу спелости. Длина колоса изменялась от 7,3 до 10,0 см. Наибольшую длину колоса сформировала линия 1361/19 (10,0 см), наименьшую – 1120/19 (7,3 см). Количество продуктивных стеблей варьировало от 471 до 924 шт./м^2. Максимальное количество продуктивных стеблей за годы исследования сформировала линия 1921/20 (758 шт./м^2), минимальное – линия 1361/19 (689 шт./м^2). Число зерен с одного растения варьировало от 61,6 до 110,6. В среднем наибольшее число зерен на одном растении сформировала линия 1638/19 (100,6 шт.), наименьшее – 1343/19 (70,4 шт.). Масса зерна с одного растения в среднем равнялась 3,54 г и варьировала от 2,26 до 4,56 г. Число зерен с колоса изменялось от 28,9 до 51,5 шт., максимальное количество сформировали линии 1361/19 (42,7 шт.) и 1638/19 (41,2 шт.). По массе зерна с колоса стандарт превысила линия 1361/19 (1,93 г), значения по показателю варьировали от 1,02 до 2,28 г.

Ключевые слова: озимая пшеница, линия, урожайность, масса 1000 зерен

Comparative evaluation of the promising lines of winter soft wheat in the south of the Rostov region

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The analysis of variability of winter soft wheat lines by quantitative traits is presented. The research was conducted in 2020–2023 in the Rostov region. Seven lines of winter soft wheat of the competitive variety trial were taken as an object of research. The Ermak variety was used as a standard. The yields of the lines during the years of study averaged from 9.78 to 10.12 t/ha with an average of 9.76 t/ha in the experiment. Plant height ranged from 85.0 to 115.0 cm. All the lines studied were classified as small- to medium-grained (32.9–45.9 g) in terms of 1000 grain weight. On average for the years of study, the minimum mass of 1000 grains was formed by the line 1638/19 (34.6 g), and the maximum – by the line 1361/19 (43.5 g). The lines had different groups of ripeness according to the indicator of the earing date. The spikelet length varied from 7.3 to 10.0 cm. The highest spikelet length was formed by the line 1361/19 (10.0 cm), the shortest – by the line 1120/19 (7.3 cm). The number of productive stems ranged from 471 to 924 stems/m^2. The maximum number of productive stems for the years of the study was formed by the line 1921/20 (758 pcs./m^2), the minimum – by the line 1361/19 (689 pcs./m^2). The number of grains per plant ranged from 61.6 to 110.6. On average, the highest number of grains per plant was formed by the line 1638/19 (100.6 pcs.), the lowest – 1343/19 (70.4 pcs.). The grain weight per plant averaged 3.54 g and ranged from 2.26 to 4.56 g. The number of grains per ear varied from 28.9 to 51.5 pieces, the maximum number was formed by the lines 1361/19 (42.7 pcs.) and 1638/19 (41.2 pcs.). In terms of the grain weight per ear the standard was exceeded by the line 1361/19 (1.93 g), the values for the indicator varied from 1.02 to 2.28 g.

Keywords: winter wheat, line, productivity, 1000-grain weight

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The authors declare no conflict of interest.

INTRODUCTION

Winter wheat is one of the main food crops. Nowadays, the growth of grain production and its quality are of great importance in agriculture, as the sustainable development of the whole industry is largely dependent on them [1].

Increase in grain production in the future is impossible without wide and comprehensive use of the latest achievements of science. The leading role, undoubtedly, belongs to breeding, new varieties and technologies of their cultivation [2].

Accelerated and sustainable increase in grain production is the main task of agriculture. In this regard, breeding is called to play a major role in solving this problem. Its main task is to increase crop yields by creating new high-yielding varieties with high grain quality [3].

Successful development of modern grain farming is impossible without engaging new varieties and hybrids of agricultural crops, including winter wheat varieties, in production. Their introduction is the least costly and one of the most effective ways to increase crop production and improve its quality [2].

The purpose of the study is to analyze the variability of quantitative traits of winter soft wheat lines.

MATERIAL AND METHODS

The research was conducted at the Agrarian Scientific Center "Donskoy" in 2020-2023 (Rostov region). Seven lines of winter soft wheat of intensive type served as the material for research. The Ermak variety was used as a standard.

The soil of the experimental field is carbonate chernozem, heavy loamy, thick with high carbonateness – up to 4.0% $CaCO_3$ in the arable layer of thick horizon (up to 140 cm). Humus content – 3.6–4.0%, mobile phosphorus – 20–23 mg/kg of soil, exchangeable potassium – 300–380 mg/kg. In general, the soil of the experimental plot by its fertility and physical and chemical properties is beneficial for growing winter wheat.

Sowing was carried out with a mounted seeder Wintersteiger Plotseed using the conventional row method. The seeding rate was 4.5 mln germinated seeds/ha, planting depth was 5–6 cm. The plot area of 10 m^2, sixfold repetition, systematic arrangement in six tiers. After sowing, the soil was rolled with ring rollers. The forecrop – green-manured fallow.

Maintenance measures were applied taking into account the crop phytosanitary condition and recommendations on the use of insecticides and fungicides in the cultivation zone. In the winter period, systematic treatment of the crops from rodents was carried out.

Harvesting was carried out with a small-sized Wintersteiger Classic combine harvester using a single-phase method at full grain ripeness. Harvested from the plot was weighed in the field and converted to 14% moisture and 100% purity.

The 2019/20 agricultural year turned out to be dry: a total of 463.7 mm of precipitation fell during the year with the norm of 582.4 mm. Their distribution by seasons and temperature regime (+1.6 ° C to the average annual norm) were atypical for our zone and not quite favorable for the growth and development of winter wheat plants, especially in the spring period. Lack of moisture in the spring-summer period led to the formation of shrinked grain.

The year 2020/21 was marked by an increased temperature regime and uneven distribution of precipitation during the year. The average annual air temperature amounted to 11.7°C, exceeding the long-term norm by 2.0°C. In general, the prevailing weather conditions allowed to obtain sufficiently high grain yields.

2021/22 was characterized by higher temperature regime in winter and uneven distribution of precipitation during the year. The average annual air temperature amounted to 11.1 ºC, exceeding the mean annual data by 1.4 ºC. The reduced temperature regime in May had a favorable effect on the growth and development of winter wheat, as well as on the formation of high grain yields.

The agricultural year 2022/23 was not quite favorable for growth and development of winter wheat, especially during the late spring - early summer, in terms of precipitation distribution by seasons, temperature regime (+1.9 °C to the average annual norm). Intense precipitation with strong gusty winds in late May – early June had a negative impact on winter wheat plants, which led to poor yield, mainly on fallow predecessors, due to lodging of crops and strong development of fungal diseases.

RESULTS AND DISCUSSION

Yield is determined by the production from one hectare of area and represents the final result of all physiological and biochemical processes of plant life in interaction with external environmental conditions[1].

The average yield of winter soft wheat lines for the years of research in the experiment was 9.76 t/ha, the variation in this trait was from 7.75 t/ha for line 1784/20 to 11.79 t/ha for line 1361/19 (see Table 1).

Plant height is an important trait because it determines other morphological traits of linear growth, with close genetic determination of the trait - genotype-medium response of the variety under vegetation conditions and has an inverse relationship with resistance to lodging [4].

In terms of plant height, the variation ranged from 85.0 to 115.0 cm, the maximum height was in line 1638/19 in 2022 and the minimum height was in line 1420/19 in 2021, the mean value of the trait was 90.6 cm.

The weight of 1000 grains determines the yield properties of the seeds and refers to varietal traits. It is well known that a high 1000 grain weight can be obtained when plants are grown under favorable meteorological conditions during the period of grain filling and ripening. With the same number of stalks and ear grain content the yield will be higher in those crops with a higher 1000 grain weight [5].

Grain size as the most important agronomic trait in genetic and breeding studies is given great attention (see footnote 1). Grain is considered coarse if the mass of 1000 grains is more

Табл. 1. Изменчивость количественных признаков озимой мягкой пшеницы (2020–2023 гг.)
Table 1. Variability of quantitative traits of winter soft wheat (2020–2023)

Trait	Average value of the trait	Variation range of the trait (min – max)	Standard deviation, σ	Coefficient of variation *V*, %
Yield t/ha	9,76	7,75–11,79	0,44	4,48
Plant height, cm	90,6	85,0–115,0	3,57	3,95
Weight of 1000 grains, g	37,9	32,9–45,9	2,99	7,90
Earing date, May	22	16–30	2,78	12,34
Ear length, cm	8,8	7,3–10,0	0,55	6,23
Productive spikelets, pcs./m^2	704	471–924	30,28	4,30
Number of grains per plant, pcs.	89,4	61,6–110,6	9,29	10,39
Grain weight per plant, g	3,54	2,26–4,56	0,37	10,35
Number of grains per ear, pcs.	38,5	28,9–51,5	2,72	7,07
Grain weight per ear, g	1,47	1,02–2,28	0,22	14,63

[1]*Klimenko S.B., Abramova I.N., Klimenko N.N., Klimenko A.S.* Evaluation of the breeding lines of soft spring wheat // Scientific research and development to the implementation of the agroindustrial complex: materials of the international scientific and practical conference of young scientists. Irkutsk, 2023, pp. 62-68.

than 47 g, medium coarse – 39–40, fine – 27–38 g. According to the mass of 1000 grains, all the studied lines were classified as fine- and medium-grained, the variation was from 32.9 to 45.9 g. The minimum weight of 1000 grains was obtained in 2020 in line 1638/19 (32.9 g), the maximum – in line 1361/19 (45.9 g), the average value of the trait – 37.9 g.

The duration of the growing season is one of the main adaptation traits that determine the suitability of varieties for cultivation in a particular zone [6]. In the south of the Rostov region, the earing phase is a more reliable criterion for determining the ripeness group than the ripening phase [7].

All varieties ripened almost simultaneously, so the assessment of their early maturity was carried out by the date of earing for 2020-2023. In the middle-early variety Ermak on average it occurred on May 19. According to the date of earing, the lines 1120/19, 1343/19, 1361/19 and 1420/19 (May 20 – 22) can be referred to the mid-early maturity group. Line 1784/20 (May 23) belongs to the medium-maturing group, and 1638/19 and 1921/20 (May 26 – 27) to the middle-late group.

An important element of ear productivity is its length. This trait varies greatly depending on varietal characteristics, as well as on the weather and climatic conditions [8]. With the average value of the trait (8.8 cm), the length of the ear for 4 years of research varied from 7.3 to 10.0 cm. The greatest ear length was formed by line 1361/19 (10.0 cm) in 2023, the least – by line 1120/19 (7.3 cm) in 2021.

Varieties with high productive spikelets (more than two stalks per plant) are recommended to cultivate in order to increase yields and increase grain yields [5]. The highest number of stems was formed in 2023 – 924 pcs/m² (1343/19), the minimum was observed in 2021 – 471 pcs/m² (1120/19). The average value of productive spikelets for the years of study amounted to 704 pieces/m².

The number of grains in an ear is important. Productive stalks form the ear, which can be long or short; the longer the ear, the greater its ear grain content and potential grain yield [9]. The varieties and lines studied differed in the number of grains in the ear and per plant. With an average value of the number of grains per ear (38.5 pieces) and the number of grains per plant (89.4 pieces), the variation in the number of grains per ear during the years of research ranged from 28.9 (1784/20) to 51.5 pieces (1361/19). In terms of the number of grains on one plant, line 1120/19 formed both minimum and maximum number, but in different years from 61.6 (2022) to 110.6 pieces (2023).

Grain weight per ear and per plant depends on the variety genotype and growing conditions [10]. The variation of grain weight per ear was from 1.02 g in line 1784/20 to 2.28 g in 1361/19, grain weight per plant – from 2.26 g in 1120/19 to 4.56 g in 1361/19. The average value of the grain weight per ear trait for the years of study was 1.47 g, grain weight per plant – 3.54 g.

The coefficients of variation for the traits presented in Table 1 had values from 3.95 to 14.63%, indicating an insignificant and average level of variability of these traits. At the same time, yield, plant height, ear length, productive spikelets, number of grains in an ear and weight of 1000 grains for 2020–2023 studies changed insignificantly, the coefficients of variation (*V*) were 4.48; 3.95; 6.23; 4.30; 7.07; 7.90%, respectively.

The earing date, number of grains per plant, grain weight per plant and grain weight per ear had medium level of variability with the coefficient of variation (*V*) of 12.34; 10.39; 10.35; 14.63%, respectively.

Yield is the result of a compromise between productivity and resistance to adverse environmental factors [2]. With the average yield of Ermak variety (8.73 t/ha), taken as a standard, the average yield of the promising lines during the years of study varied from 9.78 to 10.12 t/ha. On average for 4 years of research all seven lines significantly exceeded the standard variety Ermak in terms of yield (LSD_{05} 0.37 t/ha). The gain was from 1.05 (1120/19 and 1343/19) to 1.39 t/ha (1784/20). The maximum yield was formed by the lines 1361/19 (10.05 t/ha), 1784/20 (10.12) and 1921/20 (10.00 t/ha) (see Table 2).

The most productive lines were 1361/19 (10.01 t/ha) and 1420/19 (10.14 t/ha), as evidenced by the indicator ($\frac{\min + \max}{2}$)characterizing the variety's adaptive ability. This indicator shows the average yield of the variety in contrasting (stress and non-stress) conditions and genetic flexibility of the variety, its compensatory ability. The higher the degree of correspondence between the genotype of the variety and various environmental factors, the higher this indicator is [11, 12].

Favorable weather and climatic conditions in the spring-summer period of 2022 contributed to the formation of the highest yield of the studied lines of winter soft wheat of intensive type, the average for the experiment – 11.43 t/ha. The maximum yield was obtained in the line 1420/19 – 12.08 t/ha with the yield of the standard 10.02 t/ha and LSD_{05} – 0.38 t/ha.

In 2023 unfavorable for yield formation due to high precipitation and lodging of plants, the lowest yield in the experiment was formed – 7.98 t/ha. It was maximally high in the line 1921/20 – 8.90 t/ha, in the standard – 6.64 t/ha, LSD_{05} – 0.43 t/ha.

The coefficient of variation (V) makes it possible to give an objective assessment of the degree of variation when comparing any aggregates. When studying quantitative characteristics, it allows selecting the most stable ones. Variation is considered weak at $V \leq 10\%$, average – at V from 11 to 25% and strong – at $V > 25\%$. The lowest variation index for yield was observed in the line 1120/19 (13.10%), which indicates an average level of variability in this trait, in other lines it was from 15.40 to 18.96%, which also confirms the average level of variability in yields.

Higher yield in structural terms the studied lines formed at the expense of the following indicators: productive spikelets, number of grains per plant and grain weight per ear (line 1921/20); productive spikelets, number of grains per plant, number of grains per ear and grain weight per ear (1638/19). Of greatest interest is line 1361/19, which combines six structure elements with maximum values of 1000 grain weight, ear length, number of grains per plant and ear fineness, as well as grain weight per plant and grain weight per ear (see Table 3).

On average for 4 years, the height of the standard variety Ermak was 107.8 cm. All studied lines formed height from 93.7 to 109.4 cm and belong to low-stemmed varieties.

The studied lines differed significantly in the weight of 1000 grains. Weight gain relative to the standard was observed in three lines: 1361/19, 1420/19 and 1120/19. The best result among them was observed in line 1361/19 (43.51 g), which formed the mass of 1000 grains by 4.23 g more than the standard variety Ermak.

The spikelet length of the studied lines varied from 7.9 to 9.4 cm. The maximum spikelet length was formed by the lines 1361/19 (9.4 cm) and 1420/19 (9.3 cm).

Analyzing the average number of productive stems per 1 m^2, it should be noted that the standard variety Ermak showed the lowest value –

Табл. 2. Урожайность линий озимой мягкой пшеницы (2020–2023 гг.)
Table 2. Yield of winter soft wheat lines (2020–2023)

Variety/line	Yield t/ha			$\frac{min + max}{2}$	Coefficient of variation V, %
	min	max	average		
Ermak (standard)	6,64	10,02	8,73	8,33	18,36
1120/19 (Rostovchanka 7 × № 42 CIMMYT)	8,33	11,26	9,78	9,80	13,10
1343/19 (1567/10 × Slavna)	7,80	11,88	9,78	9,84	17,27
1361/19 (1993/10 × Slavna)	8,10	11,79	10,05	10,01	15,40
1420/19 (1602/12 × Slavna)	8,20	12,08	9,83	10,14	16,66
1638/19 (Marathon × MV 15-04)	8,11	11,35	9,80	9,73	15,69
1784/20 (1276/08 × Spivanka)	7,75	11,68	10,12	9,72	18,96
1921/20 (1514/09 × Perlina)	8,23	11,46	10,00	9,85	16,77
LSD_{05}			0,37		

Табл. 3. Элементы структуры линий озимой мягкой пшеницы (2020–2023 гг.)
Table 3. Elements of winter soft wheat line structure (2020–2023)

Variety/line	Plant height, cm	Weight of 1000 grains, g	Spike-let length, cm	Pro-ductive spike-lets, pcs./m²	Number of grains per plant, pcs.	Grain weight per plant, g	Num-ber of grains per ear, pcs.	Grain weight per ear, g
Ermak (standard)	107,8	39,28	8,5	660,8	97,4	3,89	39,8	1,59
1120/19 (Rostovchanka 7 × № 42 CIMMYT)	101,0	40,13	7,9	691,8	87,4	3,26	39,5	1,38
1343/19 (1567/10 × Slavna)	103,4	36,51	9,2	732,0	70,4	3,49	38,7	1,37
1361/19 (1993/10 × Slavna)	101,0	43,51	9,4	689,0	95,0	4,19	42,7	1,93
1420/19 (1602/12 × Slavna)	101,6	40,26	9,3	689,5	85,5	3,38	36,8	1,45
1638/19 (Marathon × MV 15-04)	109,4	34,56	9,2	713,5	100,6	3,59	41,2	1,46
1784/20 (1276/08 × Spivanka)	100,7	35,08	8,4	766,5	96,7	3,02	34,6	1,19
1921/20 (1514/09 × Perlina)	93,7	36,48	9,2	758,8	90,0	3,48	35,8	1,74
Standard deviation	3,6	2,99	0,6	30,3	9,3	0,37	2,7	0,22

660.8 pcs./m², therefore, all the analyzed lines exceeded it in this feature. On average, the maximum number of productive stems was formed by the line 1784/20 – 766 pcs./m².

On average, 39.8 grains per ear were formed in the standard and 97.4 grains per plant during the years of study. The maximum number of grains in the ear on average was formed by the lines 1361/19 (42.7 pieces) and 1638/19 (41.2 pieces), the maximum number of grains per plant was formed by the line 1638/19 (100.6 pieces).

Line 1361/19 averaged the maximum grain weight both per ear (1.93 g) and per plant (4.19 g).

CONCLUSIONS

1. Evaluation of the breeding lines of winter soft wheat in different weather conditions in the years of research showed that all lines of winter soft wheat have high and stable productivity, as well as a complex of economically valuable traits and properties regardless of the weather.

2. The studied lines formed higher yield in structural terms due to the following indicators: productive ear length, number of grains per plant and grain weight per ear – line 1921/20; productive ear length, number of grains per plant, number of grains per ear and grain weight per ear – 1638/19. Of greatest interest is the line 1361/19, which combines six elements of structure with maximum values of 1000 grain weight, ear length, number of grains per plant and ear fineness, as well as grain weight per plant and grain weight per ear. These lines are recommended for involvement in the breeding process in order to obtain new high-yielding source material.

Lines 1361/19 "Udarnik" and 1120/19 "Sarkel" were transferred to the State Variety Trial in 2023.

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Эффективность совместного возделывания фестулолиума с эспарцетом на кормовые цели в лесостепи Западной Сибири

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Представлены данные по урожайности и биологической эффективности совместного возделывания фестулолиума и эспарцета песчанного при различных способах посева и внесения азотных удобрений весной в условиях лесостепной зоны Западной Сибири. Выживаемость растений фестулолиума после прохождения зимовки первого года жизни составила 86%, эспарцета в одновидовом посеве – 86%, она снизилась при посеве с чередованием рядов до 76%, при посеве смесью семян – до 67%. Совместный посев фестулолиума с эспарцетом повысил урожайность на 22,6% по сравнению с одновидовым посевом фестулолиума (30,38 т зеленой массы /га) при черезрядном посеве и на 7,9% (до 26,73 т/га) – при посеве смесью семян. Коэффициент энергетической эффективности (КЭЭ) равен 7,7–9,0 и характеризуется как высокий, рентабельность смесей – 373%. Внесение минерального азота в дозе 30 кг д.в./га достоверно увеличило урожайность смесей фестулолиума с эспарцетом на вариантах черезрядного посева на 29,5% и на варианте посева смесью семян на 11,5% за счет увеличения облиственности бобового компонента. В эксперименте КЭЭ равен 4,4–5,2 и характеризуется как высокий, рентабельность посева смесей – 352%. При увеличении дозы минерального азота до 60 кг д.в./га максимальная урожайность на варианте посева смесью семян – 41,84 т зеленой массы /га, что на 32% выше одновидового посева фестулолиума. Прибавка обусловлена увеличением на 4% высоты растений фестулолиума и на 60% – его массы. При посеве с чередованием рядом урожайность составила 39,11 т зеленой массы/га, что выше контроля на 23,4%. КЭЭ равен 4,7–4,9 и характеризуется как средний, рентабельность посева смесей – 349–364%. Показатель эффективности использования пашни (LER) в смесях составил 0,96–1,06, что подтверждает их целесообразность.

Ключевые слова: фестулолиум, эспарцет, способы посева, азотные удобрения, конкурентная способность

The effectiveness of joint cultivation of festulolium with esparcet for forage purposes in the forest-steppe of Western Siberia

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The results of the analysis of the yield and biological efficiency in the joint cultivation of festulolium and esparcet with various methods of sowing and applying nitrogen fertilizers in spring in the conditions of the forest-steppe zone of Western Siberia are presented. The survival rate of festulolium plants after overwintering the first year of life was 86%, esparcet survival rate in single-species sowing was 86% and decreased when using the skip-row planting to 76%, when sowing with a mixture of seeds to 67%. Joint sowing of festulolium with esparcet increased the yield by 22.6% compared with single-species sowing of festulolium (30.38 t/ha of the green mass) when using the skip-row planting and by 7.9% (to 26.73 t/ha) when sown with a mixture of seeds. The energy efficiency ratio (EER) is 7.7–9.0 and is characterized as high, the profitability of the mixtures is 373%. The introduction of mineral nitrogen at a dose of 30 kg a.i./ ha significantly increased the yield of the mixtures of festulolium with esparcet in the variants skip-row planting by 29.5% and in the variant of sowing with a mixture of seeds by 11.5% due to an increase in the leafiness of the legume component. In the experiment the EER equals 4.4–5.2 and is characterized as high, the profitability of sowing the mixtures is 352%. With an increase in the dose of mineral nitrogen to 60 kg a.i. / ha, the maximum yield on the variant of sowing with a mixture of seeds is 41.84 t / ha of green mass, which is 32% higher than single–species sowing of festulolium. The increase is due to a 4% increase in the height of the festulolium plants, and 60% of its mass. When using skip-row planting, the yield was 39.11 t/ha of the green mass, which is 23.4% higher than the control. The EER equals 4.7–4.9 and is characterized as average, the profitability of sowing the mixtures is 349–364%. The arable land equivalent ratio (LER) in the mixtures was 0.96–1.06, which confirms their effectiveness.

Keywords: festulolium, esparcet, sowing methods, nitrogen fertilizers, competitive ability

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INTRODUCTION

Perennial grasses occupy a leading place in solving the problem of sustainability of the fodder base, obtaining nutritious fodder, balanced in protein, essential amino acids and vitamins. They serve as a basis for biologization of farming, increase soil fertility, protect it from wind and water erosion, with rational use of intensification factors increase ecological safety of cenoses and sustainability of cheap fodder production [1, 2].

Widely used in meadow farming traditional cereal grasses (timothy grass, cock's foot, meadow fescue, awnless brome, etc.) are characterized by insufficient content of water-soluble carbohydrates, low rate of regrowth after the next cycles of alienation, summer growth depression. In this regard, it is important to expand the range of cultivated forage crops by creation, introduction and adaptation of new species and varieties with better economically useful properties in production conditions[1] [3–6].

One of such promising fodder crops is Festulolium (*Festulolium* F. Aschers. Et Graebn.) - an artificially bred fodder crop obtained using methods of intergeneric hybridization of genera *Lolium* sp. and *Festuca* sp. Festulolium inherited from ryegrasses excellent fodder qualities (high content of sugar, protein and metabolizable energy), good feed digestibility and digestibility, the ability to intensively form a large number of well-branched vegetative shoots, from fescue - good winter hardiness, drought resistance, resistance to prolonged stratification and trampling[2] [7].

Mostly grass mixtures with festulolium have been studied in the European part of Russia [8-13], in Western Siberia such studies are conducted for the first time in the Siberian Federal Scientific Centre of AgroBioTechnologies of the

[1] *Obraztsov V.N.* Theoretical and practical bases of cultivation of festulolium for fodder and seeds in the forest-steppe of the central Chernozem region of Russia: Doctor of Science in Agriculture thesis/ V.N. Obraztsov. Voronezh: Voronezh SAU, 2018, 404 p.

[2] *Klyga E.R., Vasko P.P.* Festulolium: agrobiological aspects of cultivation. Minsk: DPC Ministry of Finances, 2016, 68 p.

Russian Academy of Sciences (SFSCA RAS) [14]. The obtained preliminary results confirm the prospects of scientific development of cultivation methods and introduction of festulolium into forage production in Western Siberia, aimed at full realization of the biological potential and obtaining sustainable yields of this crop.

The purpose of the research is to develop methods of cultivation of single-species and mixed crops of festulolium of the Izumrudny variety with esparcet in the conditions of the forest-steppe of Western Siberia.

The research objectives are to establish the expediency of joint sowing of festulolium of the Izumrudny variety with esparcet; and to determine the optimal method of sowing at application of small (starting) doses of nitrogen.

MATERIAL AND METHODS

The research was conducted at the field station of the Siberian Research Institute of Forage Crops of the SFSCA RAS, located in the northern forest-steppe of Western Siberia, Russia.

The soil type is chernozem leached medium-moist medium loamy, with humus content in 0–40 cm layer – 4.3–6.5%, which characterizes it as medium-sufficient. The soil of the experimental plot is relatively well provided with mobile forms of phosphorus and exchangeable potassium. Soil solution reaction (pH) = 7.4.

According to climatic resources, it is a moderately warm insufficiently humidified agroclimatic region with average annual precipitation of 386 mm (254 mm in April–September, 113–130 mm in June–August). The hydrothermal coefficient according to Selyaninov is 1.2.

The weather conditions in the study years were favorable for perennial grasses in 2019 (HTC = 1.15), in 2020 (1.29), in 2021 (1.0), and unfavorable in 2022 (0.6), in 2023 (0.99).

Experiment scheme.

Sowing methods (factor A):

1) festulolium (control);
2) esparcet (control);
3) festulolium 1 row + esparcet 3 rows;
4) festulolium + esparcet (seed mix sowing).

Nitrogen fertilizer application options (factor B):

1) without fertilizers (control);
2) application of N_{30};
3) application of N_{60}.

Repetition of the experiments was 4-fold with systematic arrangement of the variants. The sowing area of the plots was 36 m^2. Sowing was carried out in the second ten-day period of July. Fertilizer application was made in spring before grass regrowth in a scattered manner with subsequent incorporation with a rigid spike harrow.

The yield results were analyzed through the "land equivalent ratio" (LER) and "competitive ratio" (CR) [9]. These indicators are calculated by the formula

$$\mathrm{LER} = (Y_{AB} / Y_{AA}) + (Y_{BA} / Y_{BB}),$$

where LER – land equivalent ratio, Y_{AB} – yield of crop *A* in a mixed sowing with crop *B*, t/ha; Y_{BA} – yield of crop *B* in a mixed sowing with crop *A*, t/ha; Y_{AA} and Y_{BB} – yields of crops *A* and *B*, respectively, in single-crop sowing, t/ha.

$$\mathrm{CR}_{\mathrm{AB}} = (\mathrm{LER}_A : \mathrm{LER}_B)\,(Z_{BA} : Z_{AB}),$$
$$\mathrm{CR}_{BA} = (\mathrm{LER}_B : \mathrm{LER}_A)\,(Z_{AB} : Z_{BA}),$$

where CR_{AB} – competitive coefficient of crop *A* mixed with crop *B*; $\mathrm{CR}_{\mathrm{BA}}$ – competitive coefficient of crop *B* mixed with crop *A*; Z_{AB} и Z_{BA} – the ratio of *A* and *B* crops in the mixture, %.

The farming equipment and techniques in the experiment: early spring moisture closure in two traces by rigid spike harrows BZSS-1.0, pre-sowing cultivation KPS-4.2 with harrowing, rolling with ring rollers ZKKSH-6 before and after sowing. Sowing by SN-16 seeder at a depth of 2-3 cm. The norms of festulolium sowing: 16 kg/ha in single-crop sowing, when sowing with alternating rows - 4 kg/ha, in mixed sowing - 8 kg/ha. Esparcet sowing norms: 120 kg/ha in pure sowing, 90 kg/ha in alternating rows, 60 kg/ha in mixed sowing.

Festulolium of the Izumrudny variety and SibNIIK 30 Hungarian sainfoin were used in the experiment. Fertilizer – ammonium nitrate (N) – was applied in spring at the beginning of regrowth in a scattered manner with subsequent incorporation with a rigid spike harrow.

RESULTS AND DISCUSSION

Soil moisture at the time of sowing in the years of grass establishment was 9,7 mm in the 0–20 cm layer in 2019, in 2020 – 22.4 mm, which allowed to note the appearance of the first sprouts on the 5th – 7th day, mass sprouts – on the 15th day.

A significant change in the field germination rate depending on the sowing method and the year of grass establishment was observed. Favorable conditions for festulolium were formed in 2020, when maximum sprouts were obtained of 463–702 plants per square meter. During the period of sowing – sprouting, 84.8 mm of precipitation fell (139% of the average annual norm) with an average monthly ambient air temperature of +19.7 °C (+0.3 °C to the average annual norm). Unfavorable conditions for festulolium were observed at the 2019 planting, where the number of emerged plants was 247-342 pcs/m^2, which was due to partial death of plants because of the established drought in August: precipitation for the month was 21.5 mm, which was 32% of the average annual norm, air temperature exceeded the average annual index by +2.2 ° C (+18.4 ° C). At the same time, the share of influence of conditions of the year of sowing amounted to 13%, the sowing method – 1%.

On average, the density of festulolium in the control was 523, in mixtures – 347–377 pcs./m^2, esparcet – 80 and 45–70 pcs./m^2, respectively (see Table 1). The plant survival rate after overwintering was 86% in festulolium, in esparcet it decreased from single-crop sowing to mixtures by 23–57% and was 76% (73 pcs./m^2) in row sowing and 67% (30 pcs./m^2) in mixed sowing.

Esparcet stand density influenced its share in the yield. Thus, depending on the sowing variant, the content of festulolium in the yield of the first cutting was 1.1–2.3 times higher in mixed sowing than in the sowing with alternating rows (see Table 2). At the same time, with the increase in the dose of the applied nitrogen, the share of festulolium increased by 42.9–54.2% and amounted to 45.6 and 49.2% in the variant with alternating rows; in contrast, the share of festulolium decreased by 17.0–26.6% and amounted to 62.2 and 55.0% when sowing with a mixture of seeds. This pattern was repeated in all the years of herbage use.

When taking into account the yield of grass stands of festulolium with esparcet, it was found that on average for three years there was an increase in the efficiency of mixtures compared to single-crop sowing of festulolium (see Table 3). Collection of green mass increased from 22.6% to 30.38 t/ha in the variant of cross-row sowing due to a greater share of esparcet in the crop (up to 60.7–68.1%) and at the expense of 11% increased shoot weight of esparcet. In mixed sowing of festulolium with esparcet, green mass yield increased by 7.9% to 26.73 t/ha due to a 9% increase in shoot weight of festulolium.

Fertilizer application at the doses of N_{30} and N_{60} increased the harvest of green mass in festulolium by 2.79 and 6.92 t/ha, esparcet – by 1.82 and 9.51 t/ha due to the increase in biometric indices of plants of both crops.

When N_{30} was applied, the yield was higher when sowing with alternating rows – 35.68 t/ha due to greater leaf coverage of esparcet plants, which can be seen in the figure, where when placing cereal and legume components in sep-

Табл. 1. Густота всходов и выживаемость в одновидовых и смешанных посевах
Table 1. Germination density and survival in single-species and mixed crops

Option	Before winterization, pcs./m^2		After overwintering, pcs./m^2		Survival rate, %	
	Cereals	Legumes	Cereals	Legumes	Cereals	Legumes
Festulolium	523	–	450	–	86	–
Esparcet	–	80	–	69	–	86
Festulolium 1 row + esparcet 3 rows	377	70	323	53	86	76
Festulolium + esparcet (mixed sowing)	347	45	302	30	86	67

Табл. 2. Содержание злакового компонента в смешанных посевах фестулолиума с эспарцетом в зависимости от уровня минерального питания и года пользования, %

Table 2. The content of the cereal component in mixed crops of festulolium with esparcet, depending on the level of mineral nutrition and the year of use, %

Option	Nitrogen dose, kg a.i./ha					
	N_0		N_{30}		N_{60}	
	1st hay crop	2nd hay crop	1st hay crop	2nd hay crop	1st hay crop	2nd hay crop
First year of use (2020–2021)						
Festulolium 1 row + esparcet 3 rows	28,7	57,8	37,5	70,4	43,8	62,3
Festulolium + esparcet (mixed sowing)	90,2	79,2	63,1	88,3	49,1	80,3
Second year of use (2021–2022)						
Festulolium 1 row + esparcet 3 rows	43,8	27,8	61,1	39,7	54,6	46,2
Festulolium + esparcet (mixed sowing)	78,8	70,0	72,1	83,4	75,2	79,6
Third year of use (2022–2023)						
Festulolium 1 row + esparcet 3 rows	23,2	32,3	38,2	24,3	49,3	23,3
Festulolium + esparcet (mixed sowing)	56,1	37,3	51,6	21,0	40,7	29,1
On average over the years of use						
Festulolium 1 row + esparcet 3 rows	31,9	39,3	45,6	44,8	49,2	43,9
Festulolium + esparcet (mixed sowing)	75,0	62,1	62,2	64,2	55,0	63,0

Табл. 3. Урожайность одновидовых и смешанных посевов многолетних трав в среднем за 2020–2023 гг., т зеленой массы/га

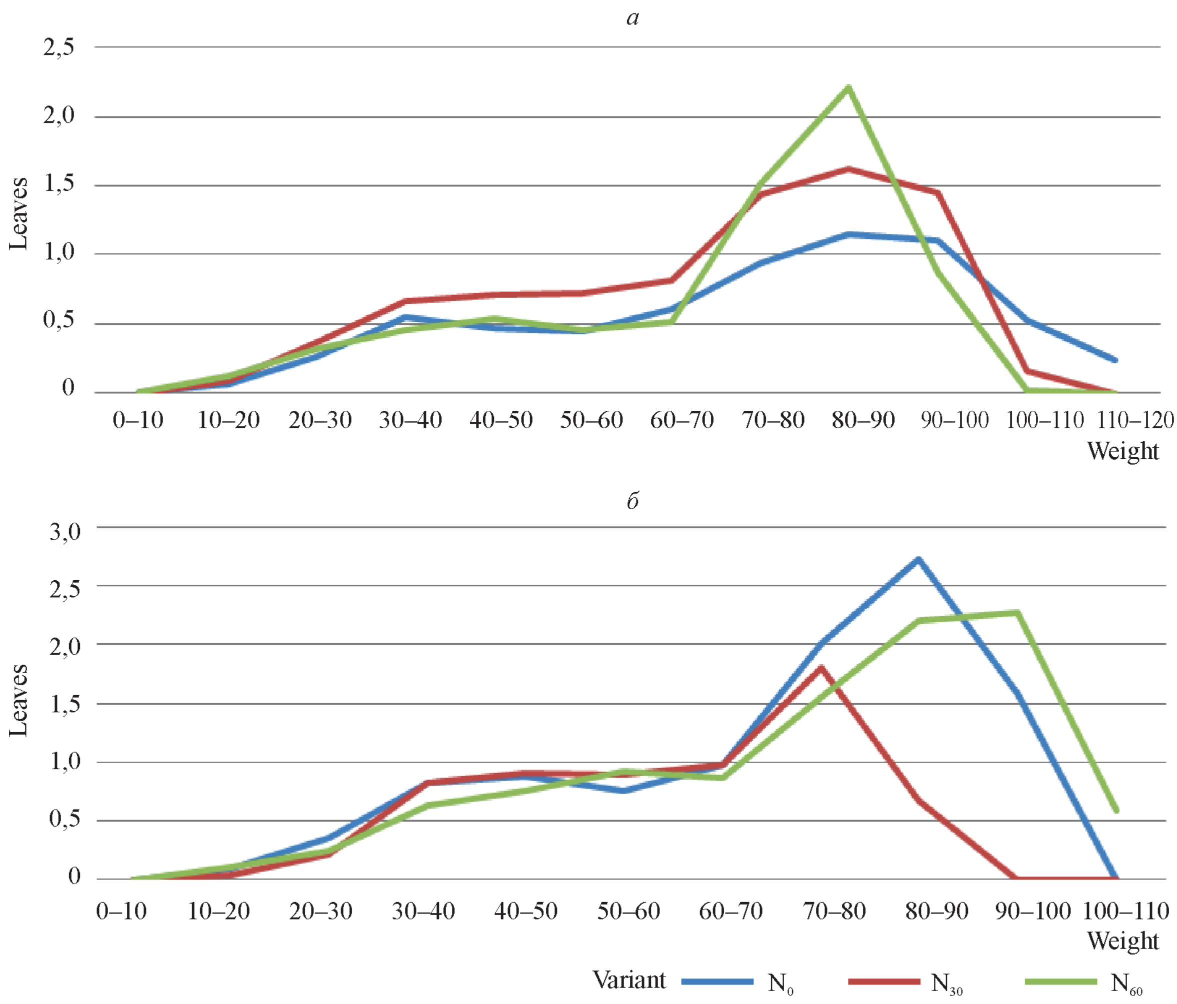
Table 3. Yield of single-species and mixed crops of perennial grasses on average for 2020–2023, t of green mass /ha

Option	Dose of applied nitrogen, kg a.i./ha			Increment, ± t/ha		
	N_0	N_{30}	N_{60}	Mixture	Fertilizer	
					N_{30}	N_{60}
Festulolium	24,77	27,56	31,69	–	+2,79	+6,92
Esparcet	34,68	36,50	44,19	–	+1,82	+9,51
Festulolium 1 row + esparcet 3 rows	30,38	35,68	39,11	+5,61	+5,30	+8,73
Festulolium + esparcet (mixed sowing)	26,73	30,73	41,84	+1,96	+4,0	+15,11
LSD_{05} *A* (mixtures)	0,99	–	–	–	–	–
B (fertilizers)	0,54	–	–	–	–	–
AB	1,72	–	–	–	–	–

arate rows, its value increases with increasing nitrogen dose. At joint sowing the reaction to nitrogen is less pronounced.

Increasing the nitrogen dose to 60 kg/ha boosted the yield of the mixtures to 39.11–41.84 tons of green mass/ha, revealing the advantage of companion sowing. At the same time, the increased mass yield was provided due to the increase in the height of festulolium plants by 4% and its mass by 60% compared to skip-row planting.

The index of evaluation of arable land equivalent ratio (LER) allows to judge about the expediency of cultivation of mixtures. In the experiment, its value ranged from 0.96 to 1.06, which confirms their feasibility (see Table 4). Without fertilizers, the efficiency was higher for festulolium in mixed sowing due to the favor-



Ярусность эспарцета:

а – вариант «фестулолиум 1 ряд + эспарцет 3 ряда»: *б* – вариант посева смесью семян, г

The tiering of the esparcet:

а – variant "festulolium 1 row + esparcet 3 rows", *б* – variant of sowing with a mixture of seeds, g

able neighborhood of crops, in skip-row planting the efficiency was higher for esparcet due to the larger occupied area in the sowing.

Nitrogen application increases the efficiency of festulolium in the mixture to 0.60– 0.80 and has the maximum value in seed mixture sowing, making it the most effective. Application of a small dose of nitrogen (30 kg/ha) in skip-row planting makes the neighborhood of crops competitive (CR value of festulolium – 0.93, esparcet – 1.04), in mixed planting festulolium is more competitive. When increasing the nitrogen dose up to 60 kg/ha, the preferential competitiveness is higher for esparcet (1.10–1.91).

Evaluation of crop cultivation efficiency is carried out through comparison of energy and economic indicators. It was found that without fertilizer application the costs of cultivation of single-species crops for three years of use were 25 308-28 458 MJ, mixtures – 26 882 MJ. Energy yield was obtained respectively 218 738-258 174 (EER = 8,6– 9,0) and 207 008- 243 229 MJ (EER = 7,7– 9,0).

Nitrogen application increased energy input to 60,588 MJ/ha and increased energy yield to 301,270 MJ/ha, while the energy efficiency ratio decreased to 4.7-4.9 and had an average value.

Табл. 4. Оценка эффективности, конкурентоспособности и агрессивности культур в ценозе
Table 4. Evaluation of the effectiveness, competitiveness and aggressiveness of the crops in the cenosis

Alternating rows of festulolium and esparcet	LER festulolium	LER esparcet	LER	CR festulolium	CR esparcet
		N_0			
1 : 3	0,49	0,55	1,04	12,93	2,38
Mixed sowing	0,79	0,20	1,00	1,97	1,21
		N_{30}			
1 : 3	0,62	0,37	1,00	0,93	1,04
Mixed sowing	0,75	0,30	1,05	7,11	1,60
		N_{60}			
1 : 3	0,60	0,35	0,96	0,88	1,10
Mixed sowing	0,80	0,26	1,06	0,66	1,91

The maximum profitability of crops without fertilizer use was observed at skip-row planting of festulolium with esparcet – 373%, at application of 30 kg a.i./ha – 352%. Increase of the nitrogen dose up to 60 kg a.i./ha reduces the level of profitability in mixtures to 349–364%.

CONCLUSIONS

1. The survival rate of festulolium plants in the first year of life after wintering is 86%. In esparcet the survival rate decreases from 86% in single-species sowing to 76% when sown with festulolium in alternating rows, and minimally when sown with seed mixture – 67%.
2. It was found that without the use of nitrogen fertilizers in spring at the beginning of vegetation on single-species sowing of festulolium the yield was 24.77 t of green mass/ha. Its companion sowing with esparcet increased the yield by 22.6% (5.61 t/ha) when sown in rows and by 7.9% (1.96 t/ha) when sown with a seed mixture. The coefficient of energy efficiency was 7.7–9.0 and is characterized as high. Profitability of mixtures sowing – 373%.
3. Application of mineral nitrogen at a dose of 30 kg a.i./ha significantly increased the yield of mixtures of festulolium with esparcet in the variants of skip-row planting by 29.5% and in the variant of sowing with a mixture of seeds by 11.5% due to an increase in the legume component. The coefficient of energy efficiency was 4.4– 5.2 and is characterized as high. Profitability of sowing mixtures – 352%.
4. When increasing the dose of mineral nitrogen up to 60 kg a.i./ha, the maximum yield was obtained in the variant sown with a mixture of seeds – 41.84 tons of green mass/ha, which is 32% higher than single-species sowing of festulolium. The increase is due to a 4% increase in the height of festulolium plants and a 60% increase in their weight. In the row rotation sowing, the yield was 39.11 tons of green mass/ha, which was 23.4% higher than the control. The coefficient of energy efficiency was 4.7–4.9 and is characterized as average. Profitability of sowing mixtures was 349-364%.
5. The index of arable land equivalent ratio (LER) in the mixtures was 0.96–1.06, which confirms their feasibility. Without nitrogen application the main share of the factor belongs to festulolium, with application of small doses of nitrogen the influence of legume component increases due to increased competitiveness (CR).

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Продуктивность картофеля на фоне применения энтомопатогенного гриба *Metarhizium robertsii* в производственных испытаниях

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Впервые на территории Западной Сибири (в Новосибирской области) были проведены двухлетние производственные испытания экспериментального прототипа препарата на основе энтомопатогенного гриба *Metarhizium robertsii*. В работе использован штамм Р-72, выделенный из погибших личинок колорадского жука *Leptinotarsa decemlineata* Say, из коллекции микроорганизмов Института систематики и экологии животных Сибирского отделения Российской академии наук. Видовая идентификация гриба осуществлена с помощью секвенирования региона гена фактора элонгации EF1α. Показана способность препарата существенно повышать параметры элементов структуры урожая картофеля на протяжении всего периода вегетации. Установлено достоверное увеличение числа выживших ростков в 1,4 раза, количества стеблей и клубней – в 1,5 раза. Ростостимулирующий эффект от использования препарата на основе энтомопатогенного гриба проявился в увеличении массы растений к фазе цветения. Прибавка урожая в среднем за два года составила 36,0% по варианту с применением *M. robertsii*, существенно превышая продуктивность картофеля в контроле. Уровень рентабельности производства картофеля с использованием энтомопатогенного гриба *M. robertsii* возрос до 92,0% (при 50,0% в контрольном варианте) за счет увеличения валового урожая и повышения качества товарной продукции. Зараженность клубней нового урожая ризоктониозом значительно снизилась в варианте, включающем проведение обработки энтомопатогенным грибом: количество клубней со склероциями уменьшилось в 2,8 раза по сравнению с контролем, что в итоге привело к повышению числа здоровых клубней и существенному (в 2,5 раза) снижению склероциального индекса.

Ключевые слова: энтомопатогенный гриб, элементы структуры урожая, ризоктониоз, продуктивность, рентабельность

Potato productivity on the background of the entomopathogenic fungus *Metarhizium robertsii* application in production trials

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For the first time in Western Siberia (Novosibirsk region), two-year production trials of an experimental prototype of a drug based on the entomopathogenic fungus *Metarhizium robertsii* have been conducted. Strain P-72 isolated from the dead larvae of Colorado potato beetle *Leptinotarsa decemlineata* Say from the collection of microorganisms of the Institute of Systematics and Ecology of Animals of the Siberian Branch of the Russian Academy of Sciences was used in this work. Species identification of the fungus was performed based on sequencing of the elongation factor gene region EF1α. The ability of the preparation to significantly increase the parameters of potato yield structure elements throughout the whole vegetation period was shown. A reliable increase in the number of surviving sprouts by 1.4 times, the number of stems and tubers by 1.5 times was found. The growth-stimulating effect of using the preparation based on entomopathogenic fungus was manifested in the increase of plant weight by the flowering phase. The average yield increase for two years amounted to 36.0% in the variant with application of *M. robertsii* significantly exceeding the productivity of potatoes in the control. The level of profitability of potato production with the use of entomopathogenic fungus *M. robertsii* increased to 92.0% (with 50.0% in the control) due to the increase in gross yield and improved quality of marketable products. Infestation of new harvest tubers with rhizoctoniose significantly decreased in the variant including treatment with entomopathogenic fungus: the number of tubers with sclerotia decreased 2.8 times compared to the control, which eventually led to an increase in the number of healthy tubers and a significant (2.5 times) decrease in the sclerotial index.

Keywords: entomopathogenic fungus, crop structure elements, rhizoctoniose, productivity, yield

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INTRODUCTION

The Novosibirsk region ranks fifth in the Siberian Federal District in terms of potato production. Potatoes are grown in 13 agricultural enterprises, 32 peasant farms and private entrepreneurs' farms in the region. In 2021, farms of all categories produced 292,000 tons of potatoes at a yield of 21.3 – 25.6 tons / ha, with the level of self-sufficiency of the product amounting to 81.0%.

The future potato yield is formed during the entire growing season, from germination to the formation of new crop tubers and harvesting. The main elements that make up the yield are as follows: number of plants (or density of productive plants) per unit area at harvest, number of tubers per bush, tuber weight[1]. The most important limiting factors for potatoes in any region of cultivation are diseases and pests that can completely destroy plantings during the growing season.

Rhizoctoniose has a stable negative impact on the formation of the elements of potato yield structure throughout the whole vegetation period among the complex of pests. The data of our long-term studies show that the seed material in the farms of the region is always infected with rhizoctoniose pathogen, and the share of the tubers infested with sclerotia of the pathogen is very high and reaches 80.0% and more, which many times exceeds the regulations.

In the period of the first element of the yield structure formation, rhizoctoniose harmfulness is manifested in sprouts damage, their complete death, sprout dropouts against the background of high degree of tuber infestation with the pathogen. During formation of the second element of the yield structure (plant biomass and number of stolons), rhizoctoniose leads to 10.0–13.2% damage and 6.8–8.0% death of potato stolons in the conditions of the region. Influence on the third element of the yield structure (tuber weight and quality) is manifested in yield reduction, deterioration of seed and marketable qualities of the tubers. At the same time, the prevalence of rhizoctoniose sclerotia averages 36.0–41.0%, and the share of small fraction of the yield increases [1].

The use of microorganisms colonizing the rhizosphere and plant tissues (e.g. bacteria of the genera *Pseudomonas* and *Bacillus*, arbuscular mycorrhiza fungi and endophytic fungi, in particular *Metarhizium* and *Baeuveria*) has a high potential as biological control agents against phytopathogens, reducing disease incidence and stimulating plant growth[2] [2, 3].

Entomopathogenic fungi used as endophytes can positively influence plant growth. Growth-stimulation mechanisms are multifaceted, related to direct, indirect and ecological effects (occupation of ecological niche). The direct effect of endophytes is caused by an increase in nutrient uptake, transfer of additional nitrogen from insects killed as a result of mycosis, exogenous production of gibberellins, as well as antagonistic activity against many phytopathogenic fungi[3]. Indirect effects are associated with stimulation of synthesis of endogenous phytohormones and enzymes, changes in the root architecture, induction of systemic resistance of plants to stress factors [4–6].

Earlier we have shown that the effectiveness of *Metarhizium robertsii* to reduce the infection of rhizoctoniose was high at all stages of potato ontogenesis and amounted to 52.0–84.0%. In addition, in laboratory experiments it was found that the fungus *M. robertsii* shows antagonistic activity, inhibits the growth of aerial mycelium, reduces the viability and size of sclerocysts of *Rhizoctonia solani* formed on the tubers [7].

The purpose of the study was to evaluate the effect of potato tuber treatment with the prototype preparation based on the conidia of *M. robertsii* on the formation of the yield structure elements under production conditions.

MATERIAL AND METHODS

The studies were conducted at the Institute of Systematics and Ecology of Animals of Siberian Branch of the Russian Academy of Sciences

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(ISEA SB RAS) and Novosibirsk State Agrarian University (NSAU). Production trials were conducted in ZAO "Priobskoe", located in the Novosibirsk region, in 2021 and 2022. The objects of research were potato variety Red Scarlet, a strain of entomopathogenic fungus *M. robertsii* (isolate P 72) and fungus *R. solani* causing rhizoctoniose.

The strain of the entomopathogenic fungus *M. robertsii* from the collection of microorganisms of the ISEA SB RAS, isolated from the dead larvae of the Colorado potato beetle *Leptinotarsa decemlineata* Say on the territory of Latvia in 1972, was used in this work[4]. Species identification of the fungus was carried out on the basis of sequencing of the elongation factor gene region EF1α [8].

Production trials of the prototype preparation based on the *M. robertsii* conidia were conducted in ZAO "Priobskoe", Novosibirsk region, at the seed potato production site under the following variants:

1) tuber treatment with water (control);
2) tuber treatment with fungus *M. robertsii*;
3) treatment of the tubers with Emesto Quantum chemical preparation ("standard").

Potato tubers were treated with *M. robertsii* conidia immediately before planting. Low-volume spraying in production containers was used. Consumption of the experimental prototype of the preparation with a titer of $5 \cdot 10^9$ conidia/g was 0.6 kg/t, consumption of the working suspension was 12 l/t. The control variant was treated with water at the rate of 12 l/t. Treatment with systemic insecto-fungicide Emesto Quantum was carried out at the recommended dose of 0.3 l/t with the working fluid consumption of 12 l/t. The area of each plot was 0.5 ha. Planting was carried out on May 14th and 20th in the first and second season, respectively, by mechanized method using a Grimme GL 34KG potato planter to a depth of 6-8 cm. The planting pattern was 75 × 20 cm. The ridges were milled with Grimme GF 75-4 5 days after the planting to create a firm loose ridge around the tuber.

Before laying the experiment, soil infestation with *R. solani* fungus was analyzed by the method of multiple soil plates using selective medium[5]. The level of soil infection was below the threshold of harmfulness, however, a high level of tuber infestation by rhizoctoniose was noted (prevalence of manifestation forms was 78.0 and 83.0%, respectively, by years of the experiments). Thus, the studies were conducted on a high natural infectious background of rhizoctoniose infestation of the seed material.

Potato rhizoctoniose infection was recorded in two stages: 1st count – 5 weeks after planting, sprouting phase; 2nd – 7 weeks after planting, budding - flowering phase. 15 plants were analyzed in fourfold repetition (i.e. 60 plants per variant) according to Frank's method[6].

For each plant, the disease progression index (DPI) was calculated according to the generally accepted formula by summing the products of the number of stems (shoots) and the corresponding scale score and then dividing by the product of the sum of the number of stems and the highest scale score, expressed as a percentage. On the same material the mass of plants was determined, as well as the number of surviving sprouts, the percentage of fallen and diseased stolons from their total number.

Assessment of tuber infestation by rhizoctoniose was carried out with determination of the sclerotial index[7] (yield from 25 plants in fourfold repetition). During the harvesting period, tuber weight, number, and fractional composition of the tubers were evaluated for the variants of the

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experiment (harvest from 25 plants in fourfold repetition).

The data were analyzed using Statistica 8[8] program. Data from the field experiments were analyzed using one-factor analysis of variance (ANOVA) followed by pairwise comparison using the Fisher test. The correlation between the indicators of pathological process intensity and parameters of yield structure elements was determined by Pearson correlation coefficient.

RESULTS AND DISCUSSION

Pre-planting treatment of potato tubers with the prototype preparation based on *M. robertsii* conidia significantly influenced the formation of the yield structure elements during the whole vegetation period.

A reliable difference between the variant, which assumed treatment with *M. robertsii*, and the control in the number of surviving shoots, number of stems, stolons and tubers by years of research was established (see Table 1). Thus, at the sprouting phase, the number of surviving shoots (plant lesions – 0 –4 points) significantly increased in the variant with tuber treatment with M. robertsii fungus ($p = 0.035$ in 2021 and $p = 0.038$ in 2022), which further led to an increase in the parameters of other elements of the yield structure. According to the results of the studies, the number of stems increased 1.3 times, stolons – 1.2 – 1.7 times, tubers – 1.4 –1.6 times in comparison with the control after application of the fungus. In addition, the study of growth-stimulating effect showed an increase in plant weight in the variant with *M. robertsii* in the flowering phase (2nd count) (see Table 1).

Significant increase in the indicators of the yield structure elements led to an increase in potato yield (see Table 2). A reliable increase in biological and gross yield in the variant with *M. robertsii* in the years of production trials was established ($p \leq 0.00021$). The average yield in-

Табл. 1. Влияние *M. robertsii* на формирование элементов структуры урожая
Table 1. Influence of *M. robertsii* on the formation of crop structure elements

Indicator	Option		
	Control	*M. robertsii*	Chemical preparation
2021			
Number of survived sprouts, pcs./bush (1st registration)	$2,35 \pm 0,05^a$	$3,115 \pm 0,262^b$	$2,635 \pm 0,125^a$
Weight of one plant, g (2nd registration)	$132,80 \pm 9,18^a$	$145,23 \pm 21,47^a$	$116,75 \pm 16,85^a$
Number of stems, pcs./bush (2nd registration)	$2,52 \pm 0,11^a$	$3,25 \pm 0,20^b$	$2,53 \pm 0,19^a$
Number of stolons, pcs./bush (2nd registration)	$5,28 \pm 0,51^a$	$6,33 \pm 1,45^a$	$4,38 \pm 0,48^a$
Number of tubers, pcs./bush (harvesting)	$4,73 \pm 0,40^a$	$7,58 \pm 0,80^b$	$5,25 \pm 0,42^a$
Weight of one tuber, g (harvesting)	$38,80 \pm 0,40^a$	$50,10 \pm 5,42^a$	$48,00 \pm 3,45^a$
2022			
Number of survived sprouts, pcs./bush (1st registration)	$2,73 \pm 0,17^a$	$3,34 \pm 0,26^b$	$2,62 \pm 0,17^a$
Weight of one plant, g (2nd registration)	$99,37 \pm 8,39^a$	$138,65 \pm 7,62^b$	$109,80 \pm 15,91^a$
Number of stems, pcs./bush (2nd registration)	$3,98 \pm 0,23^a$	$5,00 \pm 0,158^b$	$4,250 \pm 1,001^a$
Number of stolons, pcs./bush (2nd registration)	$6,70 \pm 0,85^a$	$11,60 \pm 0,47^b$	$7,10 \pm 1,79^a$
Number of tubers, pcs./bush (harvesting)	$4,30^a$	$6,13^b$	$5,20^a$
Weight of one tuber, g (harvesting)	$50,50 \pm 3,20^a$	$46,96 \pm 0,63^a$	$44,50 \pm 2,00^a$

Note. Here and in Table 2, different letters indicate significant differences between the variants ($p < 0,05$).

[8] *Hammer O., Harper D.A.T., Ryan P.D.* PAST: Paleontological Statistics Software Package for Education and Data Analysis // Palaeontologia Electronica, 2001, N 4 (1), pp. 1–9.

crease for two years amounted to 36.0% in the variant with the application of entomopathogenic fungus, significantly exceeding the productivity of potatoes in the control.

Infestation of new harvest tubers with rhizoctoniose significantly decreased in the variant with treatment with entomopathogenic fungus: the number of tubers with sclerotia decreased by 2.8 times compared to the control, which eventually led to an increase in the number of healthy tubers and a decrease in the sclerotial index by 2.5 times ($p = 0.00047$) (see Table 2).

The increase in the indicators of the yield structure elements is primarily associated with the protection of potatoes from rhizoctoniose under the conditions of application of the *M. robertsii* fungus. Production trials showed a noticeable reduction in plant infestation, which led to improvement of phytosanitary situation in plantings and an increase in agrobiological indicators (see the figure).

Both in the sprouting and flowering phases, there was a significant decrease in the disease development index on the stems after treatment of tubers with *M. robertsii* compared to the control ($p = 0.00024$ and $p = 0.00013$ for the dates of recordings, respectively), which contributed to a reliable increase in the parameters of the second element of the yield structure (plant biomass) in the variant with *M. robertsii*.

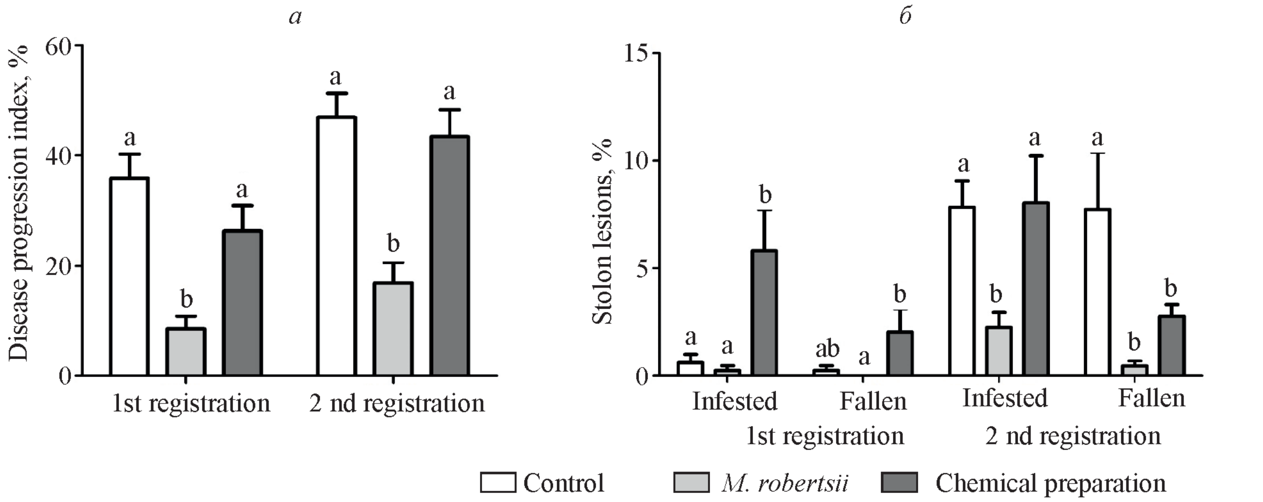
Significant reduction in the number of diseased and fallen stolons after treatment with *M. robertsii* relative to the control or chemical treatment provided a significant increase in such indicators as the number of stolons ($p \leq 0.043$) and the number of tubers per bush ($p \leq 0.016$) (see Table 1).

Our correlation analysis indicates the pres-

Табл. 2. Продуктивность картофеля на фоне применения *M. robertsii*

Table 2. Potato productivity against the background of *M. robertsii* application

Indicator	Option		
	Control	*M. robertsii*	Chemical preparation
Gross yield, t/ha:			
2021	18,82 ± 0,85^a	28,67 ± 0,96^b	21,10 ± 1,25^a
2022	18,48 ± 0,87^a	22,15 ± 1,33^b	18,70 ± 0,82^a
Yield increase (two-year average), %	–	36,08	6,65
Sclerotial index (two-year average)	2,97 ± 0,19^a	1,18 ± 0,93^b	2,35 ± 0,37^a



Индекс развития болезни (*а*) и пораженность столонов (*б*) картофеля ризоктониозом в производственных экспериментах (среднее за два года)
Различные буквы указывают на существенные различия между вариантами ($p < 0,05$).

The index of disease development (*а*) and the incidence of potato stolons (*б*) with rhizoctoniose in production experiments (average over two years)
Different letters indicate significant differences between the variants ($p < 0,05$).

ence of close dependence of yield structure elements on the intensity of pathological process of rhizoctoniose in the experiment variants. Thus, the decrease in the number of dead shoots in the variant with *M. robertsii* was negatively correlated with the number of stems per bush (R = -0.89; p = 0.0001), leading to an increase in this element of the yield structure. In addition, the number of healthy stems was positively correlated with the number of the formed stolons (R = 0.98; $p \leq 0.0001$), differing markedly in the variant with entomopathogenic fungus. In turn, the number of stolons was positively correlated with the number and weight of the formed tubers (R = 0.62; p = 0.032).

To obtain high yields of proper quality tubers, it is important to use adaptive varieties, healthy seed material and modern potato cultivation technologies. Researchers note that the formation of the yield structure elements directly depends on the phytosanitary condition of the tubers, and the health improvement of planting material reduces the prevalence of stem rhizoctoniose, increases the field germination of potatoes, increases the leaf area and, as a consequence, increases tuber yield and seed productivity of potatoes [9]. Our data indicate an increase in the parameters of the yield structure elements against the background of treatment of planting material with entomopathogenic fungus.

The presence of the *M. robertsii* fungus in the root zone of plants leads to its interaction with host plants and has a positive effect on the plant growth and nutrition, as well as on disease suppression. Thus, researchers noted that inoculation of potato with *M. robertsii* promotes active development of the root system, changes in its structure, increases nitrogen content and phosphorus bioavailability [2]. This is all the more important since its availability in soils is often limited, and its deficiency inhibits plant development[9].

However, the increase in the indicators of the yield structure elements is primarily associated with the activation of natural plant defense systems against phytopathogens and an increase in their resistance to infectious diseases[10]. It is established that plants synthesize a number of antioxidant enzymes, such as catalase, peroxidase, involved in the neutralization of free radicals. Metabolic processes are also associated with the synthesis of phytohormones in the rhizosphere of plants and induction of resistance to biotic and abiotic stresses.

Colonization of the root system of the plants by *M. robertsii* determines the efficiency of bio-control in suppressing the pathogenic fungus *R. solani*. We have shown a significant reduction of potato rhizoctoniose infestation throughout the whole vegetation period, which led to the improvement of phytosanitary situation in the plantings. In addition, in earlier studies we noted that the beginning of colonization of plants by *M. robertsii* was accompanied by a significant increase in the activity of protective enzymes (peroxidase and polyphenol oxidase) in leaves and root tissues [10], which indicates a change in the immune status of colonized plants and correlates with the data of other authors[11] [11].

CONCLUSION

Thus, two-year production tests of the experimental prototype preparation based on conidia of the entomopathogenic fungus *M. robertsii* indicate a significant increase in the parameters of the elements of the potato yield structure: health improvement and increased survival of sprouts led to an increase in the weight of the stems by 1.4 times, the number of stolons and tubers – by 1.5 times. Low-volume spraying of the planting material before planting provided an increase in the number of the tubers healthy from rhizoctoniose and an increase in the yield in the conditions of Western Siberia. The level of profitability of potato production with the use of entomopathogenic fungus *M. robertsii* increased up

[9] *Feng K., Lu H.M., Sheng H.J., Wang X.L., Mao J.* Effect of organic ligands on biological availability of inorganic phosphorus in soils // Pedosphere, 2004, vol. 14, pp. 85–92.

[10] *Bonas U., Lahaye T.* Plant disease resistance triggered by pathogen-derived molecules: refined models of specific recognition // Current opinion in microbiology, 2002, vol. 5, N 1, pp. 44–50.

[11] *Hirano E., Koike M., Aiuchi D., Tani M.* Pre-inoculation of cucumber roots with Verticillium lecanii (*Lecanicillium muscarium*) induces resistance to powdery mildew // Research Bulletin of Obihiro University, 2008, N 29, pp. 82–94.

to 92.0% (with 50.0% in the control) due to the increase in gross yield by 36.0% and improvement in the quality of marketable products.

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Изучение эффективности применения гаприна при выращивании стерляди

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В процессе эксперимента изучено влияние на показатели продуктивности осетровых рыб новых кормовых добавок, созданных на основе гаприна и представляющих собой биомассу инактивированной культуры клеток непатогенных метанокисляющих дрожжей или бактерий. Исследования проводили в Краснодарском крае на сеголетках стерляди. Длительность опыта составила 60 дней. Согласно схеме опыта, 1-я (контрольная) группа рыбы получала полнорационные комбикорма без добавок, т.е. содержащие 100,0% рыбной муки. При кормлении 2-й группы 50,0% рыбной муки заменили 50,0% гаприна. В рационе 3-й группы содержалось 25,0% рыбной муки и 75,0% гаприна. В корме для 4-й группы рыбная мука и гаприн находились в соотношении 75/25%. В 5-й группе провели полноценную замену рыбной муки на гаприн, в данном случае количество добавки составляло 10,5 кг. Сеголетки стерляди из 6-й группы получали комбикорм, в котором доля гарпина составляла 10,0%. Начальная живая масса во всех группах была одинаковая – 30 г. Включение гаприна в рацион за счет снижения обьема рыбной муки способствовало увеличению конечной живой массы стерляди в опытных группах на 4,4–19,4% по сравнению с контрольным вариантом. Исключением стали 5-я и 6-я группы, получавшие 100,0 и 90,0% гаприна вместо рыбной муки. Конечная живая масса в данных группах оказалась ниже на 2,3 и 0,9% соответственно. Затраты корма на 1 кг прироста живой массы в группах с частичной или полной заменой рыбной муки были ниже относительно 1-й группы (от 7,0 до 17,9%,). Включение в полнорационные корма гаприна способствовало увеличению прибыли от 553,00 до 1785,00 р.

Ключевые слова: гаприн, стерлядь, кормление рыб, динамика роста, биохимические показатели крови, кишечная микрофлора

Studying the efficiency of Gaprin application in sterlet farming

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In the course of the experiment, the influence of new feed additives created on the basis of Gaprin and representing biomass of inactivated cell culture of non-pathogenic methane-oxidizing yeasts or bacteria on sturgeon fish productivity indicators was studied. The research was carried out in the Krasnodar Territory on sterlet fingerlings. The experiment lasted for 60 days. According to the scheme of the experiment, the 1st (control) group of fish received complete feeds without additives, i.e. containing 100.0% fish meal. In group 2 feeding, 50.0% fishmeal was replaced with 50.0% Gaprin. Group 3 diet contained 25.0% fishmeal and 75.0% Gaprin. In the feed for group 4, fish meal and Gaprin were in the ratio of 75/25%. In Group 5, fish meal was completely replaced by Gaprin, in this case the amount of additive was 10.5 kg. Sterlet fingerlings from Group 6 received feed with 10.0% Gaprin. The initial live weight in all groups was similar at 30 g. However, the inclusion of Gaprin in the diet by reducing the amount of fish meal contributed to an increase in the final live weight of sterlets in the experimental groups by 4.4–19.4% compared to the control. The exceptions were groups 5 and 6, which received 100.0 and 90.0% Gaprin instead of fishmeal. Final live weight in these groups was lower by 2.3 and 0.9%, respectively. Feed costs per 1 kg of live weight gain in the groups with partial or complete replacement of fish meal were lower relative to the 1st group (from 7.0 to 17.9%,). Inclusion of Gaprin in complete feeds contributed to the increase in profit from 553.00 to 1785.00 rubles.

Keywords: Gaprin, sterlet, fish feeding, growth dynamics, blood biochemical parameters, intestinal microflora

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Конфликт интересов
Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest
The authors declare no conflict of interest.

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INTRODUCTION

In the current geopolitical situation, the priority importance for researchers and fish farmers is the food security of our country, which is implemented, among other things, due to the stable supply of the fishery complex with Russian-made fodder. Development of new and stable production of already used fodder components are strategic tasks of fodder production in the Russian Federation [1–3].

It is necessary to solve the issue of quality feed production in order to ensure full-fledged feeding of fish. A particular problem facing sturgeon feed producers is the shortage of quality fish meal used in the production of feed for all age groups of fish. Partial or, if possible, complete replacement of fish meal in diets represents a significant step in establishing the production of balanced feeds for sturgeon, salmon, carps and catfish family [4–7].

The choice of feed characteristics and properties is always based on the rearing technology. It must be taken into account that the requirements for fish farms that raise fish in closed water systems, pool farms, cages and ponds are different[1] [8, 9].

Gaprin can be used as an alternative for qualitative partial replacement of fishmeal or as a supplement to fishmeal that does not meet the requirements within the framework of sturgeon farming technology[2, 3].

At present, the most important thing is to develop and introduce exactly those formulations into fodder production, which by their compo-

[1] *Yurin D., Maxim E., Yurina N., Aniskina M., Gneush A., Brantova M., Kobleva E.* Obtaining feed for herbivorous fish using the aquaponic method // Fundamental and Applied Scientific Research in the Development of Agriculture in the Far East, Agricultural Innovation Systems, Ussuriysk, 2022, vol. 2, pp. 160–169.

[2] *Yaremenko A.V.* Protein production from methane // Technological innovations and scientific discoveries: Proceedings of the VII International Competition of Scientific Research Works, Ufa, 2021, pp. 11-14.

[3] *Litvinenko P.A., Korentovich M.A.* The use of biomass of methane-oxidizing bacteria (gaprin) in feeding sturgeon fish // Actual issues of science and economy: new challenges and solutions: Proceedings of the LV Student Scientific and Practical Conference Tyumen, 2021, pp. 619-625.

sition will contribute to better assimilation of all the components[4, 5].

The main objective of the study is to establish the possibility of partial or complete replacement of fish meal with alternative feed protein (gaprin) in the production of balanced sterlet feeds.

Objectives:

1) determine the effect of the developed compound feed formulations on sterlet survival rate;

2) evaluate physiological and biochemical parameters of sterlet when alternative feed protein (gaprin) is used);

3) study the economic efficiency of gaprin application in sterlet feeding.

MATERIAL AND METHODS

The study was conducted on the farm of IE Oleinik M.V. (Maikop, Republic of Adygeya). The experiment on sterlet fingerlings was carried out in pools. Water supply in the pools was provided from the pond, if necessary, water temperature was reduced by adding water from the well. The conditions of keeping corresponded to the technology of fish breeding at fish farms. Duration of the experiment was 60 days. The number of fish with an initial weight of 29.9–30.1 g – 150 pieces in each group. The scheme of the experiment is presented in Table 1.

In the course of the study, the 1st (control) group received full feed with 100.0% of fish meal in its composition. In the experimental groups fish meal was replaced with gaprin in the following ratios: 2nd group - 50/50, 3rd - 25/75, 4th - 75/25, 5th - full replacement, 6th - 90/10.

Feed additive gaprin is a biomass of inactivated cell culture of non-pathogenic methane-oxidizing yeast or bacteria. Indicators characterizing the quality of microbiological protein are shown in Table 2.

The nutritive value of the OOO "Praktika" feeds, used for the study, corresponded to the generally accepted norms of feeding, and satisfied all the needs of fish of this species.

Fish parameters under study:

Табл. 1. Схема опыта

Table 1. Design of the experiment

Group	Ratio of fish meal to supplement in the diet, %	Additive quantity, kg	Feed volume, kg
1st (control)	100/ –	–	30
2nd	50/50	5,25	30
3rd	25/75	7,87	30
4th	75/25	2,65	30
5th	– /100	10,50	30
6th	90/10	1,50	30
Total		27,77	180

Табл. 2. Питательность микробиологического белка гаприн

Table 2. Nutritional value of the microbiological protein Gaprin

Indicator	Value
Nutritional content, %	
Mass fraction of crude protein	72,6 ± 3,0
Mass fraction of fat	9,6 ± 1,0
Mass fraction of ash	5–10
Mass fraction of moisture	< 8
Ferrrum	380–700
Copper	150–250
Zinc	50–90
Amino acid profile, %	
Aspartic acid	6,36 ± 0,88
Glutamic acid + glutamine	6,84 ± 0,94
Histidine	1,65 ± 0,61
Serine	2,67 ± 0,33
Arginine	4,09 ± 0,89
Glycine	3,89 ± 0,40
Threonine	3,41 ± 0,37
Alanine	5,54 ± 0,65
Tyrosine	2,29 ± 0,73
Valine	4,10 ± 0,59
Proline	2,71 ± 0,43
Leucine + isoleucine	8,54 ± 0,90
Phenylalanine	3,02 ± 0,43
Lysine	3,89 ± 0,40
Methionine	1,80 ± 0,24
Cystine + cysteine	0,44 ± 0,11
Triptophane	1,25 ± 0,12

Note. Protein content in gaprin at least 75 – 76%.

[4] *Momeni M.A.* Gaprin - one of the points of contact between the interests of Iran and the Russian Federation // Neftegaz.RU, 2021, N 1 (109), pp. 46-50.

[5] *Zenkovich P.A., Korentovich M.A., Litvinenko A.I.* Analysis of profitability of growing young Siberian sturgeon on artificial feeds enriched with microbial protein (gaprin) and hydrogenated fatty acids // Proceedings of the LVII Scientific and Practical Conference of Students, Postgraduates and Young Scientists, Tyumen, 2023, pp. 45-51.

1) intestinal microflora composition;
2) feed ratio;
3) fatness ratio;
4) basic blood parameters.

Disinfection measures were carried out prior to planting the fish in the pools as a preventive measure. The outer surface of the pools, which is not in contact with water, was treated with lime. Hydrochemical parameters of water in the pools corresponded to the norm for fish farms.

RESULTS AND DISCUSSION

The highest final live weight was recorded in group 3 – 127.1 g, which exceeds the index of the control group by 19.4%. In the 2nd and 4th groups there was a tendency to increase live weight by 6,4 and 4,4%, respectively, in relation to the control (see Table 3). After 30 days, the absolute body length of fish in the experimental groups exceeded the control index by 1.1– 2.2 cm.

Fish survival rate for the whole period of rearing was at the same level and amounted to 100.0%. The highest fatness factor was observed in group 3 (3.60), the lowest (2.99) in group 5, where fish meal was completely replaced with gaprin.

In the experimental groups that received gaprin as part of complete feeds, the consumption of mixed fodder per 1 head tended to decrease. Reduction of feed costs per 1 kg of gain amounted to: in the 2nd group – by 8,0%, in the 3rd group – by 10,6, in the 4th group – by 11,6, in the 5th group – by 7,0, in the 6th group – by 17,9% relative to the control.

The inclusion of microbial protein in the composition of complete feeds had no negative effect on the intestinal microflora of the sterlet fingerlings (see Table 4).

The content of total protein in the blood of the control group was 21.9 g/l, in the experimental groups this indicator tended to decrease (see Table 5).

The amount of urea in group 3 was significantly lower than in group 1 by 23.11% ($p < 0.05$). In general, all blood parameters were within normal values for this age group of fish, indicating that there was no negative effect of the feed additive used.

Gross gain differed by the groups: in group 2 it was more by 0.9 kg, in group 3 – by 3.1, in group 4 – by 0.7 kg, and in groups 5 and 6 it was less by 0.3 and 0.1 kg, respectively. In the experimental groups it is possible to note a tendency to reduce the cost price of 1 kg of live weight gain relative to the control: by 10.4% – in the 2nd group, by 26.9 – in the 3rd group, by 12.6 – in the 4th group, by 3.5 – in the 5th group, by 4.6% – in the 6th group.

Table 6 shows the indicators of economic efficiency of gaprin application.

The additional profit, obtained by feeding gaprin, amounted to: in the 2nd group – 1785,00 rubles, in the 3rd group – 4745,00, in the 4th

Табл. 3. Основные рыбоводно-биологические показатели сеголеток стерляди
Table 3. The main fish-biological indicators of sterlet fingerlings

Indicator	Group					
	1st	2nd	3rd	4th	5th	6th
Average fish weight, g:						
initial	30,10 ± 0,03	30,00 ± 0,02	30,10 ± 0,04	29,90 ± 0,03	30,00 ± 0,02	30,00 ± 0,03
end	106,4 ± 0,4	113,2 ± 0,2	127,1 ± 0,3	111,0 ± 0,2	104,0 ± 0,3	105,4 ± 0,4
% to the control	100,0	106,4	119,4	104,4	97,7	99,1
Body length after 30 days of rearing, cm	14,9 ± 0,1	15,1 ± 0,2	15,2 ± 0,1	15,1 ± 0,1	15,2 ± 0,2	15,2 ± 0,1
% to the control	100,0	101,1	102,2	101,1	101,7	101,7
Gross increment of one fish for 60 days, g	76,3	83,2	96,9	81,2	74,0	75,4
Average daily gain, g	1,3	1,4	1,6	1,4	1,2	1,3
% to the control	100,0	109,0	127,0	106,4	97,0	98,8
Survival rate, %	100,0	100,0	100,0	100,0	100,0	100,0
Coefficient of fatness	3,22	3,31	3,60	3,25	2,99	3,03

Табл. 4. Состав кишечной микрофлоры сеголеток стерляди
Table 4. Composition of the intestinal microflora of sterlet fingerlings

Indicator	Group					
	1st	2nd	3rd	4th	5th	6th
Escherichia coli	$6,0 \cdot 10^7$	$3,0 \cdot 10^6$	$3,0 \cdot 10^5$	$3,0 \cdot 10^4$	$5,0 \cdot 10^6$	$4,0 \cdot 10^7$
Hay bacillus	$2,2 \cdot 10^5$	$2,5 \cdot 10^4$	$2,0 \cdot 10^4$	$1,8 \cdot 10^4$	$3,8 \cdot 10^5$	$3,8 \cdot 10^4$
Staphylococcus	$1,0 \cdot 10^6$	$1,0 \cdot 10^4$	$1,0 \cdot 10^3$	$1,0 \cdot 10^2$	$1,0 \cdot 10^3$	$1,0 \cdot 10^3$
Enterococcus	$5,0 \cdot 10^1$	$4,0 \cdot 10^1$	$1,0 \cdot 10^1$	$3,0 \cdot 10^1$	$3,0 \cdot 10^1$	$3,0 \cdot 10^1$

Табл. 5. Биохимические показатели крови стерляди ($M \pm m$; $n = 5$)
Table 5. Biochemical parameters of sterlet blood ($M \pm m$; $n = 5$)

Indicator	Group					
	1st	2nd	3rd	4th	5th	6th
Total protein, g/l	21,90 ± 0,87	14,40 ± 0,74*	13,50 ± 0,63**	14,70 ± 1,32	14,70 ± 1,32	14,70 ± 1,32
Urea, mmol/ l	3,72 ± 0,25	3,62 ± 0,21	2,86 ± 0,16*	3,12 ± 0,42	3,12 ± 0,42	3,12 ± 0,42
Glucose, mmol/ l	2,95 ± 0,13	2,99 ± 0,18	3,41 ± 0,39	3,38 ± 0,40	3,38 ± 0,40	3,38 ± 0,40
ASAT, U/ l	216,8 ± 21,6	252,0 ± 14,6	357,2 ± 31,4	317,6 ± 22,8	317,6 ± 22,8	317,6 ± 22,8
ALAT, U/ l	203,2 ± 16,9	231,2 ± 21,6	157,0 ± 34,0	236,6 ± 28,6	236,6 ± 28,6	236,6 ± 28,6
Cholesterol, mmol/ l	2,66 ± 0,15	2,68 ± 0,23	1,65 ± 0,11**	2,81 ± 0,12*	2,81 ± 0,12*	2,81 ± 0,12*
Total bilirubin, μmol/l	7,80 ± 0,10	7,90 ± 0,11	8,10 ± 0,34	8,08 ± 0,28	8,08 ± 0,28	8,08 ± 0,28

Note. Differences are significant at * $p < 0.05$; ** $p < 0.01$ relative to the control.

Табл. 6. Экономическая эффективность применения гаприна для частичной замены рыбной муки в рационах кормления стерляди
Table 6. Indicators of economic efficiency of the use of Gaprin for partial replacement of fishmeal in sterlet diets

Indicator	Group					
	1st	2nd	3rd	4th	5th	6th
Gross increment by group, kg	11,4	12,5	14,5	12,1	11,1	11,3
Feed intake per group, kg	20,6	19,4	15,9	15,8	16,6	17,0
Gaprin cost, rubles/kg	–	32,5	16,3	48,7	58,5	5,85
Cost of mixed fodder consumed, rubles	3296,0	3104,0	2544,0	2528,0	2656,0	2720,0
Electricity costs, rubles	2200,0	2200,0	2200,0	2200,0	2200,0	2200,0
Salary, rubles	3500,0	3500,0	3500,0	3500,0	3500,0	3500,0
Other expenses, rubles	1700,0	1700,0	1700,0	1700,0	1700,0	1700,0
Production costs – total, rubles	10 696,0	10 504,0	9944,0	9928,0	10 056,0	10 120,0
Cost of gross output, rubles	13 680,0	15 000,0	17 400,0	14 520,0	13 320,0	13 560,0
Cost price of 1 kg of weight gain, rubles	938,2	840,3	685,8	820,0	905,9	895,0
% to the control	100,0	89,6	73,1	87,4	96,5	95,4
Profit, rubles	2711,0	4496,0	7456,0	4592,0	3264,0	3440,0
Additional revenue, rubles	–	+ 1785,0	+ 4745,0	+ 1881,0	+ 553,0	+ 729,0

group – 1881,00, in the 5th group – 553,00, in the 6th group – 729,00 rubles. Thus, the inclusion of gaprin in complete feeds can increase the profitability of production.

CONCLUSIONS

1. The use of gaprin in sterlet feeding for 60 days resulted in a fish survival rate of 100.0% in all groups.

2. Blood parameters were within the normal range for this age group of fish; however, protein was significantly elevated in the control group, reflecting immune status and indicating a high load on the endocrine system.

3. Intestinal microflora values were normal.

4. The final weight of fish exceeded the control by 4.4–19.4%.

5. There was a decrease in feed costs per 1 kg of gain by 7.0-17.9% in the experimental groups. The highest average daily gain was characterized by the fish in group 3 – 1.6 g.

6. Gross gain differed by the groups: in the 2nd it was more than in the control by 0.9 kg, in the 3rd – by 3.1, in the 4th – by 0.7 kg, and in the 5th and 6th – less by 0.3 and 0.1 kg.

7. The cost of 1 kg of fish weight gain in group 2 decreased by 10.4%, in group 3 – by 26.9, in group 4 – by 12.6, in group 5 – by 3.5, in group 6 – by 4.6%.

8. Profit in group 2 increased by 1785.00 rubles, in group 3 by 4745.00, in group 4 by 1881.00, in group 5 by 553.00 and in group 6 by 729.00 rubles.

9. Based on the results obtained, in order to reduce feed costs, increase weight, safety and profitability of sturgeon fish farming, we recommend replacing up to 25.0% of the weight of fish meal in sterlet diets with gaprin.

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Характеристика овец Приполярья по микросателлитам и репродуктивным способностям

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Анализировали полиморфизм микросателлитов у овцематок, полученных от внутрипородных спариваний печорских полутонкорунных овец и их помесей от скрещивания с баранами куйбышевской породы. Генотипирование поголовья по *STR*-локусам провели с использованием набора реагентов COrDIS Sheep, рекомендованного Международным обществом генетики животных (International Society of Animal Genetics: ISAG). У овцематок учитывали возраст начала репродукции, плодовитость, молочность, сохранность и интенсивность роста приплода до трехмесячного возраста. В группе печорских овцематок выявили 74 аллеля, кроссбредных – 81. Наиболее полиморфными в обеих группах оказались локусы *INRA005* и *INRA023*, наименее – *ETH152.* Средняя по 12 *STR*-локусам генетическая дистанция между группами составила 0,019 ± 0,003. Печорские овцы (П) и их помеси с баранами куйбышевской породы (1/2 П + 1/2 К) достоверно различались по частотам некоторых генов *STR*-локусов. Так, аллель $INRA023^{212}$ в группе овцематок П встречался с частотой 0,174 и отсутствовал в группе 1/2 П + 1/2 К, аллель $INRA172^{126}$ – соответственно 0,326 и 0,122. Средние значения *Fis* в обеих группах были близкими к нулю. По основным генетико-популяционным параметрам группы достоверно не различались. Однако некоторое преимущество печорских овцематок по сравнению с кроссбредными овцами 1/2 П + 1/2 К по селективным признакам, по-видимому, обусловлено более высоким генетическим вкладом в их наследственность аборигенной северной короткохвостой овцы. По результатам исследования можно предположить, что возраст начала репродукции овцематок связан с уровнем их гетерозиготности по *STR*-локусам.

Ключевые слова: овцы, микросателлиты, гетерозиготность, возраст, репродукция

Characteristics of sheep in the Near Arctic region by microsatellites and reproductive abilities

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The microsatellites polymorphism was analyzed in ewe lambs obtained from intra-breed mating of the Pechora semifine-wool sheep and their littermates from crossing with the Kuibyshev rams. Genotyping of the population by *STR* loci was performed using the COrDIS Sheep reagent kit recommended by the International Society of Animal Genetics (ISAG). The age of the beginning of reproduction, fertility, milk yield, safety and growth intensity of the litter up to three months of age were taken into account in the ewe lambs. In the group of the Pechora sheep sows 74 alleles were detected, and 81 alleles were detected in the crossbred ones. *INRA005* and *INRA023* loci were the most polymorphic in both groups, while *ETH152* was the least polymorphic. The mean genetic distance between the groups for the 12 *STR* loci was 0.019 ± 0.003. Pechora sheep (P) and their litters with the Kuibyshev rams (1/2 P + 1/2 K) differed significantly in the frequencies of some *STR* loci genes. Thus, the $INRA023^{212}$ allele was found with a frequency of 0.174 in the group of P ewes and was absent in the 1/2 P + 1/2 K group, while the $INRA172^{126}$ allele was found with a frequency of 0.326 and 0.122, respectively. The mean *Fis* values in both groups were close to zero. The groups did not differ significantly in the main genetic-population parameters. However, some advantage of the Pechora ewe sows in comparison with the crossbred sheep 1/2 P + 1/2 K on selective traits, apparently, is due to a higher genetic contribution to their heredity of the indigenous northern short-tailed sheep. According to the results of the study, it can be assumed that the age of onset of reproduction of the ewe lambs is related to the level of their heterozygosity for *STR* loci.

Keywords: sheep, microsatellites, heterozygosity, age, reproduction

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INTRODUCTION

Genetic markers are a convenient tool for solving the most diverse problems of genetic analysis. It is believed that ideal genetic markers are "neutral" polymorphic hereditary systems in which the replacement of alleles in the marker locus does not affect the phenotypic manifestation of the traits of selection significance [1]. Due to their high polymorphism and relatively simple and cheap determination procedure, microsatellites are widely used as genetic markers [2]. Polymorphism of microsatellites belongs to neutral[1]. However, genes of marker loci can be linked to structural or regulatory genes that control biologically important animal traits [3]. Modern genome labeling methods make it possible to identify homozygous regions associated with "selection points" at the individual and population levels [4, 5].

The use of *STR* markers in breeding implies, at a minimum, the availability of information on the linkage of the marker to genes controlling the trait being selected[2]. In the absence of such information, it is necessary to conduct exploratory studies to analyze the possible relationship between genetic diversity at *STR* loci and/or other marker systems and genetic variability of selectively important traits [6–9].

The purpose of the research is genetic-population characterization of semi-fine fleece sheep in the Romney Marsh type by *STR*-loci and their reproductive abilities in the conditions of the circumpolar region, as well as study of possible interrelation of the level of heterozygosity on *STR*-loci with the reproductive abilities of sheep.

MATERIAL AND METHODS

The object of the study was the livestock of sheep of the peasant farm of L.A. Kaneva, located in the Ust-Tsilemsky district of the Komi Republic. The territory of the district belongs to the Atlantic-Arctic climatic zone with the geographical coordinates 65°48′13″ north latitude and 51°32′4″ east longitude[3]. Experimental animals were obtained from inbreed mating of the Pechora semi-fine wool-and-meat producing

[1]*Khlestkina E.K.* Molecular markers in genetic research and breeding // Vavilov Journal of Genetics and Breeding, 2013, vol. 17, N 4/2, pp. 1044-1054.

[2]*Obexer-Ruff G., Sattler U., Saitbekova N., Glowatzki M.–L., Gaillard C.* Association studies using random and "candidate" microsatellite loci in two infectious goat diseases // Genetics Selection Evolution, 2003, vol. 35, N 1, pp. 113–119. DOI: 10.1051/gse:2003020.

[3]*Brattsev A.* Climate // Komi Republic: Encyclopedia. Syktyvkar: Komi Book Publishing House, 1997, vol. 1, pp. 25-26.

sheep (P) and their crossing with the rams of the related Kuibyshev breed (K). Control animals were kept in groups in one room on low-concentrate diets typical for farms in the Far North. The Pechora breed group is classified as an extinct breed. The gene pool status of the Kuibyshev breed is "critical" [10].

Genotypes of purebred animals were designated by capital initial letter of the breed name, genotypes of littermates were designated by fractions: numerator – blood and abbreviation of the mother breed name, denominator - blood and abbreviation of the father breed (P - purebred ewes of the Pechora breed group; 1/2 P + 1/2 K - littermates of the first generation: ewes of the Pechora breed group, ram of the Kuibyshev breed).

Primary information on the origin, age of birth and first lambing, fertility and litter safety was obtained from zootechnical records for the period from 2010 to 2020. The study of microsatellite polymorphism was conducted in 2020-2022. DNA was extracted from the tissues of auricles cut off during animal labeling. Samples were preserved with 96% rectified ethyl alcohol. The analyses were performed commercially in the laboratory of the OOO "Gordiz" (gordiz.ru) using the COrDIS Sheep reagent kit recommended by the International Society of Animal Genetics (ISAG) which allowed to analyze polymorphism at 12 loci: *McM042, INRA006, McM527, ETH152, CSRD247, OarFCB20, INRA172, INRA063, MAF065, MAF214, INRA005, INRA023* and a gender marker *AMEL*[4].

Fecundity of the genotyped lambed ewes, starting from the second lambing, was estimated by the number of live lambs per lambing (Po). Milkiness was calculated by litter gain for the first 20 days of the suckling period[5]. For each lambing, we determined litter survival rate by the formula

$$Wp = Pw / Po,$$

where Wp is the number of lambs surviving to weaning (three months of age) in fractions of one unit, Pw is the surviving litter to weaning (heads), and a complex indicator, designated as the "reproduction rate" (RR), equal to the average number of lambs obtained from one ewe per lambing to weaning (Pw) divided by the age (years) of the first lambing of the ewe (Al): RR = Pw/Al.

The results of sheep genotyping by *STR* loci were processed using GenAlEx 6.5[6] program. The following parameters were calculated for the groups of ewe lambs: *N* – number of animals in the group, *n* – the number of recorded lambings, *Na* – average number of alleles per locus, p_{ij} – frequencies of the i-th gene in the j-th sample, *Ne* - the average effective number of alleles per locus, *Ho* – indicator of the average observed (actual) heterozygosity, *He* – estimate of the average expected heterozygosity per locus, *uHe* – unbiased estimate of the average expected heterozygosity per locus, fixation index *Fis* and genetic distance *Fst* according to the Wright model.

The average heterozygosity at 12 STR-loci was calculated for each ewe. Individual data on all sheep ewes within individual breed groups were ranked by heterozygosity, then for each breed group the data sets were divided into three subgroups depending on the level of heterozygosity of sheep ewes: modal - M0, with heterozygosity below modal (M-) and above (M+). For each of them arithmetic averages for quantitative traits - X and errors of averages ±sX, differences between averages (Δ) in pairwise comparison of groups and errors of differences (±sΔ) were calculated. Statistical processing of the data was performed in Microsoft Excel program.

[4]COrDIS Sheep. Reagent kit for multiplex analysis of 12 microsatellite markers and amelogenin locus of COrDIS Sheep. User's manual. URL: https://gordiz.ru/wp-content/uploads/2021/05/instrukcziya-cordissheep-140521.pdf (accessed on 20.01.2022).

[5]GOST 25955-83 Agricultural breeding animals // Methods of determining the productivity of sheep. Moscow: Publishing House of Standards, 1984, 8 p.

[6]*Peakall R., Smouse P.E.* GenAlEx 6.5: genetic analysis in Excel. Population genetic software for teaching and research-anupdate // Bioinformatics, 2012, vol. 28, pp. 2537–2539.

RESULTS AND DISCUSSION

The study of microsatellite polymorphism in two samples of semifine-wool sheep of different breeds revealed 86 alleles. In terms of allelic diversity, the more numerous crossbred group 1/2 P + 1/2 K was richer than group P. In group P 74 alleles were detected, 1/2 P + 1/2 K - 81. The most polymorphic loci in both groups were INRA005 and INRA023, and the least polymorphic was ETH152. The following alleles were found with high frequencies in both groups *McM04*^{281}, *INRA006*^{110}, *McM527*^{164}, *ETH152*^{186}, *ETH152*^{192}, *CSRD247*^{227}, *OarFCB20*^{91}, *INRA172*^{154}, *INRA063*^{175}, *MAF065*^{127}, *MAF214*^{189}, *INRA005*^{145}, *INRA023*^{194}. The alleles *INRA006*^{124}, *OarFCB20*^{93}, *INRA172*^{164}, *MAF065*^{129}, *INRA02*^{212} occurred in the samples with contrasting frequencies. Reliable differences were found in the frequencies of 9 alleles between the groups (see Table 1).

The maximum genetic distance according to Wright (*Fst*) between groups P and 1/2 P + 1/2 K was established by the structure of locus *INRA*023 – 0.051, high – by locus *McM527* – 0.029. The total specific weight of the contribution of these two loci to the genetic differentiation of the compared groups amounted to 38.6%. The smallest genetic distances were found for the structures of the loci *ETH152* (0,009), *INRA063* (0,009), *INRA172* (0,009), *MAF065* (0,012). The average genetic distance across the 12 *STR* loci was 0.019 ± 0.003 (see the figure).

Табл. 1. Характеристика экспериментальных групп овцематок по частотам аллелей *STR*-локусов
Table 1. Characteristics of the experimental groups of ewes by allele frequencies *STR*-loci

Locus	Allele	П (*n* = 23)		1/2 П + 1/2 К (*n* = 41)		Difference	
		$\bar{X}$	$\pm s_{\bar{X}}$	$\bar{X}$	$\pm s_{\bar{X}}$	Δ	$\pm s_{\Delta}$
1	2	3	4	5	6	7	8
INRA023	194	0,196	0,058	0,232	0,047	–0,036	0,075
	198	0,087	0,042	0,012	0,012	0,075	0,043
	200	0,043	0,030	0,378	0,054	–0,335***	0,061
	202	0,000	0,000	0,024	0,017	–0,024	0,017
	204	0,152	0,053	0,073	0,029	0,079	0,060
	206	0,239	0,063	0,146	0,039	0,093	0,074
	208	0,000	0,000	0,049	0,024	–0,049	0,024
	210	0,043	0,030	0,024	0,017	0,019	0,035
	212	0,174	0,056	0,000	0,000	0,174*	0,056
	216	0,022	0,022	0,000	0,000	0,022	0,022
	218	0,043	0,030	0,000	0,000	0,043	0,030
	220	0,000	0,000	0,061	0,026	–0,061	0,026
McM042	81	0,391	0,072	0,427	0,055	–0,036	0,090
	87	0,109	0,046	0,256	0,048	–0,147*	0,067
	89	0,065	0,036	0,085	0,031	–0,020	0,048
	93	0,043	0,030	0,000	0,000	0,043	0,030
	95	0,022	0,022	0,098	0,033	–0,076	0,039
	99	0,152	0,053	0,061	0,026	0,091	0,059
	103	0,217	0,061	0,073	0,029	0,144	0,067
INRA006	108	0,000	0,000	0,073	0,029	–0,073	0,029
	110	0,522	0,074	0,610	0,054	–0,088	0,091
	112	0,043	0,030	0,012	0,012	0,031	0,032
	116	0,109	0,046	0,085	0,031	0,023	0,055
	124	0,174	0,056	0,049	0,024	0,125	0,061
	132	0,109	0,046	0,098	0,033	0,011	0,056
	134	0,043	0,030	0,073	0,029	–0,030	0,042

Продолжение табл. 1

1	2	3	4	5	6	7	8
McM527	164	0,413	0,073	0,268	0,049	0,145	0,088
	166	0,130	0,050	0,207	0,045	–0,077	0,067
	168	0,196	0,058	0,232	0,047	–0,036	0,075
	170	0,087	0,042	0,195	0,044	–0,108	0,060
	172	0,043	0,030	0,000	0,000	0,043	0,030
	174	0,000	0,000	0,012	0,012	–0,012	0,012
	176	0,130	0,050	0,085	0,031	0,045	0,058
ETH152	186	0,326	0,069	0,390	0,054	–0,064	0,088
	188	0,239	0,063	0,110	0,035	0,129	0,072
	190	0,109	0,046	0,110	0,035	–0,001	0,057
	192	0,326	0,069	0,390	0,054	–0,064	0,088
CSRD247	213	0,348	0,070	0,232	0,047	0,116	0,084
	223	0,043	0,030	0,037	0,021	0,007	0,037
	227	0,304	0,068	0,415	0,054	–0,110	0,087
	229	0,109	0,046	0,098	0,033	0,011	0,056
	231	0,065	0,036	0,085	0,031	–0,020	0,048
	233	0,043	0,030	0,049	0,024	–0,005	0,038
	237	0,087	0,042	0,085	0,031	0,002	0,052
OarFCB20	87	0,000	0,000	0,049	0,024	–0,049	0,024
	89	0,109	0,046	0,085	0,031	0,023	0,055
	91	0,435	0,073	0,354	0,053	0,081	0,090
	93	0,022	0,022	0,195	0,044	–0,173**	0,049
	95	0,065	0,036	0,049	0,024	0,016	0,043
	99	0,022	0,022	0,024	0,017	–0,003	0,027
	101	0,043	0,030	0,098	0,033	–0,054	0,044
	105	0,304	0,068	0,146	0,039	0,158	0,078
INRA172	126	0,326	0,069	0,122	0,036	0,204*	0,078
	154	0,370	0,071	0,463	0,055	–0,094	0,090
	158	0,109	0,046	0,061	0,026	0,048	0,053
	160	0,065	0,036	0,146	0,039	–0,081	0,053
	162	0,130	0,050	0,049	0,024	0,082	0,055
	164	0,000	0,000	0,146	0,039	–0,146**	0,039
	170	0,000	0,000	0,012	0,012	–0,012	0,012
INRA063	169	0,283	0,066	0,341	0,052	–0,059	0,085
	175	0,304	0,068	0,183	0,043	0,121	0,080
	177	0,152	0,053	0,134	0,038	0,018	0,065
	183	0,196	0,058	0,183	0,043	0,013	0,072
	197	0,043	0,030	0,146	0,039	–0,103	0,049
	201	0,022	0,022	0,012	0,012	0,010	0,025
MAF065	125	0,109	0,046	0,134	0,038	–0,025	0,059
	127	0,457	0,073	0,293	0,050	0,164	0,089
	129	0,065	0,036	0,220	0,046	–0,154*	0,058
	131	0,043	0,030	0,000	0,000	0,043	0,030
	135	0,283	0,066	0,341	0,052	–0,059	0,085
	137	0,043	0,030	0,012	0,012	0,031	0,032
MAF214	183	0,043	0,030	0,098	0,033	–0,054	0,044
	187	0,000	0,000	0,073	0,029	–0,073	0,029
	189	0,609	0,072	0,427	0,055	0,182	0,090
	191	0,217	0,061	0,268	0,049	–0,051	0,078
	223	0,130	0,050	0,134	0,038	–0,004	0,062

End of the table 1

1	2	3	4	5	6	7	8
INRA005	127	0,087	0,042	0,085	0,031	0,002	0,052
	129	0,000	0,000	0,037	0,021	–0,037	0,021
	133	0,000	0,000	0,012	0,012	–0,012	0,012
	135	0,043	0,030	0,159	0,040	–0,115*	0,050
	137	0,000	0,000	0,012	0,012	–0,012	0,012
	141	0,087	0,042	0,207	0,045	–0,120	0,061
	143	0,109	0,046	0,134	0,038	–0,025	0,059
	145	0,261	0,065	0,171	0,042	0,090	0,077
	147	0,087	0,042	0,049	0,024	0,038	0,048
	151	0,283	0,066	0,122	0,036	0,161*	0,076
	153	0,043	0,030	0,012	0,012	0,031	0,032

Significance level:
*$p < 0{,}05$.
**$p < 0{,}01$.
***$p < 0{,}001$.

The locus values of genetic distances were within ± 3σ of the average for the 12 *STR* loci. However, their distribution for a number of parameters poorly corresponded to normal. The asymmetry was +1.98, the excess was +4.82, and the coefficient of variation (C.V.) was 60.9%.

The experimental groups did not differ significantly in average genetic and population parameters (see Table 2). By the number of alleles per locus, group P was noticeably inferior to 1/2 P + 1/2 K, which is probably due to the smaller sample size.

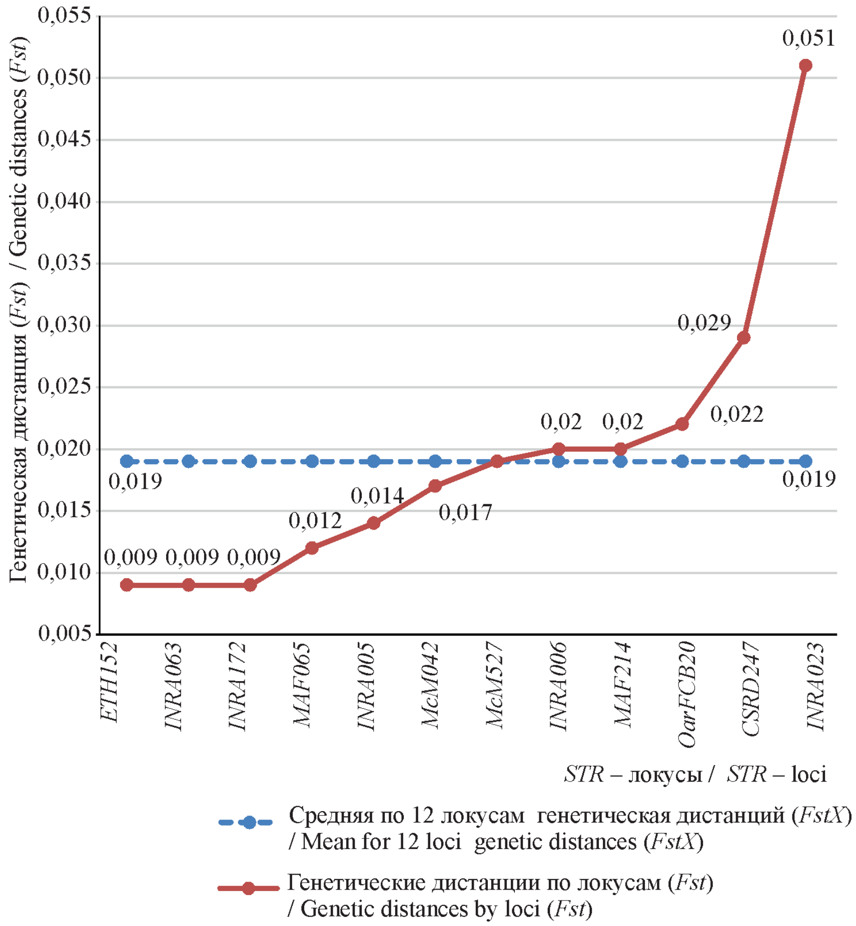
In both groups, unbiased estimates of expected heterozygosity were not significantly higher than the corresponding unadjusted *He* estimates. In group P, the *Fis* values for the *MAF214* locus reached the maximum value (0.460), were high for the loci *INRA063* (–0,252), *ETH152* (–0,211) and *McM042* (0,140), the number of alleles on these loci was respectively 4, 6, 4, 6. The minimum *Fis* values characterized the six-allelic loci: *MAF065* (–0,005), *McM527* (–0,047) and *INRA006* (0,027); nine-allelic *INRA023* (–0,038).

The interval of *Fis* locus values in group P ranged from – 0.002 to 0.427. The mean *Fis* values were close to zero (see Table 2). In the group of ewes 1/2 P + 1/2 K the distribution of *Fis* lokus values was more uniform, the interval was much narrower: from – 0,116 to 0,193. Comparison of the average genetic-population indices for the two groups of sheep for none of them allowed us to reject the null hypothesis that the analyzed samples belong to the same general population.

According to the traits characterizing the adaptability of the animals, no reliable differences between the groups of sheep were found (see Table 3).

In ewe lambs with different levels of heterozygosity for *STR*-loci, low age of the beginning of reproduction characterized the group M0, high – M–. According to this feature, the difference between these two groups was reliable at the significance level of $p< 0.05$. The difference between the M+ and M0 groups was close to reliable ($p < 0.10$). For other characteristics, all differences were not statistically reliable (see Table 4).

Earlier [11] it was suggested that the difference between P and 1/2 P + 1/2 K groups in *STR*-locus structure is most likely due to the genetic component introduced by the Kuibyshev breed, since it was in the crossbred group 1/2 P + 1/2 K that alleles that were not found in P were detected. In this connection, it should be noted that the gene pools of the Pechora breed group and the Kuibyshev breed are related. They were formed by crossing of aboriginal coarse-wool Russian sheep with English semifine-wool sheep Romney Marsh: the first – by absorptive crossing of the aboriginal northern short-tailed



Распределение полокусных генетических дистанций (*Fst*) относительно средней по 12 *STR*-локусам

Distribution of genetic distances (*Fst*) for individual loci relative to the mean for 12 *STR*-loci

Табл. 2. Характеристика групп овцематок разной породности по генетико-популяционным параметрам, вычисленным по *STR*-локусам

Table 2. Characteristics of the groups of ewes of different age of breed according to genetic and population parameters calculated from the alleles of polymorphic *STR*-loci

Group	Locus	*Na*	*Ne*	*Ho*	*He*	*uHe*	*Fis*
1	2	3	4	5	6	7	8
P (*n* = 23)	*INRA023*	9	6,151	0,870	0,837	0,856	–0,038
	McM042	7	4,133	0,652	0,758	0,775	0,140
	INRA006	6	3,032	0,652	0,670	0,685	0,027
	McM527	6	3,963	0,783	0,748	0,764	–0,047
	ETH152	4	3,550	0,870	0,718	0,734	–0,211
	CSRD247	7	4,149	0,826	0,759	0,776	–0,088
	OarFCB20	7	3,327	0,783	0,699	0,715	–0,119
	INRA172	5	3,623	0,783	0,724	0,740	–0,081
	INRA063	6	4,232	0,957	0,764	0,781	–0,252
	MAF065	6	3,245	0,696	0,692	0,707	–0,005
	MAF214	4	2,290	0,304	0,563	0,576	0,460
	INRA005	8	5,371	0,870	0,814	0,832	–0,069
Average ($\overline{X}$)		6,3	3,922	0,754	0,729	0,745	–0,024

End of the table 2

1	2	3	4	5	6	7	8
Sampling error (± $s\bar{X}$)		0,43	0,298	0,049	0,021	0,021	0,053
1/2 P + 1/2 K (*n* = 41)	*INRA023*	9	4,332	0,854	0,769	0,779	–0,110
	McM042	6	3,654	0,659	0,726	0,735	0,093
	INRA006	7	2,489	0,537	0,598	0,606	0,103
	McM527	6	4,669	0,634	0,786	0,796	0,193
	ETH152	4	3,043	0,561	0,671	0,680	0,164
	CSRD247	7	3,946	0,805	0,747	0,756	–0,078
	OarFCB20	8	4,837	0,805	0,793	0,803	–0,015
	INRA172	7	3,588	0,805	0,721	0,730	–0,116
	INRA063	6	4,483	0,854	0,777	0,787	–0,099
	MAF065	5	3,723	0,805	0,731	0,740	–0,100
	MAF214	5	3,484	0,707	0,713	0,722	0,008
	INRA005	11	7,063	0,927	0,858	0,869	–0,080
Average ($\bar{X}$)		6,8	4,109	0,746	0,741	0,750	–0,003
Sampling error (± $s\bar{X}$)		0,55	0,332	0,036	0,019	0,019	0,033

Табл. 3. Характеристика овцематок разной породности по некоторым воспроизводительным признакам

Table 3. Characteristics of the ewes of different breeds according to some reproductive traits

Ewe group	Statistics	Age of first lambing, days	Lambs for the first lambing, heads	Lamb crop, heads	Survival, in fractions of a unit	Milk yield of ewes, kg	Daily gain of lambs up to 3 months of age, g	Repro-duction rate
P (*n* = 42)	Average ($\bar{X}$)	669,5	1,14	1,05	0,929	21,5	183,7	0,595
	Standard error (± $s\bar{X}$)	17,9	0,05	0,06	0,036	1,3	11,4	0,038
1/2 P + 1/2 K (*n* = 75)	Average ($\bar{X}$)	659,1	1,09	0,97	0,893	20,0	156,2	0,572
	Standard error (± $s\bar{X}$)	16,7	0,03	0,05	0,035	0,9	8,5	0,031
Difference P – 1/2 P + 1/2 K (Δ)		10,3	0,050	0,074	0,035	1,5	27,5	0,023
Error of difference (± $s_Δ$)		24,5	0,064	0,075	0,050	1,5	14,2	0,049

coarse-wool sheep up to the third - fourth generations, the second – by crossing of the Cherkasy long thin-tailed coarse-wool sheep up to the second generation of Romney Marsh inclusive [10]. Consequently, the specific weight of the preserved genes of the northern native short-tailed sheep adapted in the Arctic Circumpolar Region and now extinct could not exceed 13% in the heritability of P ewes. In crossbred group 1/2 P + 1/2 K it was 2 times lower. According to the results of the study [11], absorptive crossbreeding for the improving breed and selection according to the target standards of semifine-wool meat-wool breeds in the Romney-Marsh type led (judging by the allelic structure of *STR*-loci) to the loss of the gene pool characteristic of the short-tailed aboriginal sheep of the Pechora semifine-wool sheep, which lived earlier in the European Subarctic and the Arctic.

However, P and 1/2 P + 1/2 K differed significantly in the frequencies of some STR-locus genes, which were found in the Pechora sheep group with high frequencies, and in the crossbred group 1/2 P + 1/2 K - with low frequencies and vice versa. Thus, according to the results of the present study, the allele $INRA023^{212}$ in the group of P ewes was found with a frequency of 0.174 and was absent in the group 1/2 P + 1/2 K, the allele $INRA172^{126}$ respectively 0.326 and 0.122, etc. (see Table 1). In pairwise comparison

Табл. 4. Характеристика овцематок с разным уровнем гетерозиготности по *STR*-локусам по некоторым воспроизводительным признакам

Table 4. Characteristics of the ewes with different levels of heterozygosity for *STR*-loci for some reproductive traits

Ewe group and number of lambings (*n*)	Average ($\bar{X}$)	Age of first lambing, days	Lambs for the first lambing, heads	Lamb crop, heads	Survival, in fractions of a unit	Milk yield of ewes, kg	Daily gain of lambs up to 3 months of age, g	Lamb reproduction rate/year
M– *n* = 33	$\bar{X}$	693,2	1,09	0,94	0,864	20,4	157	0,532
	$\pm s\bar{X}$	21,7	0,05	0,07	0,059	1,6	14,1	0,055
M0 *n* = 51	$\bar{X}$	628,2	1,10	1,00	0,922	21,5	173	0,605
	$\pm s\bar{X}$	18,1	0,04	0,05	0,035	1,1	9,9	0,033
M+ *n* = 33	$\bar{X}$	686,0	1,15	1,06	0,924	19,2	165	0,591
	$\pm s\bar{X}$	25,3	0,06	0,07	0,044	1,2	14,0	0,042
Difference M0 – M – (Δ)		–65,0*	0,007	0,06	0,058	1,1	16	0,072
± Error of difference ($\pm s_{\Delta}$)		28,2	0,066	0,089	0,069	1,9	16,8	0,064
Difference M0 – M + (Δ		–57,8	–0,053	–0,06	–0,003	2,3	8	0,014
± Error of difference ($\pm s_{\Delta}$)		31,1	0,076	0,089	0,057	1,6	16,9	0,053
Difference M– – M + (Δ)		7,2	–0,061	–0,12	–0,061	1,2	–8	–0,059
± Error of difference ($\pm s_{\Delta}$)		33,3	0,081	0,106	0,073	2,0	19,4	0,069

of groups P and 1/2 P + 1/2 K, the distribution of locus-specific estimates of genetic distances *Fst* could be considered normal with great difficulty, indicating the presence of the factors disturbing the random distribution of the estimates. Excluding the data on the *INRA023* locus with a near abnormally high Fst value from processing, the mean Fst value across 11 loci decreased from 0.019 ± 0.003 across 12 loci to 0.016 ± 0.002, C.V. – from 60.9 to 40.0%, kurtosis respectively – from 4.82 to – 0.28, skewness – from 1.98 to 0.027, i.e., the distribution of the estimates (except for the coefficient of variation) approached the parameters of a normal distribution.

Thus, if we search for the consequences of the pressure of microevolutionary factors on neutral polymorphic systems, it seems necessary, first of all, to pay attention to the loci for which deviant population genetic estimates were obtained. According to Hall [12], as a result of numerous studies of genetic distances on microsatellites between different sheep breeds, *Fst* values ranged from 0.06 – 0.10 of the median class. In our study, the Fst value between groups of fine-wool sheep close in genesis only for the *INRA023* locus approached 0.06 (see the figure) and the limit of the confidence interval for the general population, and the average value for 12 *STR*-loci was 0.019 ± 0.003, indicating a low genetic difference between the compared groups. The analysis of characterization of these groups by some traits of animal adaptability, revealed statistically unreliable, but biologically and economically important advantage of group P over 1/2 P + 1/2 K. The only exception was the age of the beginning of reproduction.

The ecological environment of the circumpolar region, where sheep lived, is characterized by specific seasonal photoperiodism (polar day and polar night), duration of pasture and stall periods, temperature and humidity regime, botanical composition of fodder plants, etc. It differs from the central regions of Russia and from South-Eastern England, where the improving breed Romney Marsh originated from. This gives reason to doubt the high adaptive value of the gene pool of the Celtic sheep in the conditions of the circumpolar region. On the contrary, according to oral testimonies of the indigenous inhabitants of the northern regions of the Komi Republic, the absorbed Romney Marsh aboriginal northern sheep had a number of valuable adaptive qualities, the main of which were unpretentiousness, early age of sexual maturity, prolificacy and polyestricity. Therefore, some advantage in adaptability to the conditions of the circumpolar area of the Pechora sheep ewes in comparison with crossbred sheep 1/2 P + 1/2 K, apparently, is due to a higher contribution of the indigenous northern short-tailed sheep to their heredity. In this case, it is very likely that rare alleles and alleles that occurred with low frequencies in the indigenous northern sheep in the course of absorptive crossing and genetic drift, were lost. The deficiency of the qualities that the extinct northern aboriginal short-tailed sheep possessed is acutely felt in the currently available initial breeding material for crossbred breeding and selection of sheep in the ecological conditions of the Arctic and Subarctic [11].

CONCLUSION

The analysis of microsatellite polymorphism in ewe lambs obtained from inbreed mating of the Pechora semifine-wool sheep in the Romney-Marsh type and their littermates from crossing with the Kuibyshev breed rams showed that in both groups the most polymorphic loci were *INRA005* and *INRA023*, the least – *ETH152*. The average genetic distance between the groups for 12 *STR* loci was 0.019 ± 0.003. No significant differences between the groups were found for the main genetic-population parameters. The average *Fis* values for both groups of sheep ewes were close to zero. However, the distribution of *Fis* values in the group of sheep ewes 1/2 P + 1/2 K was more uniform than in the P group.

Crossbreeding of ewe lambs P with rams of the Kuibyshev breed did not lead to an increase in the observed heterozygosity and improvement of the reproductive abilities in the group of crossbred ewe lambs.

The division of the experimental stock into groups according to the level of heterozygosity revealed an advantage in the rate of sexual maturation and reproduction of modal class ewe lambs over the M– and M+ groups. At the same time, the increase of heterozygosity in the M+ group did not lead to a significant increase in fertility and viability of the progeny or, on the contrary, to a decrease in its viability due to the destruction of coadapted gene complexes in the process of gamete formation in the crossbred parent [8].

Some difference in the traits of adaptability and genetic-population characteristics by microsatellites of two groups of sheep similar by the method of breeding and related by the paternal breed [10], most likely, is due to the different specific weight in their gene pools of the genes of the now extinct northern aboriginal sheep adapted in the circumpolar area.

The results of the study suggest that intrapopulation heterozygosity indices determined by *STR* loci may be correlated with the age of the beginning of sheep reproduction.

In *Ovis aries*, the position of many selectively significant and neutral *STR* loci on chromosomes is known. This information, as well as the expansion of the breed composition and increase in the number of the animals in the experimental samples, will be used in the future to obtain more extensive estimates of marker associations with selectively significant traits.

All applicable international, national and/or institutional principles of animal care and use have been observed.

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Влияние наночастиц серебра и препаратов различных фармакологических групп на бактерицидную активность *Staphylococcus aureus*

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Бактерии с множественной лекарственной устойчивостью стали одной из самых серьезных угроз для системы здравоохранения во всем мире. Злоупотребление антибиотиками способствовало возникновению и передаче механизмов устойчивости среди бактерий, ставя под угрозу терапевтический потенциал антибиотиков. Бесконтрольное применение антибактериальных средств приводит к возникновению резистентности, обусловленной мутациями в хромосомной ДНК, а также получением плазмид, интегронов от других микроорганизмов при горизонтальном переносе генов. В 2010 г. на страны БРИКС (Бразилию, Россию, Индию, Китай и Южную Африку) приходилось 76% потребления антибиотиков, при этом Индия потребляла 12,9 млрд ед., Китай – 10 млрд. По состоянию на 2017 г. наличие устойчивых к карбапенемам *Acetobacter baumannii* и Enterobacteriaceae привело к тому, что расходы на здравоохранение в США составили около 281 млн дол. В соответствии с отчетами Центра по профилактике и контролю заболеваний (Centers for Disease Control and Prevention), только в США ежегодно фиксируется около 2,3 млн эпизодов заболеваний, сопровождающихся множественной лекарственной устойчивостью микроорганизмов и приведших к 25 000 летальных исходов. В связи с этим мировое сообщество ученых активизировало изучение сочетанного применения различных антибактериальных препаратов для достижения максимальной бактерицидной активности. Проведены исследования по определению синергического эффекта при применении комбинаций препаратов различных фармакологических групп и наночастиц серебра. В нашем исследовании зафиксировано увеличение бактерицидной активности в 53,87 раза (с 2,528 до 0,0098 мкг/мл) при сочетанном использовании наночастиц серебра и ДМСО в отношении референтного штамма *Staphylococcus aureus* АТСС 25953. Тогда как при культивировании изолята *St. aureus* с ДМСО и наночастицами серебра чувствительность увеличилась в 128,2 раза (с 5,056 до 0,039 мкг/мл).

Ключевые слова: наночастицы серебра, *St. aureus*, антибиотики, антибиотикорезистентность, AgNPs, бактерии, персистентность

The effect of silver nanoparticles and preparations of various pharmacological groups on the bactericidal activity of *Staphylococcus aureus*

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Multidrug-resistant bacteria have become one of the most serious threats to public health worldwide. The abuse of antibiotics has contributed to the emergence and transmission of resistance mechanisms among bacteria, jeopardizing the therapeutic potential of antibiotics. Uncontrolled use of drugs leads to the formation of antibiotic resistance due to mutations in chromosomal DNA, as well as the production of plasmids, integrons from other bacteria during horizontal gene transfer. In 2010, the BRICS countries (Brazil, Russia, India, China and South Africa) accounted for 76% of antibiotic consumption, with India consuming 12.9 billion units and China – 10 billion units. As of 2017, carbapenem-resistant *Acetobacter baumannii* and Enterobacteriaceae resulted in approximately US$ 281 million in healthcare costs in the United States. According to numerous reports from the Center for Disease Control and Prevention, approximately 2.3 million episodes of multidrug-resistant microbial diseases resulting in 25,000 deaths are recorded annually in the United States alone. In this regard, the world community of scientists has intensified the study of the combined use of various antibacterial drugs to achieve maximum bactericidal activity. Studies have been conducted to determine the synergistic effect when using combinations of drugs of various pharmacological groups and silver nanoparticles. A significant increase in bactericidal activity by 53.87 times (from 2.528 to 0.0098 mcg/ml) was found with the combined use of AgNPs and DMSO against the reference strain *Staphylococcus aureus* ATCC 25953. While the cultivation of *St. aureus* isolate with DMSO and silver nanoparticles revealed a sensitivity increase of 128.2 times (from 5.056 to 0.039 mcg/ml).

Keywords: silver nanoparticles, *St. aureus*, antibiotics, antibiotic resistance, AgNPs, bacteria, persistence

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INTRODUCTION

In recent years, most antibacterial drugs have become ineffective in the treatment of bacterial infections [1-4]. Antibiotic resistance has become a global problem in the treatment of infectious diseases; the extensive use of antibiotics has led to the development of resistance to them in numerous human and animal bacterial pathogens. Resistance of microorganisms to antibacterial drugs can lead to a decrease in the effectiveness of therapies for bacterial diseases, as well as to increased morbidity, mortality and, in most cases, long-term bacterial carriage[1] [5, 6].

Resistance of a significant number of bacteria to many drugs causes significant economic losses in dairy farming. As a consequence, there is a need to develop relevant, cost-effective and efficient antibacterial drugs that can overcome antimicrobial drug resistance [7].

The mutually reinforcing antibacterial effect of the combined use of silver nanoparticles and chitosan against methicillin-resistant *Staphylococcus aureus*, *Proteus mirabilis*, *Pseudomonas aeruginosa* and *Acinetobacter baumannii* has been determined. Chitosan-mediated microbial cell permeability has been found to enhance the penetration of silver ions into the cell[2] [8].

The combined use of silver nanoparticles and quartzetin showed that synergistic quartzetin enhanced the antimicrobial effects of silver nanoparticles, showing significant bactericidal activity against antibiotic resistant *E. coli* and *S. aureus*[3] [9].

Innovations in the development of nanotechnology make it possible to obtain modern materials with significant antimicrobial properties with low toxicological indicators. Recently, both in medicine and veterinary medicine, silver nanoparticles with high antibacterial and antiviral activity have been used in the therapy of infectious diseases. It has been found that when silver nanoparticles and antibacterial drugs are used together, silver nanoparticles enhance these properties. After exposure of silver nanoparticles to bacteria, the latter show a significant increase in antibiotic sensitivity to a wide range of drugs [10-12]. In this regard, it is advisable to

[1] *Yuan Y.G., Peng Q.L., Gurunathan S.* Effects of silver nanoparticles on multiple drug-resistant strains of Staphylococcus aureus and Pseudomonas aeruginosa from mastitis-infected goats: an alternative approach for antimicrobial therapy // International Journal of Molecular Sciences, 2017, vol. 6, N. 18 (3), p. 569.

[2] *Huang L., Dai T., Xuan Y.* Synergistic combination of chitosan acetate with nanoparticle silver as a topical antimicrobial: efficacy against bacterial burn infections // Antimicrobial Agents and Chemotherapy, 2011, vol. 55 (7), pp. 3432–3438.

[3] *Sun D., Zhang W., Mou Z.* Transcriptome analysis reveals silver nanoparticle-decorated quercetin antibacterial molecular mechanism// ACS Applied Materials and Interfaces, 2017, vol. 9 (11), pp. 10047–10060.

study the joint use of silver nanoparticles with drugs of different pharmacological groups in order to possibly increase their bactericidal activity [11–14].

The purpose of the work was to study the bactericidal activity of the combinations of silver nanoparticles and preparations of different pharmacological groups on *St. aureus* strain ATSS 25953 and *St. aureus* isolate extracted at infectious pathology of cattle.

MATERIAL AND METHODS

To study the effect of silver nanoparticles, the preparation Argovit (OOO SPC "Vector-Vita", Novosibirsk) containing AgNPs at a dose of 13 µg/mL was used. In addition, preparations of different pharmacological groups were used:

1. Chitosan is an aminopolysaccharide obtained from crustacean shells, which is a natural source of lipophilic form of dietary fibers and has analgesic, antimicrobial effect (OOO "Alina Pharma", Russia).
2. Quartzetin is a natural biochemical substance of flavonoid group with antimicrobial, antioxidant, wound healing effect (Shaanxi, China).
3. Arabinogalactose belongs to the class of carbohydrates, polysaccharides, isolated from the pith of larch wood, possesses antimicrobial action (OOO "Level", Russia).
4. Septabik is a surfactant quaternary ammonium compound with bactericidal, fungicidal action (OOO "Abik Septa", Russia).
5. Lactic acid is a product of anaerobic metabolism of glucose, which has antimicrobial, fungicidal action (OOO "Dry Starch and Lactic Acid", Russia).
6. Dimethyl sulfoxide (DMSO) is a medicinal product with anti-inflammatory, antimicrobial, fibrinolytic action (AO "Tatkhimfarmpreparaty", Russia).

Determination of microorganisms' sensitivity to antibacterial drugs and their combinations was carried out by consecutive serial dilutions in meat-peptone broth by introducing the reference strain of *St. aureus* ATSS 25953 and *St. aureus* isolate extracted from cattle into 0.2 ml of $1.5 \cdot 10^6$ CFU/ml and subsequent incubation for 24 h at 36.5 ± 0.5 °C [4, 5].

RESULTS AND DISCUSSION

When culturing the reference strain of *St. aureus* ATCC 25953 with septabic and argovit, a 4-fold increase in antimicrobial properties was revealed (see the table). The effective concentration of septabic was 10.112 µg/ml, whereas the effective concentration of septabic in combination with argovit decreased to 2.528 µg/ml. When the *St. aureus* isolate was cultured with septabic and silver nanoparticles, a 2-fold increase in sensitivity was observed (from 2.528 to 1.264 µg/ml).

The studies revealed a two-fold decrease in the antibacterial activity of the combination of lactic acid and argovit against both the isolate and the reference strain of *St. aureus* ATCC 25953 (from 2.528 to 5.056 and from 5.056 to 10.112 µg/ml, respectively).

The study of bactericidal properties of arabinogalactose against the reference strain of *St. aureus* ATCC 25953 and *St. aureus* isolate showed that in combination with argovit the antibacterial activity increased 5-fold (from 10.112 to 5.056 and from 2.528 to 10.112 µg/ml).

Antibacterial activity of DMSO to the reference strain of *St. aureus* ATCC 25953 was characterized by a 53.87-fold increase in sensitivity in the presence of argovit (from 2.528 to 0.0098 µg/ml). At the same time, cultivation of *St. aureus* isolate with DMSO and silver nanoparticles revealed a 128.2-fold increase in sensitivity (from 5.056 to 0.039 µg/ml).

At cultivation of *St. aureus* isolate with quartzetin the growth of antibacterial activity in 4 times (from 0.158 to 0.632 µg / ml) was noted. Antibacterial activity of this preparation to the reference strain of *St. aureus* ATCC 25953 was characterized by a 4-fold increase in the presence of argovit (from 0.632 to 0.158 µg/ml).

[4]MG 4.2.1890-04. Determination of sensitivity of microorganisms to antibacterial drugs: methodological guidelines. Moscow, 2004, 101 p.

[5]EUCAST. 2022. URL: https://www.eucast.org/fileadmin/src/media/PDFs/EUCAST_files/Breakpoint_tables/v_12.0_Breakpoint_Tables.pdf (accessed on 07.03.2023).

Антибиотикочувствительность референтного штамма *St. aureus* ATCC 25953 и изолята *St. aureus* к арговиту и препаратам различных фармакологических групп
Antibiotic sensitivity of the reference strain of *St. aureus* ATCC 25953 and *St. aureus* isolate to drugs of various pharmacological groups

Antibacterial substance	Bactericidal concentration of antibacterial substances combinations, µg/ml			
	St. aureus ATCC 25953		*St. aureus*	
	Argovit	Preparation	Argovit	Preparation
Argovit	0,0395	–	0,079	–
Chitosan 10%	–	0	–	0
Chitosan 10% + argovit	0,632	2,528	1,264	5,056
Quarcetin 5%	–	0	–	0
Quarcetin 5% + argovit	0,158	0,632	0,158	0,632
Arabinogalactose 10%	–	0	–	0
Arabinogalactose 10% + argovit	0,632	5,056	1,264	10,112
Septabik	–	10,112	–	2,528
Septabik + argovit	0,316	2,528	0,158	1,264
Lactic acid	–	2,528	–	5,056
Lactic acid + argovit	0,632	5,056	1,264	10,112
DMSO	–	2,528	–	5,056
DMSO + argovit	0,0197	0,0098	0,0049	0,039

CONCLUSIONS

1. The results of the studies showed that the combined use of silver nanoparticles and the studied drugs produced various results depending on the genus and species of the microorganism. The reference strain of *St. aureus* ATCC 25953 was the most susceptible to such effects, which, apparently, is associated with the absence of previously active contact with the applied preparations.

2. An increase in bactericidal activity by 53.87 times (from 2.528 to 0.0098 µg/ml) was found with the combined use of silver nanoparticles and DMSO against the reference strain of *St. aureus* ATCC 25953. Whereas, when culturing the *St. aureus* isolate with DMSO and silver nanoparticles, a 128.2-fold increase in sensitivity (from 5.056 to 0.039 µg/ml) was recorded.

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ИНФОРМАЦИЯ ОБ АВТОРЕ

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Применение методов МАС в селекции пшеницы на устойчивость к септориозу

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Данный обзор представляет актуальную информацию по генам устойчивости мягкой пшеницы (*Triticum aestivum* L.) к септориозу (STB), возбудителями которого являются *Zymoseptoria tritici*, *Parastagonospora nodorum*, *Mycosphaerella graminicola*. Основное внимание уделено генетическому контролю устойчивости пшеницы к септориозу с точки зрения количественного и качественного характера устойчивости и ее эффективности. Обобщены достигнутые к настоящему времени успехи в идентификации генов и локусов количественных признаков пшеницы, связанных с устойчивостью к *Z. tritici* и *P. nodorum*. Представлена характеристика 15 генов устойчивости к септориозу и наиболее часто применяемых молекулярных маркеров. Приведены данные о сортах, обладающих наиболее эффективными генами устойчивости к STB: Bulgaria 88, Oasis, Sullivan, Veranopolis, Chinese spring, Tadinia, Flame, Hereword, Curtot, Tonic, Kavkaz-K4500, Arina, Riband, Balance, Apach. Рекомендованы перспективные маркеры, в основном микросателлиты, или повторы простой последовательности (SSR), для использования в селекции на устойчивость *T. aestivum* L. к септориозу. Применение в качестве молекулярных маркеров генов устойчивости культурных растений амплифицированных полиморфизмов длины фрагмента (AFLP) технически сложный процесс. По мере открытия и картирования новых генов устойчивости пополняется информация о возможности пирамидирования *Stb* генов в селекционном материале. Сочетание нескольких генов в геноме повышает устойчивость сорта, так как активность генов против STB проявляется на разных стадиях развития растений. Применение известных генов в маркер-опосредованной селекции пшеницы и поиск новых генов устойчивости позволят получать стабильные урожаи при минимальном использовании пестицидов.

Ключевые слова: пшеница, *Zymoseptoria tritici*, *Parastagonospora nodorum*, *Mycosphaerella graminicola*, септориоз, гены устойчивости *Stb*, молекулярные маркеры

Application of MAC methods in wheat breeding for resistance to Septoria blight

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The review presents up-to-date information on the genes of resistance of soft wheat (*Triticum aestivum* L.) to Septoria blight (STB), the causative agents of which are *Zymoseptoria tritici*, *Parastagonospora nodorum*, *Mycosphaerella graminicola*. The main attention is paid to the genetic control of wheat resistance to septoria blight from the point of view of the quantitative and qualitative nature of resistance and its effectiveness. The successes achieved so far in the identification of genes and loci of quantitative wheat traits associated with resistance to *Z. tritici* and *P. nodorum* are summarized. The characteristics of 15 genes of resistance to septoria blight and the most commonly used molecular markers are given. The data on the varieties with the most effective STB resistance genes are presented: Bulgaria 88, Oasis, Sullivan, Veranopolis, Chinese spring, Tadinia, Flame, Hereword, Curtot, Tonic, Kavkaz-K4500, Arina, Riband, Balance, Apach. Promising markers, mainly microsatellites, or simple sequence repeats (SSR), are recommended for use in breeding for *T. aestivum* L. resistance to septoria blight. It is technically difficult to use fragment length polymorphisms (AFLP) as molecular markers of resistance genes of cultivated plants. As new resistance genes are discovered and mapped, information about the possibility of pyramiding *Stb* genes in the breeding material is being updated. The combination of several genes in the genome increases the stability of the variety, since the activity of the genes against STB is manifested at different stages of plant development. The use of known genes in marker-mediated wheat selection and the search for new resistance genes will allow to obtain stable yields with minimal use of pesticides.

Keywords: wheat, *Zymoseptoria tritici*, *Parastagonospora nodorum*, *Mycosphaerella graminicola*, Septoria blight, *Stb* resistance genes, molecular markers

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Soft wheat is one of the most important food and feed crops in the world. Yields and economic benefits in cereal production are largely dependent on diseases that reduce yields. *Septoria tritici blotch* (STB) of soft wheat is caused by fungi *Zymoseptoria tritici* and *Parastagonospora nodorum*, anamorph *Mycosphaerella graminicola*, belonging to the class Ascomycetes. Currently, STB is the main foliar disease of wheat in many regions of the world[1, 2]. This disease is widespread in wheat growing areas. Septoriose can lead to a yield reduction of up to 10-15%, with weather conditions favorable for the pathogen, losses can reach 50%[3] [1]. Factors that provoke the development of the disease are high humidity and cool weather[4].

The traditional way to control STB is to use fungicides, which is not always efficient, cost-effective and environmentally friendly.

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Breeding varieties resistant to this disease provides a reliable and economical way to control STB, but until recently, breeders had to rely on unknown genes to select resistant varieties [2].

Qualitative resistance is usually controlled by a single gene, providing almost complete resistance and specificity for pathogen isolates with the corresponding avirulence gene [3]. As a rule, quantitative resistance to STB is controlled by multiple genes providing partial resistance and may be specific or nonspecific for different isolates[5] [4].

Creation and industrial use of wheat varieties resistant to septoriose is the most expedient for obtaining stable yields of the crop. The genes of wheat resistance to STB are not always effective against different strains, as sexual reproduction results in recombination of genetic material, and more virulent resistant forms are formed [5–7]. Currently, more than 18 STB resistance genes used in breeding have been identified and characterized [8]. But not all known genes provide protective functions of the plant against different strains of *M. graminicola*. To create the varieties that retain resistance to STB for a long time, it is necessary to combine several most effective genes in breeding material (pyramiding).

Randomly amplified polymorphic DNA fragments (RAPD)[6], restriction fragment length polymorphisms (RFLP)[7], microsatellites, or simple sequence repeats (SSR)[8], amplified fragment length polymorphisms (AFLP)[9], monomorphic DNA markers (STS, EST) are used as molecular markers of resistance genes in cultivated plants [9].

One of the first identified genes for septoriose resistance was the *Stb1* gene identified in winter wheat variety Bulgaria 88. Later this gene was used in the development of the varieties Oasis and Sullivan[10, 11]. *Stb1* is a dominant gene, which is confirmed by the studies in which crosses of gene carriers with unstable varieties were performed [10]. In addition, *Stb1* provides high resistance of carriers to STB, due to which wheat varieties can be used in production for quite a long time[12].

The studies conducted at the Department of Botany and Plant Pathology of the Purdue University in the USA showed the highest informativeness of SSR markers for *Stb1* detection in wheat samples [10]. The SSR marker Xbarc74 amplified a 188 bp fragment in the resistant line and a 175 bp DNA fragment for the susceptible cultivar Arthur. Markers Xgwm213 and Xgwm335 amplified the fragments of 160 and 205 bp in the susceptible variety Arthur, respectively. SSR marker Xgwm66 amplified a 598 bp fragment in the resistant variety, which was absent in the susceptible variety. All of the above markers are present in the variety Bulgaria 88 as well as the Oasis and Sullivan derived from Bulgaria 88. This indicates that the adhesion block was preserved in the process of backcrossing [10]. In the course of the study, it was found that other types of markers are not efficient enough for the *Stb1* diagnosis.

The *Stb2* gene was studied on the material of the resistant variety Veranopolis [11]. Mapping showed the location of the *Stb2* on chromosome 1B. The highest efficiency in determining the

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[12]*Jackson L.F., Dubcovsky J., Gallagher L.W., Wennig R.L., Heaton J., Vogt H., Gibbs L.K., Kirby D., Canevari M., Carlson H., Kearney T., Marsh B., Munier D., Mutters C., Orloff S., Schmierer J., Vargas R., Williams J., Wright S.* Regional barley and common and durum wheat performance tests in California // Agron Prog Rep, 2000, vol. 272, pp. 1–56.

gene was established for markers Xbarc008, Xbarc137 and Xgwm264. The Xbarc008 marker produced a 245 bp fragment in susceptible lines, while a 260 bp fragment was amplified in resistant lines. The Xbarc137 primer produced a 240 bp fragment in RAC875-2 and susceptible lines, while a 260 bp fragment was obtained in resistant parental and resistant lines. For Xgwm264, a single 230-bp fragment was present in Veranopolis and resistant lines and was absent in RAC875-2 and susceptible lines (the data not shown). A 230 bp amplicon was present in Veranopolis and resistant lines, but was absent in susceptible lines. A band of similar size was also detected in the resistant variety Chinese spring and nullisomic-tetrasomic lines, which are nullisomic for 3B but contain 1B. The 230-bp fragment was not detected in the lines lacking chromosome 1B. The results confirm that this amplicon is specific for 1B. According to other researchers, the wheat variety Veranopolis may contain up to four STB resistance genes [12, 13].

The *Stb4* gene is a source of septoriose resistance in the variety Tadinia. It is effective at the stage of not only seedlings, but also adult plants in field and greenhouse conditions. This is one of the genes, the presence of which allowed to maintain resistance for quite a long time. Resistance due to the presence of the *Stb4* gene was effective under field conditions in California from 1975 through the late 1990s[13].

The studies conducted at the Department of Botany and Plant Pathology at the Purdue University examined AFLP and SSR markers associated with the *Stb4* gene. The AFLP marker EcoRI-ACTG/MseI-CAAA5 and the microsatellite Xgwm111 were found to be closely linked to the *Stb4* locus on chromosome 7D. Attempts to convert AFLP markers into easily analyzed PCR-based markers were unsuccessful. The only informative SSR marker was Xgwm111, which was also linked to *Stb5* [14].

The *Stb5* gene was mapped on chromosome 7D. The closest marker was the SSR marker Xgwm44, located near the centromere at a distance of 7 cM from *Stb5*. In addition, *Stb5* is closely related to the wheat red coleoptile gene Rc3 (see footnote 8). Also, the Xgwm111 marker is located on chromosome 7D at a distance of 0.7 cM from *Stb4* and 11.9 cM from *Stb5*. Thus, Xgwm111 is a common marker for the two STB[14] resistance genes. SSR markers Xgwm121 and Xgwm437, as well as RFLP marker Xpsr490 are located at a much greater distance from *Stb5*, so they are of little significance in gene identification.

Microsatellite markers located on chromosome 3A were used in a study to map *Stb6* in the resistant wheat variety Flame [15]. The resistance to IPO323 isolate of hybrids between resistant variety Flame and susceptible variety Longbow was analyzed. The locus Xgwm369, located in the distal part of the short arm of chromosome 3A, corresponded to the *Stb6* gene. The Xwmc11 locus, located near the centromere, was weakly linked to both *Stb6* and Xgwm369. *Stb6* confers resistance to STB in the cultivar Hereward, as no susceptible plants were found among the F2 Flame × Hereward hybrids. *Stb6* was detected in the distal part of the short arm of the 3A chromosome at a distance of 2 cM from Xgwm369. The amplicons identified in susceptible and resistant cultivars differ in length. The amplifiable fragments in Longbow and Flame cultivars were 189 and 197 bp in size, respectively. Experiments with F1 hybrids of resistant varieties showed that genes in wheat varieties Shafir, Vivant, Hereward, Flame and breeding line NSL92-5719 provide resistance to IPO323 isolate [15].

The *Stb7* gene was mapped at the distal end of the chromosome 4AL. The most closely spaced microsatellite markers GWM160, WMC219, and WMC313 were noted at 0.3; 1.1; and 3.5 cM from *Stb7*. In addition to those listed, six other SSR markers (GWM397, GWM637, WMC161, WMC232, WMC262, WMC283) are included in the 108.1 cM linkage group [16]. The resistant

[13] *Somasco O.A., Qualset C.O., Gilchrist D.G.* Single gene resistance to Septoria tritici blotch in the spring wheat cultivar ‘Tadinia’// Plant Breeding, 1996, vol. 115, N 4, pp. 261–267.

[14] *Arraiano L.S., Worland A.J., Ellerbrook C., Brown J.K.* Chromosomal location of a gene for resistance to Septoria tritici blotch (Mycosphaerella graminicola) in the hexaploid wheat ‘Synthetic 6x’ // Theoretical and Applied Genetics, 2001, vol. 103, N 5, pp. 758–764.

soft wheat line ST6 was crossed with two susceptible lines, Katepwa and Erik. The presence of the gene in hybrid populations was detected using microsatellite markers. WMC219 was the only marker associated with *Stb7* in the ST6/Erik hybrid population. An ST6 amplicon of 175 bp in length was detected only in resistant hybrids. Fragments of 226 and 230 bp were detected in susceptible hybrids, and they were also isolated in the unstable varieties Erik and Katepwa, respectively. *Stb7* may be linked to other disease and pest resistance loci, as other resistance loci (H25, Lr28, Lr30, Pm16, Sr7, Wsm1, YrMin and YrND) were identified on the chromosome 4A[15].

STB resistance due to the presence of the *Stb8* gene was established in a study of synthetic hexaploid wheat W7984. The study was carried out in the USA in 1998-2001 [17]. Hybrid plants obtained by crossing the resistant variety and the susceptible Opata 85 were studied using AFLP and microsatellite markers, among which only three (Xgwm146, Xgwm577, Xgwm611) showed the highest informativity. Each primer pair amplified fragments of a specific length in resistant plants: Xgwm146 – 200 bp, Xgwm577 – 200 and 160 bp, Xgwm611 – 150 bp. The same primers amplified fragments of a different size in the susceptible variety Opata 85: Xgwm146 – 175 bp, Xgwm577 – 180 and 140 bp, Xgwm611 – 200 bp. The markers Xgwm146 and Xgwm577 were the most effective in the detection of *Stb8*, as they are located at a distance of 3.5 and 5.3 cM from *Stb8*. Xgwm611 is located at a rather significant distance from *Stb8* – 19.3 cM [17]. The use of other types of markers in the determination of Stb8 is inexpedient, since RFLPs have been found to be unrelated to the gene, and the use of AFLP markers is technically difficult.

Stb9, a gene for resistance to *S. tritici blotch* (STB), was found in two spring wheat varieties, Courtot and Tonic. It confers resistance to *M. graminicola* isolate IPO89011. This gene is located between markers Xfbb226 (3-6 cM) and XksuF1b (9 cM) on the long arm of chromosome 2B [18].

The *Stb10* gene was discovered and mapped in the early 2000s during a resistance study of the soft wheat variety Kavkaz-K4500 (Kavkaz-K4500) [19]. Kavkaz-K4500 (KK) is one of the first varieties resistant to STB. The variety was developed using the Russian winter wheat variety Kavkaz and the Brazilian variety Frontana (see footnote 3). Kavkaz-K4500 is a carrier of several STB resistance genes. Their combination provides resistance to several strains of *M. graminicola* of different origin (Israel and the Netherlands). A population of hybrids obtained by crossing Kavkaz-K4500 and the susceptible variety Shafir was studied. The susceptible variety Longbow was used as a control. *Stb10* was mapped on chromosome 1D. The localization of the *Stb12* gene was determined for the first time – it is located on chromosome 4A, as well as the *Stb7* gene known at the time of the study [16]. There are two closely related genes on the arm of the chromosome 4AL between loci Xgwm219 and Xgwm313. The gene for resistance to ISR398 is designated here for the first time as *Stb12*. The results suggest that STB resistance genes may be clustered [19]. In addition to the *Stb10* and *Stb12* genes mapped for the first time, Kavkaz-K4500 is a source of other STB resistance genes (see Table 1).

Stb7, *Stb10* and *Stb12* were found to be effective against several isolates of *M. graminicola*. *Stb7* provides resistance to ISR398, IPO87019 and ISR8036, *Stb10* – to IPO94269 and ISR8036. Thus, the pattern of "gene-for-gene" interaction between *M. graminicola* and *Triticum aestivum* is confirmed.

Gene mapping showed that one of the major QTLs for resistance to ISR398 isolate is located on the 4A chromosome near Xwmc219. The most effective markers identified correspond to the fragments of different lengths in resistant and susceptible varieties. The fragment of the variety Kavkaz-K4500 Xwmc219 was 185 bp in size, while the fragment of the variety Shafir was 215 bp. The QTL responsible for resistance to IPO87019 is located on the 4A chromosome but closer to Xwmc313. The amplicon of Kavkaz-K4500 Xwmc313 was 195 bp, the ampli-

[15] *McIntosh R.A., Hart G.E., Devos K.M., Gale M.D., Rogers W.J.* Catalogue of gene symbols for wheat 1990 supplement // Cereal Research Communications, 1990, vol. 18, N 1–2, pp. 141–157.

con of Shafir was 215 bp. The combination of STB resistance genes in Kavkaz-K4500 allows its wide use in breeding.

A new gene for resistance to *M. graminicola* isolate IPO90012, designated *Stb11*, which is mapped on the chromosome 1BS by the *Stb6* gene for resistance to isolate IPO323 and probably by the *Stb7* gene for resistance to isolate IPO87019, was found in the Portuguese breeding line TE 9111. All these genes are closely related to microsatellite markers that can be used for marker-assisted selection [20].

The septoriose resistance gene *Stb15* was identified in the Swiss variety Arina and British variety Riband. *Stb15* is located on the chromosome 6AS and provides resistance to the Ethiopian isolate IPO88004 [21]. The closest marker is the RFLP marker Xpsr904, located 14 cM from *Stb15*. Xpsr904 was identified as the only significant marker associated with specific resistance to this STB isolate [22].

Among European wheat varieties, resistance to IPO88004 isolate due to the presence of the *Stb15* gene is quite common. Perhaps, therefore, the use of such varieties in breeding for resistance to STB is not always effective and in demand. However, in combination with other *Stb* genes, the use of the *Stb15* is quite justified.

In 2012, an international group of scientists discovered two new genes of resistance to *M. graminicola* – *Stb16* and *Stb17*. As a result of screening of the hexaploid varieties, recombinant inbred lines obtained by crossing the hexaploid varieties with susceptible and different STB resistant soft wheat varieties, it was found that synthetic hexaploid wheat (SH) varieties have the highest resistance to several STB strains. Synthetic hexaploid wheat varieties combine genomes of tetraploid and diploid progenitors and can be a source of new genes of resistance to *M. graminicola* [8].

The *Stb16* gene identified in the wheat breeding line M3 has shown efficacy against *M. graminicola* both at the seedling stage and in adult plants. *Stb16* is located on the long arm of the 3D chromosome and is closely related to the microsatellite marker XGWM494. The *Stb16* gene was obtained from *Aegilops tauschii*, which was the donor of the D-genome chromosome in M3. Also in the study, the *Stb17* gene, located on the 5AL chromosome and conferring resistance to STB in adult plants, was identified. *Stb17* is linked to the SSR marker XHBG247. Tetraploid durum wheat varieties not susceptible to septoriose disease were used for M3 line work [8].

The *Stb18* gene was detected in the study of wheat varieties Balance and Apache, as well as their hybrids. The gene activity was determined against some isolates at the seedling stage and against others at the adult plant stage. QTL on the 6DS chromosome of winter wheat cultivar Balance was determined using four isolates of *M. graminicola*. Isolate IPO89011 allowed to establish the efficiency of the gene at the seedling stage, and IPO323 showed the efficiency of *Stb18* at the stage of not only seedlings but also adult plants. The closest SSR markers were Xgpw3087 and Xgpw5176 [23]. *Stb18* was also

Табл. 1. Гены, обеспечивающие устойчивость сорта пшеницы Кавказ-К4500 к *M. graminicola*
Table 1. Genes that ensure the resistance of the Kavkaz-K4500 wheat variety to *M. graminicola*

Isolate	Resistance gene	Location on the chromosome	The nearest marker
IPO323	*Stb6*; *Stbx*	*Stb6*: 3A *Stbx*: ?	Xgwm369
IPO87019	*Stb7*	4A	Xwmc313
IPO94269	*Stb10*	1D	Xgwm848
ISR398	*Stb12*; *Stb7* (?)	4A	*Stb12*: Xgwm219 *Stb7*: Xgwm313
ISR8036	*Stb10*; *Stb12*	*Stb10*: 1D *Stb12*: 4A	*Stb10*: Xgwm848 *Stb12*: Xwmc219

found to be expressed in the presence of another wheat STB resistance gene, *Stb6*. Thus, synergism of *Stb* genes with respect to *Stb6* and *Stb18* is manifested.

STB resistance genes are distributed in the genome of soft wheat on different chromosomes, as confirmed by international studies (see Table 2).

As new resistance genes are discovered and mapped, information about the possibility of pyramiding Stb genes in breeding material is replenished. The combination of several genes in the genome increases the resistance of a variety, since the activity of genes against STB is manifested at different stages of plant development. In addition, not all genes may provide resistance to different strains of *M. graminicola*. Application of known genes in marker-mediated breeding of wheat and search for new resistance genes will allow to obtain stable yields with minimal use of pesticides.

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Табл. 2. Геномы и хромосомные группы генов устойчивости к пятнистости *S. tritici* (STB)
Table 2. Genome and chromosomal group of spot resistance genes of *S. tritici* (STB)

Genome	Homeologous chromosomal group						
	1	2	3	4	5	6	7
A			*Stb6*	*Stb7*; *Stb12*	*Stb17*	*Stb15*	*Stb3*
B	*Stb11*	*Stb9*	*Stb2*		*Stb1*		*Stb8*
D	*Stb10*		*Stb16*			*Stb18*	*Stb4*; *Stb5*

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ИНФОРМАЦИЯ ОБ АВТОРАХ

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К 70-летию Николая Михайловича Иванова

Члену-корреспонденту Российской академии наук, доктору технических наук, профессору, руководителю Сибирского научно-исследовательского института механизации и электрификации сельского хозяйства Сибирского научного центра агробиотехнологий Российской академии наук (СибИМЭ СФНЦА РАН), почетному работнику АПК РФ, иностранному члену Монгольской академии аграрных наук исполнилось 70 лет.

Николай Михайлович родился 17 апреля 1954 г. в с. Ур-Бедари Беловского района Кемеровской области. В 1977 г. окончил Новосибирский сельскохозяйственный институт по специальности «Механизация сельского хозяйства».

Трудовую деятельность начал в учхозе Новосибирского сельскохозяйственного института, где в 1971, 1972 гг. трудился слесарем ремонтно-технических мастерских. С 1977 г. работал в Сибирском научно-исследовательском институте механизации и электрификации сельского хозяйства. Здесь он состоялся как инженер, ученый, талантливый организатор науки и производства, пройдя путь от инженера-стажера до директора института. Работал младшим научным сотрудником, научным сотрудником, старшим научным сотрудником; с 1993 г. – заведующим научной лабораторией, ученым секретарем, заместителем директора, с 2006 по 2016 г. директором института. В настоящее время Николай Михайлович руководитель СибИМЭ СФНЦА РАН.

В 1988 г. защитил кандидатскую диссертацию «Сепарация зерна на конических решетах с профилированной поверхностью», в 2001 г. – докторскую «Технологическое и техническое обеспечение интенсификации сушки зерна с учетом ресурсосбережения».

Н.М. Иванов – специалист в области комплексной механизации сельскохозяйственного производства, включая механизацию процессов послеуборочной обработки зерновых в условиях Сибири, автор более 282 научных работ, включая 54 патента на изобретения, 14 программ на ЭВМ, 26 рекомендаций, 4 монографии.

Под научным руководством Николая Михайловича защищено шесть кандидатских диссертаций и две докторские.

Н.М. Иванов дал теоретическое и экспериментальное обоснование системы технологического и технического обеспечения процессов комплексной механизации сельскохозяйственного производства, включая послеуборочную обработку зерна и семян в условиях Сибири. Разработал энергосберегающую технологию послеуборочной обработки зерна, объединяющую в едином технологическом процессе предварительную очистку и энергосберегающую сушку с частичной рекуперацией теплоты; обосновал технологические схемы, конструктивно-режимные параметры технических средств на основе использования инерционно-гравитационных сил. Им разработаны энергоресурсосберегающие технологические схемы, обоснованы конструктивно-технологические параметры сушилок на основе блочно-модульного исполнения, частичной рекуперации теплоты, многослойной инверсии зерновых потоков. Организовано их серийное производство.

Николай Михайлович – член экспертной группы при совете по реализации Федеральной научно-технической программы развития сельского хозяйства Российской Федерации на 2017–2025 гг., бюро координационного совета и объединенного ученого совета Отделения сельскохозяйственных наук Российской академии наук, член коллегии и научно-технического совета министерства сельского хозяйства правительства Новосибирской области, председатель общественного совета инспекции Гостехнадзора Новосибирской области, председатель диссертационного совета по защите докторских и кандидатских диссертаций 24.1.211.01, председатель ГАК ряда вузов страны, научный эксперт РАН, член редколлегии журнала «Сибирский вестник сельскохозяйственной науки», иностранный член Монгольской академии аграрных наук.

Николай Михайлович награжден медалью ордена «За заслуги перед Отечеством» II степени, удостоен звания «Почетный работник АПК России», неоднократно награжден грамотами РАСХН, СО РАСХН, губернатора и Законодательного собрания Новосибирской области.

К.С. Голохваст, А.А. Шпедт, А.А. Гаркуша, М.С. Чекусов, Е.П. Ренёв

В.В. Альт, А.С. Донченко, Н.И. Кашеваров, К.Я. Мотовилов,
В.А. Солошенко, Н.А. Сурин

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ПРАВИЛА ДЛЯ АВТОРОВ

Правила для авторов составлены на основе этических принципов, общих для членов научного сообщества, и правил публикации в международных и отечественных научных периодических изданиях, а также в соответствии с требованиями ВАК для периодических изданий, включенных в Перечень российских рецензируемых научных журналов, в которых должны быть опубликованы основные научные результаты диссертаций на соискание ученой степени доктора и кандидата наук.

Журнал публикует оригинальные статьи по фундаментальным и прикладным проблемам по направлениям:

- общее земледелие и растениеводство;
- селекция, семеноводство и биотехнология растений;
- агрохимия, агропочвоведение, защита и карантин растений;
- кормопроизводство;
- инфекционные болезни и иммунология животных;
- частная зоотехния, кормление, технологии приготовления кормов и производства продукции животноводства;
- разведение, селекция, генетика и биотехнология животных;
- технологии, машины и оборудование для агропромышленного комплекса.

Статья, направляемая в редакцию, должна соответствовать тематическим разделам журнала «Сибирский вестник сельскохозяйственной науки»:

Наименование рубрики	**Шифр и наименование научной специальности в соответствии с Номенклатурой научных специальностей, по которым присуждаются ученые степени**
Земледелие и химизация	4.1.1. Общее земледелие и растениеводство 4.1.3. Агрохимия, агропочвоведение, защита и карантин растений
Растениеводство и селекция	4.1.1. Общее земледелие и растениеводство 4.1.2. Селекция, семеноводство и биотехнология растений
Защита растений	4.1.3. Агрохимия, агропочвоведение, защита и карантин растений
Кормопроизводство	4.1.1. Общее земледелие и растениеводство 4.1.2. Селекция, семеноводство и биотехнология растений 4.1.3. Агрохимия, агропочвоведение, защита и карантин растений
Зоотехния и ветеринария	4.2.3. Инфекционные болезни и иммунология животных 4.2.4. Частная зоотехния, кормление, технологии приготовления кормов и производства продукции животноводства 4.2.5. Разведение, селекция, генетика и биотехнология животных
Механизация, автоматизация, моделирование и информационное обеспечение	4.3.1. Технологии, машины и оборудование для агропромышленного комплекса
Проблемы. Суждения Научные связи Из истории сельскохозяйственной науки Краткие сообщения Из диссертационных работ	4.1.1. Общее земледелие и растениеводство 4.1.2. Селекция, семеноводство и биотехнология растений 4.1.3. Агрохимия, агропочвоведение, защита и карантин растений 4.2.3. Инфекционные болезни и иммунология животных 4.2.4. Частная зоотехния, кормление, технологии приготовления кормов и производства продукции животноводства 4.2.5. Разведение, селекция, генетика и биотехнология животных 4.3.1. Технологии, машины и оборудование для агропромышленного комплекса

В журнале также публикуются обзоры, краткие сообщения, хроника, рецензии, книжные обозрения, материалы по истории сельскохозяйственной науки и деятельности учреждений и ученых.

Число публикаций одного автора в номере журнала не должно превышать двух, при этом вторая статья допустима лишь в соавторстве.

К рассмотрению принимаются материалы от различных категорий исследователей, аспирантов, докторантов, специалистов и экспертов в соответствующих областях знаний.

Все статьи рецензируются и имеют зарегистрированный в системе CrossRef индекс DOI.

Публикации для авторов **бесплатны**.

При направлении статьи в редакцию журнала «Сибирский вестник сельскохозяйственной науки» рекомендуем руководствоваться следующими правилами.

РЕКОМЕНДАЦИИ АВТОРУ ДО ПОДАЧИ СТАТЬИ

Представление статьи в журнал «Сибирский вестник сельскохозяйственной науки» подразумевает, что:

- статья ранее не была опубликована в другом журнале;
- статья не находится на рассмотрении в другом журнале;
- все соавторы согласны с публикацией текущей версии статьи.

Перед отправкой статьи на рассмотрение необходимо убедиться, что в файле (файлах) содержится вся необходимая информация на русском и английском языках, указаны источники информации, размещенной на рисунках и в таблицах, все ссылки оформлены корректно.

ПОРЯДОК НАПРАВЛЕНИЯ РУКОПИСЕЙ СТАТЕЙ

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Сопроводительные документы к рукописи статьи:

- скан-копия письма от организации с подтверждением авторства и разрешением на публикацию (образец на **http://sibvest.elpub.ru/**);
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- скан-копия справки из аспирантуры (для очных аспирантов).

2. Все поступающие в редакцию рукописи статей регистрируются через систему электронной редакции. В личном кабинете автора отражается текущий статус рукописи.

ПОРЯДОК ОФОРМЛЕНИЯ СТАТЬИ

Текст рукописи оформляется шрифтом Times New Roman, кеглем 14 с интервалом 1,5, все поля 2,0 см, нумерация страниц внизу. Объем статьи не более 15 страниц (включая таблицы, иллюстрации и библиографию); статей, размещаемых в рубриках «Из диссертационных работ» и «Краткие сообщения», – не более 7 страниц.

Структура оформления статьи:

1. **УДК**
2. **Заголовок статьи на русском и английском языках (не более 70 знаков).**
3. **Фамилии и инициалы авторов, полное официальное название научного учреждения, в котором проведены исследования, на русском и английском языках.**

Если в подготовке статьи принимали участие авторы из разных учреждений, необходимо указать принадлежность каждого автора к конкретному учреждению с помощью надстрочного индекса.

4. **Реферат на русском и английском языках.** Объем реферата не менее 200–250 слов. Реферат является кратким и последовательным изложением материала статьи по основным разделам и должен отражать основное содержание, следовать логике изложения материала и описания результатов в статье с приведением конкретных данных. Не следует включать впервые введенные термины, аббревиатуры (за исключением общеизвестных), ссылки на литературу. В реферате не следует подчеркивать новизну, актуальность и личный вклад автора; место исследования необходимо указывать до области (края), не упоминать конкретные организации.
5. **Ключевые слова на русском и английском языках.** 5–7 слов по теме статьи. Желательно, чтобы ключевые слова дополняли реферат и название статьи.
6. **Информация о конфликте интересов либо его отсутствии.** Автор обязан уведомить редактора о реальном или потенциальном конфликте интересов, включив информацию о конфликте интересов в соответствующий раздел статьи. Если конфликта интересов нет, автор должен также сообщить об этом.

Пример формулировки: «Автор заявляет об отсутствии конфликта интересов».

7. **Благодарности на русском и английском языках.** В этом разделе указываются все источники финансирования исследования, а также благодарности людям, которые участвовали в работе над статьей, но не являются ее авторами.
8. **Основной текст статьи.** При изложении оригинальных экспериментальных данных рекомендуется использовать подзаголовки:

ВВЕДЕНИЕ (постановка проблемы, цели, задачи исследования)

МАТЕРИАЛ И МЕТОДЫ (условия, методы (методика) исследований, описание объекта, место и время проведения)

РЕЗУЛЬТАТЫ И ОБСУЖДЕНИЕ

ЗАКЛЮЧЕНИЕ или **ВЫВОДЫ**

СПИСОК ЛИТЕРАТУРЫ. Количество источников не менее 15. В список литературы включаются только рецензируемые источники: статьи из научных журналов и монографии. Самоцитирование не более 10% от общего количества. Библиографический список должен быть оформлен в виде общего списка в порядке упоминания в тексте, желательны ссылки на источники 2–3-летнего срока давности. Правила оформления списка литературы – в соответствии с ГОСТ Р 7.05–2008 (требования и правила составления библиографической ссылки). В тексте ссылка на источник отмечается порядковой цифрой в квадратных скобках, например [1]. Литература в списке дается на тех языках, на которых она издана. В библиографическое описание публикации необходимо вносить всех авторов, не сокращая их одним, тремя и т.п. Недопустимо сокращение названий статей, журналов, издательств.

Если необходимо сослаться на авторефераты, диссертации, сборники статей, учебники, рекомендации, учебные пособия, ГОСТы, информацию с сайтов, статистические отчеты, статьи в общественно-политических газетах и прочее, то такую информацию следует оформить в *сноску* в конце страницы. Сноски нумеруются арабскими цифрами, размещаются постранично сквозной нумерацией.

Внимание! Теоретические, обзорные и проблемные статьи могут иметь произвольную структуру, но обязательно должны содержать реферат, ключевые слова, список литературы.

ПРИМЕРЫ ОФОРМЛЕНИЯ СПИСКА ЛИТЕРАТУРЫ, REFERENCES И СНОСОК

СПИСОК ЛИТЕРАТУРЫ:

Монография

Климова Э.В. Полевые культуры Забайкалья: монография. Чита: Поиск, 2001. 392 с.

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Пакуль А.Л., Лапшинов Н.А., Божанова Г.В., Пакуль В.Н. Технологические качества зерна мягкой яровой пшеницы в зависимости от системы обработки почвы // Сибирский вестник сельскохозяйственной науки. 2018. Т. 48. № 4. С. 27–35. DOI: 10.26898/0370-8799-2018-4-4.

REFERENCES:

Составляется в том же порядке, что и русскоязычный вариант, по следующим правилам:

Фамилии И.О. авторов в устоявшемся способе транслитерации, англоязычное название статьи, *транслитерация названия русскоязычного источника (например, через сайт: https://antropophob.ru/translit-bsi) = англоязычное название источника.* Далее оформление для монографии: город, англоязычное название издательства, год, количество страниц; для журнала: год, том, номер, страницы. (In Russian).

Пример: Avtor A.A., Avtor B.B., Avtor C.C. Title of article.

Транслитерация авторов. Англоязычное название статьи

Zaglavie jurnala = Title of Journal, 2012, vol. 10, no. 2, pp. 49–54.

Транслитерация источника = Англоязычное название источника

Монография

Klimova E.V. *Field crops of Zabaikalya*. Chita, Poisk Publ., 2001, 392 p. (In Russian).

Часть книги

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).

Периодическое издание

Pakul A.L., Lapshinov N.A., Bozhanova G.V., Pakul V.N. Technological grain qualities of spring common wheat depending on the system of soil tillage. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2018, vol. 48, no. 4, pp. 27–35. (In Russian). DOI: 10.26898/0370-8799-2018-4-4.

СНОСКИ:

Цитируемый текст[1].

[1]*Климова Э.В., Андреева О.Т., Темникова Г.П.* Пути стабилизации кормопроизводства Забайкалья // Проблемы и перспективы совершенствования зональных систем земледелия в современных условиях: материалы науч.-практ. конф. (Чита, 16–17 октября 2008 г.). Чита, 2009. С. 36–39.

Цифровой идентификатор Digital Object Identifier – DOI (когда он есть у цитируемого материала) необходимо указывать в конце библиографической ссылки.

Пример:

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.

Наличие DOI статьи следует проверять на сайте http://search.crossref.org/ или https://www.citethisforme.com. Для этого нужно ввести в поисковую строку название статьи на английском языке.

РИСУНКИ, ТАБЛИЦЫ, СКРИНШОТЫ И ФОТОГРАФИИ

Рисунки должны быть хорошего качества, пригодные для печати. Все рисунки должны иметь подрисуночные подписи. Подрисуночную подпись необходимо перевести на английский язык. Рисунки нумеруются арабскими цифрами по порядку следования в тексте. Если рисунок в тексте один, то он не нумеруется. Отсылки на рисунки оформляются следующим образом: «На рис. 3 указано, что …» или «Указано, что … (см. рис. 3)». Подрисуночная подпись включает порядковый номер рисунка и его название: «Рис. 2. Описание жизненно важных процессов». Перевод подрисуночной подписи следует располагать после подрисуночной подписи на русском языке.

Таблицы должны быть хорошего качества, пригодные для печати. Предпочтительны таблицы, пригодные для редактирования, а не отсканированные или в виде рисунков. Все таблицы должны иметь заголовки. Название таблицы должно быть переведено на английский язык. Таблицы нумеруются арабскими цифрами по порядку следования в тексте. Если таблица в тексте одна, то она не нумеруется. Отсылки на таблицы оформляются следующим образом: «В табл. 3 указано, что …» или «Указано, что … (см. табл. 3)». Заголовок таблицы включает порядковый номер таблицы и ее название: «Табл. 2. Описание жизненно важных процессов». Перевод заголовка таблицы следует располагать после заголовка таблицы на русском языке.

Фотографии, скриншоты и другие нерисованные иллюстрации необходимо загружать отдельно в виде файлов формата *.jpeg (*.doc и *.docx – в случае, если на изображение нанесены дополнительные пометки). Разрешение изображения должно быть >300 dpi. Файлам изображений необходимо присвоить название, соответствующее номеру рисунка в тексте. В описании файла следует отдельно привести подрисуночную подпись, которая должна соответствовать названию фотографии, помещаемой в текст.

Следует обратить внимание на написание формул в статье. Во избежание путаницы необходимо греческие (α, β, π и др.), русские (А, а, Б, б и др.) буквы и цифры писать прямым шрифтом, латинские – курсивным (W, Z, m, n и др.). Математические знаки и символы нужно писать также прямым шрифтом. Необходимо четко указывать верхние и нижние надстрочные символы (W^1, F_1 и др.).

ВЗАИМОДЕЙСТВИЕ МЕЖДУ ЖУРНАЛОМ И АВТОРОМ

Редакция просит авторов при подготовке статей руководствоваться изложенными выше правилами.

Все поступающие в журнал «Сибирский вестник сельскохозяйственной науки» статьи проходят предварительную проверку на соответствие формальным требованиям. На этом этапе редакция оставляет за собой право:

- принять статью к рассмотрению;
- вернуть статью автору (авторам) на доработку с просьбой устранить ошибки или добавить недостающие данные;
- вернуть статью автору (авторам) без рассмотрения, оформленную не по требованиям журнала;
- отклонить статью из-за несоответствия ее целям журнала, отсутствия оригинальности, малой научной ценности.

Переписка с авторами рукописи ведется через контактное лицо, указанное в рукописи.

Все научные статьи, поступившие в редакцию журнала «Сибирский вестник сельскохозяйственной науки», проходят обязательное двухстороннее «слепое» рецензирование (double-blind – автор и рецензент не знают друг о друге).

Рукописи направляются по профилю научного исследования на рецензию членам редакционной коллегии, а также приглашенным рецензентам – ведущим специалистам по тематике рецензируемых материалов. Решение о выборе того или иного рецензента для проведения экспертизы статьи принимает главный редактор, заместитель главного редактора, научный редактор. Срок рецензирования составляет 4–6 недель.

В спорных случаях редактор может привлечь к процессу рецензирования нескольких специалистов, а также главного редактора. При положительном заключении рецензента статья передается редактору для подготовки к печати.

При принятии решения о доработке статьи замечания и комментарии рецензента передаются автору. Автору дается 2 месяца на устранения замечаний. Если в течение этого срока автор не уведомил редакцию о планируемых действиях, статья снимается с очереди публикации.

При принятии решения об отказе в публикации статьи автору отправляется соответствующее решение редакции.

Ответственному (контактному) автору принятой к публикации статьи направляется финальная версия верстки, которую он обязан проверить.

ПОРЯДОК ПЕРЕСМОТРА РЕШЕНИЙ РЕДАКТОРА/РЕЦЕНЗЕНТА

Если автор не согласен с заключением рецензента и/или редактора или отдельными замечаниями, он может оспорить принятое решение. Для этого автору необходимо:

- исправить рукопись статьи согласно обоснованным комментариям рецензентов и редакторов;
- ясно изложить свою позицию по рассматриваемому вопросу.

Редакторы содействуют повторной подаче рукописей, которые потенциально могли бы быть приняты, однако были отклонены из-за необходимости внесения существенных изменений или сбора дополнительных данных, и готовы подробно объяснить, что требуется исправить в рукописи для того, чтобы она была принята к публикации.

ДЕЙСТВИЯ РЕДАКЦИИ В СЛУЧАЕ ОБНАРУЖЕНИЯ ПЛАГИАТА, ФАБРИКАЦИИ ИЛИ ФАЛЬСИФИКАЦИИ ДАННЫХ

Редакция научного журнала «Сибирский вестник сельскохозяйственной науки» в своей работе руководствуется традиционными этическими принципами научной периодики и сводом принципов «Кодекса этики научных публикаций», разработанным и утвержденным Комитетом по этике научных публикаций, требуя соблюдения этих правил от всех участников издательского процесса.

ИСПРАВЛЕНИЕ ОШИБОК И ОТЗЫВ СТАТЬИ

В случае обнаружения в тексте статьи ошибок, влияющих на ее восприятие, но не искажающих изложенные результаты исследования, они могут быть исправлены путем замены pdf-файла статьи. В случае обнаружения в тексте статьи ошибок, искажающих результаты исследования, либо в случае плагиата, обнаружения недобросовестного поведения автора (авторов), связанного с фальсификацией и/или фабрикацией данных, статья может быть отозвана. Инициатором отзыва статьи может быть редакция, автор, организация, частное лицо. Отозванная статья помечается знаком «Статья отозвана», на странице статьи размещается информация о причине ее отзыва. Информация об отзыве статьи направляется в базы данных, в которых индексируется журнал.

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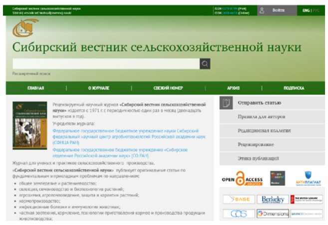

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