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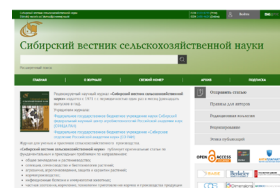
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СОДЕРЖАНИЕ

CONTENTS

ЗЕМЛЕДЕЛИЕ И ХИМИЗАЦИЯ

AGRICULTURE
AND CHEMICALIZATION

Ахмедова П.М. Экономическая эффективность производства томатов отечественных сортов с использованием биопрепарата

5 Akhmedova P.M. Economic efficiency of domestic tomato varieties production with the use of biopreparations

РАСТЕНИЕВОДСТВО И СЕЛЕКЦИЯ

PLANT GROWING AND BREEDING

Коробейников Н.И., Валекжанин В.С. Среднеранний сорт мягкой яровой пшеницы Спикер

16 Korobeinikov N.I., Valekzhanin V.S. Middle-early soft spring wheat variety Speaker

Никонорова Ю.Ю., Косых Л.А., Столпивская Е.В., Шиповалова А.В., Ермилина Н.Н. Оценка новых сортов и перспективных линий ярового ячменя по содержанию белка и лизина в конкурсном сортоиспытании

27 Nikonorova Yu.Yu., Kosykh L.A., Stolpivskaya E.V., Shipovalova A.V., Ermilina N.N. Evaluation of the new varieties and promising lines of spring barley for protein and lysine content in competitive variety trials

Ермошкина Н.Н. Взаимосвязь между урожайностью и элементами ее структуры сортообразцов диплоидной и тетраплоидной озимой ржи в условиях Западно-Сибирского региона

36 Ermoshkina N.N. Relationships between the yield and the elements of its structure of diploid and tetraploid winter rye varieties under the conditions of the West Siberian region

ЗАЩИТА РАСТЕНИЙ

PLANT PROTECTION

Лунева Н.Н., Закота Т.Ю. Активность сорных растений в посевах полевых культур степной зоны Краснодарского края

45 Luneva N.N., Zakota T.Yu. Activity of weed plants in field crops in the steppe zone of the Krasnodar Territory

ЗООТЕХНИЯ И ВЕТЕРИНАРИЯ

*ZOOTECHNICS
AND VETERINARY MEDICINE*

Краснова О.А., Коник Н.В., Тлецерук И.Р., Эльжирокова З.Л., Улимбашев М.Б. Производственное использование коров красных молочных пород в регионах разведения Российской Федерации

57 Krasnova O.A., Konik N.V., Tletseruk I.R., Elzhirokova Z.L, Ulimbashhev M.B. Production use of the Red dairy breed cows in the breeding regions of the Russian Federation

Гаджиев И.М.О., Сизов А.А., Сизов Д.А., Стеблева Г.М., Донченко А.С. Экспериментальная иммунотерапия ассоциативных инфекций желудочно-кишечного тракта новорожденных телят с использованием обогащенного специфическими иммуноглобулинами класса Y желточного меланжа

68 Gadjiev I.M.O., Sizov A.A., Sizov D.A., Stebleva G.M., Donchenko A.S. Experimental immunotherapy of association infections of the gastrointestinal tract of newborn calves using yolk melange enriched with specific Y class immunoglobulins

Зазнобина Т.В., Ефимова Л.В. Влияние иммуногенетических факторов на воспроизводительную способность и продуктивное долголетие коров красно-пестрой породы

75 Zaznobina T.V., Efimova L.V. Influence of immunogenetic factors on the reproductive ability and productive longevity of Red-and-White cows

- Шемуранова Н.А., Гарифуллина Н.А., Филатов А.В., Сапожников А.Ф.** Гематологические показатели коров при разных схемах использования биодобавки Ламарин Saldonum 86 **Shemuranova N.A., Garifullina N.A., Filatov A.V., Sapozhnikov A.F.** Hematological parameters of cows with different schemes of using the dietary supplement Lamarin Saldonum

- Сумарокова А.Д., Афонюшкин В.Н., Миронова Т.Е., Черепушкина В.С., Афонюшкин А.В., Стацевич Л.Н., Сильников В.Н.** Изучение биологической активности препаратов серебра на организменной модели инфекции болезни Ньюкасла 96 **Sumarokova A.D., Afonyushkin V.N., Mironova T.E., Cherepushkina V.S., Afonyushkin A.V., Statsevich L.N., Silnikov V.N.** Study of the biological activity of silver preparations on an organismal model of Newcastle disease infection

*МЕХАНИЗАЦИЯ, АВТОМАТИЗАЦИЯ,
МОДЕЛИРОВАНИЕ
И ИНФОРМАЦИОННОЕ ОБЕСПЕЧЕНИЕ*

*MECHANISATION, AUTOMATION,
MODELLING AND DATAWARE*

- Яковлев Н.С., Рассомахин Г.К., Иванов А.Б., Чернышов А.П.** Изменение физических свойств залежных земель при их восстановлении 106 **Yakovlev N.S., Rassomakhin G.K., Vakhrushev V.V., Chernyshov A.P.** Changes in the physical properties of fallow lands during their regeneration

ПРОБЛЕМЫ. СУЖДЕНИЯ

PROBLEMS. SOLUTIONS

- Каличкин В.К.** О необходимости трансформации парадигмы научных исследований в области земледелия (*сообщение первое*) 117 **Kalichkin V.K.** On the need to transform the paradigm of scientific research in agriculture (*the first message*)



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Экономическая эффективность производства томатов отечественных сортов с использованием биопрепарата

✉ Ахмедова П.М.

Федеральный аграрный научный центр Республики Дагестан

Махачкала, Республика Дагестан

✉ e-mail: apm64@mail.ru

Представлены результаты испытаний отечественных сортов томата с применением биостимулятора роста на продуктивность растений в условиях открытого грунта Терско-Сулакской подпровинции Дагестана. Целью исследований было изучение новых отечественных сортов томата селекции Федерального научного центра овощеводства (ФНЦО) и оценка экономической эффективности применения биопрепарата Реликт Р (жидкий). Новые отечественные сорта томата, выведенные учеными-селекционерами ФНЦО для зон рискованного земледелия, в условиях юга России показали достаточно высокие результаты по основным хозяйственно ценным показателям. На посадках применен Реликт Р – препарат на основе солей гуминовых и фульвокислот, обладающий ростостимулирующими, адаптогенными и защитными свойствами для широкого спектра сельскохозяйственных культур. Препарат разработан в Сибирском отделении Российской академии наук. Компания-производитель – ООО НПП «Генезис» (Россия). Томаты выращивались по общепринятой технологии в условиях открытого грунта. Все сорта являются раннеспелыми с продолжительностью вегетационного периода 93–110 сут. По урожайности наилучшими показателями обладали сорта Восход ВНИИССОКа, Благодатный и Содружество (85,3; 83,6 и 78,2 т/га). Все сорта также отличались высокой ранней урожайностью (24,2–42,5 т/га). Содержание сухого вещества варьировало от 4,1 до 6,9%. Лучшими сортами оказались Викинг, Содружество, Благодатный, их индекс составил 15,2; 13,1 и 8,2 соответственно. Содержание аскорбиновой кислоты варьировало от 24,85 до 45,20 мг%. Сорт Викинг отличался высоким содержанием витамина С (45,20 мг%), а также витаминов В1, В2, В6, В5 (0,074; 0,058; 0,083; 0,258 мг%). Сорт Магнат отличался самым высоким содержанием витамина В3 (0,511 мг%). Применение биопрепарата значительно повысило урожайность по сравнению с контролем (на 4,1 т/га), она оказалась выше запланированной урожайности (80 т/га). Урожайность томатов при использовании средства Реликт Р составила 85,3 т/га. Использование биопрепарата обеспечило высокий положительный экономический эффект – чистый доход и уровень рентабельности были выше при использовании средства Реликт Р и составили 3928,5 тыс. р./га и 12% соответственно. По результатам исследований рекомендуется использовать гуминовый препарат Реликт Р (жидкий) на томатах для повышения урожайности и качественных показателей в условиях юга страны.

Ключевые слова: томат, сорта, биопрепарат, межфазные периоды, масса плода, урожайность, сухие вещества, витамины, экономическая эффективность

Economic efficiency of domestic tomato varieties production with the use of biopreparations

✉ Akhmedova P.M.

Federal Agrarian Scientific Center of the Republic of Dagestan

Makhachkala, Republic of Dagestan

✉ e-mail: apm64@mail.ru

The results of domestic tomato varieties testing with application of growth biostimulant on plant productivity in open ground conditions of the Tersko-Sulak subprovince of Dagestan are presented. The

purpose of the research was to study new domestic tomato varieties of the Federal Research Center for Vegetable Growing (FRC VG) selection and to assess the economic efficiency of the application of biopreparation Relict R (liquid). New domestic tomato varieties, bred by scientists-breeders of the Federal Research Center for Vegetable Growing for risky farming zones, in the conditions of southern Russia have shown quite high results on the main economically valuable indicators. Relict R, a preparation based on salts of humic and fulvic acids with growth-stimulating, adaptogenic and protective properties for a wide range of crops, was applied at the plantings. The preparation was developed at the Siberian Branch of the Russian Academy of Sciences. The manufacturing company was OOO RPE "Genesis" (Russia). Tomatoes were grown according to generally accepted technology under open ground conditions. All varieties were early maturing with a growing season duration of 93–110 days. Voskhod VNI-ISSOK, Blagodatny and Sodruzhestvo varieties showed the best yields (85.3; 83.6 and 78.2 t/ha). All varieties were also distinguished by high early yields (24.2–42.5 t/ha). Dry matter content ranged from 4.1 to 6.9%. The best varieties were Viking, Sodruzhestvo, and Blagodatny, with indexes of 15.2; 13.1; and 8.2, respectively. The ascorbic acid content ranged from 24.85 to 45.20mg%. The Viking variety was distinguished by high content of vitamin C (45.20mg%), as well as vitamins B1, B2, B6, B5 (0.074; 0.058; 0.083; 0.258 mg%). The Magnat variety stood out for the highest content of vitamin B3 (0.511 mg%). Application of the biopreparation significantly increased the yield compared to the control (by 4.1 t/ha), it was higher than the planned yield (80 t/ha). Tomato yield when using Relict R was 85.3 t/ha. The use of biopreparation provided a high positive economic effect – net income and profitability level were higher when using Relict R and amounted to 3928.5 thousand rubles/ha and 12%, respectively. According to the results of the research it is recommended to use humic preparation Relict R (liquid) on tomatoes to increase yield and quality indicators in the conditions of the south of the country.

Keywords: tomato, varieties, biological product, interphase periods, fruit weight, yield, dry substances, vitamins, economic efficiency

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INTRODUCTION

One of the important problems of agricultural development is the economic independence and food security of the country. The industry is able to meet the needs of the population with environmentally friendly safe food products, and agricultural producers with quality seeds at the expense of domestic production. The ultimate goal

of agricultural producers is to obtain a product with high profitability and low production costs [1].

Tomato *Solanum lycopersicum* L. is one of the main vegetable crops, samples and varieties of which are characterized by a low level of genomic polymorphism. In introgressive tomato breeding, related wild *Solanum* species are used

to improve varieties for stress tolerance and fruit quality traits [2].

Since tomatoes are cultivated in different ecological conditions on different soils, under irrigation and in dryland areas, there is a need to select the varieties of this crop in accordance with the needs of agribusiness. Insufficient heat resources do not allow growing tomato varieties with a long growing season in the Piedmont Dagestan. Therefore, it is necessary to select them properly, taking into account the microzonal differences [3].

An increase in the yield and economic efficiency of tomato cultivation can be achieved by introduction of new high-yielding varieties and hybrids adapted to local acutely arid climatic conditions, as well as the introduction of advanced elements of technology [4].

The required level of soil moisture in combination with the application of the calculated doses of mineral fertilizers during the growing season ensures the planned yields of vegetables, including tomatoes [5].

Foliar dressing of tomatoes with microelements on the background of the main fertilizer also increased the accumulation of vitamin C in ripening fruits, had a favorable effect on more active movement of vitamin in tomato fruits. Mineral elements had a positive effect on more active movement of vitamin C from the place of their synthesis (leaves) to the place of their accumulation (fruits) [6].

At present, there is a growing interest in the qualitative and quantitative increase in the content of healthy compounds in tomato fruits in order to further increase the nutraceutical potential of the crop. Modern biochemical research is aimed at identifying and quantifying components of plant raw materials and assessing their biological activity. Such data are also necessary for the development of useful food and nutraceutical supplements [7].

Ascorbic acid (ascorbate, vitamin C) plays an important role in various metabolic processes in both plants and humans; therefore, increasing ascorbate content in plant cells using breeding approaches is important in order to increase both the nutritional value of fruits and plant resistance

to stress. It is known that tomato has a high potential as a source of ascorbate in the human diet [8].

It is known that varieties with fruits of crimson and yellow color are in high demand among the population. And their price, as a rule, is higher than that of the red-fruited varieties. Raspberry tomatoes with large fruits are especially attractive; the flavor qualities of raspberry-fruited varieties are almost always higher than those of the red-fruited varieties [9].

The fruit size control in *Solanum lycopersicum* L. is carried out by a group of loci that regulate the processes of cell division and expansion at four different stages of fruit development, from oocyte development and ovary formation after fertilization to cell division and expansion of the cells forming the mature fruit. To date, 37 such loci are known [10].

The Ripening Inhibitor (TF RIN) transcription factor is one of the key regulators of the tomato fruit ripening cascade. By controlling both ethylene-dependent and ethylene-independent ripening pathways, TF RIN triggers the operation of a variety of structural and regulatory genes that determine such aspects of tomato fruit ripening as chlorophyll loss, biosynthesis of carotenoids, aromatic components, organic acids, modification of cell wall structure, and accumulation of sugars [11].

Literature sources note the positive effect of humic preparations on germination ability and germination energy of seeds, on acceleration of phenological phases of development, increase in the yield and quality of products, active effect on metabolism, as well as on increasing plant resistance to biotic and abiotic environmental factors.

Humic substances are the most important component of soil organic matter. Numerous studies have revealed a wide range of effects of humic substances on plants. Humic substances contribute to the improvement of the general condition of plants and optimization of their development, effective assimilation of nutrient elements by plants [12].

One of the main technological operations in the extraction of humates is additional grinding of water-peat or water-coal suspension in order

to accelerate the physical and chemical processes of humic acid extraction. For this purpose, various types of pulverizers are currently used: dispersants, dismembrators, cavitators, ball mills and other types [13].

Properties and availability of humic substances allow to use them as promising reagents for the task of solving various environmental problems, but the natural origin, as well as the complexity and diversity of the material composition require the development of technologies for the production and use of humic preparations [14].

Humic preparations are used to increase seed germination, accelerate growth and development of plants, increase yield and quality of products. They adapt plants to natural and anthropogenic influences, accelerate the phenological phases of development, have an active effect on metabolism, limit the entry of toxicants into the plant¹⁻³.

The purpose of the research is to study new domestic varieties of tomato (*Lycopersicon esculentum*) of the Federal Research Center for Vegetable Growing selection and to evaluate the economic efficiency of the application of the bio-preparation Relict R on the yield of the crop.

MATERIAL AND METHODS

The experimental work was carried out on the basis of the Federal Agrarian Scientific Center of the Republic of Dagestan (FASC RD) in the Kizlyarsky district of the Tersko-Sulak sub-province.

The soil was alluvial-meadow, medium-solonchak, medium loamy. Soil reaction was slightly alkaline. The saturation with bases was up to 98–99%. Humus content in the arable layer was 2.8–3.0%, hydrolyzable nitrogen – 3.5–3.7 mg/100 g of soil, mobile phosphorus P_2O_5 – 1.8–3.5 mg/100 g of soil and exchangeable potassium – 37–43 mg/100 g of soil.

The forecrop was winter wheat. Agrotechnics of tomato cultivation was the one generally accepted in the Republic of Dagestan.

After harvesting the forecrop, two cultivations with disc implements were carried out at a depth of 8–10 cm with simultaneous harrowing to the extent of weed growth. In autumn at the end of September plowing to a depth of 30 cm was carried out and a fertilizer was applied, in spring harrowing, two cultivations and the installation of a drip irrigation system. Tomato was grown by a seedling method using drip irrigation. The seedlings were grown in a greenhouse for 45 days and planted in the field in the second ten-day period of April. Weeding was carried out, when necessary, as part of weed control. Watering was carried out, maintaining soil moisture at 75–80% MWC, with an irrigation rate of 85–100 m³/ha. Care of tomato plantings included plant protection from pests and diseases. Aktellik, Aktara and Iskra M were used against pests, while Hom, Quadris and Ridomil Gold were used against diseases. Tomatoes were harvested manually as the fruits ripened.

Calcium nitrate, potassium nitrate, monocalcium phosphate, ammophos, and biopreparation Relict R were used as mineral fertilizers. The calculated dose of fertilizers for the planned yield of tomatoes in 80 t/ha according to the experimental method was $N_{120}P_{170}K_{150}$. Mineral fertilizers were added to the main fertilizer and as part of the top dressing by a drip irrigation method.

Relict R preparation (manufacturer – OOO RPE “Genesis” (Russia)) is composed of salts of humic and fulvic acids 40–60 g/l + microelements. The rate of consumption in the experiment was 5 l/ha.

Soil and plant samples were analyzed in the analytical laboratory of the FASC RD according to the generally accepted GOSTs.

The 45-day-old seedlings were planted in the open ground manually according to the scheme 150 × 25. The number of the variants – 7, repetition of the experiment 3-fold. The area of the registration plot – 15 m².

¹Malkhasyan A.B., Pavlov I.N. Influence of natural growth regulators on the yield and quality of white cabbage // Izvestia Orenburg State Agrarian University, 2018, N 6, pp. 116-119.

²Kirdey T.A. Humic preparations in agrotechnologies // Zemledelie, 2013, N 5, pp. 12-14.

³Shcherba E.V., Potapova S.S., Galeev R.R. Quality of seedlings of early maturing white cabbage depending on growth regulators in the forest-steppe of the Novosibirsk Priobie // Bulletin of Altai State Agricultural University, 2013, N 3 (101), pp. 8-12.

Six varieties of the FSBSI FASC RD (VNISSOK) selection were studied: Blagodatny, Viking, VNISSOK Voskhod, Magnate, Severyanka, Sodruzhestvo, and Fakel (control).

Laying of the field experiments was carried out in accordance with the methodological instructions⁴.

Statistical processing of the yield data was carried out according to B.A. Dospekhov⁵ using computer programs for statistical data processing.

Meteorological observations were carried out taking into account the periods of growth and development of the studied crop (see Fig. 1, 2).

RESULTS AND DISCUSSION

According to the vegetation period, the studied tomato varieties belong to very early – Severyanka, Blagodatny, Magnat, VNISSOK Voskhod, Viking (from sprouting to maturity 90–100 days), early – Sodruzhestvo (106 days) and middle-early – Fakel (110 days) (see Table 1). This trait varies greatly depending on soil-climate and light zones of the country. The difference between the varieties in the duration of the germination – flowering period was 1–6 days. This period was the longest (52 days) for the varieties Sodruzhestvo and Fakel. The

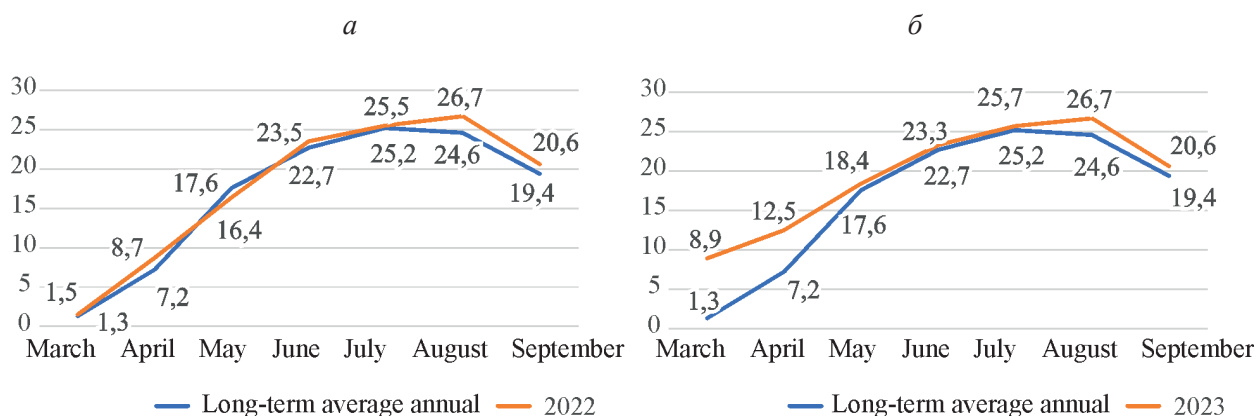


Рис. 1. Температура воздуха в период вегетации, °C: а – 2022 г.; б – 2023 г.

Fig. 1. Air temperature during the growing season, °C: а – 2022; б – 2023

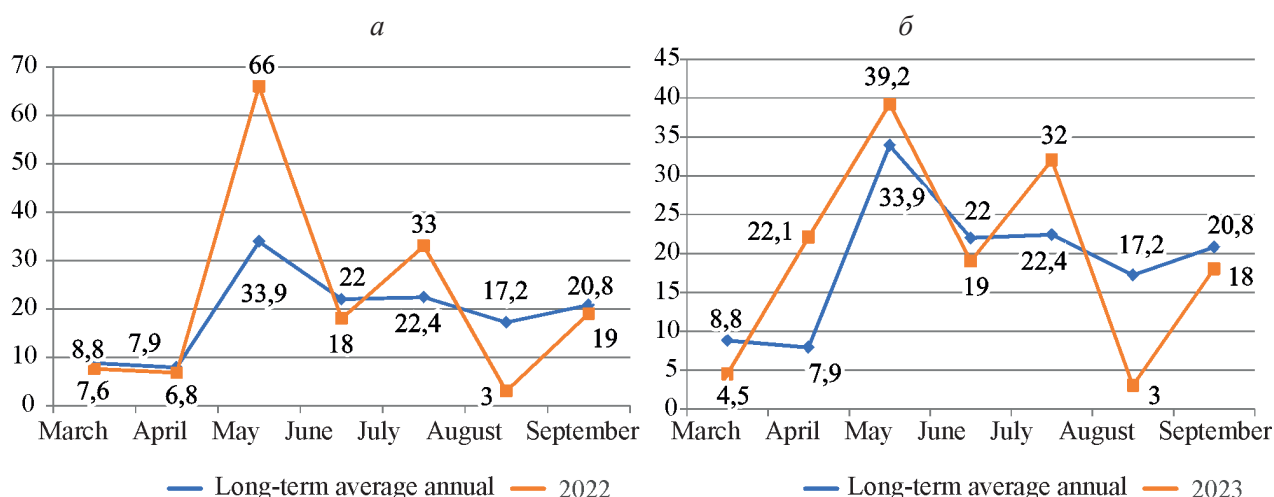


Рис. 2. Количество выпавших осадков в период вегетации, мм: а – 2022 г.; б – 2023 г.

Fig. 2. Amount of precipitation during the growing season, mm: а – 2022; б – 2023

⁴Methodological guidelines for selection of tomato varieties and hybrids for open and protected soil. Moscow, VNISSOK, 1986, 64 p.

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

difference between the varieties is also manifested in the duration of the flowering – ripening period. Duration of this period varied from 44 (in the Voskhod VNISSOK variety) to 58 (in the Fakel variety). The results of the 2023 research show some advance (by 4–7 days) in the duration of the sprouting – ripening period compared to 2022. This was promoted by the technological method with the use of a covering film. The most biologically early maturing varieties in 2023 were the varieties Voskhod VNISSOK (90 days), Severyanka, Blagodatny (93 days), Magnat (94 days).

According to the bush type, the studied varieties belong to common and half-standard forms. The height of the main stem varied from 48 (Magnat) to 77 cm (Viking).

All the studied varieties are early maturing with a growing season duration of 93–110 days. The yield of tomato varieties ranged from 43.5 to 85.3 t/ha (see Table 2). A significant increase in the yield by 41.8; 40.1 and 34.7 t/ha at LSD_{05} of 4.1 t/ha was observed in the varieties Voskhod VNISSOK, Blagodatny and Sodruzhestvo (85.3; 83.6 and 78.2 t/ha). For the varieties Severyanka and Magnat, the increase in the fruit yield was 11.6 and 14.2 t/ha.

The yield of the Viking variety was at the level of the control. All the studied varieties were distinguished by high early yield (24.2 – 42.5 t/ha). The early yield was influenced by the use of

the covering film from the moment of seedling planting (12.04) until the establishment of optimal weather conditions for the growth and development of tomato culture, in our experience until (05.05). The fruit weight ranged from 76 to 114 g. The highest fruit weight was observed in the varieties Blagodatny, Sodruzhestvo, Voskhod VNISSOK and amounted to 111, 113, 114 g, which is a significant increase compared with the control by 31–33 g at $LSD_{05} = 10$.

Dry matter content varied from 4.1 to 6.9% in the studied varieties.

Sugar content varied from 3.20 to 3.49%. The best varieties were Viking, Sodruzhestvo, and Blagodatny, their index being 15.2; 13.1 and 8.2, respectively.

The Severyanka variety had an index of 7.4. VNISSOK Voskhod was slightly lower in this index (with an index of 6.8). The Magnat variety was behind the control, its index amounted to 4.1.

According to Table 3, the high content of vitamins B1, B2, B6, and B5 was characterized by yellow-fruited fruits of the Viking variety (0.074; 0.058; 0.083; 0.258 mg%). The Magnat variety was characterized by the highest content of vitamin B3 (0.511 mg%). Other varieties were at the level of the control variety in terms of vitamin B content.

The ascorbic acid content varied from 24.85 to 45.20 mg%. The Viking and Sodruzhestvo

Табл. 1. Продолжительность межфазных периодов у исследуемых образцов томата

Table 1. Duration of the interphase periods in the studied tomato samples

Variety	Sowing		Sprouting – flowering		Flowering – ripening		Sprouting – ripening	
	2022	2023	2022	2023	2022	2023	2022	2023
Severyanka	1.03	7.03	54	47	43	46	97	93
Magnat	1.03	7.03	56	48	44	46	100	94
Blagodatny	1.03	7.03	51	47	48	46	99	93
Voskhod VNISSOK	1.03	7.03	52	46	48	44	100	90
Viking	1.03	7.03	53	51	50	49	103	100
Sodruzhestvo	1.03	7.03	59	52	52	54	111	106
Fakel (control)	1.03	7.03	59	52	55	58	114	110

Табл. 2. Хозяйственно ценные показатели детерминантных сортов томата
Table 2. Economic valuable indicators of determinant tomato varieties

Variety	Vegetation period		Yield, t/ha		Early yield, t/ha		Marketability, %		Fruit weight, g		Solids, %		Total sugar, %		Sugar-acid index	
	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
Severyanka	97	93	51,0	55,1	30,0	32,1	82	85	74	76	5,3	4,1	3,0	3,20	5,8	7,4
Magnat	100	94	53,1	57,7	28,3	30,0	80	83	75	78	5,5	4,7	3,2	3,17	4,7	4,1
Blagodatny	99	93	86,3	83,6	42,8	41,7	91	92	110	111	6,4	6,8	3,4	3,22	8,3	8,2
Voskhod VNISSOK	100	90	82,7	85,3	40,1	42,5	92	93	107	114	6,3	6,9	3,2	3,20	7,3	6,8
Viking	103	100	41,4	45,7	15,2	27,3	79	80	80	95	4,4	6,5	2,8	3,49	8,5	15,2
Sodruzhestvo	111	106	77,6	78,2	18,9	24,2	88	90	130	113	6,2	5,2	3,3	3,42	9,7	13,1
Fakel (control)	114	110	42,2	43,5	12,5	17,7	78	77	76	80	5,3	5,8	3,0	3,22	5,4	5,2
LSD _{0,5} , t/ha	9,0	8,7	4,3	4,1	2,1	2,0	8	9	11	10	0,4	0,5	0,04	0,05		

varieties were characterized by higher vitamin C content in the fruits – 45.20–45.03 mg%. Significantly lower vitamin C content was observed in the variety Severyanka (24.85 mg%, control – 32.38 mg%). Other varieties did not show significant differences compared to the control.

All the obtained data reflect the high effect of application of the biopreparation Relict R. Table 4 shows some indicators of the fruit quality in the variety Voskhod VNISSOK.

Application of the biopreparation contributed to an increase in dry matter content by 0.6–1.0%. The highest accumulation of dry matter was observed in tomato fruits grown in 2023 with the use of the Ground + Relict R technology, the index was 1.0% higher than the control.

The effective variant (feeding scheme) for accumulation of sugars in tomato fruits was Ground + Relict R – 3.1–3.2%, which was higher than in the control by 0.2–0.3% by years.

According to the results of the tasting evaluation, the fruits of the tomatoes Voskhod VNISSOK got 4.7–4.9 points on a five-point scale under the feeding scheme Ground + Relict R, which was 0.3–0.4 points higher than the control depending on the year of use.

The positive effect of the humic preparation on the yield increase in our studies is shown in Table 5. When using the feeding scheme Ground + Relict R, the yield of the tomato variety Voskhod VNISSOK increased by 4.1 t/ha, which is significantly higher compared to the control.

Analysis of economic efficiency of the biopreparation application showed that sales revenue increased by 287 thousand rubles/ha on average.

Net profit from the use of the Ground + Relict R amounted to 3928.5 million rubles/ha, which is 275 thousand rubles/ha higher than the control variant. At the same time, profitability was higher by 12% of the control variant.

CONCLUSION

According to the results of our research, the interphase periods of new domestic tomato varieties were determined. All varieties are early maturing with duration of the vegetation period

Табл. 3. Содержание витаминов в плодах изучаемых сортов томата
Table 3. Vitamin content in the fruits of the studied tomato varieties

Variety	Vitamin content, mg%											
	Vitamin B1		Vitamin B2		Vitamin B6		Vitamin C		Vitamin B3		Vitamin B5	
	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
Severyanka	0,041	0,046	0,033	0,035	0,071	0,073	24,657	24,855	0,397	0,407	0,202	0,208
Magnat	0,039	0,041	0,054	0,052	0,053	0,054	27,438	28,335	0,510	0,511	0,238	0,242
Blagodatny	0,057	0,055	0,040	0,039	0,067	0,068	34,855	34,811	0,414	0,424	0,209	0,212
Voskhod VNISSOK	0,054	0,052	0,043	0,044	0,078	0,080	37,783	38,054	0,336	0,304	0,257	0,260
Viking	0,072	0,074	0,056	0,058	0,080	0,083	44,362	45,202	0,347	0,352	0,251	0,258
Sodruzhestvo	0,064	0,068	0,041	0,043	0,050	0,051	43,408	45,033	0,305	0,302	0,239	0,241
Fakel (control)	0,052	0,051	0,034	0,039	0,051	0,054	31,275	32,380	0,360	0,410	0,248	0,255

Табл. 4. Показатели качества плодов томата в зависимости от применения биопрепарата Реликт Р, 2022, 2023 гг.
Table 4. Tomato fruit quality parameters depending on the application of the bio-preparation Relict R, 2022, 2023

Variety	Solids, %	Total sugars, %	Tasting evaluation of tomato fruits on a five-point scale			
			Consistency	Taste	Flavor	Total score
1. Control ($N_{120}P_{170}K_{150}$) – ground	5,7–5,9	2,8–3,0	4,4–4,5	4,6–4,7	4,3–4,5	4,4–4,5
2. Ground + Relict R	6,3–6,9	3,1–3,2	4,7–5,0	4,9–5,0	4,6–4,8	4,7–4,9

Табл. 5. Экономическая эффективность производства томатов в открытом грунте с применением биопрепарата, среднее за 2022, 2023 гг.
Table 5. Economic efficiency of tomato production in open ground with the use of a biopreparation, average 2022, 2023

Indicator	Control ($N_{120} + P_{150} + K_{150}$) – ground	Ground + Relict R
Average yield, t/ha	81,2	85,3
Production costs, rubles/ha	2 030 000	2 042 500
Cost price, thous. rubles/ha	2500	1800
Average selling price, rubles/kg	70	70
Revenue from sales, rubles/ha	5 684 000	5 971 000
Net income, rubles/ha	3 654 000	3 928 500
Profitability, %	180	192

of 93–110 days. The best yields were obtained by the Voskhod VNISSOK, Blagodatny and Sodruzhestvo varieties (85.3; 83.6 and 78.2 t/ha).

All varieties were also characterized by high early yields (24,2–42,5 t/ha).

Dry matter content varied from 4.1 to 6.9%. The best varieties were Viking, Sodruzhestvo, and Blagodatny, with an index of 15.2; 13.1; and 8.2, respectively.

The Viking variety was characterized by high content of vitamins B1, B2, B6, B5 (0.074; 0.058; 0.083; 0.258 mg%). The ascorbic acid content varied from 24.85 to 45.20 mg%.

Application of the biopreparation significantly increased the yield compared to the control by 4.1 t/ha, it was higher than the planned yield (80 t/ha). Tomato yield at use of Relict R preparation amounted to 85.3 t/ha.

The use of the biopreparation gave a high positive economic effect – net income and profitability level were higher when using Relict R and amounted to 3928.5 thousand rubles/ha and 192%, respectively.

In order to increase the yield and quality of tomato fruits, it is recommended to use biopreparation Relict R as a top dressing against the background of basic nutrition. The studied agro-technical approach to increasing tomato yields will also be effective when using other varieties and hybrids in different subprovinces of Dagestan.

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ИНФОРМАЦИЯ ОБ АВТОРЕ

✉ **Ахмедова П.М.**, кандидат сельскохозяйственных наук, ведущий научный сотрудник; **адрес для переписки:** Россия, 367014, Республика Дагестан, Махачкала, мкр. Научный городок, ул. А. Шахбанова, 30; e-mail: apm64@mail.ru

AUTHOR INFORMATION

✉ **Patimat M. Akhmedova**, Candidate of Science in Agriculture, Lead Researcher; **address:** 30, A. Shakhbanova St., Nauchny Gorodok, Makhachkala, Republic of Dagestan, 367014, Russia; e-mail: apm64@mail.ru

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Среднеранний сорт мягкой яровой пшеницы Спикер

✉ Коробейников Н.И., Валекжанин В.С.

Федеральный Алтайский научный центр агrobiотехнологий

Барнаул, Россия

✉ e-mail: nikkor733@gmail.ru

Представлены результаты исследований по созданию среднераннего сорта мягкой яровой пшеницы с улучшенными параметрами урожайности, толерантностью к раннелетней засухе, слабой восприимчивостью к болезням и вредителям, предназначенного для возделывания в Алтайском крае и смежных регионах Сибири. Сорт Спикер создан в результате межсортовой гибридизации (Ершовская 33/Омская 36) с последующим двухкратным индивидуальным отбором в расщепляющихся поколениях. Спикер относится к среднеранней группе генотипов с вегетационным периодом 79 дней. Новый сорт формирует средней крупности пирамидальный безостый неопушенный колос белой окраски и крупное красное зерно. Сорт среднерослый, обладает достаточно прочной, частично выполненной соломиной с устойчивостью к полеганию на уровне стандарта. В конкурсном сортоиспытании Спикер достоверно превысил по урожайности стандарт Алтайская 70 на 0,67 т/га (21,4%) и лучший районированный сорт Омская 36 на 0,60 т/га (18,8%). Высокая экологическая пластичность нового сорта подтверждается относительной стабильностью урожайности по годам исследований, а также результатами испытания в различных пунктах Сибирского региона, где средняя прибавка к стандартным сортам составила 1,48 т/га (30%). Преимущество по зерновой продуктивности нового сорта формируется за счет лучшей сохранности растений к уборке (+0,42 т/га, или 62,7% от общей прибавки) и большей массы зерна с растения, обусловленной лучше развитым побегом кущения (+0,22 т/га, 32,8% от общей прибавки). По комплексу признаков качества зерна Спикер соответствует требованиям для ценной пшеницы. Сорт обладает иммунитетом к местным популяциям патогенных грибов мучнистой росы и пыльной головки, слабо восприимчив к бурой ржавчине и средневосприимчив к стеблевой ржавчине. На фоне интенсивного проявления листостебельных заболеваний превосходит по урожайности восприимчивые контрольные сорта на 45–53%. Спикер включен в Государственный реестр селекционных достижений по Западно-Сибирскому региону в 2023 г.

Ключевые слова: яровая пшеница, гибридизация, отбор, урожайность, сорт Спикер

Middle-early soft spring wheat variety Speaker

✉ Korobeinikov N.I., Valekzhanin V.S.

Federal Altai Scientific Centre of Agro-BioTechnologies

Barnaul, Russia

✉ e-mail: nikkor733@gmail.ru

The results of research on the development of a middle-early variety of soft spring wheat with improved yield parameters, tolerance to early summer drought, low susceptibility to diseases and pests, intended for cultivation in the Altai Territory and adjacent regions of Siberia are presented. The variety Speaker was created as a result of intervarietal hybridization (Ershovskaya 33/Omskaya 36) followed by two-fold individual selection in split generations. Speaker belongs to the middle-early group of genotypes with a vegetation period of 79 days. The new variety forms a medium-sized pyramidal awnless plain spikelet of white color and large red grain. The variety is medium-grown, has a rather

strong, partially solid straw with resistance to lodging at the level of the standard. In the competitive variety trial Speaker significantly exceeded the yield of the standard Altayskaya 70 by 0.67 t/ha (21.4%) and the best released variety Omskaya 36 by 0.60 t/ha (18.8%). The high ecological plasticity of the new variety is confirmed by the relative stability of the yield over the years of research, as well as by the results of testing in various locations in the Siberian region, where the average gain to the standard varieties amounted to 1.48 t/ha (30%). The advantage in grain productivity of the new variety is formed due to better preservation of plants for harvesting (+0.42 t/ha, or 62.7% of the total increase) and higher grain weight per plant due to better developed tillering shoots (+0.22 t/ha, 32.8% of the total increase). According to the complex of grain quality traits, Speaker meets the requirements for valuable wheat. The variety is immune to local populations of pathogenic powdery mildew and loose smut fungi, weakly susceptible to brown rust and moderately susceptible to stem rust. Against the background of intensive manifestation of leaf-stalk diseases, it exceeds the yield of susceptible control varieties by 45–53%. The Speaker was included in the State Register of Breeding Achievements for the West Siberian region in 2023.

Keywords: spring wheat, hybridization, selection, yield, variety Speaker

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Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Altai Territory is the leader in Siberia in terms of gross wheat grain yields and is one of the five major grain producers in Russia¹. At present, despite a significant reduction in sown areas, spring wheat remains the leading crop in the territory and occupies about 1.7 million hectares annually. According to the Altai branch of Rosselkhozcenter, 86 varieties of soft spring wheat of domestic and foreign selection were sown in the Altai Territory in 2023. The varieties are represented mainly by medium-maturing and middle-late genotype groups. Only 13 varieties of Siberian and Ural breeding belong to the middle-early and early maturing ones. This group of genotypes in 2023 occupied 180 thousand ha in the Altai Territory, or 13% of the total crop sown with varietal seeds. These data indicate an obvious imbalance in the ratio of sown

areas of the varieties of different growing seasons in the Altai Territory, which does not best affect the level of average yield of the crop in the region and grain quality [1, 2]. In the Omsk region, the share of the early maturing varieties is 25–30% [3, 4]. In the Krasnoyarsk region, early maturing and middle-early varieties are predominantly cultivated, they occupy more than 85% of the sown area of the crop [5].

Despite the fact that early maturing varieties under favorable growing conditions are inferior in yield to medium-maturing and middle-late genotypes [6], under specific manifestation of stress factors they have a number of important advantages: in the years with summer drought they reduce productivity to a lesser extent than the late-type genotypes [7]; during the manifestation of leaf-stalk diseases (as a rule, the second half of vegetation) they are able to “escape” from diseases²; due to active growth, this group

¹Kashevarov N.I. Scientific basis of the record // *Science in Siberia*, 2022, N 45, p. 5.

²Likhenko I.E., Salina E.A., Artemova G.V., Sovetov V.V. Prospects for the development of crop breeding in Siberia // *Adaptability of agricultural crops in extreme conditions of the Central and East Asian macro-region: Proceedings of the symposium with international participation*. Novosibirsk, 2018, pp. 25–34.

of varieties is less damaged by hidden stem pests. An extremely important advantage of the early maturing varieties is their ability to stably form grain with a high content of protein and gluten [7–9], as well as to provide high sowing qualities of seeds due to early harvesting. In the steppe zone of the Altai Territory, middle-early varieties are the most justified variant for sowing at a later date with the expectation of July precipitation. In recent years in Siberia there has been a tendency to reduce sown areas under early maturing varieties [7], which emphasizes the relevance of effective selection of soft spring wheat for early maturity.

The only middle-early variety of local breeding Altayskaya 70³, although it has been in demand in the Altai Territory and beyond for 15 years and by now still occupies considerable sown areas, requires significant improvement in a number of parameters (e.g., resistance to leaf diseases and pests, drought resistance).

The purpose of this work is to present the results of research on the development of a new middle-early variety with improved yield parameters, tolerance to early summer drought, low susceptibility to diseases and pests, intended for cultivation in the Altai Territory and adjacent regions of Siberia.

Research Objectives:

- description of morphological and developmental characteristics of the new variety;
- experimental determination of the yield level of the Speaker variety in different ecological conditions and its advantages in comparison with the standards;
- analysis of the yield structure, as well as evaluation of grain quality traits and the level of resistance of the variety to fungal diseases and lodging.

MATERIAL AND METHODS

Breeding research on soft spring wheat was conducted at the experimental field of the Federal Altai Scientific Center of Agrobiotechnologies (FASCA) within the framework of the full breeding process from 2009 to 2020 according to the methods, the main provisions of which are reflected in the prospective research program of the Altai Breeding Center of FASCA up to 2030⁴. Intraspecific hybridization was used as the main method of obtaining genetic diversity in experimental populations for individual selection of initial recombinant forms with the planned morphobiology.

The selected lines were evaluated for agronomically important traits at different stages of the breeding process, starting from breeding nurseries to multi-year competitive trials. Competitive testing of the breeding lines was carried out in accordance with the SVT⁵ methodology on the plots with the registration area of 25 m² in fourfold repetition. The breeding experiments were laid on clean fallow at the rate of 500 germinated seeds/m² using a SSFK-7 seeder at the optimal sowing dates for the forest-steppe zone of the Altai Territory (from May 10 to 15). Harvesting was carried out in the phase of full ripeness by direct threshing of plots with the selection combine “Wintersteiger-Classic”. The yields of the breeding lines and varieties were compared with the corresponding index of the standard Altayskaya 70 and the best zoned variety Omskaya 36. Reliability of differences in yield was evaluated using factor analysis as described by G.F. Lakin⁶. Yield structure was analyzed on a random sample of 50 plants from the sample sheaf. Grain quality parameters (weight of 1000 seeds, protein and gluten content in grain, rheological properties of dough) were determined in the laboratory of grain qual-

³Korobeinikov N.I., Valekzhanin V.S., Peshkova N.V. Principles and main results of selection of spring soft wheat in the Altai Krai // Achievements of Science and Technology of AIC, 2015, vol. 29, N 6, pp. 21–26.

⁴Korobeinikov N.I., Shukis E.R., Rozova M.A., Boradulina V.A., Musalitin G.M., Gurkova E.V., Kostrova L.I. Work Program of the Altai Research Institute of Plant Breeding up to 2030 / under the general ed. of N.I. Korobeinikov, Barnaul, 2011, 90 p.

⁵Methodology of state varietal testing of agricultural crops. Moscow, 1985, Issue 1, 267 p.

⁶Lakin G.F. Biometrics. Moscow: Higher School, 1990, 352 p.

ity assessment of the Altai Selection Center according to standard methods. The degree of plant damage by leaf diseases was determined in accordance with the methods described by E.E. Geshele⁷. The resistance of wheat varieties and lines to the local population of loose smut was evaluated according to the method of V.I. Krivchenko⁸.

Meteorological conditions of the vegetation period of plants (May - August) in the years of the competitive trial (2017- 2020) differed significantly both in the dynamics of the average daily temperature and the amount and nature of distribution of precipitation, which was reflected in the level of yield of the varieties in the nursery.

The most favorable conditions for growth and development of wheat until earing occurred in 2018 and 2019, when precipitation in June exceeded the climatic norm by 5.8 and 16.6 mm with average daily temperature close to the norm. In contrast, the processes of establishment of the main productivity traits of wheat varieties in 2017 and 2020 took place with a significant lack of precipitation against the background of high average daily temperature in June, especially in 2017. Rainy weather in the second half of the 2017 growing season caused severe stem rust damage, which resulted in even more significant yield reductions in susceptible varieties. The variability of weather conditions and disease manifestations allowed a fuller appreciation of the advantages of the new variety.

RESULTS AND DISCUSSION

Breeding work on the creation of a new middle-early variety with a complex of positive economic and biological traits was started in 2009 on the basis of intraspecific hybridiza-

tion of morphobiologically distant initial forms with separate useful traits, which were planned to be combined as a result of recombination in one of the population genotypes. The long history of wheat breeding has repeatedly confirmed the effectiveness of such an approach in selecting the components of the crosses⁹ [10–12]. Yershovskaya 33, a medium-ripening variety of intensive type, was used as a maternal form, which is characterized by such important properties in the conditions of the Altai Territory as resistance to local populations of brown rust and powdery mildew, as well as weak susceptibility to stem rust, which was established during the study of the collection material in 2007–2008. The resistance of Ershovskaya 33 to diseases, as well as the ability to form yields stably over the years has been noted in a number of studies [13, 14].

Subsequently, partial fulfillment of the straw of this variety was found [15], which allows it to form a dense stalk against the background of damage to soft wheat by the wheat sawfly-borer.

Beginning from 2007 in the Altai Territory, the spread and pest rate of wheat sawfly-borer¹⁰ has been gradually increasing. Semi-intensive middle-early variety Omskaya 36 (Lutescens 150-86-10/Runar)¹¹, which has increased drought tolerance, resistance to the local population of dusty head, coarse grain size and active tillering and is widespread in Siberia, was used as a male component in the crossing. Participation in hybridization of a variety adapted to regional conditions, as a rule, increases the probability of selection of the recombinants with high and stable yield in local conditions¹².

Hybridization of the original parent forms was carried out in 2009 with subsequent reproduction of the first-generation seeds (2010)

⁷Geshele E.E. Fundamentals of phytopathologic evaluation in plant breeding. Moscow: Kolos, 1978, 204 p.

⁸Krivchenko V.I. Resistance of grain spikelets to pathogens of cereal diseases, Moscow: Kolos, 1984, 304 p.

⁹Nettevich E.D., Morgunov A.I., Maksimenko M.I. Increasing the efficiency of selection of spring wheat for stability of yield and grain quality // Vestnik of the Russian Agricultural Science, 1985, N 1 (340), pp. 66–73.

¹⁰Stetsov G. Ya., Dolmatova L.S. Biology and harmfulness of stem bread sawfly in the conditions of the Priobie region of the Altai Territory // Bulletin of Altai State Agricultural University, 2013, N 5 (103), pp. 63–66.

¹¹State Register of Protected Breeding Achievements. <https://gossortrf.ru/registry/>.

¹²Davydova N.V., Kazachenko A.O. Features of selection of source material for selection of spring soft wheat in the conditions of the Central Non-Black Earth Region // Bulletin of Altai State Agricultural University, 2013, N 5 (103), pp. 5–9.

and sowing of the second-generation hybrid population in the field in 2011, where the first individual selection of 100 initial spikes was carried out. The large-seeded progeny of this selection was sown successively in the breeding nurseries of the first and second years of the study. In the most productive F4 families of the breeding nursery of the second year, a repeated individual selection by ear was carried out. A middle-early line *Lutescens* 1134, possessing a complex of positive traits of adaptability to limiting environmental factors, was isolated from the obtained progeny at successive stages of the breeding process. This line was comprehensively studied in a competitive variety trial (2017–2020) in comparison with the standard and subsequently transferred to the SVT as a new variety Speaker.

The Speaker variety belongs to the *Lutescens* type and is characterized by the following morphological features of the plant, grain and spikelet. The spikelet is white, plain, awnless with short awn-like shoots, of medium length (6–7 cm) and density, waxy, pyramidal. The glume is medium in size, elongated, with a short, slightly curved notch and a narrow, raised shoulder. The granule is large, semi-long, red. Coleoptile uncolored, the bush is semi-erect. The straw has medium plumpness, 85–90 cm long with a strong waxy patina on the upper internode. The flag leaf is medium long, slanted, with waxy patina.

In terms of the development rhythm, the new variety differs somewhat from the standard *Altayskaya* 70. It is characterized by a longer tillering phase, as well as a slower process of grain ripening, which is probably due to the coarse grain size. On average during the years of competitive study the variety ripened 2 days later than the standard (see Table 1). Under field conditions, Speaker is not affected by loose smut, has good straw strength and the plant stand resistance to lodging at the level of the standard, which provides the possibility of seed production of the new variety without seed dressing in a wide range of agroecological conditions.

The level of grain productivity of the new variety was evaluated in comparison with the standard and the most productive middle-early variety *Omskaya* 36 released in the Altai Territory. The average yield of the varieties in the years of testing ranged widely from 2.32 to 4.81 t/ha, which allowed to differentiate the genotypes not only by average productivity, but also its stability in a number of years. The variety Speaker in all the years of testing significantly exceeded the best released variety *Omskaya* 36 in grain yield, as well as the standard, except for 2018 with a positive gain within the LSD (see Table 2). On average, a statistically significant gain to the variety *Altayskaya* 70 was 0.67 t/ha (21.4%), to *Omskaya* 36 0.60 t/ha (18.8%). The new variety is characterized by a significantly lower variation of productivity depending on

Табл. 1. Биологические особенности сорта мягкой яровой пшеницы Спикер (2017–2020 гг.)
Table 1. Biological features of spring soft wheat cultivar Speaker (2017–2020)

Variety	Interphase period, days					Resistance	
	Sprouting – tillering	Tillering – booting	Booting – earing	Sprouting – earing	Sprouting – ripening	to loose smut, %	to lodging, score
Speaker	11	11	18	40	79	0	4,2
Altayskaya 70 (standard)	11	10	18	39	77	0	4,2
Omskaya 36	11	11	19	41	80	0	3,6
± to the standard	0	+1	0	+1	+2	–	0

the vegetation conditions ($CV = 27.9\%$), forming the highest yield both in unfavorable conditions (2020) and on the background of good moisture availability in 2018. Relative stability of yield and additions to the standard in different growing conditions is one of the important indicators of good adaptability of the variety [16]. It should be noted that Speaker formed the maximum yield increase to the control varieties (1.05–1.17 t/ha, 45-53%) in 2018 against the background of intensive damage of susceptible varieties by brown and stem rusts.

The results of the evaluation of structural yield traits of the new variety are shown in Table 3, from which it follows that Speaker surpassed the standard by an average of 23 plants/m², grain weight per plant by 0.13 g, grain weight per tillering shoot by 0.16 g, but was inferior to Altayskaya 70 in grain weight per main ear and its earliness. The new variety formed a larger grain (+2.0 g), exceeded the standard on the harvest index at lower plant height. The contribution of the resulting trait “plant grain weight” to the yield increase amounted to 0.42 t/ha (0.13 g × 319 pieces/m² = 42.0 g/m²), or 62.7%. Due to the advantage in the density of productive plant stand by the time of harvesting, 0.22 tons of additional grain per hectare (0.98 g × 23 pcs/m² = 22.0 g/m²) was formed, or 32.8% of the total gain. The rest of the yield gain of the new variety (0.03 t/ha) is due to the joint contribution of the two resulting traits (0.13 g × 23 units/m² = 3.0 g/m²). Thus, the leading trait of the yield structure of the new variety, which gives it an advantage over the standard, is a higher grain

weight per plant due to better development of an additional shoot (see Table 3).

The response of the new variety to different agro-ecological conditions was evaluated in three locations in the Siberian region in 2019, 2020. The yield of the Speaker variety was higher than the standard varieties by 0.37–3.01 t/ha at all locations of the ecological trial, indicating its pronounced ecological plasticity (see Table 4). On average, the yield of the new variety was 4.94 t/ha with an increase of 1.48 t/ha compared to the standard variety (30,0%).

Analysis of grain quality parameters showed the advantage of the new variety in comparison with Altayskaya 70 in grain size, grain nature, valorimetric evaluation and volume of bread baked from 100 g of flour (see Table 5).

In terms of protein content, gluten content in the grain and overall baking evaluation Speaker is at the level of the standard, inferior to it in terms of flour strength and gluten elasticity (Fiber Deformation Measurement – FDM). According to the complex of grain quality indicators, the new variety meets the requirements for valuable wheat.

The Speaker variety, as shown by the assessments of fungal diseases in natural field conditions and on the background of artificial infection, is immune to loose smut, which allows the production of original and elite seeds without additional costs for fungicide treatment of the seed material (see Table 6). Against the natural background of leaf disease development, the new variety showed immunity to powdery mildew with strong lesion of the standard in 2019,

Табл. 2. Урожайность сорта мягкой яровой пшеницы Спикер
Table 2. Yield of spring soft wheat cultivar Speaker

Variety	Yield, t/ha					± to the varieties		Coefficient of variation, %
	2017	2018	2019	2020	average	t/ha	%	
Speaker	3,37	5,08	4,14	2,60	3,80	–	–	27,9
Altayskaya 70 (standard)	2,20	4,88	3,38	2,06	3,13	+0,67	21,4	41,8
Omskaya 36	2,32	4,63	3,56	2,30	3,20	+0,60	18,8	35,0
Average	2,63	4,81	3,69	2,32	–	–	–	–
LSD ₀₅	0,28	0,38	0,32	0,26	–	0,33	–	–

Табл. 3. Элементы структуры урожая сорта Спикер (2017–2020 гг.)**Table 3.** Elements of the Speaker variety yield structure (2017–2020)

Variety	Number of plants, pcs./m ²	Productive bushiness	Grain weight, g			Number of ear grains	Weight of 1000 grains, g	Harvest index, %	Plant height, cm
			plant	main ear	tillering shoot				
Speaker	342	1,43	1,11	0,86	0,25	23,1	37,1	36,2	89,7
Altayskaya 70 (standard)	319	1,17	0,98	0,89	0,09	24,9	35,1	35,2	97,7
Omskaya 36	315	1,38	1,03	0,86	0,17	21,8	39,5	35,4	98,3
± to the standard	+23	+0,26	+0,13	–0,03	+0,16	–1,8	+2,0	+1,0	–8,0

Табл. 4. Урожайность сорта Спикер в экологическом испытании (2019, 2020 гг.)**Table 4.** Yield of the Speaker variety in an ecological trial (2019, 2020)

Testing station	Variety	Yield, t/ha	± to the standard, t/ha
Omsky ASC	Speaker	5,86	+3,01
	Omskaya 36 (standard)	2,85	–
Uyarsky SCTS, Krasnoyarsk Territory	Speaker	5,07	+0,37
	Novosibirskaya 49 (standard)	4,70	–
Barnaulsky SCTS	Speaker	3,90	+1,05
	Altayskaya 70 (standard)	2,85	–
Average across the testing stations	Speaker	4,94	+1,48

Табл. 5. Показатели качества зерна сорта Спикер (2017–2019 гг.)**Table 5.** Grain quality indicators of the Speaker variety (2017–2019)

Variety	Weight of 1000, g	Nature, g/l	Protein, %	Gluten, %	FDM	Flour strength, e.a.	Valorimeter, %	Volume of bread, ml	Bread grade, score
Speaker	42,7	786	13,4	27,1	80	315	55	651	4,4
Altayskaya 70 (standard)	37,1	748	13,5	27,0	67	385	51	617	4,4
Omskaya 36	43,4	753	12,6	26,3	78	321	58	646	4,5
± to the standard	+5,6	+38	–0,1	+0,1	+13	–70	4	+34	0,0

weak susceptibility to brown rust and medium susceptibility to stem rust with very high susceptibility to rust fungi of the Altayskaya 70 in 2017 and 2018. The results of field evaluations allow characterizing the new variety as weakly susceptible to a complex of wheat diseases widespread in the Altai Territory.

The Speaker variety was in the State variety trial at the State Variety Testing Center of the West Siberian region from 2021 to 2022. Based on the positive results of the trial, the variety was included in the State Register of Breeding Achievements admitted to use since 2023 (patent № 13021 from 15.03.2023). Currently,

Табл. 6. Степень поражения болезнями сорта Спикер (2017–2019 гг.), %
Table 6. Disease infestation rate of the Speaker variety (2017–2019), %

Year	Natural background				Artificial background
	Powdery mildew	Brown rust	Stem rust	Loose smut	Loose smut *
<i>Speaker</i>					
2017	0	0	40	0	0
2018	0	10	10	0	0
2019	0	0	0	0	0
Average	0	3	17	0	0
<i>Altayskaya 70 (standard)</i>					
2017	20	10	80	0	4,0
2018	0	80	40	0	0,7
2019	60	10	0	0,01	4,0
Average	27	33	40	0,003	2,9
± to the standard	–27	–30	–23	–0,003	–2,9
<i>Altayskaya 50 (indicator)</i>					
Average	26	53	47	0,02	25,6

* Artificial infestation.

FASCA has organized production of commercial batches of original and elite seeds of the new variety.

CONCLUSIONS

1. As a result of intervarietal hybridization (Ershovskaya 33/Omskaya 36) followed by two-fold individual selection in split generations for early maturity, yield and resistance to limiting environmental factors, the breeding line Lyutescens 1134 was isolated. After many years of evaluation in competitive and ecological variety trials, the promising number Lutescens 1134 was transferred to the State Variety Trial as a new variety Speaker.
2. Speaker belongs to the middle-early group of varieties with a vegetation period of 79 days. It matures on average 2 days later than the standard Altayskaya 70 as a result of longer periods of tillering - booting and earing - ripening. During the vegetation process it forms medium-sized pyramidal awnless plain spikelets of white color and large red grain, which defines its variety as lutescens. The variety is medium-grown, has a sufficiently strong, par-

- tially executed straw with resistance to lodging at the level of the standard.
3. The new variety on average for 4 years of competitive variety testing significantly exceeded the yield of the standard Altayskaya 70 by 0.67 t/ha (21.4%) and the best released variety Omskaya 36 by 0.60 t/ha (18.8%). High ecological plasticity of Speaker is confirmed by the relative stability of yields over the years of research in the Altai Selection Center, as well as by the results of testing in various locations in the Siberian region, where the average gain to standard varieties was 1.48 t/ha (30%). As a result of the yield structure analysis, it was found that the advantage in grain productivity of the new variety is formed due to better preservation of plants for harvesting (+0.42 t/ha, or 62.7% of the total increase) and higher grain weight per plant due to better developed tillering shoots (+0.22 t/ha, 32.8% of the total increase).
4. By a complex of grain quality attributes Speaker meets the requirements for valuable wheat, while surpassing the standard for the weight of 1000 grains and its nature, as well as for the valorimetric evaluation of dough and the volume of bread baked from 100 g of flour. The

variety is inferior to the standard in gluten elasticity and flour strength.

5. The new variety is immune to local populations of the pathogenic fungi of powdery mildew and loose smut, slightly susceptible to brown rust and moderately susceptible to stem rust. On the background of intensive manifestation of leaf rust diseases (rust), the variety exceeds the yield of susceptible control varieties by 45–53%.

6. According to the results of the State variety testing for economic suitability and identification by distinctive features, the variety Speaker was recognized as an original breeding achievement (patent No. 13021) and recommended for production use in the West Siberian region. The patentee organized production of original and elite seeds of the new variety.

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ИНФОРМАЦИЯ ОБ АВТОРАХ

✉ **Коробейников Н.И.**, кандидат биологических наук, ведущий научный сотрудник; **адрес для переписки:** Россия, 656910, Алтайский край, Барнаул, п. Научный городок, 35; e-mail: nikkor733@gmail.ru

Валекжанин В.С., кандидат сельскохозяйственных наук, ведущий научный сотрудник

AUTHOR INFORMATION

✉ **Nikolay I. Korobeinikov**, Candidate of Science in Biology, Lead Researcher; **address:** 35, Nauchny Gorodok, Barnaul, Altai Territory, 656910, Russia; e-mail: nikkor733@gmail.ru

Vitaly S. Valekzhanin, Candidate of Science in Agriculture, Lead Researcher

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Оценка новых сортов и перспективных линий ярового ячменя по содержанию белка и лизина в конкурсном сортоиспытании

✉ Никонорова Ю.Ю., Косых Л.А., Столпивская Е.В., Шиповалова А.В., Ермилина Н.Н.

Самарский федеральный исследовательский центр

Российской академии наук

Самарская область, г. Кинель, Россия

✉ e-mail: yuliya_zinkova12@mail.ru

В статье изложены результаты анализа биохимического состава выделенных в конкурсном сортоиспытании новых сортов и перспективных линий ярового ячменя, исследованных на опытном поле Поволжского научно-исследовательского института селекции и семеноводства им. П.Н. Константинова в 2020–2022 гг. В результате исследования была выделена группа высокоурожайных и высокобелковых ячменей с улучшенной кормовой ценностью: три сорта, один из которых находится на государственном сортоиспытании, и четыре перспективные линии. Размах варьирования содержания белка в зерне у этих сортов и линий составил от 11,2 до 13,5%, лизина – от 0,3 до 0,4%, массы 1000 зерен – от 39 до 47 г. В условиях лесостепной зоны Среднего Поволжья в засушливые годы сорта и перспективные линии ячменя имели максимальные показатели белка (14,1%) и незаменимой аминокислоты лизина (0,4%). По полученным данным, наибольшее содержание белка отмечено у перспективной линии Субмедикум 2338/01: в среднем 13,5%, прибавка 11% по отношению к стандартному сорту Беркут. Самый максимальный сбор белка в среднем за годы исследований составил 4,4 ц/га, лизина – 0,12 ц/га при средней урожайности 34,0 ц/га. Перечисленные показатели зафиксированы у нового сорта Поволжский приз. Перспективная линия Нутанс 2294/01 оказалась более продуктивной по урожайности (35,5 ц/га), но уступила новому сорту по содержанию белка и лизина в зерне, хотя превысила стандарт по сбору белка с 1 га на 19%, лизина – на 20%. При оценке показателей натуре и массы 1000 зерен у изучаемых образцов выделились новый сорт Поволжский янтарь и перспективная линия Субмедикум 2352/06: у них средняя за годы изучения натура составила 669 и 666 г/л соответственно при массе 1000 зерен 46–47 г. Выделенные линии и новые сорта независимо от погодных условий смогли обеспечить получение высокобелкового зерна на кормовые цели, сохраняя при этом хорошую урожайность.

Ключевые слова: селекция, яровой ячмень, сорт, белок, лизин, качество зерна, урожайность

Evaluation of the new varieties and promising lines of spring barley for protein and lysine content in competitive variety trials

✉ Nikonorova Yu.Yu., Kosykh L.A., Stolpivskaya E.V., Shipovalova A.V., Ermilina N.N.

Samara Federal Research Scientific Center of the Russian Academy of Sciences

Kinzel, Samara region, Russia

✉ e-mail: yuliya_zinkova12@mail.ru

The article presents the results of the analysis of biochemical composition of new varieties and promising lines of spring barley isolated in the competitive variety trial, studied in the experimental field of the Povolzhsky Scientific Research Institute of Selection and Seed Growing named after P.N. Konstantinov in 2020–2022. As a result of the study, a group of high-yielding and high-protein barley with improved fodder value was identified: three varieties, one of which is on the State Variety Trial, and four promising lines. The range of variation of the protein content in grain in these varieties and lines was from 11.2 to 13.5%, lysine – from 0.3 to 0.4%, weight of 1000 grains – from 39 to 47 g. In the conditions of the forest-steppe zone of the Middle Volga region in dry years, barley varieties and promising lines had the maximum indices of protein (14.1%) and essential amino acid lysine (0.4%). According to the data obtained, the highest protein content was observed in the promising line Submedicum 2338/01: an average of 13.5%, an increase of 11% in relation to the standard variety Berkut. The maximum protein harvest averaged 4.4 c/ha, lysine – 0.12 c/ha with an average yield of 34.0 c/ha. The above-mentioned indicators were recorded in the new variety Povolzhsky Priz. The promising

line Nutans 2294/01 was more productive in terms of yield (35.5 c/ha), but was inferior to the new variety in terms of protein and lysine content in grain, although it exceeded the standard in terms of protein yield per 1 ha by 19%, lysine – by 20%. When evaluating the parameters of the natural weight and 1000 grain weight in the studied samples, the new variety Povolzhsky Yantar and the promising line Submedicum 2352/06 stood out: their average natural weight over the years of study amounted to 669 and 666 g/l, respectively, with the weight of 1000 grains 46–47 g. The selected lines and new varieties, regardless of weather conditions, were able to provide high-protein grain for fodder purposes, while maintaining good yields.

Keywords: breeding, spring barley, variety, protein, lysine, grain quality, yield

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Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Barley as a grain-forage crop is important in meeting the needs of livestock in vegetable protein. Fodder merits of barley depend on the content of protein in its grain. The value of the latter is determined by the amino acid composition, primarily by the presence of essential amino acids, among which the leading importance belongs to lysine and methionine. In this regard, breeding to increase the quantity and improve the quality of plant products is becoming an increasingly important direction [1].

The main component of energy nutrition of feed grain is the increased content of protein and essential amino acids. Barley surpasses other grains in the composition of essential amino acids, particularly in terms of lysine content barley mixed feed is indispensable for pigs and other monogastric animals [2].

It is established that any drought (air or soil) promotes protein accumulation in barley grain, and as a result it reduces starch and extractive

substances in it. In the conditions of the Middle Volga region forest-steppe zone, the highest level of protein was observed in dry and very dry years [3].

High-protein and high-lysine forms used for grain production should be characterized by a number of useful properties, primarily high yield, resistance to lodging and diseases [4].

With the help of system selection for ecological plasticity, use of the newest, most productive forms and sources with high protein content in crossing, application of new breeding methods, we have created promising barley varieties with high bioenergetic value for fodder purposes¹. Unlike foreign analogs, domestic forage varieties are more competitive and widely demanded in different regions of our country².

The purpose of the research is to study the biochemical parameters of varieties and promising lines of competitive variety trials to isolate yielding and high-protein barley with improved fodder value in comparison with the standard variety.

¹Khokonova M.B., Karashaeva A.S., Zavalin A.A. Quality of brewing malt depending on the storage conditions of barley // Russian Agricultural Sciences, 2015, vol. 41, N 6, pp. 508–511.

²Zemlyankina Yu.N., Stolpivskaya E.V., Shipovalova A.V. Study of the source material of spring barley in the breeding process // International Journal of Humanities and Natural Sciences, 2017, N 11, pp. 75–77.

MATERIAL AND METHODS

The experimental part of the work was carried out in 2020-2022 on the experimental fields of the Povolzhsky Scientific Research Institute of Selection and Seed Growing named after P.N. Konstantinov located in the forest-steppe zone of the Kinel'sky district of the Samara region. Agrotechnical measures were carried out according to the generally accepted technology for the forest-steppe zone of the Middle Volga region. Sowing of spring barley was carried out by a selective seeder SNTS 10 in a row method with row spacing of 15 cm in optimal terms. Seeding rate was 4.5 million germinating grains/ha. The forecrop used was spring wheat. The accounting area of the plot was 25 m² with four-fold repetition of the experiment. The plots were harvested at the phase of full ripeness by a SAMPO 130 combine harvester.

The soil of the experimental plot is typical low-humus (5–6% on average) medium light clayey chernozem. The nutrient elements content in the soil was as follows: mobile phosphorus 61.4–77.0 mg/kg (average), exchangeable potassium 374.0–423.0 mg/kg (very high), easily hydrolysable nitrogen 28.5–49.4 mg/kg (low and average). According to the degree of acidity, the soil of the experimental plot was slightly acidic (pH = 5.4).

The objects of research were the varieties and promising lines of spring barley: new variety Povolzhsky Yantar, included in the State Register of Breeding Achievements, approved for use in 2023; Povolzhsky Priz - a new variety, submitted for variety testing in 2022, as well as four promising lines obtained as a result of intraspecific hybridization using the varieties of local and foreign breeding. Of the 44 varieties that participated in the competitive variety trial, these varieties showed a reliable increase in relation to the standard.

Berkut (Tselinniy 5 × Donetsk 40) × (Donetsk 4 × Donetsk 8), variety – submedicum, was used as a standard. The variety is released in the Middle Volga (7) and Lower Volga (8)

regions of the Russian Federation. It is characterized as medium-maturing, drought-resistant, susceptible to loose smut. Due to its large grain, it is used not only for fodder purposes, but also in the cereal industry [5].

Biochemical indicators of barley grain quality were determined by infrared spectroscopy on the device “InfraLUM FT-12”. The study of physical and chemical properties of the breeding material was carried out in accordance with the normative and technical documents³.

Mathematical processing of the data was carried out using the computer program “Microsoft Office Excel” according to the field experiment methodology⁴.

RESULTS AND DISCUSSION

Meteorological conditions, which differed during the growing season 2020-2022, contributed to a versatile evaluation of the breeding material. This allowed giving a more objective assessment of new spring barley lines based on the prevailing environmental conditions (see Table 1).

The growing season 2020 was characterized by dry and hot weather in general. If considering weather conditions by phases of barley plant development, it should be noted that the phase of sprouting – tillering took place in favorable conditions in terms of moisture. The air temperature at this time was 2.6 °C lower than the average annual values. The weather was dry and hot during the earing-ripening period (HTC = 0,11).

In 2021, the growing season was relatively wet and hot. The average air temperature was 23.3°C, which is 5.6°C above the long-term average. Precipitation was 103 mm (4% more than the average annual values). The period from sowing to tillering (18 days) was characterized by a lack of moisture: the amount of precipitation was 2.8 mm, which is 6.5 times lower than the long-term average. From tillering to maturity (53 days) 100.2 mm of precipitation occurred, which created optimal conditions for the full development of barley plants.

³Kilchevsky A.V., Khotyleva L.V. Method for assessing the adaptive capacity and stability of genotypes and differentiation capacity of the environment. Message 1 // Genetics, 1985, vol. 21, N 9. pp. 1481–1489.

⁴Methodology of state varietal testing of agricultural crops. Moscow, 2019, Issue 1: General part, 384 p.

Табл. 1. Метеоданные за вегетационный период 2020–2022 гг. (п.г.т. Усть-Кинельский, Самарский государственный аграрный университет)

Table 1. Meteodata for the vegetation periods 2020–2022 (Ust-Kinelsky settlement, Samara State Agrarian University)

Development phase	Indicator	2020	2021	2022	Average annual value
Sowing – sprouting	Precipitation, mm	4,9	0,0	16,4	8,2
	Average air temperature, °C	16,8	22,8	13,7	12,5
	HTC	0,36	0,0	1,50	
Sprouting – tillering	Precipitation, mm	12,9	2,8	42,6	9,9
	Average air temperature, °C	11,5	23,6	18,0	14,1
	HTC	0,61	0,12	2,63	
Tillering – earing	Precipitation, mm	49,5	83,8	15,2	39,1
	Average air temperature, °C	18,6	21,2	20,0	17,3
	HTC	0,78	1,36	0,29	
Earing – ripening	Precipitation, mm	9,2	16,4	13,8	45,3
	Average air temperature, °C	22,7	25,4	23,4	20,2
	HTC	0,11	0,23	0,18	
For the entire vegetation period	Precipitation, mm	69,4	103,0	71,6	99,0
	Average air temperature, °C	19,8	23,3	21,0	17,7
	HTC	0,41	0,68	0,50	
Environmental conditions index		+0,40	–0,42	+0,02	

The growing season 2022 was characterized by generally dry and hot weather conditions. During the growing season 71.6 mm of precipitation was recorded (72.3% of mean annual values). The air temperature during the growing season of barley amounted to 21.0 °C, which is 3.3 °C higher than the average annual values. The hydrothermal coefficient in the reporting year for the entire growing season amounted to 0.5 (which corresponds to dry weather). The distribution of precipitation was uneven across barley development phases. The sowing – sprouting phase (8 days) was favorable for grain germination and getting early sprouts. HTC during this period was 1.5, which corresponds to moderate moisture content. Sprouting – tillering phase (10 days) was excessively moistened (HTC = 2.6). The other periods of barley growth and development were under moisture deficiency and increased temperature regime. According to the

HTC value for the vegetation period, very dry conditions prevailed in the years of the experiments (HTC < 0,7) (see Table 1).

The variety yield is one of the main parameters determining its potential and value for production [6].

In 2020 yields ranged from 36.1 to 40.0 c/ha with 35.7 c/ha of the standard variety Berkut. Indicators of the standard significantly exceeded the six studied varieties and lines with a gain of 0.4 and 4.3 c/ha. The highest yield was observed in the line Submedicum 2352/06 – 40.0 kg / ha (see Table 2).

In 2021, the minimum yield (28.2 c/ha) was recorded in two lines – Submedicum 2338/01 and Submedicum 2352/06. The highest yield was recorded in the promising line Nutans 2294/01 – 37.9 c/ha with the standard yield of 27.9 c/ha. All varieties and lines significantly exceeded the

Табл. 2. Урожайность ярового ячменя в конкурсном сортоиспытании
Table 2. Spring barley yield in competitive variety trials

Variety, line	Yield, c/ha			Average yield over the years of the study, c/ha	Deviation from the standard, c/ha
	2020	2021	2022		
Berkut (standard)	35,7	27,9	28,7	30,8	—
Povolzhsky Yantar	37,8	32,4	30,7	33,6	2,8
Povolzhsky Priz	38,4	30,7	33,0	34,0	3,2
Nutans 2294/01	36,1	37,9	32,6	35,5	4,7
Nutans 2200/04	39,2	30,2	31,3	33,6	2,8
Submedicum 2338/01	39,2	28,2	30,2	32,5	1,7
Submedicum 2352/06	40,0	28,2	31,7	33,4	2,6
Average	38,0	30,7	31,1	—	—
LSD ₀₅ , c/ha	1,3	1,1	1,4	1,6	—

standard in yield with an increase from 0.3 to 10.0 c/ha.

In 2022, high yield was shown by the variety Volga Priz (33.0 c/ha) and the line Nutans 2294/01 (32.6 c/ha), significantly exceeding the yield of the variety Berkut by 4.3 and 3.9 c/ha, respectively. It should be noted that over the years of research stable yield was observed in the promising line Nutans 2294/01 – 35.5 c/ ha, which is 4.7 c/ha more than the standard (30.8 c/ha).

Calculation of the index of environmental conditions by years showed that of the three years of study 2020 was the most favorable for the growth and development of barley, which had an index of environmental conditions of +0.40. The average yield of the varieties for 2020 was 38.0 kg/ha. In unfavorable 2021 with an index of environmental conditions of -0.42, the average yield of the varieties reached 30.7 kg/ha (see Table 2).

The new varieties and promising lines studied in the experiment have relatively high and stable yields over the years compared to the standard.

As a result of the research conducted in different moisture availability years, a group of high-yielding and high-protein barley varieties was identified among the numbers of competitive variety trials (see Table 3).

Proteins play a crucial role in all life processes of plant cells and the whole organism. Proteins have a complex chemical composition. Their main chemical components are amino acids.

Numerous data indicate a significant influence of the weather conditions on the quality of spring barley grain. It is established that any

Табл. 3. Показатели качества зерна сортов и линий ярового ячменя
Table 3. Grain quality indicators of spring barley varieties and lines

Variety, line	Protein content, %			Lysine content, %		
	2020	2021	2022	2020	2021	2022
Berkut (standard)	12,12	13,04	11,14	0,29	0,35	0,32
Povolzhsky Yantar	12,84	12,14	11,97	0,33	0,30	0,32
Povolzhsky Priz	12,31	13,44	13,30	0,32	0,37	0,32
Nutans 2294/01	12,49	12,94	11,26	0,31	0,36	0,31
Nutans 2200/04	13,42	12,13	11,73	0,37	0,33	0,33
Submedicum 2338/01	12,73	14,08	13,63	0,35	0,39	0,35
Submedicum 2352/06	10,60	11,12	11,94	0,30	0,30	0,31
LSD ₀₅ , c/ha	0,19	0,22	0,16	0,03	0,03	0,03

drought (air or soil) contributes to protein accumulation and deterioration of the main chemical and technological indicators of grain quality. As a rule, in the conditions of the forest-steppe zone of the Middle Volga region, the highest protein level is observed in dry and very dry years [7].

In drought 2021, the protein and lysine contents were the highest. Thus, the protein content of the new variety Povolzhsky Priz and promising line Submedicum 2338/01 amounted to 13.44 and 14.08%, respectively, lysine – 0.37 and 0.39% (see Table 3).

Volume weight (nature) and mass of 1000 grains, characterizing grain coarseness, are the main indicators of grain quality as a raw material for the production of food products.

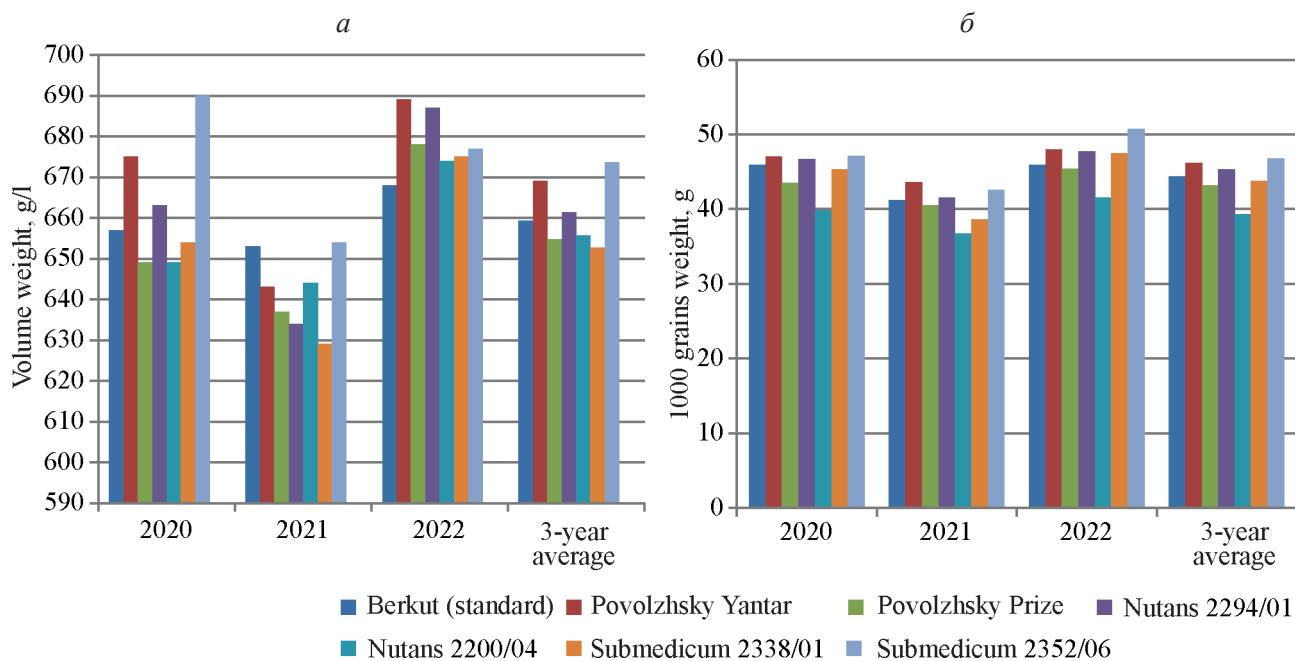
When evaluating grain that is more or less equalized in terms of moisture and weediness, its natural weight is a reliable indicator of barley quality and protein content. On the basis of the obtained data, it can be concluded that the greater the volume weight of the grain, the lower the percentage of protein content in it. In the new variety Povolzhsky Yantar and promising line Submedicum 2352/06 the average nature for the years of research amounted to 669 and 666 l/g, respectively, with protein content of 12.3 and

11.2% (see the figure). The maximum protein content for the years of study was observed in the promising line Submedicum 2338/01 – 13.48%, while the minimum volume weight was 653 l/g.

Due to the fact that nature cannot give a comprehensive idea of the physical quality of the grain under study, the mass of 1000 grains is also determined. This indicator is considered to be additional to the volumetric weight. Some specialists believe that the weight of 1000 grains is a more reliable measure of grain merit [8].

The chemical composition depends on the ratio of carbohydrates and proteins in the endosperm [9]. In addition, the ratio of germ and endosperm has a greater influence on the total chemical composition, which is determined mainly by the degree of grain plumpness during its filling. This caused some authors to argue that there is an inverse relationship between the weight of 1000 grains and the protein content [10, 11].

Our data show that the weight of 1000 grains in Nutans line 2200/04 for the years of study was the lowest among the studied samples and varied from 37 to 42 g with protein content from 13.4 to 11.7% (see the figure). The highest average for 2020–2022 was observed in line Submedicum



Объемный вес (а) и масса 1000 зерен (б) сортов и перспективных линий ярового ячменя
Volume weight (a) and 1000 grain weight (б) of the varieties and promising lines of spring barley

Табл. 4. Характеристика высокоурожайных сортов и линий ячменя, выделившихся по кормовым качествам (2020–2022 гг.)

Table 4. Characteristics of high-yielding barley varieties distinguished by fodder qualities (2020–2022)

Variety, line	Protein content, %	Protein yield, c/ha	Lysine content, %	Lysine yield, c/ha
Berkut (standard)	12,10	372,68	0,32	9,86
Povolzhsky Yantar	12,32	413,95	0,32	10,75
Povolzhsky Priz	13,02	442,68	0,34	11,56
Nutans 2294/01	12,23	434,17	0,32	11,36
Nutans 2200/04	12,43	417,65	0,34	11,42
Submedicum 2338/01	13,48	438,10	0,36	11,70
Submedicum 2352/06	11,22	374,75	0,30	10,02
LSD ₀₅	0,21	0,07	0,02	0,01

2352/06 (47 g) with the lowest protein content (11,2%).

In our experiments, the protein content in the grain of different varieties and promising lines of spring barley for the years of research on average varied from 11.2 to 13.0%, while lysine ranged from 0,3 to 0,4%.

According to the obtained data (see Table 4), the highest protein and lysine yield for the years of research was observed in the new variety Povolzhsky Priz – 442.7 and 11.6 c/ha with an average yield of 34.0 c/ha. The promising line Nutans 2294/01 was more productive in terms of yield (35.5 kg / ha), but was inferior to the new variety for protein and lysine content in the grain, although it exceeded the standard for protein and lysine collection by 17 and 15% per hectare.

CONCLUSION

Breeding to improve the quality of grain-forage barley should be aimed at optimizing the morphological parameters of the grain and increasing adaptability to soil and climatic stresses. Thus, the yield of the promising line Nutans 2294/01 averaged 35.5 c/ha for all the years of research, exceeding the indicators of all participating in the competitive variety trial, but was

inferior in terms of protein and lysine content in the grain, although it exceeded the indicators of the standard variety Berkut.

The grain of spring barley variety Povolzhsky Priz and the promising line Submedicum 2338/01 had the highest nutritive value: with yields of 34.0 and 32.5 c/ha, the protein collection amounted to 4.4 and 4.3 c/ha, essential amino acid lysine – 0.12 c/ha.

Thus, the selected lines and new varieties, regardless of weather conditions, were able to provide high-protein and high-lysine grain for fodder purposes, while maintaining crop yields.

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ИНФОРМАЦИЯ ОБ АВТОРАХ

✉ **Никонорова Ю.Ю.**, младший научный сотрудник; **адрес для переписки:** Россия, 446442, Самарская область, г. Кинель, ул. Шосейная, 76; e-mail: yuliya_zinkova12@mail.ru

Косых Л.А., кандидат сельскохозяйственных наук, ведущий научный сотрудник, ученый секретарь

Столпивская Е.В., научный сотрудник, заведующая лабораторией

Шиповалова А.В., младший научный сотрудник

Ермилина Н.Н., младший научный сотрудник

AUTHOR INFORMATION

✉ **Yulia Yu. Nikonorova**, Junior Researcher; **address:** 76, Shosseynaya St., Kinel, Samara Region, 446442, Russia; e-mail: yuliya_zinkova12@mail.ru

Larisa A. Kosykh, Candidate of Science in Agriculture, Lead Researcher, Scientific Secretary

Evgenia V. Stolpivskaya, Researcher, Laboratory Head

Anna V. Shipovalova, Junior Researcher

Natalia N. Ermilina, Junior Researcher

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Взаимосвязь между урожайностью и элементами ее структуры сортообразцов диплоидной и тетраплоидной озимой ржи в условиях Западно-Сибирского региона

✉ Ермошкина Н.Н.

*Сибирский научно-исследовательский институт растениеводства и селекции –
филиал Федерального исследовательского центра «Институт цитологии и генетики
Сибирского отделения Российской академии наук»
Новосибирская область, р.п. Краснообск, Россия
✉ e-mail: natali.erm@bk.ru*

Представлены результаты изучения корреляции между урожайностью и ее структурными элементами у сортообразцов диплоидной и тетраплоидной озимой ржи в условиях Западно-Сибирского региона. Исследования проведены в Новосибирской области с 2019 по 2021 г. Всего исследовано 28 сортообразцов диплоидной ($2n$) и тетраплоидной ($4n$) озимой ржи различного эколого-географического происхождения. В результате дисперсионного анализа данных определено достоверное ($p < 0,05$) влияние на урожайность озимой ржи условий выращивания (22,2%) и сортовых особенностей (31,8%), а также взаимодействия сорта с уровнем пloidности (18,2%). Более урожайным (626,3 г/м²) оказался набор сортообразцов тетраплоидной озимой ржи в сравнении с сортами диплоидной, который имел высокие показатели признаков. У сортов тетраплоидной ржи длина колоса составляла 12,0–13,3 см, масса 1000 зерен – 50,1–53,0 г, масса зерна с колоса – 2,18–2,79 г, с растения – 7,17–8,70 г. У набора сортообразцов диплоидной ржи урожайность была снижена (565,0 г/м²), при этом у них были более высокие показатели признаков структуры урожая: продуктивная кустистость – 3,8–4,3 шт., озерненность колоса – 81,1–89,1%, число зерен с колоса – 55,0–56,9 шт. С учетом всех перечисленных данных разнозначности структурных компонентов диплоидной и тетраплоидной ржи корреляционный анализ показал, что основной вклад в повышение урожайности в условиях Западно-Сибирского региона вносят продуктивная кустистость (r – от 0,59 до 0,78), число колосков в колосе (r – от 0,54 до 0,70) и масса зерна с растения ($r = 0,79$). В селекционной работе подбор родительских форм и отбор высокоурожайных образцов коллекции озимой ржи разного уровня пloidности необходимо вести по этим элементам продуктивности.

Ключевые слова: диплоидная рожь, тетраплоидная рожь, корреляция, признак, урожайность

Relationships between the yield and the elements of its structure of diploid and tetraploid winter rye varieties under the conditions of the West Siberian region

✉ Ermoshkina N.N.

*Siberian Research Institute of Plant Production and Breeding –
Branch of the Federal Research Center “Institute of Cytology and Genetics
of the Siberian Branch of the Russian Academy of Sciences”
Krasnoobsk, Novosibirsk region, Russia
✉ e-mail: natali.erm@bk.ru*

The results of studying the correlation between the yield and its structural elements in the varieties of diploid and tetraploid winter rye under the conditions of the West Siberian region are presented. The research was conducted in the Novosibirsk region from 2019 to 2021. A total of 28 varieties of diploid ($2n$) and tetraploid ($4n$) winter rye of different ecological and geographical origin were studied. As a result of the variance analysis of the data, a reliable ($p < 0.05$) effect of the growing conditions (22.2%) and varietal characteristics (31.8%), as well as the interaction between the variety and the ploidy level (18.2%) on winter rye yield was determined. A set of tetraploid winter rye varieties was more yielding (626.3 g/m²) in comparison with diploid varieties, which had high trait indices. In tetraploid rye varieties, ear length was 12.0–13.3 cm, 1000 grain weight was 50.1–53.0 g, grain weight

per ear was 2.18–2.79 g and per plant was 7.17–8.70 g. A set of diploid rye varieties had lower yields (565.0 g/m²), while they had higher yield structure traits: productive bushiness – 3.8–4.3 pieces, ear grain content – 81.1–89.1%, number of grains per ear – 55.0–56.9 pieces. Taking into account all the above-mentioned data of the diploid and tetraploid rye structural components diversity, correlation analysis showed that the main contribution to the increase in yield in the conditions of the West Siberian region is made by productive bushiness (r – from 0.59 to 0.78), number of spikelets per ear (r – from 0.54 to 0.70) and grain weight per plant ($r = 0.79$). In breeding work selection of seed parents and selection of high-yielding samples of winter rye collection of different ploidy levels should be carried out according to these elements of productivity.

Keywords: diploid rye, tetraploid rye, correlation, trait, yield

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Conflict of interest

The author declares no conflict of interest.

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INTRODUCTION

Winter rye is an important food crop in Russia, which has a high emergency potential. High winter hardiness and frost resistance of winter rye allow giving stability to gross yields of food grain in unfavorable years¹ [1, 2]. The main areas of winter rye cultivation remain moderately cold and low fertility areas, including Western Siberia with its sharply continental climate. In this region, diploid ($2n = 14$) and tetraploid ($4n = 28$) varieties and F_1 hybrids of winter rye are cultivated. The main share (more than 80%) of cultivated varieties (hybrids) is represented by tetraploid rye varieties, the share of diploid rye varieties and hybrids is less significant². According to long-term studies conducted at the

Siberian Research Institute of Plant Production and Breeding – branch of the Federal Research Center “Institute of Cytology and Genetics SB RAS” (SibNIIRS – branch of the Institute of Cytology and Genetics SB RAS) and at the Scientific and Practical Center of the National Academy of Sciences of Belarus on Agriculture, the average yield of diploid and tetraploid rye varieties is approximately at the same level³ [3]. A relevant issue is the comparative study of potential and real possibilities of diploid and tetraploid varieties of winter rye on the complex of economically valuable traits. It is known that the yield potential directly depends on the aggregate contribution of structural traits, such as the number of productive stems and ear produc-

¹Wieslaw P. Rye Genetic Resources in Europe // Plant Breeding and Seed Science, 2003, vol. 48 (2/2), pp. 37–44.

²Artemova G.V., Ponomarenko V.I., Stepanov P.I. Results and methods of adaptive breeding of winter crops in SibNIIRS // Gene pool and plant breeding: abstracts of II Intern. conf. dedicated to the 80th anniversary of SibNIIRS. Novosibirsk: ICIG, 2016, pp. 9–10.

³Artemova G.V., Gubarenko P.G. Breeding evaluation of diploid and tetraploid rye varieties under cultivation in the Siberian region // Adaptive systems of breeding and seed production: Collection of scientific works SB RAAS. Novosibirsk, 2008, pp. 12–17.

tivity⁴. In this regard, when working with the collection material of winter rye, it is necessary to study in detail the structural elements of winter rye collection material, which make up the yield, as well as the dependence of some traits on the others [4].

For this purpose, correlation analysis is used, which allows revealing more fully the potential of varietal features of formation of productivity elements in diploid and tetraploid winter rye under certain growing conditions and adjusting breeding work in accordance with the available source material [5, 6].

The purpose of the study was to investigate the correlations between the yield and its structural elements in varieties of diploid and tetraploid winter rye under the conditions of the West Siberian region.

MATERIAL AND METHODS

The studies were conducted in 2019-2021 at the experimental plot of SibNIIRS – branch of ICIG SB RAS. The soil of the experimental field is represented by leached medium semi-loam chernozem. The content of humus according to Tyurin is 4.2%, total nitrogen – 0.34%, mobile phosphorus and potassium according to Chirikov 29 and 13 mg/100 g of soil, respectively, pH_{water} = 6.7–6.8. The depth of arable

layer is 41–46 cm⁵. The forecrop was complete fallow. The plot area was 1 m², threefold repetition with a seeding rate of 300 germinated grains/m².

Sowing was carried out in optimal for the crop terms in the first ten-day period of September, harvesting was carried out in the beginning of the first ten-day period of August.

The study material was a collection of winter rye obtained from the All-Russian Institute of Plant Genetic Resources named after N.I. Vavilov and the National Research Center for Agriculture of the National Academy of Sciences of Belarus. A total of 28 varieties of winter rye of different ecological and geographical origin, among them 14 diploid and 14 tetraploid varieties of winter rye were studied (see Table 1). The diploid winter rye variety Korotkostebel'naya 69, registered in the State Register of Breeding Achievements and allowed for use in the West Siberian region, and the tetraploid variety Tetra Korotkaya were used as a standard.

According to the data of the GEM “Ogurtsovo”, agrometeorological conditions in 2019-2021 differed among themselves in temperature regime, amount, nature and frequency of precipitation during the spring-summer vegetation of plants, which contributed to an objective assessment of the studied collection samples of

Табл. 1. Изучаемые сортообразцы диплоидной и тетраплоидной озимой ржи

Table 1. Diploid and tetraploid winter rye varieties under study

Ploidy	Origin	Sample
Diploid rye	Russian Federation	Korotkostebel'naya 69, Sibirskaya 87, Chulpan, Pamyati Kunakbaeva, Sinilga, Alisa
	Republic of Belarus	Lota, Kalinka, Golubka, Vostok, Verdena, Talisman, Zubrovka, Yubileynaya
Tetraploid rye	Russian Federation	Tetra Korotkaya, Vlada, Sibir 4, Rokot 95
	Republic of Belarus	Igumenskaya Hl, Belaya Vezha, Plamya, Dubinskaya, Zazerskaya 3, P78, Polnovesnaya, Puhovchanka, Iskra, Igumenskaya 78, Druzhina

⁴Goncharenko A.A., Krahmalev S.V., Ermakov S.A. Genetic analysis of productivity traits of winter rye in diallel crosses // Bulletin of Saratov State Agrarian University named after N.I. Vavilov, 2012, N 10, pp. 25-29.

⁵Farming system of experimental-production farm “Elite” / Yu.I. Chulkin, I.A. Pugin. Novosibirsk: SB VASKHNIL, 1983, 36 p.

winter rye. To compare weather conditions from May to July in the years of study, the hydrothermal coefficient of Selyaninov was calculated⁶.

The growing season 2019 was characterized by insufficient moisture (HTC = 1.03). In May, there was an alternation of high (maximum – 28 °C) and low temperatures (minimum – 4.8 °C) with a deficit of precipitation (HTC = 0.94). Mean monthly air temperature in the summer period was close to the mean annual temperature: in June – 16.4 °C (deviation – 0.7 °C), in July – 19.2 °C (deviation – 0.2 °C). Precipitation was distributed unevenly: in June with very low moisture availability (HTC = 0.51), in July – with excessive moisture availability (HTC = 1.65).

The more favorable period is considered to be 2020 with optimal moistening (HTC = 1.24). The period from the beginning of spring tillering to earing was characterized by increased temperature (maximum – 34.0 °C) against the background of optimal moisture (HTC = 1.19). As a consequence, the date of flowering phase was shifted to early June (10 days earlier). The average monthly air temperature in the summer period was close to the mean annual temperature: in June – 16.6 °C (deviation – 0.5 °C), in July – 19.7 °C (deviation – 0.3 °C). As in 2019, uneven distribution of precipitation was recorded: in June there was very low moisture availability (HTC = 0.50), in July – excess moisture availability (HTC = 2.02).

The growing season 2021 was unfavorable for the development of winter rye. The hydrothermal regime in the spring-summer period was characterized by insufficient moisture (HTC = 0.88). In May, warm weather was observed (average daily air temperature was 14.3 °C, which is 2.4 °C above the mean annual value) with very low moisture availability (HTC = 0.57).

The average monthly air temperature during the summer period was close to the average for the year: in July – 19.7 °C (deviation – 0.2 °C), in June it was 1.4 °C colder (average daily air temperature was 16.2 °C). In June, excessive moistening was established (HTC = 1.51), which was replaced by moisture deficit in July (HTC = 0.57).

The study of the main elements of the productivity structure, which were evaluated by eight traits: productive bushiness, ear length and ear grain content, the number of spikelets and grains in the ear, grain weight per ear and per plant, the weight of 1000 grains. The yield records and analysis of the main economically valuable traits of the rye collection were carried out in accordance with the “Methodological guidelines for the study of the world rye collection” and “Methodology of state variety testing of agricultural crops”^{7, 8}.

Statistical processing of experimental data was performed according to the method using Snedecor V5⁹ program. Pearson's correlation coefficient (r) was used to identify the dependence between the studied features. To interpret the correlation coefficient the following scale was used: at $r < 0.30$ the strength of the relationship between the studied features is weak, at $r = 0.30-0.70$ – medium, at $r > 0.70$ – strong. The positive value of the correlation coefficient shows that with the increase in the values of one attribute the value of the second attribute increases, the negative value shows the opposite relationship between the features.

RESULTS AND DISCUSSION

According to the results of the analysis of variance, it was reliably ($p < 0.05$) found that the greatest contribution to the variability of the trait under consideration is made by chang-

⁶Zoidze E.K., Khomyakova T.V. Modeling of moisture availability formation on the territory of European Russia in modern conditions and the basis for assessment of agroclimatic security // *Meteorologiya i Gidrologiya*, 2006, N 2, pp. 98–105.

⁷Methodological guidelines for the study of the world rye collection. SPb.: VIR, 2015, 44 p.

⁸Methodology of the State Variety Testing of Agricultural Crops. Cereals, cereals, legumes, corn and fodder crops // edited by V.I. Golovachev, E.V. Kirilovskaya. Moscow: Kalinin regional printing house, 1989, Issue 2, 194 p.

⁹Dospekhov B.A. Methodology of field experiment; 4th ed., rev. and supplement. Moscow: Kolos, 1979, 416 p.

ing conditions of vegetation (share of influence 22.2%) and selection variability (share of influence 31.8%), the smallest – the level of ploidy of winter rye varieties studied (share of influence 4.8%). A reliable ($p < 0.05$) interaction of factors of year conditions with genotype (variety) and genotype (variety) with ploidy level (influence share 3.7 and 18.2%, respectively) was also revealed (see Table 2). Consequently, the yield is determined by the growing conditions, the potential of the variety and its ploidy level. In the years with optimal moisture (2019 and 2020), a high level of yield was observed for the whole set of winter rye samples: diploid – 572.6 g/m² (2019) and 610.4 g/m² (2020), tetraploid – 612.5 g/m² (2019) and 745.8 g/m² (2020). Under insufficient moisture in 2021, the lowest yield of varietal samples was formed in comparison with other years of the study. The

average yield for a set of varieties of diploid rye was 512.0 g/m², tetraploid – 520.6 g/m².

The yield of a set of tetraploid rye varieties exceeded the yield of diploid rye varieties in the years with optimal moisture by 6.5–18.2%, in the year with insufficient moisture by 1.7%. On average for 3 years of study samples of tetraploid rye formed a higher yield (626.3 g/m²) compared to varieties of diploid rye (565.0 g/m²). It was found that the limits of variation of yield variation by cultivars are higher in tetraploid rye than in diploid rye: from 485 (Druzhina) to 803.1 g/m² (Vlada), from 332.5 (Vostok) to 760.0 g/m² (Yubileinaya). Rye varieties Vlada (803.1 g/m²), Sibirskaia 87 (689.0) and Yubileynaya (706.0 g/m²) had high yield values in relation to the standard.

To determine the relationship between yield and elements of yield structure, correlation

Табл. 2. Урожайность зерна и величина элементов продуктивности сортообразцов диплоидной и тетраплоидной озимой ржи

Table 2. Grain yield and the value of productivity elements of diploid and tetraploid winter rye varieties

Indicator	2019	2020	2021	2019–2021
<i>Diploid rye</i>				
Yield, g/m ²	572,6 ± 53,2	610,4 ± 72,5	512,0 ± 51,0	565,0 ± 56,0
Productive bushiness, pcs.	3,9 ± 0,2	3,8 ± 0,3	4,3 ± 0,3	4,0 ± 0,2
Ear length, cm	11,3 ± 0,7	11,5 ± 0,6	11,2 ± 0,6	11,3 ± 0,6
Number of spikelets, pcs.	30,9 ± 1,3	30,9 ± 1,5	32,7 ± 1,1	31,5 ± 1,2
Number of grains per ear, pcs.	53,9 ± 3,0	55,0 ± 3,0	56,9 ± 2,2	55,3 ± 2,3
Ear grain content, %	89,1 ± 1,3	81,1 ± 2,7	88,3 ± 1,6	86,2 ± 1,1
Grain weight, g:				
per ear	2,25 ± 0,2	2,06 ± 0,1	2,02 ± 0,2	2,11 ± 0,2
per plant	7,04 ± 0,3	7,39 ± 0,9	7,10 ± 0,6	7,18 ± 0,4
Weight of 1000 grains, g	38,6 ± 2,6	35,6 ± 2,5	35,6 ± 2,5	36,0 ± 2,3
<i>Tetraploid rye</i>				
Yield, g/m ²	612,5 ± 83,6	745,8 ± 51,3	520,6 ± 62,1	626,3 ± 51,7
Productive bushiness, pcs.	3,0 ± 0,4	3,3 ± 0,2	3,5 ± 0,3	3,3 ± 0,2
Ear length, cm	13,3 ± 0,4	12,7 ± 0,6	12,0 ± 0,6	12,7 ± 0,5
Number of spikelets, pcs.	32,0 ± 0,9	31,2 ± 1,1	29,5 ± 1,1	30,9 ± 0,9
Number of grains per ear, pcs.	50,0 ± 1,7	51,4 ± 1,6	46,2 ± 1,9	49,2 ± 1,4
Ear grain content, %	82,8 ± 1,4	82,1 ± 2,0	77,7 ± 3,2	80,9 ± 1,7
Grain weight, g:				
per ear	2,79 ± 0,1	2,74 ± 0,1	2,18 ± 0,1	2,57 ± 0,1
per plant	7,57 ± 0,8	8,70 ± 0,6	7,17 ± 0,6	7,79 ± 0,4
Weight of 1000 grains, g	52,5 ± 2,0	53,0 ± 2,9	50,1 ± 1,8	51,8 ± 1,9

analysis was carried out, as a result of which the dependence of their variation on meteorological conditions and rye ploidy level was established (see Table 3).

Yield is greatly influenced by productive bushiness (r – from 0.33 to 0.86), which depends primarily on the genetic potential of rye varieties and moisture availability of the year [7]. In a set of diploid rye varieties, productive bushiness was higher and ranged from 3.8 to 4.3 plants. In tetraploid rye samples, productive bushiness was lower and amounted to 3.0–3.5 pieces. At low yield in 2021, high productive bushiness was observed in a set of varieties of diploid (4.3 pieces) and tetraploid (3.3 pieces) rye. At the same time, an average positive correlation between the traits was found ($r = 0.34$ and 0.33 for diploid and tetraploid varieties, respectively). In 2019 and 2020, a significant average correlation was found between the yield and the number of productive stems in a set of diploid rye varieties ($r = 0.60$ and 0.58 in 2019 and 2020, respectively). Productive bushiness ranged from 3.8 (2020) to 4.3 pieces (2021). For tetraploid rye varieties reliable correlation between the studied traits was established in 2019 ($r = 0.86$). In this case, the average value of productive bushiness was 3.3 pcs, yield – 612 g/m^2 .

During 3 years of study, the trait of productive bushiness with yield had reliable positive correlations in a set of varieties of diploid ($r = 0.78$) and tetraploid ($r = 0.59$) rye varieties.

Spikelet length is the most phenotypically stable element of productivity and depends on varietal characteristics¹⁰. It was revealed that a set of tetraploid varieties of rye has a longer ear (from 12.0 to 13.3 cm) than the diploid ones (from 11.2 to 11.5 cm). Spikelet length of diploid rye variety samples ranged from 11.2 to 11.5 cm and had a positive correlation coefficient ($r = 0.46$ to 0.57). Varieties of tetraploid rye form a longer ear (12.0–13.3 cm) and in the years of study had unstable correlation (r – from -0.17 to 0.54). Despite the different ear length in diploid and tetraploid rye varieties, the rye ear has low density (loose) – less than 32 spikelets per ear. In a set of diploid and tetraploid rye varieties, the number of spikelets in the ear was at the same level (from 29.5 to 32.7 pieces) with positive correlation coefficients (r – from 0.28 to 0.59). Over the years of research positive reliable correlation with the yield was revealed in a set of varieties of diploid ($r = 0.54$) and tetraploid ($r = 0.70$) rye.

Ear grain content is considered to be a complex element of yield structure, which is deter-

Табл. 3. Корреляционный анализ зависимости урожайности от элементов структуры продуктивности озимой ржи

Table 3. Correlation analysis of yield dependence on the elements of winter rye productivity structure

Indicator	Diploid rye (2n)				Tetraploid rye (4n)			
	2019	2020	2021	2019–2021	2019	2020	2021	2019–2021
Productive bushiness, pcs.	0,60*	0,58*	0,34	0,78*	0,86*	0,35	0,33	0,59*
Ear length, cm	0,57*	0,47	0,46	0,55*	-0,17	0,44	0,54*	0,56*
Number of spikelets, pcs.	0,44	0,46	0,59*	0,54*	0,59*	0,28	0,57*	0,70*
Ear grain content, %	-0,24	-0,11	0,11	-0,06	-0,13	0,11	0,00	-0,08
Number of grains per ear, pcs.	0,09	0,41	0,41	0,38	0,28	0,41	0,37	0,50
Grain weight, g:								
per ear	0,12	0,05	0,01	0,01	-0,41	0,01	0,09	-0,25
per plant	0,44	0,70*	0,27	0,79*	0,79*	0,71*	0,60*	0,79*
Weight of 1000 grains, g	0,12	-0,30	-0,34	-0,31	-0,33	-0,25	-0,41	-0,56*

* Correlation is significant at 5% significance level, where $r = 0,53$.

¹⁰Torop A.A., Kuzmenko S.A., Torop E.A. Changes in yield, its elements and morphobiological traits of winter rye in the process of selection // Achievements of science and technology of AIC, 2015, vol. 29, N 4, pp. 20–23.

mined by the number of spikelets and grains in the spikelet [8]. A set of diploid rye varieties had a high (86.2%) level of ear greenness. The number of spikelets in the ear amounted to 31.5 pieces, the number of grains – 55.3 pieces; in tetraploid rye varieties, the number of spikelets in the ear was 80.9 pieces, the number of spikelets – 30.9, the number of grains in the ear – 49.2 pieces. At the same time, the level of ear grain content in a set of diploid rye varieties was small (13.8%), in tetraploid varieties – average (19.1%). A weak non-significant correlation between the yield and ear grain content was found in the range of r from – 0.24 to 0.11 irrespective of the ploidy level of winter rye. Significant correlation between the number of grains per ear and the yield was not found for varieties of both ploidy levels.

The mass of 1000 grains characterizes the yield properties of seeds and refers to varietal traits [9]. In a set of diploid winter rye varieties, the weight of 1000 grains averaged 36.0 g with a variation from 35.6 to 38.6 g, in tetraploid rye varieties – 51.8 g with a variation from 50.1 to 53.0 g. It follows that the grain of tetraploid winter rye is larger compared to diploid rye. Significant correlation of the 1000 grain weight trait with yield in diploid and tetraploid winter rye varieties was not determined.

Grain weight per ear is a complex trait and depends on ear grain control and 1000 grain weight (see footnote 10). Varieties of tetraploid winter rye exceeded the samples of diploid rye by grain weight per ear (2.57 and 2.11 g, respectively). In all years of study, no reliable correlation was found in diploid and tetraploid winter rye varieties between yield and grain weight per ear (r from –0.25 to 0.12), as well as with such traits as ear grain control and 1000-grain weight.

Grain weight per plant is the most important trait of productivity. It is determined by the number of productive spikelets and their ear grain content, as well as by the weight of 1000 grains [10, 11]. Samples of tetraploid winter rye exceeded diploid varieties in grain weight per plant (7.79 and 7.18 g, respectively). The lev-

el of yield of diploid winter rye varieties was in strong positive dependence on grain weight per plant in 2020 ($r = 0.70$). In tetraploid rye in all years of study established a reliable correlation with the considered trait in 2019 ($r = 0.79$), 2020 ($r = 0.71$) and 2021 ($r = 0.60$).

During the study it was found that the main contribution to the increase in yield of diploid and tetraploid rye is made by productive bushiness (r – from 0.59 to 0.78), the number of spikelets in the ear (r – from 0.54 to 0.70) and grain weight per plant ($r = 0.79$). Unstable correlation between the yield and ear length was also revealed (r – from 0.55 to 0.56).

CONCLUSIONS

1. As a result of the data analysis of variance, a significant ($p < 0.05$) effect of growing conditions (22.2%) and varietal characteristics (31.8%), as well as the interaction of variety with ploidy level (18.2%) on winter rye yield was determined.

2. Varieties of tetraploid winter rye were more productive (626.3 g/m²), which also had high indices of ear length (12.0–13.3 cm), 1000 grain weight (50.1–53.0 g), grain weight per ear (2.18–2.79 g) and per plant (7.17–8.70 g). Diploid rye varieties had lower yields (565.0 g/m²). At the same time, they were characterized by higher indices of yield structure traits: productive bushiness (3.8–4.3 pieces), ear grain content (81.1–89.1%), number of grains per ear (55.0–56.9 pieces).

3. Taking into account all the above differences between diploid and tetraploid varieties on the value of structural components, correlation analysis showed that the main contribution to the increase in yield in the conditions of the West Siberian region make productive bushiness (r – from 0.59 to 0.78), the number of spikelets in the ear (r – from 0.54 to 0.70) and grain weight per plant ($r = 0.79$). In breeding work, selection of parental pairs and selection of high-yielding forms of winter rye should be carried out taking into account the value of these elements of productivity.

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ИНФОРМАЦИЯ ОБ АВТОРЕ

✉ Ермошкина Н.Н., научный сотрудник;
адрес для переписки: Россия, 630501, Новосибирская область, р.п. Краснообск, а/я 375; e-mail: natali.erm@bk.ru

AUTHOR INFORMATION

✉ Natalia N. Ermoshkina, Researcher;
address: PO Box 375, Krasnoobsk, Novosibirsk Region, 630501, Russia; e-mail: natali.erm@bk.ru

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Активность сорных растений в посевах полевых культур степной зоны Краснодарского края

✉ Лунева Н.Н., Закота Т.Ю.

Всероссийский научно-исследовательский институт защиты растений

Санкт-Петербург, Россия

✉ e-mail: natalja.luneva2010@yandex.ru

В агрофитоценозах полевых культур в западной части степной зоны Краснодарского края произрастают более 150 видов сорных растений, из которых лишь 38 проявляют себя активными в той или иной степени в ценофлоре агрофитоценозов. Выявлено, что наибольшую активность проявили 9 видов, показатели требовательности которых к фактору тепла (сумма активных температур выше $+5\text{ }^{\circ}\text{C} = 1366\text{--}3536$) были наиболее близки к показателям теплообеспеченности зоны обследования ($3400\text{--}3800\text{ }^{\circ}\text{C}$). Они засоряли посевы всех обследованных полевых культур (подсолнечника, кукурузы, пшеницы озимой, овса, сои, люцерны, картофеля): *Ambrosia artemisiifolia* L., *Convolvulus arvensis* L., *Cirsium setosum* (Willd.) Bess., *Amaranthus retroflexus* L., *Chenopodium album* L., *Echinochloa crusgalli* (L.) Beauv., *Abutilon theophrastii* Medik., *Persicaria maculosa* S.F. Gray, *Lactuca serriola* L. Менее активными были виды, пределы показателей оптимального уровня требовательности которых к фактору тепла (сумма активных температур выше $+5\text{ }^{\circ}\text{C} = 1152\text{--}2078$) были заметно ниже, чем у видов предыдущей группы: *Lactuca tatarica* (L.) C.A. Mey., *Descurainia sophia* (L.) Webb. ex Prantl, *Sinapis arvensis* L., *Amaranthus blitoides* S. Watson., *Taraxacum officinale* Wigg., *Portulaca oleraceae* L. Агрофитоценозы всех полевых культур включали еще 19 главным образом довольно- и малоактивных видов. Пределы показателей оптимальной требовательности этих видов к фактору тепла в зоне вредоносности (сумма активных температур выше $+5\text{ }^{\circ}\text{C} = 953\text{--}2107$) значительно ниже, чем у видов в первой и второй группах, и более значительно отличаются от показателей теплообеспеченности зоны обследования. Выявленное соотношение видов разной активности будет сохраняться при условии сохранения погодно-климатических условий в зоне исследования, а также при поддержании современного уровня технологии возделывания полевых культур, оно составит содержание многолетнего регионального прогноза, включая названные выше виды, которые будут наиболее активно оказывать вредоносное влияние на рост и развитие культурных растений.

Ключевые слова: активность видов, сорная флора, многолетний прогноз

Activity of weed plants in field crops in the steppe zone of the Krasnodar territory

✉ Luneva N.N., Zakota T.Yu.

All-Russian Institute of Plant Protection

Saint-Petersburg, Russia

✉ e-mail: natalja.luneva2010@yandex.ru

More than 150 species of weeds grow in agrophytocenoses of field crops in the western part of the steppe zone of the Krasnodar Territory, of which only 38 are active to one degree or another in the cenoflora of agrophytocenoses. It has been revealed that 9 species showed the greatest activity, the indicators of their demands on the heat factor (the sum of active temperatures above $+5\text{ }^{\circ}\text{C} = 1366\text{--}3536$) were closest to the indicators of heat supply in the survey area ($3400\text{--}3800\text{ }^{\circ}\text{C}$). They clogged the crops of all examined field crops (sunflower, corn, winter wheat, oats, soybeans, alfalfa, potatoes):

Ambrosia artemisiifolia L., *Convolvulus arvensis* L., *Cirsium setosum* (Willd.) Bess., *Amaranthus retroflexus* L., *Chenopodium album* L., *Echinochloa crusgalli* (L.) Beauv., *Abutilon theophrastii* Medik., *Persicaria maculosa* S.F. Gray, *Lactuca serriola* L. Less active were the species, which optimal level of requirement for heat factor (the sum of active temperatures above +5 °C = 1152–2078) was noticeably lower than in the species of the previous group: *Lactuca tatarica* (L.) C.A. Mey., *Descurainia sophia* (L.) Webb. ex Prantl, *Sinapis arvensis* L., *Amaranthus blitoides* S. Watson., *Taraxacum officinale* Wigg., *Portulaca oleraceae* L. Agrophytocenoses of all field crops included 19 more, mainly quite active and low-active species. The limits of the optimal requirements of these species to the heat factor in the zone of harmfulness (the sum of active temperatures above +5 °C = 953–2107) are significantly lower than those of the species in the first and second groups, and differ more significantly from the indicators of heat supply of the examination zone. The revealed ratio of species of different activity will be maintained provided that the weather and climatic conditions in the study area are preserved, as well as maintaining the current level of technology for cultivating field crops, and will amount as the content of a long-term regional forecast, including the above-mentioned species that will most actively have a harmful effect on the growth and development of the cultivated plants.

Keywords: species activity, weed flora, long-term forecast

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Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

The formation of crop yields is largely determined by the influence of harmful objects [1], including weeds, the forecast of their development serves as a basis for planning protective measures, production or purchase of chemical means of protection and necessary equipment, as well as the calculation of future costs. The annually published regional reviews of phytosanitary condition of crops do not contain data on the growth of specific weed species in crops of individual cultures, nor do they forecast their presence in agroecosystems for the next field season¹. Only the section on biological efficacy of applied plant protection products contains herbicides recommended for use against biological groups of weeds (annual, perennial, cereals, dicotyledons), in very rare cases - against groups

of plant species: bristlegrass, wild buckwheat, sow thistle, etc. Such information is of little use for practical application, because in different regions the same biological group includes different species from different families, which determines the use of different herbicides [2].

The formation of regional complexes of weed plants is ecologically and geographically conditioned: those weed species for which the level of heat and moisture availability corresponds to the species' requirements for heat and moisture² grow in each region [3, 4]. A weed species is not equally harmful in the whole area of its range. The area where the species finds suitable conditions for successful growth and development is the zone of its main distribution, on the arable lands of which the weed species weeds crops. Near its borders, the frequency of occurrence of

¹Review of phytosanitary condition of crops in the Krasnodar Territory in 2021 and forecast of development of harmful objects in 2022 // Branch of FSBI "Rosselkhozcenter for Krasnodar Territory", Krasnodar, 2022, 108 p.

²Luneva N.N. Theoretical substantiation and practical realization of phytosanitary zoning of weed plants: thesis of the Dr. of Science in Biology, SPb., 2022. URL: http://vizrsbp.ru/assets/docs/disser/LunevaNN/LunevaNN_disser.pdf.

the species and its importance as a segetal plant decreases, and outside this zone separate points of the species location are registered. Practically for each weed species within the zone of main distribution on the territory of the Russian Federation there is a zone where its most active participation in the formation of agrocenoses is noted – this is the zone of its harmfulness³.

The heat requirement of a plant species is dominant compared to other factors [5], and it has been previously found that the frequency of occurrence of the same species is higher in those regions where the level of heat availability corresponds more closely to the level of heat requirement of these species (see footnote 3).

B.A. Yurtsev introduced the concept of species activity, i.e., the measure of life success of a species in a given territory, in botanics to assess the role of species in plant communities and to evaluate the degree to which species master the territory of different landscapes. He proposed to distinguish and evaluate partial activity of species, i.e. the role of species in a certain ecotope⁴.

Researchers began to study the ecological and cenotic activity of species both in relation to species of regional floras [6-8] and invasive species [9]. On this scientific basis, T.A. Palkina developed a method for determining the agrophytocenotic role of weed species identified in a certain agrolandscape using a species activity scale. The study revealed the constancy of participation of weed species in the composition of agrocenoses. “Permanence, this is the main indicator of the placement of species in the territory, the distribution of species into groups by stages of permanence gives a certain idea of the place that the species occupies among others in the communities”⁵.

Studies of species activity have been extended to weeds [10, 11]. These studies have shown that the activity of species is not a constant value, but is determined by their degree of

adaptation to culture, which allows determining the role of each individual weed species in the composition of agrocenoses of individual crops and on the territory of the region. The vast majority of active species are characterized by a wide agrocenotic range, which indicates a high degree of their adaptation to the conditions of all or most types of agrocenoses and stability in them. This makes it possible to predict the future presence of these species in the crops surveyed (see footnote 5).

Predictability of weed species composition in agrophytocenoses of individual crops is due to the fact that the complex of species composing a separate agrophytocenosis (biocenosis of an ecotope of a segmental habitat) is the flora of this ecotope or partial flora. Separated, but floristically and ecologically homogeneous partial floras of agrophytocenoses together represent cenoflora. Cenoflora as “practically any complete territorial aggregates of plant species, as well as their parts (species complexes), are conditioned ecologically and historically”, therefore, have a certain stability of species composition, which is predictable [12].

The purpose of the study is to identify active species of weeds in field crops in the western part of the steppe zone of the Krasnodar Territory with the prediction of phytosanitary situation in field crops in the near future.

MATERIAL AND METHODS

The material was the data of field studies in several districts (Slavyansky, Kanevsky, Krasnoarmeysky, Krasnodar Urban District) of the western part of the steppe zone of the Krasnodar Territory. In 2012–2015, 2017–2018 and 2022 354 fields of field crops were surveyed: 71 fields of winter wheat, 27 fields of oats, 63 fields of sunflower, 63 fields of corn, 54 fields of soybean, 36 fields of alfalfa, 40 fields of potato planting. The studies were conducted according

³Agroecological atlas of Russia and neighboring countries: agricultural plants, their pests, diseases and weeds // A.N. Afonin, S.L. Green, N.I. Dzyubenko, A.N. Frolov (edited). 2008. URL: <http://www.agroatlas.ru>.

⁴Yurtsev B.A. Flora of Suntar-Khayat: Problems of the history of high-mountain landscapes of the North-East of Siberia. L.: Nauka, 1968, 236 p.

⁵Palkina T.A. Structure of segetal flora of the Ryazan region // Herald of Ryazan State Agrotechnological University Named after P.A. Kostychev, 2015, N 27 (3), pp. 26-32.

to the methodology of field studies developed and used in VIZR⁶, aimed at identifying the entire species composition of the weed component of agrophytocenosis, which is possible during the flowering period of most weed species, and used to develop a multi-year forecast of its development. According to this method, the projective coverage of a particular weed species was determined visually on each of 10–20 (depending on the field size) survey plots of 1 m² as a percentage of its coverage by individuals of this species.

The activity of a weed species in the formation of agrocenoses in the crops of one culture (partial) was determined taking into account two indicators: the constancy of occurrence of this species in the crops of this culture and the average projective cover in the cenoflora. Six classes of constancy were identified: I – the species occurs in less than 10% of descriptions; II – 10–20% of descriptions; III – 21–40% of descriptions; IV – 41–60% of descriptions; V – 61–80% of descriptions; Class VI – the species occurs in 81–100% of descriptions. Abundance classes were identified by projective cover of species in communities: 1st class – single plants; 2nd class – abundance less than 0.5%; 3rd class – abundance 0.5–1.0%; 4th class –

abundance 1.1–2.0%; 5th class – abundance 2.1–5.0%; 6th class – abundance more than 5.0%. Based on the combination of these indicators, weed field species were categorized into six categories (1 – particularly active, 2 – highly active, 3 – moderately active, 4 – fairly active, 5 – low active, 6 – inactive) according to the scale given in Table 1 (see footnote 5).

Also, to compare the activity of species in a set of field crops, we used an index of the ratio of the number of crops in which the species was particularly-, highly-, moderately- and fairly active to the number of the crops in which the species was low- and inactive.

Indicators of the values of the factor limiting the distribution of plant species in the northern direction were determined using electronic maps of weed species ranges, as well as the map of distribution of the indicators of average annual sums of active temperatures (SAT) above +5 °C, presented in the Internet resource “Agroecological atlas of Russia and neighboring countries: economically important plants, their diseases, pests and weeds” (see footnote 3). By superimposing the map of distribution of the above heat factor on the map of the species' area for each of them the values of indices of the isoline of the mean annual SAT above +5 °C, describing

Табл. 1. Баллы парциальной активности видов растений сеgetальной флоры (в агрофитоценозах культуры) (по Палкиной, 2015)

Table 1. Partial activity scores of the plant species of segetal flora (in agrophytocenoses of the culture) (according to Palkina, 2015)

Abundance Score	PP, %	Activity score in the constancy class					
		VI	V	IV	III	II	I
		81–100	61–80	41–60	21–40	10–20	< 10
6	> 5	1	1	2	3	4	5
5	2,1–5,0	2	2	3	4	4	5
4	1,1–2,0	2	2	3	4	4	5
3	0,5–1,0	3	3	4	5	5	5
2	< 0,5	4	4	4	5	5	6
1	Sporadically	5	5	5	5	6	6

⁶Luneva N.N. Technological methods of accounting and monitoring of weed plants in agroecosystems // High-performance and high-precision technologies and methods of phytosanitary monitoring: collection of articles. St. Petersburg: All-Russian Research Institute of Plant Protection, 2009, pp. 39–56.

the northern boundary of the zone of its harmfulness, were calculated using GIS. The work was carried out using the program IDRISI Selva 17.0⁷.

Names of the weed species are given according to a summary specially formed for practitioners in plant protection⁸.

RESULTS AND DISCUSSION

In the western part of the steppe zone of the Krasnodar Territory, more than 150 species of weeds grow in field crops, confirming the thesis of a high level of phytodiversity on agricultural lands [13].

During the years of research in sunflower crops 106 species of weeds were detected, among which 2 particularly active ones – barnyard grass (barnyard millet) *Echinochloa crus-galli* (L.) Beauv. and green amaranth *Amaranthus retroflexus* L., 6 highly active species – China jute *Abutilon theophrastii* Medik., corn bindweed *Convolvulus arvensis* L., lamb's-quarters *Chenopodium album* L., common ragweed *Ambrosia artemisiifolia* L., common persicaria *Persicaria maculosa* S.F. Gray, yellow thistle *Cirsium setosum* (Willd.) Bess, as well as 1 medium active species – bird vetch *Vicia cracca* L. and 3 rather active species – groundnut peavine *Lathyrus tuberosus* L., field mustard *Sinapis arvensis* L. and prickly lettuce *Lactuca serriola* L.

93 species were recorded in maize crops, including: 7 highly active species – barnyard grass, corn bindweed, common ragweed, yellow thistle, China jute, lamb's-quarters and prostrate amaranth *Amaranthus blitoides* S. Watson.; 3 medium active species – green amaranth, yellow Foxtail *Setaria pumila* (Poir.) Schult., common persicaria; 4 rather active species – knotgrass *Polygonum aviculare* L. s. str., wild buckwheat *Fallopia convolvulus* (L.) A. Löve, Italian ryegrass *Lolium multiflorum* Lam., black henbane *Hyoscyamus niger* L.

87 species were recorded in soybean crops, but only a few are active: 8 highly active species – barnyard grass, corn bindweed, common ragweed, common persicaria, green amaranth, groundnut peavine, China jute and lamb's-quarters; 2 medium active species – prickly lettuce and yellow thistle; 4 rather active species – common cocklebur *Xanthium strumarium* L., coco grass *Cyperus rotundus* L., couch grass *Elytrigia repens* (L.) Nevski, German camomile *Tripleurospermum inodorum* (L.) Sch. Bip.

Winter wheat crops are infested with 159 species of weeds, including 6 highly active species – common ragweed, cleavers *Galium aparine* L., corn bindweed, common persicaria, shepherd's purse *Capsella bursa-pastoris* (L.) Medik. and yellow thistle, as well as 5 medium active species – lamb's-quarters, forking larkspur *Consolida regalis* S.F. Gray, prickly lettuce, knotweed and tansy mustard *Descurainia sophia* (L.) Webb. ex Prantl; 4 rather active species – couch grass, green amaranth, field pennycress *Thlaspi arvense* L. and German camomile.

In oat crops 98 species of weeds were detected, but only a few were active: 7 highly active species – corn bindweed, yellow foxtail, common ragweed, barnyard grass, wild buckwheat, mountain bluet *Acroptilon repens* (L.) DC., China jute; 6 medium active species – common persicaria, Canada thistle *Cirsium arvense* (L.) Scop., couch grass, knotgrass, green amaranth, oatgrass *Avena fatua* L. s. l., and 5 rather active species – forking larkspur, Tatar lettuce *Lactuca tatarica* (L.) C.A. Mey., lamb's-quarters, cleavers and yellow thistle.

In alfalfa crops – 115 species, of which only 7 highly active species – common ragweed, couch grass, horseweed *Erigeron canadensis* L., German camomile, black foxtail *Alopecurus myosuroides* Huds., corn bindweed, common persicaria; also 8 rather active species – common dandelion *Taraxacum officinale* Wigg.,

⁷Clark Labs IDRISI Selva Edition 17.02. Clark University. Worcester MA, USA, 2013. Available from: <https://clarklabs.org/terreset/idrisi-gis>.

⁸Luneva, N.N., Mysnik E.N. Modern botanical nomenclature of weed plant species of the Russian Federation // Supplements to the journal "Plant Protection Bulletin", 2018, vol. 26, 80 p. DOI: 10.5281/zenodo.1241599.

lamb's-quarters, shepherd's purse, barnyard grass, green amaranth, Canada thistle, prickly lettuce, yellow thistle.

83 weed species were recorded in potato plantings. Of them 9 were highly active species – corn bindweed, common ragweed, yellow thistle, barnyard grass, China jute, groundnut peavine, common cocklebur, black nightshade *Solanum nigrum* L. and common persicaria. Medium active species totaled 3 – wild buckwheat, green amaranth and lamb's-quarters; 6 rather active species: thorn apple *Datura stramonium* L., spiny annual sow thistle *Sonchus asper* (L.) Hill., prickly lettuce, field pennycress, German camomile and common purslane *Portulaca oleraceae* L. [14].

In agrophytocenoses of all the surveyed crops 38 species of weed plants were registered, which showed themselves to be particularly-, highly-, moderately- and fairly active in crops of one or all field crops. The relationship between the activity of weed species and the level of heat availability in the survey area was analyzed. Indicators of the sum of active temperatures (SAT) in the survey area are in the range of 3400–3800 °C⁹. It turned out that those species, the indices of which requirements to the heat factor were closer to these indices, occurred more often and with higher abundance indices than other species, i.e. were more active in field crops of the survey area.

The greatest activity in the formation of agrophytocenoses in field crops was shown by 9 species, the indices of their requirements to the heat factor were the closest to the heat availability of the surveyed area. These species infested the crops of all 7 crops surveyed, and the index of the ratio of the number of crops in which the species was particularly-, highly-, moderately- and fairly active to the number of crops in which the species was low- and inactive was the highest in this group (7.0–2.5) (see Table 2).

The territory of the zone of harmfulness of each of these species, partially coinciding with the territory of the steppe zone of the Krasnodar

Territory, exceeds its limits, so the limits of the values of the indicators of requirement of the above species to the heat factor in the zone of harmfulness (SAT 1064–3536), although lower than the indicators of heat availability of the study area (3400–3800 °C), but are closest to them compared to the indicators of other species, from which it follows that for this group of species this territory is closest to the conditions of heat availability. No heat demand indicators were calculated for common persicaria, as there is no map of its range within the Russian Federation, but high values of the index (7) allow us to include it in this group of species.

The next group includes 6 species with low index scores, despite the fact that the pest zone partially overlaps with the survey area (see Table 3).

The zone of harmfulness of these species partially coincides with the study area (see footnote 3), but the limits of indicators of the optimal level of requirement of these species to the heat factor (SAT 1152–2078) are noticeably lower than those of the first group of species (SAT 1366–3536). The index values indicate that the study area is less suitable for these species, whose optimal growing conditions are in the areas less supplied with heat, than for the species of the first group and does not contribute to the manifestation of a high level of activity in agrophytocenoses.

The next group is represented by 19 species, which are located in the western part of the steppe zone of the Krasnodar Territory in the zone of their main distribution, and the zones of harmfulness of these species are located outside the boundaries of the Territory, in more northern regions (see footnote 3). The limits of the indicators of the optimal requirement of these species for the heat factor in the pest zone (SAT 953–2107) are much lower than in the first (SAT 1366–3536) and second (SAT 1152–2078) groups and differ significantly from the indicators of heat availability of the survey area. In

⁹Romanenko A.A., Toloraya T.R., Malakanova V.P., Lomovskoy D.V. Weeds in corn crops and measures to combat them. Krasnodar: Edvi, 2007, 208 p.

Табл. 2. Виды сорных растений, активные в агрофитоценозах всех или большинства обследованных полевых культур. Краснодарский край. 2012–2015 гг. и 2017, 2018, 2022 гг.

Table 2. Weed species that are active in agrophytocenoses of all or most of the field crops examined. Krasnodar Territory. 2012–2015 and 2017, 2018, 2022.

Name of weed species	EHS AH	Number of crops where the species showed specific activity	Index
Ragweed	3122	7 (HPS)	7
Corn bindweed	1718	7 (HPS)	7
Yellow thistle	1366	7 (4 HPS, 1 MAS, 2 FAS)	7
Redroot amaranth	1892	7 (1 HAS, 1 HPS, 2 FAS, 3 MAS, 2 FAS)	7
Lamb's-quarters	1064	7 (3 HPS, 2 MAS, 2 FAS)	7
Barnyard grass	1933	7 (1 HAS, 4 HPS, 1 FAS, 1 LAS)	6
Prickly lettuce	2085	7 (3 FAS, 2 MAS, 2 LAS)	2,5
China jute	3536	7 (5 HPS, 1 LAS, 1 IS)	2,5
Common persicaria	No data	7 (5 HPS, 2 MAS)	7
Indicator limits	(1064) 1366–3536	7 crops are infested	7–2,5

Here and in tables 3, 4: EHS – effective heat sum higher than +5 °C; AH – area of harmfulness; HPS – high-potent species; HAS – highly active species; MAS – middle-active species, FAS – fairly active species; LAS – low-active species, IS – inactive species.

Табл. 3. Виды сорных растений, засоряющие посевы не всех полевых культур и показавшие меньший уровень активности. Краснодарский край. 2012–2015 гг. и 2017, 2018, 2022 гг.

Table 3. Weed species infesting crops of not all field crops and showing lower activity level. Krasnodar Territory. 2012–2015 and 2017–2018, 2022.

Name of weed species	EHS AH	Number of crops where the species showed specific activity	Index
Tatar lettuce	2078	7 (1 FAS, 6 LAS)	0,17
Descurainia sophia	1152	5 (1 MAS, 1 LAS, 3 IS)	0,25
Field mustard	1701	5 (1 FAS, 3 LAS, 1 IS)	0,25
Amaranthus blitum	1985	5 (1 HPS, 3 LAS, 1 IS)	0,25
Common dandelion	1693	3 (1 FAS, 1 LAS, 1 IS)	0,5
Common purslane	1873	1 FAS	–
Indicator limits	1152–2078	(1) 3– 5 (7) crops are infested	0,5–0,17

this regard, species showed themselves as active in fewer crops, and as low- and inactive in more crops, which was reflected in the index values (1.33–0.17) (see Table 4).

No indicators of requirements to heat and moisture factors were revealed for foxtail due to the absence of a map of the species' range structured into the zone of main distribution and the zone of harmfulness (see footnote 3).

In the field crops of the survey area several other species of weeds infesting the crops of 3–5 field crops with an index of 0.5 were registered. For two of them - Italian ryegrass and thorn apple - there are no data on the indicators of factors limiting their distribution in the north and south direction due to the lack of maps of their distribution areas on the territory of the Russian Federation (see footnote 3), which does not allow drawing a conclusion about the level of suitability of the survey area for their growth. These species are not listed in scientific sources as weeds of field crops cultivated in the Krasnodar Territory. Coco grass is a species whose range extends outside the Russian Federation,

where it is a pernicious weed, especially in the zone of irrigated agriculture (see footnote 3); therefore, introduced into the moisture-poor steppe zone, it is not active enough in field crops.

As for the cocklebur, in the territory of the steppe zone of the Krasnodar Territory as a weed plant in crops, the researchers indicate

California cocklebur as a weedy plant *Xanthium californicum* Greene in Pittonia [15, 16], recognized as a synonym for eastern cocklebur *Xanthium orientale* L.¹⁰, so is the strumose cocklebur *Xanthium strumarium* L. (see footnote 3). Currently strumose cocklebur is being displaced by eastern cocklebur (California) in the nearby Rostov, Volgograd¹¹ and Saratov regions¹². Researchers have noted that the consid-

Табл. 4. Виды сорных растений, засоряющие все или большинство полевых культур, но показавшие невысокий уровень активности. Краснодарский край. 2012–2015 гг. и 2017, 2018, 2022 гг.

Table 4. Weed species that infest all or most of the field crops, but have shown a low level of activity. Krasnodar Territory. 2012–2015 and 2017, 2018, 2022.

Name of weed species	EHS AH	Number of crops where the species showed specific activity	Index
German camomile	1577	7 (1 HPS, 3 FAS, 2 LAS, 1 IS)	1,33
Couch grass	1468	7 (1 HPS, 2 FAS, 1 MAS, 3 LAS)	1,33
Climbing buckwheat	953	7 (1 HPS, 1 FAS, 1 MAS, 4 LAS)	0,78
Creeping chickling	1904	7 (2 HPS, 1 FAS, 2 LAS, 2 IS)	0.78
Knotweed	1188	7 (1 FAS, 2 CA, 4 LAS)	0.75
Shepherd's purse	1366	7 (1 HPS, 1 FAS, 1 LAS, 4 IS)	0,4
Field pennycress	1230	7 (2 FAS, 1 LAS, 4 IS)	0,4
Canada thistle	1822	7 (1 FAS, 1 MAS, 2 LAS, 3 IS)	0,4
Forking larkspur	1812	6 (1 FAS, 1 MAS, 4 IS)	0,5
Bristlegrass	2107	6 (1 HPS, 1 MAS, 4 LAS)	0,5
Cleavers	1970	7 (1 HPS, 1 FAS, 5 LAS)	0,4
Black henbane	2015	4 (1 FAS, 1 LAS, 2 IS)	0,33
Bird vetch	1162	5 (1 MAS, 3 LAS, 1 IS)	0,25
Wild oat	1848	6 (1 MAS, 3 LAS, 2 IS)	0,2
Canada fleabane	1782	6 (1 HPS, 2 LAS, 3 IS)	0,2
Prickly sow thistle	1886	6 (1 FAS, 1 LAS, 4 IS)	0,2
Russian centaury	1840	7 (1 HPS, 2 LAS, 4 IS)	0,17
Black nightshade	1908	7 (1 HPS, 2 LAS, 4 IS)	0,17
Black foxtail	No data	7 (1 HPS, 3 LAS, 3 IS)	0,17
Indicator limits	953–2107	7–4 crops are infested	1,33–0,17

¹⁰*Xanthium orientale* L. Propagation // Plants of the World Online, 2023. URL: <https://powo.science.kew.org/taxon/260872-1>.

¹¹*Flora of the Lower Don (determinator)* // ed. by G.M. Zozulin, V.V. Fedyaeva. Fedyaeva. Rostov-on-Don: Rostov Institute Publishing House, 1985, Part 2, 240 p.

¹²*Elenevsky A.G., Bulanyi Y.I., Radygina V.I.* Identifier of vascular plants of the Saratov region. Saratov: Bazhenov, 2009, 248 p.

erable similarity of morphological characters of these species leads to errors in determining the species affiliation of specimens found in crops (see footnote 12), including, probably, in our studies. The territory is favorable in terms of heat supply for strumose cocklebur, for eastern cocklebur it is not clear, and since species in agrophytocenoses of individual crops are not identified, it is difficult to judge their distribution by crops and activity classes, but in general it is obvious that species are inactive.

All species that showed themselves active in our studies to different degrees are given in scientific sources concerning research on weed plants in the Krasnodar Territory (see footnote 9) [16–18].

CONCLUSION

Of 159 species of weeds infesting crops in the western part of the steppe zone of the Krasnodar Territory, only 38 have shown themselves to varying degrees active in plants of all or individual crops. Provided weather and climatic conditions in the study area are maintained, the structure of the cultivated areas, and the current level of cultivation of field crops (which determines the preference of weed species for a particular crop), the multi-year regional forecast includes 9 species that will most actively participate in the formation of agrophytocenoses of all field crops and have a harmful effect on the growth and development of cultivated plants: ragweed, corn bindweed, yellow thistle, green amaranth, lamb's-quarters, barnyard grass, prickly lettuce, China jute, common persicaria. In plantings of many field crops, less active will be Tatar lettuce, tansy mustard, field mustard, prostrate amaranth, common dandelion and common purslane. The agrophytocenoses of all field crops will include 19 more of the mostly fairly- and low-active species identified above.

The following active species will be the most harmful in individual crops: in sunflower crops – barnyard grass (barnyard millet), green amaranth, China jute, corn bindweed, lamb's-quarters, common ragweed, common persicaria, yellow thistle; in corn crops – barnyard grass,

corn bindweed, common ragweed, yellow thistle, China jute, lamb's-quarters and prostrate amaranth, green amaranth, bristlegrass, common persicaria; in soy crops – barnyard grass, corn bindweed, common ragweed, common persicaria, green amaranth, groundnut peavine, China jute, lamb's-quarters, prickly lettuce and yellow thistle; in winter wheat crops – common ragweed, cleavers, corn bindweed, common persicaria, shepherd's purse, yellow thistle, lamb's-quarters, forking larkspur, prickly lettuce, knotgrass and tansy mustard; in oat crops – corn bindweed, bristlegrass, common ragweed, barnyard grass, wild buckwheat, mountain bluet, China jute, common persicaria, Canada thistle, couch grass, knotgrass, green amaranth, oatgrass; in alfalfa crops – common ragweed, couch grass, Canada fleabane, German camomile, foxtail, corn bindweed, common persicaria; in potato plantings – corn bindweed, common ragweed, yellow thistle, barnyard grass, China jute, groundnut peavine, common cocklebur, black nightshade, common persicaria, wild buckwheat, green amaranth and lamb's-quarters.

The results obtained do not indicate that these species are active only in the survey area: they will be active in the formation of agrocenoses in crops and in other regions that are included in the zones of main distribution of each of them. At the same time, species with rather extensive territories of the main distribution zones (field bindweed, yellow thistle, lamb's-quarters, etc.) are active in many regions of the Russian Federation, while species with relatively small territories of the main distribution zones (China jute, forking larkspur, etc.) will be active mainly in southern regions. The results of the study make it possible to explain the different level of activity of certain weed species identified in crops in a particular region by the different level of correspondence of the indicators of their requirements to the heat factor with the level of heat availability of the survey area.

The developed multi-year regional forecast provides anticipation of the presence of the above-mentioned active weed species in field

crops in the western part of the steppe zone of the Krasnodar Territory in a significant time perspective not only because it is based on long-term surveys of a large number of fields, but also because it is ecologically-geographically conditioned.

This forecast is the basis for optimizing the strategy and technology of protection of field crops in the western part of the steppe zone of the Krasnodar Territory from weeds. Preventive knowledge of weed species that have been actively infesting crops of certain field crops for many years will allow to identify the dynamics of weed infestation indicators when changing the structure of crop areas, applying new cultivation technologies or making changes in the system of protective measures.

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ИНФОРМАЦИЯ ОБ АВТОРАХ

✉ **Лунева Н.Н.**, доктор биологических наук, заведующая сектором; **адрес для переписки:** Россия, 196608, Санкт-Петербург, Пушкин, ш. Подбельского, 3; e-mail: natalja.luneva2010@yandex.ru

Закота Т.Ю., младший научный сотрудник

AUTHOR INFORMATION

✉ **Natalia N. Luneva**, Doctor of Science in Biology, Section Leader; **address:** 3, Podbelsky Ave., Pushkin, Saint Petersburg, 196608, Russia; e-mail: natalja.luneva2010@yandex.ru

Tatiana Yu. Zakota, Junior Researcher

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Производственное использование коров красных молочных пород в регионах разведения Российской Федерации

Краснова О.А.¹, Коник Н.В.², Тлецерук И.Р.^{3,4}, Эльжирокова З.Л.⁵, ✉ Улимбашев М.Б.⁶

¹Удмуртский государственный аграрный университет

Удмуртская Республика, Ижевск, Россия

²Саратовский государственный университет генетики, биотехнологии и инженерии им. Н.И. Вавилова

Саратов, Россия

³Майкопский государственный технологический университет

Майкоп, Россия

⁴Краснодарский научный центр по зоотехнии и ветеринарии

Краснодарский край, п. Знаменский, Россия

⁵Кабардино-Балкарский государственный аграрный университет им. В.М. Кокова

Нальчик, Россия

⁶Северо-Кавказский федеральный научный аграрный центр

Ставропольский край, г. Михайловск, Россия

✉ e-mail: murat-ul@yandex.ru

Проведен анализ производственного использования коров красных пород крупного рогатого скота в Российской Федерации и регионах их разведения за 2020–2022 гг. Объектом исследования стали красная степная, красная горбатовская, красная датская, красная эстонская, Шведиш Ред и суксунская породы. В хозяйствах всех категорий и племенных репродукторах среди красных молочных пород раньше всех возраста первого отела достигли животные пород красной датской и Шведиш Ред, позже – красной эстонской породы, минимальные значения которого приходились на 2021 г. (999 сут). Вызывает озабоченность увеличение возраста первого отела с 2020 по 2022 г. по красной горбатовской породе на 127 сут, красной датской – на 46 и Шведиш Ред – на 55 сут. У пород суксунской, красной горбатовской и Шведиш Ред отмечено увеличение возраста выбытия на 0,92; 1,16 и 0,50 отела. В красной датской и красной эстонской породах он снизился на 0,45–0,60 отела. Анализ длительности сервис-периода свидетельствует, что у коров всех пород его уровень был выше 100 сут, за исключением 2021 г. по породе Шведиш Ред (95 сут). У всех пород красного «корня» продолжительность от отела до плодотворного осеменения с 2020 по 2022 г. увеличилась. Наибольшее увеличение характерно для коров красной эстонской породы (26 сут) и красной горбатовской (51 сут). Следует отметить существенное увеличение (на 11 гол.) в племенных репродукторах выхода телят от 100 коров красной датской породы. В суксунской породе отмечено увеличение возраста выбытия коров на один отел и выхода телят на 6,7 гол. от каждых 100 коров во всех категориях хозяйств. В расчете на 100 коров увеличился выход телят на 9 гол. и у животных породы Шведиш Ред.

Ключевые слова: молочные породы, красный скот, федеральные округа, возраст, отел, выбытие, сервис-период, сухостойный период, выход телят

Production use of the Red dairy breed cows in the breeding regions of the Russian Federation

Krasnova O.A.¹, Konik N.V.², Tletseruk I.R.^{3,4}, Elzhirokova Z.L.⁵, ✉ Ulimbashev M.B.⁶

¹Udmurt State Agricultural University

Izhevsk, Udmurt Republic, Russia

²*Saratov State University of Genetics, Biotechnology and Engineering named after N.I. Vavilov
Saratov, Russia*

³*Maikop State Technological University
Maikop, Russia*

⁴*Krasnodar Research Centre for Animal Husbandry and Veterinary Medicine
Znamensky, Krasnodar Territory, Russia*

⁵*Kabardino-Balkarian State Agricultural University named after V.M. Kokov
Nalchik, Russia*

⁶*North Caucasus Federal Scientific Agrarian Center
Mikhailovsk, Stavropol Territory, Russia
(✉) e-mail: murat-ul@yandex.ru*

Analysis of production utilization of cows of the Red breeds of cattle in the Russian Federation and regions of their breeding for 2020–2022 has been carried out. Red Steppe breed, Red Gorbatov, Danish Red, Red Estonian, Swedish Red and Suksun breeds were the object of the study. In the farms of all categories and pedigree reproducers among the Red dairy breeds, the earliest age of first calving was reached by the animals of the Danish Red and Swedish Red breeds, later – by the Estonian Red breed, the minimum values of which occurred in 2021 (999 days). The increase in the age of first calving in the period between 2020 and 2022 for the Red Gorbatov breed by 127 days, Danish Red by 46 days and Swedish Red by 55 days is of concern. The Suksun, Red Gorbatov and Swedish Red breeds showed an increase in the age of retirement by 0.92; 1.16 and 0.50 of the calving. It decreased by 0.45–0.60 of the calving in the Danish Red and Estonian Red breeds. The analysis of the service period duration shows that cows of all the breeds had its level above 100 days, with the exception of 2021 for the Swedish Red breed (95 days). In all the Red "root" breeds, the duration from calving to fruitful insemination increased from 2020 to 2022. The greatest increase is observed in the Red Estonian cows (26 days) and Red Gorbatov cows (51 days). A significant increase (by 11 cows) in calf yield from 100 cows of the Danish Red breed in the breeding reproducers should be noted. There was an increase in the age of cow retirement per calving and calf yield by 6.7 calves from every 100 cows in all farm categories in the Suksun breed. Calf yield per 100 cows increased by 9 calves and in the animals of the Swedish Red breed.

Keywords: dairy breeds, Red cattle, federal districts, age, calving, retirement, service period, dry period, calf yield

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Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Various organizational and economic mechanisms of management in the agro-industrial complex have revealed the priority in the use of the gene pool of dairy cattle breeds. The prevailing preference in breeding of foreign breeds and their dominance in numbers among all breeds cultivated on the territory of the Russian Federation is explained, as a rule, by their greater

milk yield. Without denying the opinion of supporters of universal use of the world gene pool, attention should be paid to the need to preserve the gene pool of domestic breeds of cattle, characterized by known valuable qualities, which are insufficiently expressed, and sometimes weakly manifested in cattle imported into the country. Naturalized cattle are mostly used at modern industrial complexes for milk production for no more than 3–4 lactations, which does

not allow to reach the level of the highest productivity and realize in full the genetic potential for milk yield. The reasons for this are high susceptibility to diseases, presence of recessive genes, intensive metabolism, which reduce the possibility of long-term productive and healthy use of animals.

In 2022, out of the relative number of controlled cattle of dairy and dairy-meat breeds of the Russian Federation, the share of the Red Steppe breed animals amounted to 2.54%, Red Gorbatov – 0.01, Danish Red – 0.14, Red Estonian – 0.02, Suksun – 0.08 and Swedish Red – 0.01%. In the gene pool farms of the country the Red Steppe breed is cultivated, the evaluated livestock of which amounted to 1.76 thousand heads, including 1.04 thousand cows.

Studies on the Red Gorbatov cattle testify to the regularity of increasing productive longevity with increasing milk yield of first heifers. The cows, whose milk yield for the first lactation was at the level of 5–6 thousand kg, were characterized by long productive life (4.8 lactations). Long economic use (5.5 lactations on average) is also inherent in the cows of the Red Gorbatov breed, whose milk yields for the highest lactation varied from 5 to 6 thousand kg of milk. Exceeding this level of productivity causes a decrease in productive longevity [1]. Russian [2–5] and foreign [6–8] scientists made a great contribution to the direction of research on the study of lifetime productivity and productive longevity. Sufficiently detailed longevity of dairy cattle depending on a number of factors is presented in a review article published in the journal “Animal” [9].

Analysis of the current state of dairy cattle breeding in the Russian Federation indicates that profitable production of dairy raw materials can be in the case when the farms have established selection and breeding work aimed not only at increasing the level of milk yield of the cows, but also at increasing their reproductive capacity, resistance to diseases, improved health and prolonged utilization [10].

The decrease in the efficiency of using high-blooded Holsteinized cows, in which the

longevity of the animals decreases with each new generation, has been shown in a number of studies [11–13].

In the studies on the influence of the country of origin of the father on the productive longevity of daughters of the Red Steppe breed, the superiority of the descendants of bulls of the Russian origin over their German breeding counterparts in terms of lifetime milk yield, longevity and profitability of milk production has been shown [14].

The lack of manifestation of transmitting ability of foreign bulls-producers of Angler, Holstein Red and White breeds and Danish Red breeds on the indicators of productive use of cows, evaluated by milk traits of the Holstein Breed Association (USA), is stated in the studies of O.V. Perminova [15], conducted on the mother stock of the Red Steppe breed cattle. At the same time, in the case of analyzing the transmission ability of the bulls of Russian selection on the Red Steppe breed cows, a positive effect on productive longevity has been established [14].

The competitiveness assessment of the Russian dairy cattle breeds showed that Red Steppe breed cows were culled at the age of 3.49 calvings, while Black and White Holstein cows were culled at 2.67 calvings. At the same time, such domestic dairy breeds as Bestuzhevskaya, Kostroma, Sychevskaya and Holmogory produce over four calvings with lifetime milk yields of 15.3; 24.8; 16.1 and 22.2 tons, respectively [16].

In this aspect, it is very relevant to monitor the indicators of reproduction and duration of economic use of the cows of Red dairy breeds in the regions of their breeding.

The purpose of the study is to analyze the production utilization of the Red breed cattle cows in the Russian Federation and the regions of their breeding.

To address this goal, objectives were set to study the reproductive performance, herd age and culling rates of the Red dairy cows during 2020–2022 both nationally and in their breeding territories.

MATERIAL AND METHODS

The information base of the “Yearbooks on breeding work in dairy cattle breeding in the farms of the Russian Federation for the period 2020–2022” served as initial values for the analysis of indicators of cow production utilization. The analyzed indicators of analytical studies included the age at first calving, in calving, culling of cows, as well as the duration of service and dry periods, calf yield per 100 cows. Monitoring of these indicators was carried out in all categories of farms and breeding organizations (plants and reproducers). The object of research were cows of the Red Steppe breed of cattle – Red Steppe, Danish Red, Red Gorbatov, Suksun, Red Estonian, Swedish Red.

RESULTS AND DISCUSSION

The production utilization of the Red breed cows on the national scale can be judged from the materials of Table 1.

Age monitoring at the first calving indicates that in all the analyzed years animals of the Danish Red and Swedish Red breeds calved earlier than the representatives of other Red “root” breeds. This pattern was also observed in the breeding reproducers of the country.

The latest age of first calving was characteristic of the Red Estonian breed, with the minimum values occurring in 2021 (999 days).

The increase in the age of first calving from 2020 to 2022 in all categories of farms in the Red Gorbatov breed by 127 days, Danish Red breed by 46 days and Swedish Red breed by 55 days is of concern. At the same time, this indicator, regardless of the category of farms, did not change much for such breeds as Red Steppe breed and Suksun breed during these years.

As a result of breed inventory, it was revealed that prolonged use of Holstein bulls' seed on the cows of the analyzed breeds provided high-blooded progeny, which became the representatives of the improving breed. The remaining purebred animals are less fast-ripening, which probably explains the later dates of the first insemination and calving accordingly.

The Suksun, Red Gorbatov and Swedish Red

breeds showed positive dynamics of increasing the age of cow culling. Thus, the differences in the values of this indicator in all categories of farms, obtained in 2020 and 2022, amounted to 0.92; 1.16 and 0.5 calvings for the listed breeds. The age of culling of the cows of Danish Red and Estonian Red breeds decreased by 0.45–0.6 calvings. On the contrary, in the breeding reproducers for cultivation of the Danish Red cattle breed, this indicator during the analyzed period increased by 0.4 calvings.

According to the “Yearbook on breeding work in dairy cattle breeding in the farms of the Russian Federation (2021)”, cows of the Red Estonian breed in 2020 dropped out of herds at the age of 5.0 calvings, while the representatives of the Red Gorbatov – 4.05, Suksun – 3.96, Red Steppe breed – 3.77, Danish Red and Swedish Red – 3.20 and 3.30 calvings, respectively, which indicates significant interbreed differences.

Analysis of service period duration in all the analyzed years in both commercial and breeding organizations shows that in the cows of all breeds its level was above 100 days (ideal duration is considered to be up to 90 days), with the exception of 2021 for Swedish Red breed (95 days). In all Red “root” breeds, the duration from calving to fruitful insemination increased from 2020 to 2022. The greatest increase was characteristic for the Red Estonian (26 days) and Red Gorbatov cows (51 days). Of all the breeds monitored, only the Red Gorbatov cows showed a significant increase in the length of the drying period – from 55 days in 2020 to 84 days in 2022.

No significant differences were found in the production use of the Red Gorbatov breed in 2021, bred in all categories of farms and breeding plants, which is probably due to the small number of organizations engaged in cultivation of this breed. In 2022, the analyzed values of the indicators of production use of the Gorbatov breed livestock in all categories of farms and breeding organizations were identical due to the fact that only one farm is engaged in the breeding of animals of this breed. A similar picture

Table 1. Change in the indicators of production use of the Red breed cows in the Russian Federation

Breed affiliation	Breed																	
	Red Steppe			Red Gorbatov			Danish Red			Red Estonian			Suksun			Swedish Red		
	2020	2021	2022	2020	2021	2022	2020	2021	2022	2020	2021	2022	2020	2021	2022	2020	2021	2022
	All categories of farms																	
Age: of the first calving, day in calvings cow losses, calvings Duration of the period, days: service interlactation Calf yield per 100 cows, heads	866 2,96 3,77	869 2,96 3,68	872 2,97 3,64	795 3,73 4,05	810 3,98 5,21	922 6,70 –	726 2,30 3,20	775 2,24 2,93	772 2,50 2,75	1038 3,00 5,00	999 2,90 4,20	1017 2,70 4,40	827 4,01 3,96	827 3,68 4,95	830 4,13 4,88	735 2,50 3,30	738 2,70 3,70	790 2,60 3,80
	118 62	123 62	126 61	115 55	111 60	166 84	103 64	113 62	118 71	125 57	160 57	151 56	116 60	119 63	128 61	112 60	95 61	116 70
	84,4	82,2	79,4	81,8	82,2	82,0	87,0	90,0	85,8	86,0	83,0	83,0	79,7	86,4	85,1	84,0	93,0	84,0
	Stud farms																	
Age: of the first calving, day in calvings cow losses, calvings Duration of the period, days: service interlactation Calf yield per 100 cows, heads	863 2,79 4,16	867 2,84 3,93	927 2,86 3,62	801 4,10 4,60	809 4,10 5,30	922 6,70 –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –
	119 59	120 58	121 55	115 54	111 60	166 84	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –
	90,4	87,8	79,1	80,0	81,0	82,0	–	–	–	–	–	–	–	–	–	–	–	–
	Pedigree breeding units																	
Age: of the first calving, day in calvings cow losses, calvings Duration of the period, days: service interlactation Calf yield per 100 cows, heads	881 3,08 3,92	867 2,97 3,71	856 2,99 3,84	– – –	– – –	– – –	726 2,30 3,20	710 2,60 3,00	806 2,60 3,60	1038 3,00 5,00	999 2,90 4,20	1017 2,70 4,40	830 4,20 4,30	844 4,10 5,40	839 4,30 5,00	735 2,50 3,30	738 2,70 3,70	790 2,60 3,80
	103 66	114 66	112 64	– –	– –	– –	103 64	102 64	107 71	125 57	160 57	151 56	103 58	118 60	118 58	112 60	95 61	116 70
	89,3	85,0	84,6	–	–	–	87,0	98,0	97,0	86,0	83,0	83,0	82,0	87,0	87,0	84,0	93,0	84,0

was observed for animals of the Red Estonian and Swedish Red breeds, which are raised in pedigree breeding units.

A significant increase in calf yield from 100 cows of the Danish Red breed from 2020 to 2021 should be noted, which increased by 11 calves, while in all categories of farms it increased by only 3 calves.

A positive trend in the Suksun breed from 2020 to 2021 can be considered an increase in the age of cow culling per calving and calf yield by 6.7 calves from every 100 cows in all categories of farms. Approximately the same increase was demonstrated by the representatives of this breed in the pedigree breeding units. Calf yield per 100 cows increased in the animals of the Swedish Red breed, which increased by 9 calves per 100 cows during the analyzed period.

The results of production utilization of the Red breed cows in all categories of farms of the Federal Districts of their breeding are presented in Table 2.

Monitoring of production utilization of the Red Steppe breed cows indicates their distribution on the territory of five federal districts. The obtained data indicate significant differences in the analyzed indicators depending on the zone of the Red Steppe cattle breeding. The earlier achievement of the age of the first calving is characterized by the animals bred in the Southern Federal District, in which this indicator varied during the last years in the range of 793–811 days. The animals from the North Caucasian Federal District were slightly inferior (809–858 days). The cows of the Volga District stand out in terms of cow age in the herds of federal districts, where it amounted to 3.5 calvings in 2022 and increased by 0.74 calvings over the last 3 years. In the other breeding zones, it practically did not change, except for the Far Eastern District, where it decreased by 1.07 calvings. In terms of the age of the breeding stock culling, the animals of the Far Eastern, North Caucasus and Volga Federal Districts stand out, which amounted to four or more calvings in 2022. During the last three years, cows from the Southern Federal District were the least

used in the herds, with the age of culling varying between 2.95 and 3.24 calvings. Cows from the North Caucasian (93–114 days) and Volga (102–103 days) federal districts were characterized by zootechnically justified duration of the service period, while in the representatives of other districts it amounted to 4–6 months, which reduces the reproductive performance of the herds. Duration of the dry period of cows of the considered districts in all the years of analysis was approximately at the same level, corresponding to the species as a whole. Rather peculiar results were obtained by calf yield per 100 cows in the Volga Federal District, where in 2020 it amounted to 110 calves, then decreased to 91 calves and by the end of the analyzed period amounted to 69 calves. Even worse results were obtained in the Far Eastern Federal District, where calf yield amounted to 47.4–69.8 calves with a decrease of 22.4 calves. Regardless of the analyzed year, the highest calf yield from 100 cows was achieved in the Siberian Federal District and in the south of the country with a variation in the range of 78–86 calves.

Red Gorbato breed is currently represented in the Volga Federal District (Nizhny Novgorod region) at the only stud farm engaged in pedigree breeding of animals of this breed. In previous years its breeding was also carried out in the Central Federal District, where the animals showed satisfactory production utilization with high calf yield per 100 cows of 95–98 calves. The increase in the age of the first calving in the Volga Federal District, where it increased from 792 to 922 days, as well as the duration of the service period from 116 to 166 days, is of concern. At the same time, positive dynamics of the age of cows was noted, which increased for the analyzed period by 2.74 calvings, reaching the average value of 6.70 calvings. Calf yield exceeds 80 calves for every 100 cows of the Red Gorbato breed.

The animals of the Danish Red breed until 2022 were present only in the Central Federal District, currently also in the Volga Federal District. According to the age of lactating and calving cows in 2022, animals from the Volga

Табл. 2. Производственное использование красных пород крупного рогатого скота в федеральных округах Российской Федерации
Table 2. Production Use of the Red breeds of cattle in the Federal Districts of the Russian Federation

Breed affiliation	Breed																	
	Red Steppe			Red Gorbatov			Danish Red			Red Estonian			Suksun			Swedish Red		
	2020	2021	2022	2020	2021	2022	2020	2021	2022	2020	2021	2022	2020	2021	2022	2020	2021	2022
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	Central Federal District																	
Age: of the first calving, day in calvings cow losses, calvings Duration of the period, days: service interlactation Calf yield per 100 cows, heads				840 1,40 2,20	840 2,30 3,60		726 2,30 3,20	775 2,24 2,93	771 2,30 2,74							735 2,50 3,30	738 2,70 3,70	790 2,60 3,80
				102 67	108 67		103 64	113 62	116 71							112 60	95 61	116 70
				95,0	98,0		87,0	90,0	87,5							84,0	93,0	84,0
	North-Western Federal District																	
Age: of the first calving, day in calvings cow losses, calvings Duration of the period, days: service interlactation Calf yield per 100 cows, heads										1038 3,00 5,00	999 2,90 4,20	1017 2,70 4,40						
										125 57	160 57	151 56						
										86,0	83,0	83,0						
	Southern Federal District																	
Age: of the first calving, day in calvings cow losses, calvings Duration of the period, days: service interlactation Calf yield per 100 cows, heads	793 2,48 2,95	804 2,57 3,12	811 2,66 3,24															
	134 64	142 62	136 61															
	79,5	78,8	77,7															

Окончание табл. 2

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Privolzhsky Federal District																		
Age:	895	819	957	792	809	922			793				827	827	830			
of the first calving, day	2,76	3,09	3,50	3,96	4,10	6,70			3,20				4,01	3,68	4,13			
in calvings	4,34	4,36	4,00	4,16	5,30	–			3,50				3,96	4,95	4,88			
cow losses, calvings																		
Duration of the period, days:	102	102	103	116	111	166			125				116	119	128			
service	60	60	57	55	60	84			70				60	63	61			
interlactation																		
Calf yield per 100 cows, heads	109,9	91,0	69,3	80,5	81,0	82,0			80,0				79,7	86,4	85,1			
Siberian Federal District																		
Age:	989	887	888															
of the first calving, day	2,94	2,90	2,88															
in calvings	3,81	3,69	3,65															
cow losses, calvings																		
Duration of the period, days:	123	123	129															
service	60	60	59															
interlactation																		
Calf yield per 100 cows, heads	82,7	82,6	79,6															
Far Eastern Federal District																		
Age:	986	1011	867															
of the first calving, day	4,05	3,36	2,98															
in calvings	3,70	5,05	4,44															
cow losses, calvings																		
Duration of the period, days:	154	173	184															
service	56	60	55															
interlactation																		
Calf yield per 100 cows, heads	69,8	51,0	47,4															
North Caucasian Federal District																		
Age:	809	852	858															
of the first calving, day	3,41	3,32	3,34															
in calvings	4,81	4,20	4,20															
cow losses, calvings																		
Duration of the period, days:	93	111	114															
service	69	71	69															
interlactation																		
Calf yield per 100 cows, heads	85,7	83,2	84,7															

District exceed the values obtained in the Central Federal District by 0.90 and 0.76 calvings, respectively. The length of the service period and dry cows from the analyzed districts do not differ much among themselves, and in terms of the calf yield per 100 cows, the representatives of the Central Federal District rank first (+7.5 calves per 100 cows).

Red Estonian, Suksun and Swedish Red breeds are represented by one breeding district and testify to their small number in the territory of the country. Animals of these breeds practically by all indicators of production use are characterized by valuable qualities. Further use in breeding and pedigree work will allow to preserve their gene pool and breed structure of the dairy cattle.

CONCLUSION

The presented monitoring of production utilization of the cows of the Red breeds of Russia indicates the necessity of further work with these populations in the direction of decreasing the age of first calving and the duration of the service period with simultaneous increase of the productive longevity and calf yield per 100 cows.

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ИНФОРМАЦИЯ ОБ АВТОРАХ

Краснова О.А., доктор сельскохозяйственных наук, доцент

Коник Н.В., доктор сельскохозяйственных наук, доцент

Тлецерук И.Р., доктор сельскохозяйственных наук, доцент

Эльжирокова З.Л., кандидат сельскохозяйственных наук

✉ **Улимбашев М.Б.**, доктор сельскохозяйственных наук, доцент: **адрес для переписки:** Россия, 356241, Ставропольский край, г. Михайловск, ул. Никонова, 49; e-mail: murat-ul@yandex.ru

AUTHOR INFORMATION

Oksana A. Krasnova, Doctor of Science in Agriculture, Associate Professor

Nina V. Konik, Doctor of Science in Agriculture, Associate Professor

Irina R. Tletseruk, Doctor of Science in Agriculture, Associate Professor

Zalina L. Elzhirokova, Candidate of Science in Agriculture

✉ **Murat B. Ulimbashev**, Doctor of Science in Agriculture, Associate Professor: **address:** 49, Nikonova St., Mikhailovsk, Stavropol Region, 356241, Russia; e-mail: murat-ul@yandex.ru

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Экспериментальная иммунотерапия ассоциативных инфекций желудочно-кишечного тракта новорожденных телят с использованием обогащенного специфическими иммуноглобулинами класса Y желточного меланжа

Гаджиев И.М.¹, (✉) Сизов А.А.², Сизов Д.А.², Стеблева Г.М.², Донченко А.С.²

¹Азербайджанский научно-исследовательский институт ветеринарии
Баку, Азербайджанская Республика

²Сибирский федеральный научный центр агробиотехнологий Российской академии наук
Новосибирская область, р.п. Краснообск, Россия

(✉) e-mail: alexander.sizov62@yandex.ru

Массовые желудочно-кишечные болезни новорожденных телят, проявляющиеся симптомами диареи, обусловлены различными этиологическими факторами и протекают чаще всего в форме смешанных инфекций. По сравнению с моноинфекцией при смешанных инфекциях диарея протекает в более тяжелой форме. Экономические последствия таких инфекций из-за высокой распространенности, частой летальности и потери продуктивности при дальнейшей эксплуатации животного могут быть значительными. Самыми частыми возбудителями желудочно-кишечных заболеваний вирусной этиологии у новорожденных телят являются рота- и коронавирусная инфекции. Смешанная (вирусно-бактериальная) инфекция может привести к 100%-й гибели заболевших телят. Специфическая вакцинация стельных коров против возбудителей желудочно-кишечной инфекции телят, которая проводится с целью увеличения количества патогеноспецифических иммуноглобулинов в молозиве при рождении теленка, и прием молозива телятами в течение первых 4 ч жизни являются важнейшими стратегиями предотвращения тяжелой диареи. Но как показывает практика, не всегда этого бывает достаточно. Цель проведенных работ – изучить эффективность иммунопрофилактики ассоциативных инфекций желудочно-кишечного тракта новорожденных телят с применением меланжа, приготовленного из яиц кур, предварительно иммунизированных вакциной «Ротагал» (Pharmagal-BIO s.r.o., Словакия), используемой для профилактики эшерихиоза, рота- и коронавирусной инфекций крупного рогатого скота. В результате исследования установлено, что добавление желточного меланжа, богатого специфическими иммуноглобулинами класса Y, в молозиво в первые часы жизни телят имеет выраженный профилактический эффект, облегчает протекание инфекционного процесса в случае возникновения заболевания, экономит расходы на лечение больных животных, повышает выживаемость, способствует ускорению набора живой массы. Применение иммунобиологического препарата на основе трансовариальных иммуноглобулинов оказывает положительное действие на показатели неспецифической резистентности новорожденных телят по сравнению с телятами, переболевшими в раннем постнатальном периоде и подвергнувшимися лечению антибиотиками.

Ключевые слова: иммуноглобулины класса Y, иммунотерапия, желудочно-кишечные заболевания телят, желточный меланж

Experimental immunotherapy of association infections of the gastrointestinal tract of newborn calves using yolk melange enriched with specific Y class immunoglobulins

Gadjiev I.M.¹, (✉) Sizov A.A.², Sizov D.A.², Stebleva G.M.², Donchenko A.S.²

¹Azerbaijan Scientific Research Veterinary Institute
Baku, Republic of Azerbaijan

²Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences
Krasnoobsk, Novosibirsk region, Russia

(✉) e-mail: alexander.sizov62@yandex.ru

Mass gastrointestinal diseases of newborn calves manifested by symptoms of diarrhea are caused by various etiological factors and most often occur in the form of mixed infections. Mixed infections have a more severe diarrhea than mono-infections. The economic consequences of such infections due

to the high prevalence, frequent mortality and loss of productivity during further exploitation of the animal can be significant. The most common causative agents of gastrointestinal diseases of newborn calves of viral etiology is rotavirus and coronavirus infections. Mixed (viral-bacterial) infection can lead to 100% mortality of the diseased calves. Specific vaccination of springer cows against gastrointestinal pathogens in calves, which is performed to increase the number of pathogen-specific immunoglobulins in the colostrum at calf birth, and ingestion of colostrum by the calves during the first 4 hours of life are the most important strategies to prevent severe diarrhea. But as practice shows, this is not always enough. The purpose of this work was to study the effectiveness of immunoprophylaxis of associative infections of the gastrointestinal tract of newborn calves with the use of melange prepared from chicken eggs previously immunized with the vaccine "Rotagal" (Pharmagal-BIO s.r.o., Slovakia), used for the prevention of colibacillosis, rotavirus and coronavirus infections of cattle. As a result of the study, it was established that the addition of yolk melange rich in specific immunoglobulins of Y class to the colostrum in the first hours of life of the calves has a pronounced prophylactic effect, facilitates the course of the infectious process in case of the disease, saves costs for the treatment of sick animals, increases survival rate, contributes to the acceleration of live weight gain. The use of an immunobiological preparation based on transovarial immunoglobulins has a positive effect on the indicators of nonspecific resistance of newborn calves compared to the calves with early postnatal disease and antibiotic treatment.

Keywords: Y class immunoglobulins, immunotherapy, gastrointestinal diseases of calves, yolk melange

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Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Nowadays in the dairy cattle breeding industry scientists and practitioners face the task of increasing milk productivity of cows along with the task of increasing their productive longevity and improving their reproductive capacity.

According to the “Yearbook on breeding work in dairy cattle breeding”, in 2022 the average age of retired cows in agricultural enterprises of the Krasnoyarsk region was 3.15 calvings¹. At the same time, the highest productivity of cows occurs in the fourth – fifth lactation [1],

therefore, animals are retired from the herd, not realizing fully their genetic potential, which adversely affects the economic performance of the farms engaged in the breeding of cattle of dairy productivity direction.

At short-term production use of cows, it is necessary to introduce 25–30% and more high-yielding first heifers into the main herd annually, which becomes impossible at low level of reproduction, calf yield and calf safety [2].

One of the methods of the breeding process is early testing of animals using erythrocyte an-

¹Yearbook on breeding work in dairy cattle breeding at the farms of the Russian Federation. Moscow: VNIIPlem, 2023, 84 p.

tigens as polymorphic markers of economically useful traits [3–5]. Immunogenetic analysis allows to reveal the degree of genetic influence of individuals on the total gene pool of the herd, as well as the formation of the allele pool in certain groups of animals [6].

Both foreign scientists² [7–9] and Russian scientists [10–12] are engaged in the study of the genetic structure of cattle populations in order to identify certain genes affecting the economically useful traits of animals.

Positive relationships between the presence of certain antigens and indicators of productive longevity and reproductive ability of cows, found in one herd, may not be confirmed in another, because in addition to genetic factors, environmental factors influence these traits.

The purpose of the study was to investigate the influence of immunogenetic factors on the reproductive ability and productive longevity of Red-and-White cows.

MATERIAL AND METHODS

Scientific research was carried out at ZAO “Nazarovskoye”, Krasnoyarsk region. The object of research were Red-and-White cows.

To analyze the relationships of the antigens with productive longevity and reproductive ability, the IAS “Selax” data of the primary breeding record of 305 cows at the farm, which retired from the herd from 2019 to 2022 and had the results of immunogenetic testing of blood groups, were used.

Blood groups were determined according to 11 genetic systems in the laboratory of immunogenetic control of authenticity of animal origin of the OAO “Krasnoyarskagroplem”.

The antigen frequency was determined by the ratio of the number of cows – antigen carriers – to the total number of cows in the sample. In the studies the effect of the composition and occurrence of the antigens with a frequency of 0.3 or more in the sample on the reproductive ability of cows (age of first calving, service period), lifetime milk productivity (lifetime milk yield, milk yield per milking day), longevity (duration of economic use, months; age of retired cows, years) were analyzed. The cows were categorized into carriers and non-carriers of each antigen.

Computer programs “Biometric analysis of quantitative traits in zootechnics” (No. 2021619580, 2021)³ and “Analysis of immunogenetic data of cattle” (No. 2022660011, 2022)⁴ were used for biometric data processing. Reliability of the difference between the groups for quantitative traits was determined by the Student's criterion. The share of influence of the antigenic factors (η^2) on the reproductive ability and productive longevity of cows was established by the method of dispersion analysis with the determination of reliability by the Fisher's criterion.

RESULTS AND DISCUSSION

As a result of analyzing the immunogenetic data of cows of the farm, it was found that a total

²Tsuruta S., Lourenco D., Misztal I., Lawlor T.J. Genotype by environment interactions on culling rates and 305-day milk yield of Holstein cows in 3 US regions // *Journal of Dairy Science*, 2015, vol. 98, Is. 8, pp. 5796–5805. DOI: 10.3168/jds.2014-9242.

³Certificate of state registration of computer program No. 2021619580 (Russian Federation). Biometric analysis of quantitative traits in zootechnics // L.V. Efimova; right holder Federal Research Center “Krasnoyarsk Scientific Center of the Siberian Branch of the Russian Academy of Sciences”; No. 2021618613; applied 04.06.2021; publ. 15.06.2021.

⁴Certificate of state registration of computer program No. 2022660011 (Russian Federation). Analysis of immunogenetic data of cattle: 2022619287 // L.V. Efimova; right holder Federal Research Center “Krasnoyarsk Scientific Center of the Siberian Branch of the Russian Academy of Sciences”; applied 25.05.2022; publ. 27.05.2022.

Табл. 1. Схема гипериммунизации кур
Table 1. Scheme of hyperimmunization of chickens

Injection number	Interval between injections, days	Antigen dosage, ml
1	7	1,0
2	7	1,2
3	7	1,5
4	5	2,0
5	5	2,5
6	5	3,0
7	5	3,0
8	20 (booster vaccination)	4,0

of 74 antigens with frequency (p) from 0.003 to 0.961 and 15 alleles with frequency from 0.003 to 0.033 were found in the cows in blood groups. More frequently ($p > 0,8$) the cows had the antigens B₂ ($0,81 \pm 0,022$), F ($0,961 \pm 0,011$) and H' ($0,872 \pm 0,019$). With a frequency of more than 0.6, the cows had the antigens A₂ ($0,646 \pm 0,027$), B' ($0,705 \pm 0,026$), E' ($0,679 \pm 0,027$), G'' ($0,718 \pm 0,026$), Q' ($0,636 \pm 0,028$), C₂ ($0,672 \pm 0,027$), E ($0,734 \pm 0,025$), X₂ ($0,656 \pm 0,027$), R₂ ($0,613 \pm 0,028$), Z ($0,689 \pm 0,027$), W ($0,685 \pm 0,027$), L ($0,718 \pm 0,026$), with a frequency of more than 0,5 – V ($0,567 \pm 0,028$), F/V ($0,528 \pm 0,029$), O₃ ($0,593 \pm 0,028$), T₂ ($0,584 \pm 0,028$), O' ($0,57 \pm 0,028$), S₁ ($0,534 \pm 0,029$), S₂ ($0,59 \pm 0,028$) (see Fig. 1).

The earliest age of the first calving was observed in the cows - Y' and E antigen carriers (–0,9 and –0,8 months to the antigen non-carriers; $p < 0,01$ and $p < 0,05$), as well as in the cows whose blood group lacked antigens C2

(–1,1 months, $p < 0,001$), O', L, H'' (–0,9–1,0 months, $p < 0,01$), I₂, Y₂, E', S₁, H' (–0,6–1,1 months, $p < 0,05$). The shortest service period was observed in the cows having the antigen P'2 (–15,7 days, $p < 0,05$) and those with no antigen L (–17,0 days, $p < 0,05$) (see Table 1).

The cows with the highest life expectancy and the longest period of economic use had V antigen present in their blood (+0,9 years and +5,9 months; $p < 0,001$) and did not have antigen C₂ (+0,9 years; $p < 0,001$ and +9,4 months; $p < 0,01$). In the cows - carriers of O' antigen the period of economic utilization was longer by 5.9 months ($p < 0,05$), when antigen H'' is absent, this period, on the contrary, was 6,5 months shorter ($p < 0,05$) (see Table 2).

The highest number of milking days was found in the cows with antigen V (the difference with cows - non-carriers of the antigen amounted to 298.41 days; $p < 0,001$) and having no antigen H'' (the difference with carrier cows was 169,5 days; $p < 0,05$). The highest lifetime milk yield was in the cows carrying the antigen V (+6036 kg; $p < 0,001$) and in the cows not carrying the antigen I₂ (+3283 kg; $p < 0,05$). The highest milk yield per milking day was observed in the cows with antigen F (+0,8 kg; $p < 0,05$) and in the cows having no antigens G₃, C₂, H' (+0,28–0,41 kg; $p < 0,05–0,01$) (see Table 3).

Also, in terms of lifetime milk yield, the cows carrying antigen W had an advantage (+4142 kg to antigen non-carriers; $p < 0,05$) and antigen C₂ non-carriers (+5751 kg to antigen carriers; $p < 0,01$), I₂ and H'' (3283 and 3766 kg; $p < 0,05$).

The established influence of individual antigens on the reproductive ability, productive longevity and lifetime productivity of cows was confirmed by the analysis of variance: the share of influence of the Y', E antigens on the

age of first calving amounted to 2,7 and 1,7% ($p < 0,05-0,01$), P₂ antigen on the service period – 2,1% ($p < 0,05$), V antigen on the age of cows – 5,2% ($p < 0,001$), V and O' antigens on the duration of economic use – 4,2 and 1,3% ($p < 0,05-0,001$), V antigen on the number of milking days and lifetime milk production – 5,7 and 4,3% ($p < 0,001$), W antigen on lifetime milk production – 1,8% ($p < 0,05$) (see Fig. 2).

CONCLUSION

As a result of the research, it was found that the earliest age of the first calving was in the cows - carriers of antigens Y' and E (–0,9 and –0,8 months), the shortest service period in the carriers of antigen P₂ (–15,7 days). The longest period of economic use was observed in the cows - carriers of antigens V and O' (+5,9 months), the longest lifetime milk production – in the carriers of antigens V and W (+6036 and +4142 kg). The share of influence of these antigens amounted to 1,3–4,3 %.

When carrying out selection and breeding work to increase the period of economic use of Red-and-White cows and improve their reproductive ability, it is necessary to take into ac-

count the influence of antigenic composition of blood groups.

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Табл. 2. Средняя масса телят в эксперименте, кг
Table 2. Average weight of calves in the experiment, kg

Control group		Experimental group	
At birth	Control weighing	At birth	Control weighing
35,368	132,579	24,885	149,605

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ИНФОРМАЦИЯ ОБ АВТОРАХ

Гаджиев И.М. оглы, кандидат ветеринарных наук, ведущий научный сотрудник

✉ **Сизов А.А.**, кандидат биологических наук, ведущий научный сотрудник; **адрес для переписки:** Россия, 630501, Новосибирская область, р.п. Краснообск, а/я 463; e-mail: alexander.sizov62@yandex.ru

Сизов Д.А., научный сотрудник

Стеблева Г.М., кандидат ветеринарных наук, доцент, старший научный сотрудник

Донченко А.С., доктор ветеринарных наук, академик РАН

AUTHOR INFORMATION

Itifat Muzaffar oglu Gadjiev, Candidate of Science in Veterinary Medicine, Lead Researcher

✉ **Alexander A. Sizov**, Candidate of Science in Biology, Lead Researcher; **address:** PO Box 463, Krasnoobsk, Novosibirsk region, 630501, Russia; e-mail: alexander.sizov62@yandex.ru

Dmitry A. Sizov, Researcher

Galina M. Stebleva, Candidate of Science in Veterinary Medicine, Senior Researcher

Alexander S. Donchenko, Doctor of Science in Veterinary Medicine, Academician of the Russian Academy of Sciences

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Влияние иммуногенетических факторов на воспроизводительную способность и продуктивное долголетие коров красно-пестрой породы

(✉) **Зазнобина Т.В., Ефимова Л.В.**

Красноярский научно-исследовательский институт сельского хозяйства – обособленное подразделение Федерального исследовательского центра «Красноярский научный центр Сибирского отделения Российской академии наук»
Красноярск, Россия
(✉) e-mail: tv-kulakova@mail.ru

В настоящее время одним из актуальных направлений научных исследований в отрасли животноводства является выявление определенных генов, влияющих на продуктивные и репродуктивные качества крупного рогатого скота, методом раннего тестирования животных с использованием эритроцитарных антигенов в качестве полиморфных маркеров. В данной работе изучено влияние иммуногенетических факторов на воспроизводительную способность и продуктивное долголетие коров красно-пестрой породы. Для проведения исследований в хозяйстве Красноярского края была сформирована база данных с помощью программы «Селэкс». Данная программа включает сведения о продуктивном долголетии, молочной продуктивности и воспроизводительной способности 305 коров, выбывших из стада с 2019 по 2022 г. и имеющих результаты иммуногенетического тестирования групп крови. Анализировали влияние состава и встречаемости антигенов, имеющих частоту в выборке 0,3 и более, на показатели воспроизводительной способности коров, пожизненной молочной продуктивности и долголетия. Коровы были распределены на носителей и не носителей каждого антигена. Установлено, что наиболее ранний возраст первого отела был у коров – носителей антигенов Y' и E (–0,9 и –0,8 мес), самый короткий сервис-период – у носителей антигена P₂' (–15,7 дня). Наибольший срок хозяйственного использования отмечен у коров – носителей антигенов V и O' (+5,9 мес), наибольший пожизненный удой – у носителей антигенов V и W (+6036 и +4142 кг). Доля влияния этих антигенов составила 1,3–4,3%. При проведении селекционно-племенной работы по увеличению срока хозяйственного использования коров красно-пестрой породы и улучшению их воспроизводительной способности необходимо учитывать влияние антигенного состава групп крови.

Ключевые слова: красно-пестрая порода, антиген, продуктивное долголетие, пожизненный удой, возраст первого отела, сервис-период

Influence of immunogenetic factors on the reproductive ability and productive longevity of Red-and-White cows

(✉) **Zaznobina T. V., Efimova L. V.**

Krasnoyarsk Research Institute of Agriculture – Division of Federal Research Center “Krasnoyarsk Scientific Center of the Siberian Branch of the RAS”
Krasnoyarsk, Russia
(✉) e-mail: tv-kulakova@mail.ru

Currently, one of the most relevant areas of scientific research in the livestock industry is the identification of certain genes that affect the productive and reproductive qualities of cattle by early animal testing using erythrocyte antigens as polymorphic markers. The influence of immunogenetic factors on the reproductive ability and productive longevity of Red-and-White cows has been studied in this work. A database was formed in the farm of the Krasnoyarsk Territory using the program "Selax" to conduct research. This program includes information on the productive longevity, milk production and reproductive performance of 305 cows retired from the herd from 2019 to 2022 with blood group immunogenetic testing results. The influence of the composition and occurrence of the antigens with a sample frequency of 0.3 or more on the reproductive performance of cows, lifetime milk production and longevity was analyzed. Cows were divided into carriers and non-carriers of each antigen. As a re-

sult, it was found that the earliest age of the first calving was observed in the cows carrying antigens Y⁺ and E (–0.9 and –0.8 months), and the shortest service period was in the carriers of antigen P₂⁺ (–15.7 days). The longest period of economic use was noted in the cows carrying antigens V and O⁺ (+5.9 months), the highest lifetime yield was in the carriers of antigens V and W (+6036 and +4142 kg). The share of the effect of these antigens was 1,3–4,3%. It is necessary to take into account the influence of the antigenic composition of blood groups when carrying out breeding work to increase the period of economic use of Red-and-White cows and improve their reproductive ability.

Keywords: Red-and-White breed, antigen, productive longevity, lifetime milk production, age at first calving, service period

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Conflict of interest

The authors declare no conflict of interest.

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INTRODUCTION

Nowadays in the dairy cattle breeding industry scientists and practitioners face the task of increasing milk productivity of cows along with the task of increasing their productive longevity and improving their reproductive capacity.

According to the “Yearbook on breeding work in dairy cattle breeding”, in 2022 the average age of retired cows in agricultural enterprises of the Krasnoyarsk region was 3.15 calvings¹. At the same time, the highest productivity of cows occurs in the fourth – fifth lactation [1], therefore, animals are retired from the herd, not realizing fully their genetic potential, which adversely affects the economic performance of the farms engaged in the breeding of cattle of dairy productivity direction.

At short-term production use of cows, it is necessary to introduce 25–30% and more

high-yielding first heifers into the main herd annually, which becomes impossible at low level of reproduction, calf yield and calf safety [2].

One of the methods of the breeding process is early testing of animals using erythrocyte antigens as polymorphic markers of economically useful traits [3–5]. Immunogenetic analysis allows to reveal the degree of genetic influence of individuals on the total gene pool of the herd, as well as the formation of the allele pool in certain groups of animals [6].

Both foreign scientists² [7–9] and Russian scientists [10–12] are engaged in the study of the genetic structure of cattle populations in order to identify certain genes affecting the economically useful traits of animals.

Positive relationships between the presence of certain antigens and indicators of productive longevity and reproductive ability of cows,

¹Yearbook on breeding work in dairy cattle breeding at the farms of the Russian Federation. Moscow: VNIIPlem, 2023, 84 p.

²Tsuruta S., Lourenco D., Misztal I., Lawlor T.J. Genotype by environment interactions on culling rates and 305-day milk yield of Holstein cows in 3 US regions // *Journal of Dairy Science*, 2015, vol. 98, Is. 8, pp. 5796–5805. DOI: 10.3168/jds.2014-9242.

found in one herd, may not be confirmed in another, because in addition to genetic factors, environmental factors influence these traits.

The purpose of the study was to investigate the influence of immunogenetic factors on the reproductive ability and productive longevity of Red-and-White cows.

MATERIAL AND METHODS

Scientific research was carried out at ZAO “Nazarovskoye”, Krasnoyarsk region. The object of research were Red-and-White cows.

To analyze the relationships of the antigens with productive longevity and reproductive ability, the IAS “Selax” data of the primary breeding record of 305 cows at the farm, which retired from the herd from 2019 to 2022 and had the results of immunogenetic testing of blood groups, were used.

Blood groups were determined according to 11 genetic systems in the laboratory of immunogenetic control of authenticity of animal origin of the OAO “Krasnoyarskagroplem”.

The antigen frequency was determined by the ratio of the number of cows – antigen carriers – to the total number of cows in the sample. In the studies the effect of the composition and occurrence of the antigens with a frequency of 0.3 or more in the sample on the reproductive ability of cows (age of first calving, service period), lifetime milk productivity (lifetime milk yield, milk yield per milking day), longevity (duration of economic use, months; age of retired cows, years) were analyzed. The cows were categorized into carriers and non-carriers of each antigen.

Computer programs “Biometric analysis of quantitative traits in zootechnics” (No. 2021619580, 2021)³ and “Analysis of immunogenetic data of cattle” (No. 2022660011, 2022)⁴ were used for biometric data processing. Reliability of the difference between the groups for quantitative traits was determined by the Stu-

dent's criterion. The share of influence of the antigenic factors (η^2) on the reproductive ability and productive longevity of cows was established by the method of dispersion analysis with the determination of reliability by the Fisher's criterion.

RESULTS AND DISCUSSION

As a result of analyzing the immunogenetic data of cows of the farm, it was found that a total of 74 antigens with frequency (p) from 0.003 to 0.961 and 15 alleles with frequency from 0.003 to 0.033 were found in the cows in blood groups. More frequently ($p > 0,8$) the cows had the antigens B_2 ($0,81 \pm 0,022$), F ($0,961 \pm 0,011$) and H' ($0,872 \pm 0,019$). With a frequency of more than 0.6, the cows had the antigens A_2 ($0,646 \pm 0,027$), B' ($0,705 \pm 0,026$), E'_3 ($0,679 \pm 0,027$), G'' ($0,718 \pm 0,026$), Q' ($0,636 \pm 0,028$), C_2 ($0,672 \pm 0,027$), E ($0,734 \pm 0,025$), X_2 ($0,656 \pm 0,027$), R_2 ($0,613 \pm 0,028$), Z ($0,689 \pm 0,027$), W ($0,685 \pm 0,027$), L ($0,718 \pm 0,026$), with a frequency of more than 0,5 – V ($0,567 \pm 0,028$), F/V ($0,528 \pm 0,029$), O_3 ($0,593 \pm 0,028$), T_2 ($0,584 \pm 0,028$), O' ($0,57 \pm 0,028$), S_1 ($0,534 \pm 0,029$), S_2 ($0,59 \pm 0,028$) (see Fig. 1).

The earliest age of the first calving was observed in the cows - Y' and E antigen carriers ($-0,9$ and $-0,8$ months to the antigen non-carriers; $p < 0,01$ and $p < 0,05$), as well as in the cows whose blood group lacked antigens C_2 ($-1,1$ months, $p < 0,001$), O' , L , H'' ($-0,9$ – $1,0$ months, $p < 0,01$), I_2 , Y_2 , E'_3 , S_1 , H' ($-0,6$ – $1,1$ months, $p < 0,05$). The shortest service period was observed in the cows having the antigen P'_2 ($-15,7$ days, $p < 0,05$) and those with no antigen L ($-17,0$ days, $p < 0,05$) (see Table 1).

The cows with the highest life expectancy and the longest period of economic use had V antigen present in their blood ($+0,9$ years and $+5,9$ months; $p < 0,001$) and did not have antigen C_2 ($+0,9$ years; $p < 0,001$ and $+9,4$ months; $p < 0,01$). In the cows - carriers of O' antigen

³Certificate of state registration of computer program No. 2021619580 (Russian Federation). Biometric analysis of quantitative traits in zootechnics / L.V. Efimova; right holder Federal Research Center “Krasnoyarsk Scientific Center of the Siberian Branch of the Russian Academy of Sciences”; No. 2021618613; applied 04.06.2021; publ. 15.06.2021.

⁴Certificate of state registration of computer program No. 2022660011 (Russian Federation). Analysis of immunogenetic data of cattle: 2022619287 / L.V. Efimova; right holder Federal Research Center “Krasnoyarsk Scientific Center of the Siberian Branch of the Russian Academy of Sciences”; applied 25.05.2022; publ. 27.05.2022.

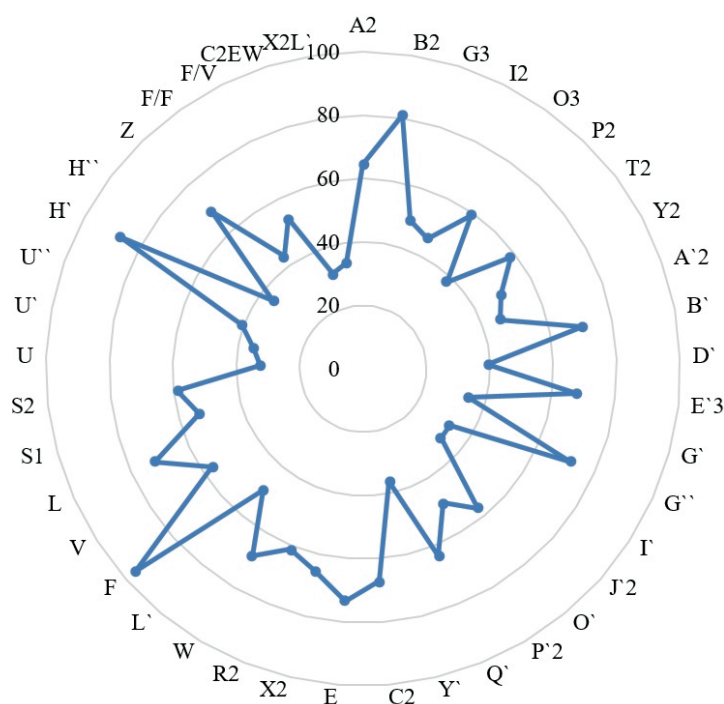


Рис. 1. Частота встречаемости антигенов у коров
Fig. 1. Frequency of antigen occurrence in cows

the period of economic utilization was longer by 5.9 months ($p < 0,05$), when antigen H'' is absent, this period, on the contrary, was 6,5 months shorter ($p < 0,05$) (see Table 2).

The highest number of milking days was found in the cows with antigen V (the difference with cows - non-carriers of the antigen amounted to 298.41 days; $p < 0,001$) and having no antigen H'' (the difference with carrier cows was 169,5 days; $p < 0,05$). The highest lifetime milk yield was in the cows carrying the antigen V (+6036 kg; $p < 0,001$) and in the cows not carrying the antigen I_2 (+3283 kg; $p < 0,05$). The highest milk yield per milking day was observed in the cows with antigen F (+0,8 kg; $p < 0,05$) and in the cows having no antigens G_3 , C_2 , H' (+0,28–0,41 kg; $p < 0,05–0,01$) (see Table 3).

Also, in terms of lifetime milk yield, the cows carrying antigen W had an advantage (+4142 kg to antigen non-carriers; $p < 0,05$) and antigen C_2 non-carriers (+5751 kg to antigen carriers; $p < 0,01$), I_2 and H'' (3283 and 3766 kg; $p < 0,05$).

The established influence of individual antigens on the reproductive ability, productive longevity and lifetime productivity of cows

was confirmed by the analysis of variance: the share of influence of the Y' , E antigens on the age of first calving amounted to 2,7 and 1,7% ($p < 0,05–0,01$), P'_2 antigen on the service period – 2,1% ($p < 0,05$), V antigen on the age of cows – 5,2% ($p < 0,001$), V and O' antigens on the duration of economic use – 4,2 and 1,3% ($p < 0,05–0,001$), V antigen on the number of milking days and lifetime milk production – 5,7 and 4,3% ($p < 0,001$), W antigen on lifetime milk production – 1,8% ($p < 0,05$) (see Fig. 2).

CONCLUSION

As a result of the research, it was found that the earliest age of the first calving was in the cows - carriers of antigens Y' and E (–0,9 and –0,8 months), the shortest service period in the carriers of antigen P'_2 (–15,7 days). The longest period of economic use was observed in the cows - carriers of antigens V and O' (+5,9 months), the longest lifetime milk production – in the carriers of antigens V and W (+6036 and +4142 kg). The share of influence of these antigens amounted to 1,3–4,3 %.

Табл. 1. Частота антигенов и воспроизводительная способность у коров – носителей
и не носителей антигенов

Table 1. Antigen frequency and reproductive capacity in carrier and non-carrier cows

Antigen, allele	heads		Frequency	Age of first calving, months		Service period, days	
	+	–	+	+	–	+	–
1	2	3	4	5	6	7	8
<i>System A</i>							
A ₂	197	108	64,6 ± 2,74	28,6 ± 0,19	28,8 ± 0,26	66,3 ± 4,27	73,2 ± 6,03
B ₂	247	58	81,0 ± 2,25	28,5 ± 0,17	29,3 ± 0,36	69,5 ± 3,94	65,9 ± 7,53
G ₃	150	155	49,2 ± 2,86	28,4 ± 0,20	28,9 ± 0,22	64,9 ± 4,49	72,6 ± 5,32
I ₂	140	165	45,9 ± 2,85	28,3 ± 0,22*	29,0 ± 0,21	68,8 ± 4,78	68,8 ± 4,91
O ₃	181	124	59,3 ± 2,81	28,7 ± 0,19	28,6 ± 0,25	67,9 ± 4,73	70,0 ± 5,13
P ₂	116	189	38,0 ± 2,78	29,0 ± 0,29	28,5 ± 0,17	65,2 ± 5,48	71,1 ± 4,52
T ₂	178	127	58,4 ± 2,82	28,6 ± 0,20	28,7 ± 0,23	68,7 ± 4,59	69,0 ± 5,39
Y ₂	151	154	49,5 ± 2,86	28,3 ± 0,21*	29,0 ± 0,22	66,9 ± 4,10	70,6 ± 5,60
A ₂ '	140	165	45,9 ± 2,85	28,7 ± 0,22	28,7 ± 0,20	72,3 ± 5,36	65,3 ± 4,50
B'	215	90	70,5 ± 2,61	28,8 ± 0,18	28,3 ± 0,29	68,1 ± 3,99	70,5 ± 7,08
<i>System B</i>							
D'	120	185	39,3 ± 2,80	28,7 ± 0,23	28,7 ± 0,20	67,8 ± 5,59	69,4 ± 4,47
E ₃ '	207	98	67,9 ± 2,67	28,4 ± 0,19*	29,2 ± 0,25	65,8 ± 3,82	75,4 ± 7,34
G'	105	200	34,4 ± 2,72	28,6 ± 0,23	28,7 ± 0,20	72,9 ± 6,59	66,6 ± 4,03
G''	219	86	71,8 ± 2,58	28,6 ± 0,17	28,7 ± 0,31	67,4 ± 3,95	72,6 ± 7,31
Γ	99	206	32,5 ± 2,68	28,8 ± 0,28	28,6 ± 0,18	71,8 ± 6,46	67,4 ± 4,15
J ₂	100	205	32,8 ± 2,69	28,5 ± 0,28	28,7 ± 0,18	68,2 ± 6,05	69,0 ± 4,28
O'	174	131	57,0 ± 2,83	28,2 ± 0,18**	29,2 ± 0,25	69,7 ± 4,82	67,5 ± 5,00
P ₂ '	150	155	49,2 ± 2,86	28,5 ± 0,23	28,8 ± 0,20	60,8 ± 3,79*	76,5 ± 5,72
Q'	194	111	63,6 ± 2,76	28,6 ± 0,19	28,8 ± 0,25	66,2 ± 3,76	73,3 ± 6,94
Y'	111	194	36,4 ± 2,76	29,2 ± 0,23	28,3 ± 0,2**	68,4 ± 5,78	69,0 ± 4,39
<i>System C</i>							
C ₂	205	100	67,2 ± 2,69	28,3 ± 0,17***	29,4 ± 0,29	69,9 ± 4,38	67,0 ± 5,78
E	224	81	73,4 ± 2,53	28,9 ± 0,18	28,1 ± 0,26*	69,4 ± 4,09	67,0 ± 6,69
X ₂	200	105	65,6 ± 2,72	28,6 ± 0,19	28,7 ± 0,25	67,2 ± 4,21	72,1 ± 6,24
R ₂	187	118	61,3 ± 2,79	28,6 ± 0,19	28,8 ± 0,26	71,2 ± 4,69	64,9 ± 5,07
W	209	96	68,5 ± 2,66	28,7 ± 0,18	28,5 ± 0,28	70,2 ± 4,39	65,1 ± 5,31
L'	151	154	49,5 ± 2,86	28,8 ± 0,23	28,5 ± 0,20	69,4 ± 5,16	68,2 ± 4,70
<i>System F–V</i>							
F	293	12	96,1 ± 1,11	28,6 ± 0,15	29,2 ± 0,94	69,6 ± 3,60	47,1 ± 7,86
V	173	132	56,7 ± 2,84	28,8 ± 0,20	28,5 ± 0,23	68,3 ± 4,81	69,5 ± 5,01
<i>System L</i>							
L	219	86	71,8 ± 2,58	28,4 ± 0,18**	29,3 ± 0,27	73,6 ± 4,50	56,6 ± 4,43*
S ₁	163	142	53,4 ± 2,86	28,4 ± 0,20*	29,0 ± 0,23	65,2 ± 4,26	72,5 ± 5,55
S ₂	180	125	59,0 ± 2,82	28,8 ± 0,19	28,4 ± 0,24	71,6 ± 4,74	64,6 ± 5,03

End of Table 1

1	2	3	4	5	6	7	8
<i>System S</i>							
U	99	206	32,5 ± 2,68	28,3 ± 0,26	28,8 ± 0,19	62,3 ± 5,47	71,5 ± 4,38
U'	107	198	35,1 ± 2,73	28,7 ± 0,24	28,7 ± 0,20	66,8 ± 5,89	69,9 ± 4,34
U''	124	181	40,7 ± 2,81	28,7 ± 0,24	28,6 ± 0,20	70,6 ± 6,17	67,6 ± 4,17
H'	266	39	87,2 ± 1,91	28,5 ± 0,16*	29,6 ± 0,40	70,4 ± 3,88	58,6 ± 7,07
H''	109	196	35,7 ± 2,74	28,0 ± 0,22**	29,0 ± 0,20	73,2 ± 5,89	66,4 ± 4,33
<i>System Z</i>							
Z	210	95	68,9 ± 2,65	28,5 ± 0,18	29,0 ± 0,29	65,9 ± 3,61	74,7 ± 7,68
<i>System C</i>							
C ₂ EW	96	209	31,5 ± 2,66	28,7 ± 0,26	28,7 ± 0,19	71,2 ± 6,80	67,7 ± 4,03
X ₂ L'	103	202	33,8 ± 2,71	29,0 ± 0,28	28,5 ± 0,18	69,3 ± 6,56	68,5 ± 4,06

Here and in Tables 2, 3:

* $p < 0,05$.

** $p < 0,01$.

*** $p < 0,001$.

Табл. 2. Долголетие коров – носителей и не носителей антигенов

Table 2. Longevity of carrier and non-carrier cows

Antigen, allele	Age, completed years		Duration of economic use, months	
	+	–	+	–
1	2	3	4	5
A ₂	4,6 ± 0,16	4,6 ± 0,21	32,4 ± 1,83	33,0 ± 2,41
B ₂	4,6 ± 0,14	4,8 ± 0,27	32,2 ± 1,65	34,1 ± 3,05
G ₃	4,7 ± 0,19	4,5 ± 0,17	33,9 ± 2,17	31,3 ± 1,94
I ₂	4,3 ± 0,19*	4,9 ± 0,16	29,6 ± 2,26	35,1 ± 1,87
O ₃	4,6 ± 0,17	4,6 ± 0,18	32,6 ± 1,94	32,5 ± 2,19
P ₂	4,7 ± 0,20	4,6 ± 0,16	33,1 ± 2,28	32,2 ± 1,88
T ₂	4,7 ± 0,17	4,6 ± 0,18	33,0 ± 2,02	32,0 ± 2,05
Y ₂	4,6 ± 0,18	4,7 ± 0,17	32,3 ± 2,16	32,8 ± 1,95
A' ₂	4,8 ± 0,20	4,5 ± 0,20	34,6 ± 2,27	30,8 ± 1,90
B'	4,6 ± 0,15	4,8 ± 0,24	31,7 ± 1,69	34,6 ± 2,83
D'	4,8 ± 0,21	4,5 ± 0,16	34,1 ± 2,44	31,6 ± 1,80
E' ₃	4,7 ± 0,16	4,6 ± 0,21	33,2 ± 1,82	31,3 ± 2,40
G'	4,7 ± 0,22	4,6 ± 0,15	33,3 ± 2,52	32,2 ± 1,78
G''	4,6 ± 0,14	4,7 ± 0,26	32,0 ± 1,66	34,1 ± 2,95
I'	4,7 ± 0,24	4,6 ± 0,14	32,7 ± 2,78	32,5 ± 1,69
J' ₂	4,9 ± 0,24	4,5 ± 0,14	35,4 ± 2,79	31,2 ± 1,68
O'	4,8 ± 0,18	4,4 ± 0,17	35,1 ± 2,09	29,2 ± 1,91*
P' ₂	4,8 ± 0,18	4,5 ± 0,18	34,2 ± 2,12	31,0 ± 1,99
Q'	4,6 ± 0,16	4,8 ± 0,20	31,9 ± 1,88	33,8 ± 2,27

End of Table 2				
1	2	3	4	5
Y'	4,5 ± 0,18	4,7 ± 0,17	30,5 ± 2,07	33,8 ± 1,95
C ₂	4,3 ± 0,16***	5,2 ± 0,19	29,5 ± 1,86**	38,9 ± 2,14
E	4,7 ± 0,14	4,5 ± 0,26	32,8 ± 1,66	31,9 ± 2,99
X ₂	4,8 ± 0,16	4,3 ± 0,20*	34,4 ± 1,85	29,1 ± 2,30
R ₂	4,7 ± 0,16	4,4 ± 0,19	34,0 ± 1,90	30,4 ± 2,24
W	4,8 ± 0,15	4,2 ± 0,23*	34,7 ± 1,72	27,9 ± 2,65*
L'	4,7 ± 0,18	4,5 ± 0,18	33,6 ± 2,07	31,6 ± 2,05
F	4,6 ± 0,13	4,8 ± 0,65	32,5 ± 1,48	34,8 ± 7,87
V	5,0 ± 0,17	4,1 ± 0,17***	37,1 ± 2,00	26,6 ± 2,00***
L	4,5 ± 0,14	4,9 ± 0,27	31,8 ± 1,64	34,6 ± 3,03
S ₁	4,5 ± 0,18	4,8 ± 0,17	31,0 ± 2,06	34,4 ± 2,03
S ₂	4,8 ± 0,17	4,4 ± 0,19	34,4 ± 1,92	29,9 ± 2,21
U	4,3 ± 0,22	4,8 ± 0,15	28,9 ± 2,55	34,4 ± 1,76
U'	4,9 ± 0,21	4,5 ± 0,15	35,8 ± 2,51	30,8 ± 1,77
U''	4,4 ± 0,19	4,8 ± 0,16	29,6 ± 2,23	34,6 ± 1,91
H'	4,6 ± 0,14	4,6 ± 0,25	32,7 ± 1,62	31,7 ± 2,63
H''	4,2 ± 0,19*	4,9 ± 0,16	28,4 ± 2,25*	34,9 ± 1,87
Z	4,6 ± 0,16	4,6 ± 0,20	32,6 ± 1,82	32,5 ± 2,38
C ₂ EW	4,8 ± 0,24	4,5 ± 0,15	35,2 ± 2,84	31,4 ± 1,67
X ₂ L'	4,9 ± 0,23	4,5 ± 0,15	34,9 ± 2,68	31,4 ± 1,71

Табл. 3. Пожизненная молочная продуктивность коров – носителей и не носителей антигенов
Table 3. Lifetime milk productivity of antigen carrier and non-carrier cows

Antigen	Milking days, total		Milk yield, kg			
			life-long		for one milking day	
	+	–	+	–	+	–
1	2	3	4	5	6	7
A ₂	1036,3 ± 49,44	1031,8 ± 65,05	18538 ± 1038,4	18817 ± 1370,6	21,6 ± 0,08	21,6 ± 0,12
B ₂	1036,0 ± 45,15	1029,7 ± 78,32	18393 ± 932,8	19677 ± 1774,0	21,5 ± 0,08	21,8 ± 0,16
G ₃	1060,0 ± 58,91	1009,4 ± 52,13	19181 ± 1219,3	18111 ± 1121,8	21,4 ± 0,09**	21,8 ± 0,09
I ₂	1033,6 ± 65,93	1035,5 ± 48,48	16861 ± 1271,5*	20144 ± 1071,6	21,5 ± 0,11	21,6 ± 0,09
O ₃	1049,9 ± 52,85	1013,4 ± 58,65	18673 ± 1104,3	18585 ± 1244,5	21,6 ± 0,09	21,6 ± 0,11
P ₂	1011,5 ± 60,60	1050,1 ± 51,64	18995 ± 1306,7	18418 ± 1068,3	21,6 ± 0,12	21,6 ± 0,08
T ₂	1074,6 ± 55,50	982,1 ± 54,12	18821 ± 1143,6	18379 ± 1176,2	21,6 ± 0,09	21,7 ± 0,11
Y ₂	1031,0 ± 60,00	1038,3 ± 51,26	18440 ± 1226,2	18830 ± 1114,9	21,6 ± 0,10	21,6 ± 0,09

End of Table 3

1	2	3	4	5	6	7
A ₂	1038,5 ± 61,03	1031,1 ± 50,10	19838 ± 1292,9	17618 ± 1061,0	21,6 ± 0,10	21,6 ± 0,10
B ₂	996,8 ± 45,58	1129,3 ± 76,27	18140 ± 959,1	19825 ± 1613,3	21,6 ± 0,08	21,7 ± 0,12
D ₂	1122,5 ± 65,68	981,1 ± 48,60	19554 ± 1390,8	18043 ± 1022,1	21,6 ± 0,11	21,6 ± 0,08
E ₂	1037,4 ± 49,49	1028,8 ± 63,14	18879 ± 1028,2	18126 ± 1384,8	21,5 ± 0,08	21,7 ± 0,13
G ₂	1053,6 ± 67,73	1024,7 ± 48,34	19264 ± 1466,1	18308 ± 1000,2	21,7 ± 0,13	21,5 ± 0,08
G ₂	999,5 ± 44,88	1129,8 ± 79,67	18302 ± 948,9	19490 ± 1665,6	21,6 ± 0,08	21,6 ± 0,14
I ₂	1091,5 ± 78,41	1009,6 ± 44,84	18719 ± 1583,2	18598 ± 961,4	21,5 ± 0,14	21,6 ± 0,08
J ₂	1159,1 ± 74,27	976,6 ± 45,49*	20198 ± 1577,6	17876 ± 957,6	21,5 ± 0,11	21,6 ± 0,08
O ₂	1101,8 ± 56,33	941,8 ± 50,81*	20026 ± 1178,9	16793 ± 1103,5	21,5 ± 0,09	21,7 ± 0,11
P ₂	1088,7 ± 56,09	982,5 ± 54,86	19537 ± 1197,4	17766 ± 1140,9	21,6 ± 0,10	21,6 ± 0,10
Q ₂	1016,7 ± 51,74	1065,8 ± 59,32	18089 ± 1053,7	19595 ± 1330,7	21,5 ± 0,08	21,8 ± 0,12
Y ₂	964,8 ± 54,39	1074,5 ± 53,18	17497 ± 1189,9	19289 ± 1106,5	21,6 ± 0,11	21,6 ± 0,09
C ₂	1007,4 ± 53,76	1078,7 ± 55,02	16751 ± 1044,1**	22503 ± 1252,7	21,5 ± 0,09*	21,8 ± 0,11
E ₂	1029,2 ± 44,50	1051,0 ± 83,30	18853 ± 948,1	18040 ± 1685,5	21,6 ± 0,08	21,5 ± 0,13
X ₂	1066,0 ± 49,63	970,1 ± 63,02	19679 ± 1051,8	16653 ± 1308,3	21,6 ± 0,08	21,6 ± 0,12
R ₂	1065,5 ± 50,92	984,2 ± 61,49	19338 ± 1070,6	17526 ± 1297,6	21,5 ± 0,08	21,7 ± 0,11
W ₂	1060,7 ± 45,26	968,6 ± 78,24	19941 ± 982,3	15799 ± 1491,1*	21,6 ± 0,08	21,6 ± 0,13
L ₂	1045,4 ± 54,98	1023,6 ± 56,37	19296 ± 1186,5	17991 ± 1153,2	21,7 ± 0,10	21,5 ± 0,09
F ₂	1029,5 ± 40,16	1174,2 ± 201,68	18612 ± 845,3	19262 ± 4275,7	21,6 ± 0,07	20,8 ± 0,32*
V ₂	1159,8 ± 51,46	861,4 ± 56,86***	21249 ± 1133,5	15213 ± 1137,9***	21,6 ± 0,08	21,6 ± 0,11
L ₂	1007,8 ± 43,89	1103,2 ± 83,13	18178 ± 930,3	19807 ± 1729,8	21,6 ± 0,08	21,5 ± 0,12
S ₁	1028,3 ± 58,04	1041,3 ± 53,00	17700 ± 1173,4	19713 ± 1154,6	21,6 ± 0,08	21,6 ± 0,11
S ₂	1070,3 ± 51,00	980,3 ± 61,48	19681 ± 1095,5	17134 ± 1249,7	21,6 ± 0,08	21,6 ± 0,12
U ₂	915,6 ± 74,00	1055,0 ± 46,67	16612 ± 1463,2	19610 ± 997,0	21,7 ± 0,12	21,6 ± 0,08
U ₂	1105,5 ± 65,97	994,4 ± 48,76	20471 ± 1426,7	17646 ± 1009,0	21,5 ± 0,11	21,6 ± 0,09
U ₂	981,9 ± 61,92	1068,1 ± 50,76	17031 ± 1262,2	19737 ± 1087,3	21,7 ± 0,11	21,5 ± 0,09
H ₂	1050,2 ± 44,48	937,1 ± 59,62	18680 ± 921,0	18344 ± 1548,2	21,5 ± 0,07*	21,9 ± 0,16
H ₂	924,0 ± 62,44*	1093,5 ± 49,70	16217 ± 1279,1*	19983 ± 1061,9	21,5 ± 0,13	21,7 ± 0,08
Z ₂	1055,7 ± 50,06	991,5 ± 61,91	18621 ± 1028,2	18673 ± 1377,7	21,6 ± 0,08	21,6 ± 0,13
C ₂ EW	1104,1 ± 77,34	1002,3 ± 44,85	20029 ± 1590,2	17998 ± 959,5	21,5 ± 0,12	21,6 ± 0,08
X ₂ L ₂	1085,6 ± 72,46	1007,7 ± 46,26	20025 ± 1536,2	17929 ± 970,7	21,6 ± 0,12	21,6 ± 0,08

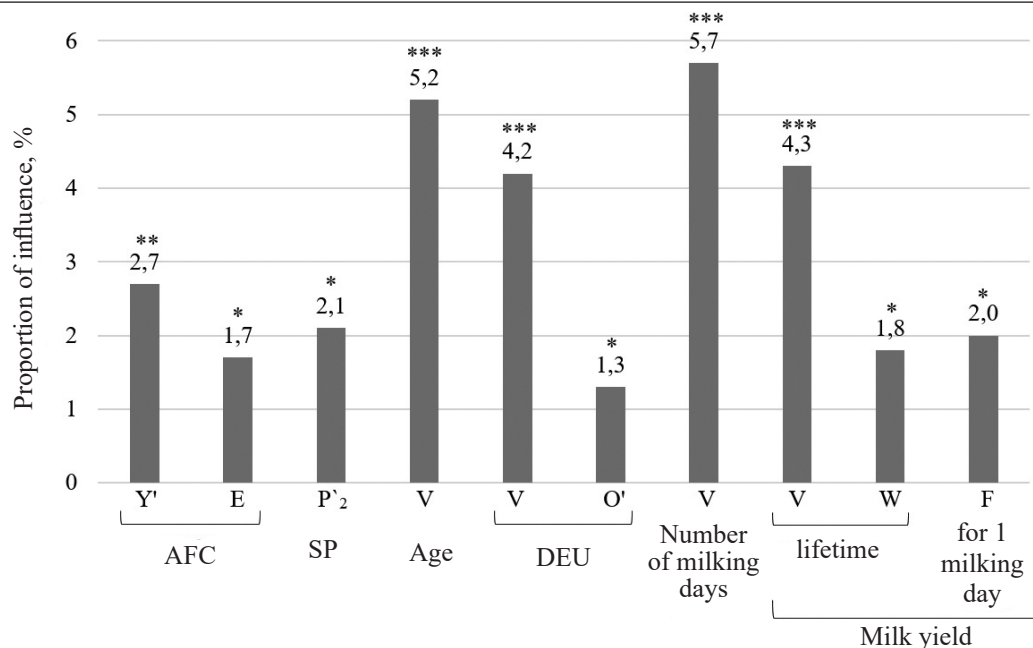


Рис. 2. Доля влияния антигенных факторов на воспроизводительную способность, продуктивное долголетие и пожизненный удой коров

Примечание. ВПО – возраст первого отела; СП – сервис-период; ПХИ – продолжительность хозяйственного использования.

Fig. 2. Proportion of influence of antigenic factors on the reproductive capacity, productive longevity and lifetime milk yield of cows

Note. AFC – age of first calving; SP – service period; DEU – duration of economic use

When carrying out selection and breeding work to increase the period of economic use of Red-and-White cows and improve their reproductive ability, it is necessary to take into account the influence of antigenic composition of blood groups.

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ИНФОРМАЦИЯ ОБ АВТОРАХ

✉ **Зазнобина Т.В.**, научный сотрудник;
адрес для переписки: Россия, 660041, Красно-
ярск, пр. Свободный, 66; e-mail: tv-kulakova@
mail.ru

Ефимова Л. В., кандидат сельскохозяйствен-
ных наук, ведущий научный сотрудник

AUTHOR INFORMATION

✉ **Tatiana V. Zaznobina**, Researcher; **address:**
66, Svobodny ave., Krasnoyarsk, 660041, Russia;
e-mail: tv-kulakova@mail.ru

Lubov V. Efimova, Candidate of Science in Ag-
riculture, Lead Researcher

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Гематологические показатели коров при разных схемах использования биодобавки Ламарин Saldonum

✉ Шемуранова Н.А.¹, Гарифуллина Н.А.¹, Филатов А.В.², Сапожников А.Ф.²

¹Федеральный аграрный научный центр Северо-Востока им. Н.В. Рудницкого
Киров, Россия

²Вятский государственный агротехнологический университет
Киров, Россия

✉ e-mail: nashem85@yandex.ru

Представлены результаты исследования, проводимого с целью установить влияние разных схем применения биодобавки Ламарин Saldonum на организм высокопродуктивных коров в период раздоя. Научно-хозяйственный опыт проводили на базе племенного хозяйства, расположенного в Котельничском районе Кировской области. Для эксперимента были сформированы три опытные группы коров ($n = 10$), получавших добавку Ламарин Saldonum в дозе 0,4 г/кг живой массы в сутки в течение 60 дней. В 1-й группе (схема 1) скормливание добавки начали за 30 дней до предполагаемой даты отела, во 2-й группе (схема 2) – за 60 дней, в 3-й (схема 3) – в день отела. Для оценки влияния разных схем применения фитодобавки на организм животных использовали морфологические и биохимические показатели их крови. Забор крови проводили дважды: через 30 и 60 дней после отела. В ходе исследований установлено, что наиболее оптимально для сохранения здоровья коров в период раздоя начинать скормливание изучаемой добавки за 30 дней до предполагаемого отела (схема 1). Такая схема применения оказывает благоприятное влияние на организм животных в период раздоя, о чем свидетельствует более высокое содержание гемоглобина по сравнению со 2-й опытной группой (превышение на 13,81%, $p < 0,05$), достоверно больший уровень общего белка (на 7,92 и 16,62%), глобулинов (на 20,09 и 43,88%), глюкозы (на 70,06 и 86,84%), кальция (на 13,90 и 23,43%) в первый месяц лактации по сравнению со 2-й и 3-й группами, снижение количества мочевины (на 39,45 и 58,70%) и фосфора (на 50,84 и 66,59%), а также аланинаминотрансферазы (на 22,15%) в сравнении с 3-й группой в этот же период.

Ключевые слова: кровь, морфологические показатели, биохимические показатели, ламинария японская, расторопша пятнистая

Hematological parameters of cows with different schemes of using the dietary supplement Lamarin Saldonum

✉ Shemuranova N.A.¹, Garifullina N.A.¹, Filatov A.V.², Sapozhnikov A.F.²

¹Federal Agrarian Scientific Center of the North-East named after N.V. Rudnitsky
Kirov, Russia

²Vyatka State Agrotechnological University
Kirov, Russia

✉ e-mail: nashem85@yandex.ru

The results of the research conducted to establish the effect of different schemes of Lamarin Saldonum bio supplement application on the organism of high-yielding cows during days in milk are presented. Scientific and economic experience was carried out on the basis of a breeding farm located in the Kotelnichsky district of the Kirov region. For the experiment, three experimental groups of cows ($n = 10$) receiving Lamarin Saldonum supplement at a dose of 0.4 g/kg live weight per day for 60 days were formed. In group 1 (scheme 1) feeding of the supplement was started 30 days before the expected calving date, in group 2 (scheme 2) – 60 days, in group 3 (scheme 3) – on the day of calving. Morphological and biochemical indices of their blood were used to evaluate the effect of different schemes of phyto supplement application on the organism of the animals. Blood sampling was performed twice: 30 and 60 days after the calving. It was found in the course of the research that the most optimal way to preserve the health of cows during the days in milk is to start feeding the studied supplement 30 days before the expected calving (scheme 1). This scheme of application has a favorable effect on

the organism of the animals during days in milk, as evidenced by a higher hemoglobin content compared to the 2nd experimental group (an excess of 13.81%, $p < 0.05$), a significantly higher level of total protein (by 7.92 and 16.62%), globulins (by 20.09 and 43.88%), glucose (by 70.06 and 86.84%), calcium (by 13.90 and 23.43%) in the first month of lactation in comparison with the 2nd and 3rd groups, decrease of urea (by 39.45 and 58.70%) and phosphorus (by 50.84 and 66.59%), as well as alanine aminotransferase (by 22.15%) in comparison with the 3rd group in the same period.

Keywords: blood, morphological parameters, biochemical parameters, sea tangle, blessed milk thistle

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Conflict of interest

The authors declare no conflict of interest.

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INTRODUCTION

High milk productivity of cows is inextricably linked to the intensity of metabolic processes in their body and the balance of the diet in nutrients and biologically active substances. Often metabolic disorders caused by nutritional factors, at the initial stage do not have pronounced clinical manifestations, which complicates their early diagnosis and leads to the development of serious pathologies [1–3].

The main informative markers of animal health are morphological and biochemical blood parameters [4]. It is recommended to monitor them when predicting the future productivity of purebred and crossbred animals [5], assessing the impact of climatic conditions [6, 7] and housing conditions [8]. Hematological studies can also be used to determine the adequacy of animal nutrition [9], diagnose disorders of protein, carbohydrate and mineral metabolism [10], timely eliminate the detected deviations by means of diet correction and develop appro-

priate preventive measures. In addition, these studies are necessary in determining the degree of influence on the organism and the effectiveness of the use of new drugs [11, 12], medicinal compositions [13], feed products and biologically active additives [14, 15].

One such supplement is Saldonum lamarinum. It consists of Japanese kelp, milk thistle, and lactic acid used as an extracting agent. Tests conducted earlier showed that this additive has a stimulating effect on the body of animals. Thus, when using it in the feeding of high-yielding cows an increase in their productivity and improvement of reproductive function were observed [16].

The purpose of the study was to evaluate the morphobiochemical status of blood of dairy cows during the milking period at different schemes of use of biologically active supplement Lamarin Saldonum.

Scientific novelty of the work consists in the fact that for the first time the effect on the organ-

ism of high-yielding cows during the milking period of herbal bio-additive Lamarin Saldonum when administered in different physiological periods has been established.

MATERIAL AND METHODS

The study was conducted in 2021 in one of the breeding farms of the Kotelnichsky district of the Kirov region. Four groups of high-yielding cows of the Black-and-White Holstein breed at the age of 2–5 lactation with an average milk yield for the last completed lactation of 7500 kg were formed for scientific and economic experiment by the method of analogous groups. There were 10 cows in each group.

The studied feed additive was introduced into the diet of dairy cows at a dose of 0.4 g/kg body weight daily. Three schemes of bioadditive application were used. According to scheme 1 (1st group), feeding Lamarin Saldonum was started 30 days before the expected calving date. According to the scheme 2 (2nd group) the supplement was administered 60 days before the expected date of calving. According to scheme 3 (3rd group) feeding of the supplement was started on the day of the calving. In all three schemes, the total duration of phytosupplementation was 60 days (see Table 1).

To determine the effect of different schemes of application of the studied additive on the organism of the animals, morphological and biochemical studies of blood were carried out. Blood was collected from the tail vein 4 hours after morning feeding. Blood was studied twice: 30 and 60 days after the calving. Blood morphological parameters were determined using hematological analyzer Abacus Junior B (Diatron, Austria). Biochemical studies of blood serum were performed on an iMagic V7 biochemical analyzer (iCUBIO, China). Standard reagents and approved methods were used for each analyzer. Blood counts were evaluated using reference values reported in the reference literature ^{1,2}.

Табл. 1. Схема эксперимента

Table 1. Scheme of the experiment

Group	Number of cows, heads	Scheme of feeding the phytonutrient
1st	10	BD + Lamarin Saldonum at a dose of 0.4 g/kg live weight 30 days before the expected calving date and within 30 days thereafter
2nd	10	BD + Lamarin Saldonum at a dose of 0.4 g/kg live weight 60 days before the expected calving date for 60 days
3rd	10	BD + Lamarin Saldonum at a dose of 0.4 g/kg live weight starting from the day of calving for 60 days

Note. BD – basic diet adopted at the enterprise and corresponding to the physiological condition of the animals.

RESULTS AND DISCUSSION

The internal environment of the organism, possessing relative constancy, reacts quickly enough to qualitative and quantitative changes in the diet, including the intake of new biologically active substances with feed. The study showed that the use of different schemes of feeding Lamarin Saldonum bioadditive had no significant effect on the morphological parameters of blood of the experimental animals. Minor deviations from the physiological norm were recorded in all three groups (see Table 2). However, it should be noted that the lowest hemoglobin content at the end of the first month of lactation was registered in group 2 of the animals, which were fed the supplement 60 days before calving. According to this indicator they were inferior to cows of the 1st group by 13,81% ($p < 0,05$), 3rd group by 8,45%. In the next month of lactation, hemoglobin concentration increased and returned to the physiological norm, which is probably related to the recovery of mother cows after childbirth. In the 1st and 3rd groups, receiving the phytosupplement Lamarin Saldonum in the first month after calving contributed to the maintenance of hemoglobin level within physiological values.

¹Kondrakhin I.P. Methods of veterinary clinical laboratory diagnostics: reference book. Moscow: Kolos, 2004, 520 p.

²Shestakova A.N., Sapozhnikov A.F., Varaksina J.V. Clinical evaluation of the results of laboratory tests in veterinary practice: textbook. Kirov, 2009, 68 p.

Табл. 2. Морфологические показатели крови коров при разных схемах применения биодобавки Ламарин Saldonum (*n* = 10)

Table 2. Morphological parameters of cows' blood at different schemes of Lamarin Saldonum bio supplement application (*n* = 10)

Indicator	Norm	Group		
		1st	2nd	3rd
Hemoglobin, g/l	90,0–120,0	95,60 ± 2,62	84,00 ± 3,53 ²	91,10 ± 3,07
		91,90 ± 2,78	91,70 ± 2,18	94,44 ± 1,97
Erythrocytes, × 10 ¹² /l	5,0–8,0	5,13 ± 0,16	4,97 ± 0,22	4,95 ± 0,17
		5,20 ± 0,18	5,19 ± 0,22	5,20 ± 0,15
Leukocytes, × 10 ⁹ /l	4,5–12,0	12,37 ± 1,19	13,93 ± 1,46	13,23 ± 0,85
		12,74 ± 1,30	12,44 ± 1,13	8,86 ± 0,51 ^{1, 2}

Notes: 1. In the numerator – 1 month after calving, in the denominator – 2 months after calving. 2. The differences are reliable: at 1p < 0,001 relative to the previous eigenvalues; 2p < 0,05 relative to group 1 in the same period.

In terms of erythrocyte count, all three experimental groups had no statistically significant differences both in the first and second month of lactation. As for the content of leukocytes, the changes were observed in the 3rd group, where Lamarin Saldonum was applied from the first day after calving. In the second month of lactation in cows of this group there was a decrease in the number of leukocytes in relation to their own values of the first month by 33,03% (*p* < 0,001), in relation to similar values of the 1st group by 43,79% (*p* < 0,05). The increase in leukocyte content is characteristic of cows after calving and is associated with the restructuring of the organism from the process of carrying the fetus to milk production, as well as with the occurrence of metabolic pathologies, the cases of which are more frequent in highly productive animals. Application of biologically active supplement during the first two months of lactation in the 3rd group promoted a more physiological course of the postpartum period, rapid completion of involutional processes in the genital organs, as evidenced by the return of morphological blood parameters to the limits of normal by the end of the second month of lactation.

When studying the biochemical parameters of blood serum of cows on the background of different schemes of Lamarin Saldonum supplementation, their changes were established, which in some cases had statistical significance

(see Table 3). The intensity of protein metabolism in the body of cows was estimated by the indicators of total protein, its albumin and globulin fractions and urea. The content of total protein in all the experimental groups was within the limits of physiological norm, the lowest index was registered in cows of the 3rd group in the first month of lactation: in relation to the 1st group in the same period the level of total protein was lower by 16,62% (*p* < 0,001), in relation to the 2nd group by 8,05% (*p* < 0,05). In the second month of lactation in the 1st and 2nd groups there was a slight decrease in the studied index in relation to the initial values without statistical significance, which is due to the growing needs of the organism in components for milk synthesis.

The level of albumin in the blood serum of cows reflects the provision of protein in the diet, and globulin fractions of protein indicate the protective properties of the organism. In our study, the content of albumin in cows in the first two months of lactation in all groups was at the level of the upper limit of physiological norm or slightly exceeded it. The concentration of globulin fractions in blood serum, on the contrary, tended to the lower limit of reference values. The exception was the animals of the 1st group in the first month of lactation, whose blood had a maximal content of globulins. The lowest level of globulins was recorded in group 3 in

Табл. 3. Биохимические показатели сыворотки крови коров при разных схемах применения биодобавки Ламарин Saldonum ($n = 10$)

Table 3. Biochemical parameters of blood serum of cows with different schemes of the bio supplement Lamarin Saldonum application ($n = 10$)

Indicator	Norm	Group		
		1st	2nd	3rd
Total protein, g/l	60,0–86,0	$81,96 \pm 1,99$ $76,33 \pm 2,63$	$75,94 \pm 1,65^4$ $74,07 \pm 2,34$	$70,28 \pm 2,07^{6,7}$ $72,42 \pm 2,25$
Albumin, g/l	27,5–39,4	$38,81 \pm 0,46$ $40,60 \pm 0,73$	$40,01 \pm 0,58$ $39,54 \pm 0,73$	$40,29 \pm 0,75$ $40,28 \pm 0,56$
Globulins, g/l	32,5–46,6	$43,15 \pm 1,83$ $35,73 \pm 2,62^1$	$35,93 \pm 1,74^4$ $34,53 \pm 1,91$	$29,99 \pm 2,55^6$ $32,14 \pm 2,10$
Urea, mmol/l	3,0–8,8	$3,99 \pm 0,34$ $7,79 \pm 0,38^3$	$6,59 \pm 0,74^5$ $8,85 \pm 0,70^1$	$9,66 \pm 0,42^{6,8}$ $9,68 \pm 0,37^5$
Glucose, mmol/l	2,0–4,0	$2,84 \pm 0,11$ $1,51 \pm 0,10^3$	$1,67 \pm 0,08^6$ $1,50 \pm 0,07$	$1,52 \pm 0,09^6$ $1,58 \pm 0,09$
Total cholesterol, mmol /l	1,30–4,42	$4,73 \pm 0,27$ $5,06 \pm 0,26$	$4,17 \pm 0,38$ $5,04 \pm 0,36$	$4,44 \pm 0,34$ $4,24 \pm 0,16^4$
Alkaline phosphatase, units/l	30,0–150,0	$95,14 \pm 6,86$ $71,90 \pm 6,08^1$	$66,56 \pm 9,18^4$ $85,53 \pm 8,02$	$82,19 \pm 9,73$ $77,49 \pm 10,24$
AST, units/l	45,0–110,0	$85,46 \pm 5,33$ $79,88 \pm 7,33$	$90,04 \pm 6,62$ $86,38 \pm 5,07$	$89,98 \pm 10,87$ $95,69 \pm 7,89$
ALAT, units/l	5,0–40,0	$18,56 \pm 0,80$ $21,49 \pm 1,63$	$17,88 \pm 1,92$ $24,36 \pm 2,14^1$	$23,84 \pm 1,67^{4,7}$ $25,28 \pm 0,98$
de Ritis coefficient	2,75–9,00	$4,66 \pm 0,34$ $3,82 \pm 0,30$	$5,38 \pm 0,51$ $3,74 \pm 0,34^1$	$3,83 \pm 0,38^7$ $3,80 \pm 0,30$

Notes: 1. In the numerator – 1 month after calving, in the denominator – 2 months after calving. 2. The differences are reliable: at $1p < 0,05$, $2p < 0,01$, $3p < 0,001$ relative to the previous eigenvalues; $4p < 0,05$, $5p < 0,01$, $6p < 0,001$ relative to group 1 in the same period; $7p < 0,05$, $8p < 0,01$ relative to group 2 in the same period.

the first month of lactation: the difference with the values of group 1 of the same period was 43.88% ($p < 0.001$), group 2–19.81%.

Another indicator characterizing the intensity of protein metabolism is the concentration of urea in blood serum. Its highest level was registered in the blood of animals of the 3rd group. In the first month of lactation, the value of this indicator exceeded the values of the 1st and 2nd groups, respectively, 2.42 ($p < 0.001$) and 1.46 times ($p < 0.01$). In the second month of lactation, urea content in the blood of the animals of all groups increased. If in group 3 the growth of this index was insignificant, in groups 1 and 2 the changes were reliable and amounted to 95.24 ($p < 0.001$) and 34.29% ($p < 0.05$), respectively, in relation to their own previous values. At the same time, reliable differences between the groups during this period were registered only in group 1 in relation to group 3 (the difference

was 19.52% ($p < 0.01$) in favor of the latter).

High concentration of urea in blood serum at the simultaneous low content of glucose may indicate an imbalance in the energy-protein ratio of the diet. In our study the level of glucose in blood serum of cows only in the 1st group in the first month of lactation corresponded to the physiological norm with a subsequent sharp decrease by the end of the second month of lactation by 46.83% ($p < 0.001$). In the other two groups, the values of the studied index were below the physiological norm and ranged from 1.50 ± 0.07 to 1.67 ± 0.08 mmol/l.

Low glucose content in cows during the milking period may be due to the discrepancy between the actual consumption of the nutrients from the feed and their expenditure on the processes of vital activity and milk formation, because even if all the currently known requirements for balanced diets are met, ani-

mals are physically unable to consume a sufficient amount of feed. It can be assumed that the use of the studied supplement 30 days before calving for 60 days allowed in the first month of lactation to level out the energy imbalance observed in the animals of the other two groups.

The body compensates for the lack of energy in the diet by consuming fats. In our study, during lactation in the 1st and 2nd groups, an increase in total cholesterol in relation to its own values was observed by 6.98 and 20.86%, respectively, but without statistical significance. In the 3rd group, where Lamarin Saldonum was used from the day of calving, there was a decrease in the level of total cholesterol in the second month of lactation both in relation to their own values (by 4.50%) and in comparison, with the 1st and 2nd groups in the same period (by 19.34 ($p < 0.05$) and 18.87%).

The intensity of protein, carbohydrate and lipid metabolism is inextricably linked to the functional state of the liver. The activity of alkaline phosphatase (ALKP), aspartate aminotransferase (ASAT) and alanine aminotransferase (ALAT) in all three groups was within normal values both in the first and second month of lactation. Among statistically significant changes a decrease in ALAT activity by 24.43% ($p < 0.05$) in the cows of the 1st group in the second month of lactation can be noted, as well as a higher ALAT indicator in the 3rd group in the first month: exceeding the indicators of the 1st and 2nd groups by 22.15 ($p < 0.05$) and 25.00% ($p < 0.05$), respectively. In the second month of lactation, an increase in ALAT activity was observed in all three groups.

De Ritis ratio is used for differentiated diagnostics at detection of any deviations in the activity of aminotransferases. In our study no deviations of ASAT and ALAT indices from the norm were detected, therefore, the de Ritis ratio did not go beyond the norm.

Thus, feeding of biologically active supplement Lamarin Saldonum regardless of the scheme of application had a positive effect on

the functional state of the liver of dairy cows, which is especially important in the period after calving, when simultaneously with the growth of milk productivity in the body of animals the recovery processes after childbirth and resumption of sexual cycles occur.

To assess the process of mineral metabolism, the content in blood serum of calcium and phosphorus, as well as a number of trace elements: copper, zinc, iron and magnesium was studied (see Table 4). The lowest amount of calcium was recorded in the blood of animals of group 3 in the first month of lactation: it was lower than the same indicator of groups 1 and 2, respectively, by 23.43 ($p < 0.001$) and 8.37% ($p < 0.05$). In the second month of milking in the groups where one month or more had passed since the end of Lamarin Saldonum supplementation (schemes 1 and 2), a decrease in the amount of calcium was observed. So, in relation to own values in the 1st group the decrease of the index amounted to 11.53% ($p < 0.001$), in the 2nd group it was 6.18% ($p < 0.05$). In group 3, where Lamarin Saldonum was fed during the first two months of lactation, the calcium level increased in relation to its own values by 7.95% ($p < 0.05$) and entered the limits of physiological norm.

Dynamics of inorganic phosphorus content in blood serum of cows differed from the dynamics of calcium parameters. Compliance with the physiological norm was observed only in the animals that received the supplement at the time of blood sampling for two months: group 1 in the first month of lactation, group 3 in the second. In other periods of the study, the phosphorus content exceeded the reference values in cows of the 2nd group that received the supplement during the dry period. The combination of high phosphorus concentration with calcium concentration tending to the lower limit of physiological norm led to the formation of extremely low calcium-phosphorus ratio, which only in cows of group 1 in the first month of lactation was close to the optimal value, while in

Табл. 4. Динамика показателей крови, связанных с минеральным обменом веществ, на фоне разных схем использования Ламарин Saldonum ($n = 10$)

Table 4. Dynamics of blood parameters of cows related to mineral metabolism against the background of different schemes of Lamarin Saldonum application ($n = 10$)

Indicator	Norm	Group		
		1st	2nd	3rd
Calcium, mmol/l	2,5–3,8	$2,95 \pm 0,04$ $2,61 \pm 0,03^2$	$2,59 \pm 0,05^3$ $2,43 \pm 0,03^{1,4}$	$2,39 \pm 0,07^{4,5}$ $2,58 \pm 0,05^{1,5}$
Phosphorus, mmol/l	1,4–2,9	$1,47 \pm 0,14$ $3,01 \pm 0,20^2$	$2,99 \pm 0,07^4$ $3,26 \pm 0,15$	$4,40 \pm 0,08^{4,6}$ $1,65 \pm 0,09^{2,4,6}$
Calcium-phosphorus ratio	2 : 1	$2,13 \pm 0,16$ $0,89 \pm 0,06^2$	$0,87 \pm 0,03^4$ $0,76 \pm 0,03^1$	$0,55 \pm 0,02^{4,6}$ $1,61 \pm 0,11^{2,4,6}$
Magnesium, mmol/l	0,82–1,23	$0,98 \pm 0,04$ $1,00 \pm 0,07$	$1,05 \pm 0,04$ $0,98 \pm 0,05$	$1,08 \pm 0,03$ $0,97 \pm 0,03^1$
Iron, $\mu\text{mol/l}$	17,90–28,64	$15,77 \pm 2,10$ $15,87 \pm 2,75$	$15,41 \pm 1,73$ $14,30 \pm 1,86$	$20,55 \pm 1,28^5$ $21,72 \pm 1,43^{3,5}$
Zinc, $\mu\text{mol/l}$	15,30–22,95	$13,64 \pm 0,81$ $13,84 \pm 1,36$	$12,31 \pm 0,95$ $11,78 \pm 0,77$	$11,54 \pm 0,35^3$ $11,20 \pm 0,55$
Copper, $\mu\text{mol/l}$	12,60–18,90	$19,50 \pm 0,80$ $24,14 \pm 0,86^2$	$35,82 \pm 1,73^4$ $20,94 \pm 1,15^{2,3}$	$24,14 \pm 1,43^{3,6}$ $17,40 \pm 0,55^{2,4,5}$

Notes: 1. In the numerator – 1 month after calving, in the denominator – 2 months after calving. 2. The differences are reliable: at $1p < 0,05$, $2p < 0,001$ relative to the previous eigenvalues; $3p < 0,05$, $4p < 0,001$ relative to group 1 in the same period; $5p < 0,05$, $6p < 0,001$ relative to group 2 in the same period.

groups 2 and 3 in this period it was significantly lower by 2.45 and 3.87 times, respectively.

The obtained data indicate that there was a violation of calcium-phosphorus metabolism in the animals of all groups during the milking period. The use of biologically active additive in accordance with scheme 1 had a positive effect on the balance of calcium and phosphorus in the body of cows in the first month of lactation.

No significant differences in magnesium content between the groups were noted.

Zinc content in the serum of cows did not reach the lower limit of physiological norm. Significant differences were observed only in the first month of lactation between the 1st and 3rd groups and amounted to 18,20% ($p < 0,05$) in favor of the 1st group. Iron deficiency was also observed in the animals of the first two groups within 11,34–20,11% of the physiological norm. In group 3 the iron content corresponded to the reference values both in the first and second month of lactation.

Excess copper was recorded in the blood serum of the cows of all groups. The index of group 1 was closest to physiological values in the first month of milking, in group 3 in the second month.

CONCLUSION

The results of the conducted studies showed that a stronger positive effect on morphobiochemical composition of blood of dairy cows, and, accordingly, on the physiological state of the animals had the use of the supplement according to the scheme 1 – the beginning of feeding 30 days before the expected calving at the total duration of feeding for 60 days (group 1). Despite the enormous load on the body of cows in the form of childbirth and the subsequent increase in milk synthesis during the milking period, the use of the supplement according to the specified scheme allowed stabilizing the condition of the animals to a greater

extent, keeping most of the studied indicators within the physiological norm (especially in the first month of lactation). This is confirmed by: higher hemoglobin level in comparison with the 2nd experimental group (13.81% excess, $p < 0.05$); reliable increase in the level of total protein, globulins, glucose in the first month of lactation in comparison with the 2nd and 3rd groups (respectively by 7.92 and 16.62; 20.09 and 30.50; 70.06 and 86.84%); decrease of urea concentration in comparison with the 2nd (by 39.45%) and 3rd groups (by 58.70%), as well as ALAT in comparison with the 3rd group (by 22.15%). These differences are statistically significant. In addition, the use of the supplement according to scheme 1 contributed to the normalization of calcium-phosphorus metabolism in the body of cows in the first month of lactation. This is confirmed by a reliable increase in the calcium content in the 1st group during this period in relation to the 2nd and 3rd groups by 13.90 and 23.43%, respectively, and a decrease in the phosphorus level during the same period by 50.84 and 66.59%.

Positive moments of biologically active supplement application according to the third scheme (beginning of feeding on the day of calving), namely normalization of morphological blood parameters, increase of iron content in blood serum, improvement of calcium-phosphorus metabolism should also be noted. All these changes were achieved by the end of the second month of Lamarin Saldonum feeding.

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ИНФОРМАЦИЯ ОБ АВТОРАХ

✉ Шемуранова Н.А., кандидат сельскохозяйственных наук, заведующая лабораторией, старший научный сотрудник; **адрес для переписки:** Россия, 610007, г. Киров, ул. Ленина, 166а; e-mail: nashem85@yandex.ru

Гарифуллина Н.А., младший научный сотрудник

Филатов А.В., доктор ветеринарных наук, профессор

Сапожников А.Ф., кандидат ветеринарных наук, доцент

AUTHOR INFORMATION

✉ **Natalia A. Shemuranova**, Candidate of Science in Agriculture, Laboratory Head, Senior Researcher; **address:** 166a, Lenina St., Kirov, 610007, Russia; e-mail: nashem85@yandex.ru

Natalia A. Garifullina, Junior Researcher

Andrey V. Filatov, Doctor of Science in Veterinary Medicine, Professor

Alexandr F. Sapozhnikov, Candidate of Science in Veterinary Medicine, Associate Professor

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Изучение биологической активности препаратов серебра на организменной модели инфекции болезни Ньюкасла

Сумарокова А.Д.¹, (✉)Афонюшкин В.Н.^{2,3}, Миронова Т.Е.², Черепушкина В.С.²,
Афонюшкин А.В.¹, Стацевич Л.Н.¹, Сильников В.Н.⁴

¹Новосибирский государственный аграрный университет
Новосибирск, Россия

²Сибирский федеральный научный центр агробιοтехнологий Российской академии наук
Новосибирская область, р.п. Краснообск, Россия

³Томский государственный политехнический университет
Томск, Россия

⁴Институт химической биологии и фундаментальной медицины
Сибирского отделения Российской академии наук

Новосибирск, Россия

(✉)e-mail: lisocim@mail.ru

В связи с быстрорастущей антибиотикорезистентностью микроорганизмов и все большей распространенностью вирусных заболеваний особое внимание уделяется созданию новых эффективных лекарственных препаратов. Препараты наносеребра уже давно изучают и применяют в качестве противомикробных и противовирусных средств. Противовирусные средства с ви-роцидной активностью действуют непосредственно на вирусные частицы, разрушая вирусные мембраны при контакте с ними или путем связывания с белками вирусного капсида. Изучена биологическая активность препаратов серебра в форме наночастиц (Арговит) и органических молекул (Аргосил) на организменной модели инфекции болезни Ньюкасла у лабораторных животных. В эксперименте использованы мыши ICR (масса 15–23 г, водопотребление 6–7 мл/гол., возраст 2 мес). Для моделирования развития инфекции, вызванной возбудителем Ньюкаслской болезни, мыши были заражены вирусом болезни Ньюкасла вакциной штамма «Ла-Сота». Вакцину вводили однократно интраназально индивидуально в дозе 20 мкл/гол. (20 доз). Для определения биологической активности препаратов использовали гистологические исследования по стандартной методике, а также анализ изменений вирусной нагрузки методом ОТ-ПЦР в режиме реального времени у мышей ICR, инфицированных вирусом Ньюкасла. Обнаружено отсутствие геномной РНК вируса болезни Ньюкасла в легких у животных, получавших препараты Аргосил и Арговит-Макси. Отмечены менее выраженные воспалительные изменения в тканях легких у мышей опытных групп в сравнении с животными контрольной группы. Представляется перспективным применение ви-роцидных средств на основе нано- и органического серебра в период, предшествующий формированию поствакцинального иммунитета для фармакопрофилактики болезни Ньюкасла.

Ключевые слова: ви-роцидные препараты, Арговит, Аргосил, болезнь Ньюкасла, наночастицы, органические молекулы

Study of the biological activity of silver preparations on an organismal model of Newcastle disease infection

Sumarokova A.D.¹, (✉)Afonyushkin V.N.^{2,3}, Mironova T.E.², Cherepushkina V.S.²,
Afonyushkin A.V.¹, Statsevich L.N.¹, Silnikov V.N.⁴

¹Novosibirsk State Agrarian University
Novosibirsk, Russia

²Siberian Federal Scientific Centre of AgroBioTechnologies of the Russian Academy of Sciences
Krasnoobsk, Novosibirsk region, Russia

³Tomsk State Polytechnic University
Tomsk, Russia

⁴Institute of Chemical Biology and Fundamental Medicine of the Russian Academy of Sciences
Novosibirsk, Russia

(✉)e-mail: lisocim@mail.ru

Due to the rapidly growing antibiotic resistance of microorganisms and the increasing prevalence of viral diseases, special attention is paid to the creation of new effective drugs. Nanosilver preparations

have long been studied and used as antimicrobial and antiviral agents. Antiviral agents with virocidal activity act directly on viral particles destroying viral membranes upon contact or by binding to viral capsid proteins. The biological activity of silver preparations in the form of nanoparticles (Argovit) and organic molecules (Argosil) was studied on an organismal model of Newcastle disease infection in laboratory animals. ICR mice (weight 15–23 g, water consumption 6–7 ml/animal, age 2 months) were used in the experiment. To model the development of infection caused by the Newcastle disease pathogen, mice were infected with Newcastle disease virus with the La Sota strain vaccine. The vaccine was administered once intranasally individually at a dose of 20 µl/animal (20 doses). To determine the biological activity of the drugs, histological studies were used using standard methods, as well as analysis of changes in viral load using real-time RT-PCR in ICR mice infected with Newcastle virus. The absence of genomic RNA of the Newcastle disease virus was found in the lungs of the animals treated with Argosil and Argovit-Maxi. There were less pronounced inflammatory changes in the lung tissues in mice of the experimental groups, compared to animals in the control group. The use of virocidal agents based on nano- and organic silver in the period preceding the formation of postvaccinal immunity in terms of pharmacoprophylaxis of Newcastle disease seems promising.

Keywords: virocidal drugs, Argovit, Argosil, Newcastle disease, nanoparticles, organic molecules

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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

Newcastle disease virus (NDV) is an RNA-containing virus of the Paramyxoviridae family, PMV-1 [1]. The paramyxovirus family contains pathogens dangerous to humans and animals, including measles, epidemic mumps, Nipah, parainfluenza 5 (PIV5) and VND viruses [2–4]. Newcastle disease (*Pseudopestis avium*) is the most contagious and dangerous viral disease that is distributed worldwide and causes severe infection in wild and domestic birds, mainly chickens¹ [5]. Mild systemic Newcastle disease (ND) infection, affecting only the respiratory and neurological systems, can be observed in both animals and humans [6].

The World Animal Health Organization has listed Newcastle disease as one of the most dangerous diseases that affects several species of domestic and wild birds, with potential implications for the poultry industry [7].

In recent years, the creation of means for the treatment and prevention of viral infections is of great importance for all mankind. Nanosilver preparations have long been studied and used as antimicrobial and antiviral agents, antitumor drugs, as well as analgesics and biologically active additives aimed at increasing productivity, immune status of animals, and even as synergists for antibiotics [8–10].

Antiviral agents with virocidal activity differ from traditional antiviral drugs in that they

¹Nurkhodjaev N.O., Asanov N.G., Musoev A.M., Bazarbaev R.K. Results of laboratory diagnosis of Newcastle disease // Global Science and Innovations 2020: proceedings (Tashkent, March 6, 2020). Tashkent: DARA, 2020, pp. 271–274.

act directly on viral particles by destroying viral membranes on contact with them or by binding to viral capsid proteins². For example, such a drug is Triviron, which belongs to the group of synthetic ribonucleases. The active substance of the drug is small molecules capable of penetrating into capsids of viral particles and exerting an inhibitory effect on the main structural components of the virus. At the same time, synthetic ribonucleases do not affect antibodies and defense cells produced by the macroorganism, and one molecule of ribonuclease can destroy several molecules of RNA-containing viruses [11]. However, the interaction of silver nanoparticles (SNPs) with viruses is still an underexplored field.

Because of their unique physical and chemical properties, silver nanoparticles have attracted particular attention and have already justified their potential as an effective antiviral agent [12–14].

Usually, virocidal agents act directly on viral particles by binding to viral envelope proteins and interfering with structural interactions or functions³. Silver nanoparticles have several advantages over conventional chemical agents targeting viruses^{4–6}. They can attach to the surface glycoproteins of the virus and penetrate into host cells, where they exhibit virulicidal activity by interacting with the viral genome⁷.

Silver nanoparticles can be used to prevent multiple viral infections by inhibiting the virus in infected cells or by directly inactivating viruses such as herpes simplex virus, respiratory syncytial virus and adenovirus type 3 [12]. Silver nano-objects have high antiviral activity due to their large surface area, which facilitates contact with viral particles (see footnote 3).

Silver nanoparticles are promising for the development of new antiviral agents, as they can attack a wide range of viruses with a lower probability of developing resistant antiviral strains compared to traditional antiviral drugs [7].

The purpose of the study was to investigate the biological activity of silver preparations in the form of nanoparticles and organic molecules on an organismal model of Newcastle disease infection in ICR mice.

MATERIAL AND METHODS

The following silver preparations were used in the experiment:

– Argosil is an agent, which is a dihydroxocystinodiaminodiaryl sodium dihydroxocystine diargenate with antibacterial activity. It is a complex of two silver ions with the dynatrium salt of the natural amino acid L-cystine, linked by a coordination bond, corresponding to the formula $C_6H_{12}Ag_2N_2Na_2O_6S_2$;

– Argovit-Maxi is a highly dispersed (clustered) silver stabilized with a medical grade polymer low molecular weight polyvinylpyrrolidone (K-17). Silver nanoparticles have a spheroidal shape with a size from 1 to 90 nm and an average diameter of 35 ± 12 nm. The drug has a wide spectrum of antimicrobial action against Gram-positive and Gram-negative bacteria. It exhibits high virulicidal (antiviral) and fungicidal (antifungal) activity, has a pronounced anti-inflammatory effect.

ICR mice (weight 15–23 g, water consumption 6–7 ml/head, age 2 months) were used in the experiment. To model the development of infection caused by the Newcastle disease pathogen, mice were infected with Newcastle disease virus by the “La Sota” strain vaccine. The vaccine was

²Lara H.H., Ayala-Nuñez N.V., Ixtapan-Turrent L., Rodríguez-Padilla C. Mode of antiviral action of silver nanoparticles against HIV-1 // *Journal of nanobiotechnology*, 2010, vol. 8, N 1, pp. 1–10. DOI: 10.1186/1477-3155-8-1.

³Khandelwal N., Kaur G., Kumar N., Tiwari A. Application of silver nanoparticles in viral inhibition: a new hope for antivirals // *Digest Journal of Nanomaterials & Biostructures (DJNB)*, 2014, vol. 9, N 1, pp. 175–186.

⁴Dorjnamji, D., Ariunaa M., Shim Y.K. Synthesis of silver nanoparticles using hydroxyl functionalized ionic liquids and their antimicrobial activity // *International journal of molecular sciences*, 2008, vol. 9, N 5, pp. 807–820.

⁵Sondi L., Goia D.V., Matijević E. Preparation of highly concentrated stable dispersions of uniform silver nanoparticles // *Journal of colloid and interface science*, 2003, vol. 260, N 1, pp. 75–81.

⁶Aamodt K., Abelev B., Quintana A.A., Adamova D., Adare A.M., Aggarwal M.M., Barroso V.C. Elliptic flow of charged particles in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV // *Physical review letters*, 2010, vol. 105, N 25, pp. 252–302.

⁷Galdiero S., Falanga A., Vitiello M., Cantisani M., Marra V., Galdiero M. Silver nanoparticles as potential antiviral agents // *Molecules*, 2011, vol. 16, N 10, pp. 8894–8918.

administered once intranasally individually at a dose of 20 µl/head. (20 doses).

After infection, three groups ($n = 5$) were formed: one control and two experimental groups:

- control group mice were not infected with Newcastle disease virus (NDV) and did not receive nanosilver preparations;

- Mice of the 1st experimental group, which were infected with the ND vaccine strain, were dosed with Argosil at a dose of 1 µg/g live weight daily;

- mice of the 2nd experimental group infected with the ND vaccine strain were dosed with Argovit-Maxi at the rate of 1 µg/g live weight daily.

After 5 days of the experiment, the mice were removed from the experiment by cerebral-cervical dislocation in accordance with the principles of humanity and the requirements of the European Convention for the Protection of Vertebrate Animals Used for Experiments or Other Scientific Purposes.

Histologic studies were performed according to the standard technique. Tissue pieces were fixed in 10% buffered formalin, dehydrated with alcohols and soaked in paraffin using STP-120 histoprocessor. Paraffin sections were deparaffinized with xylene and stained with hematoxylin-eosin according to the Ehrlich method.

Viral load analysis by real-time OT PCR method. RNA was isolated from the internal organs (lungs, spleen, intestine) and RT-PCR was performed. RNA was isolated by phenolchloroform extraction using Lira reagent (Biolabmix LLC, Novosibirsk) according to the manufacturer's instructions. cDNA synthesis was performed using oligonucleotide N7.

To confirm successful infection, the presence of NDV genomic RNA was tested by real-time RT-PCR. PCR was performed in a final volume of 20 µl containing 67 mM Tris. – HCl (pH 8.9), 16 mM (NH₄)₂SO₄; 2.4 mM MgCl₂; 0.01% Tween 20; 0.2 mM dNTPs; 0.3 mM solutions of oligonucleotide primers 5'-atgctcaacctgtgtccctagca-3' 5'-tcaaactgcggatcatcatcacgt-3' and probe FAM-tggaagtagtagtgacg-cgcgccaac-BHQ, 1-2 units. HotStart Taq-DNA polymerase. PCR was performed on a CFX am-

plifier (BioRad) using the following program: initial denaturation – 95 °C for 15 min, then 40 cycles: denaturation – 95 °C for 10 s, annealing – 60 °C for 30 s.

Control of RNA isolation from the samples was performed using real-time PCR specific to the mRNA of the housekeeping gene glyceraldehyde-3-phosphate dehydrogenase (GAPDH) mRNA according to the protocol above using the following primers: U 5' taGGCATGGACT-GTGGGCATGA, R 5' taTTCACCACCATG-GAGAGAAGGC, and ROX 5' taTGCATCCT-GCACCACCACCAACTG-CTTAG-BHQ2 probe. The annealing temperature of the primers was 64 °C.

PCR buffer composition 1 × 60 mM Tris-HCl (pH 8.5 at 25 °C); 1.5 mM MgCl₂; 25 mM KCl; 10 mM 2-mercaptoethanol; 0.1% Triton X-100. PCR mixture was also supplemented with dNTP to a concentration of 0.25 mM and Hot-start TaqDNA polymerase 2 units per reaction. The reaction was performed using a CFX real-time amplifier (BioRad Laboratory).

RESULTS AND DISCUSSION

Analysis of viral load changes in ICR mice infected with Newcastle disease virus using virucidal preparations Argovit-Maxi and Argosil. PCR analysis of the presence of the Newcastle disease virus in the lungs of the animals of the 1st and 2nd experimental groups (receiving virucidal preparations based on nanosilver) was characterized by the absence of genomic RNA of this virus. In the animals of the control group the virus was detected by PCR method.

The virus was most widely represented in the gastrointestinal tract in the animals of all groups (its concentration was the highest), which allows us to explain the mechanisms of decreasing the concentration of the Newcastle disease virus in the lungs through suppression of the transport of viral particles from the intestine to the lungs via the bloodstream (see Fig. 1).

In the animals of the experimental groups on the 6th day after infection viral RNA in the lungs was not detected in contrast to the animals of the control group, where the virus concentration reached $3,19 \pm 1,26 \text{ Log } 10 \text{ GE/5ml}$.

Infection with the ND virus intranasally was accompanied by the presence of virus in the lungs only in the animals of the control group. This allows us to consider the use of silver-based virocidal agents (including Argovit, known to be non-absorbable), despite the persistence of virus in the intestine in animals of the experimental groups.

Despite the intranasal route of infection in laboratory models, the inevitable entry of the virus into the intestine from the nasopharynx is evident. Studies for 2020–2022 have already mentioned the relatively low intensity of SARS-CoV-2 virus spread through lung tissue. At the same time, the nasopharynx and intestine were considered as the main sources of entry of the viral agent into both the body and the lungs [15–17]. Obviously, the presence of the intestine/lung axis (*Gut/Lung*) remains a significant factor for transport, including paramyxoviruses to the lungs.

Results of pathologoanatomical autopsy of mice of the control and experimental groups. During the experiment there was no death of

mice in any of the groups. At autopsy, animals of the control group (infected with NB virus) showed large-focal serous pneumonia characterized by areas of hyperemia and part of lungs with signs of emphysema. In mice of the 2nd experimental group a more uniform change of lung color by the type of “carmine lung”, indicating a violation of microcirculation of inflammatory character, was observed. Pathological changes in the lungs of animals of the 1st experimental group were absent (see Fig. 2).

Features of histologic changes in the lungs when using virocidal silver preparations in the model of viral pneumonia in ICR mice. Signs of interalveolar septum thickening and vascular hyperemia were observed in the animals of the control group. Occasionally there were separate emphysematous areas of lungs, which may indicate compensatory dyspnea (see Fig. 3).

The expressed vascular reaction was mainly of focal character. Separate lobules of lungs were affected (lobular pneumonia) (see Fig. 4). Such type of pathology was observed only in the animals of the control group, which did not receive silver preparations with virocidal activity.

Despite the absence of the virus genome in the lungs of mice of the experimental groups, pathologic changes were observed on histologic preparations, which may be associated with an intense immune response to viral infection. As in the case of COVID-19 infection, there may be an uncontrolled systemic inflammatory

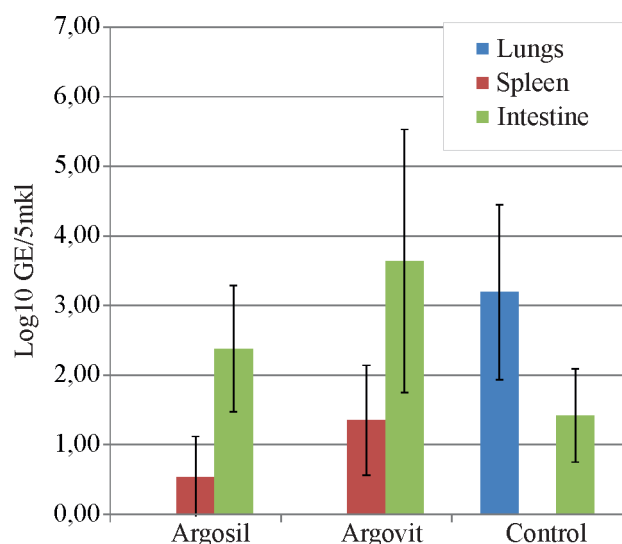


Рис. 1. Распределение вирусной нагрузки во внутренних органах у мышей, зараженных ВНБ, в группах, получающих вирулицидные препараты Аргосил, Арговит, и контрольной группы, Log10 GE/5mkl ($M \pm SD$)

Fig. 1. Distribution of the viral load in the internal organs of mice infected with VND, in groups receiving virucidal drugs Argosil, Argovit and the control group, Log10 GE/5mkl ($M \pm SD$)

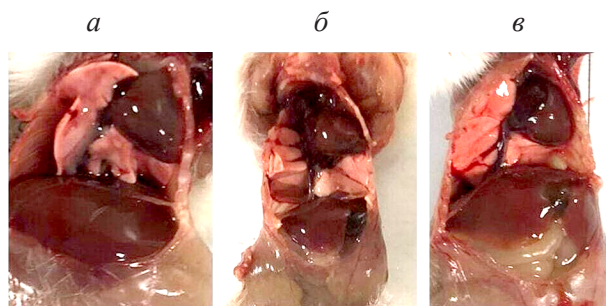


Рис. 2. Картина патологоанатомического вскрытия мышей, зараженных вирусом НБ: а – контрольная группа; б – 1-я опытная; в – 2-я опытная

Fig. 2. A picture of a pathological autopsy of mice infected with the ND virus: а – control group, б – 1st experimental, в – 2nd experimental

reaction - cytokine release syndrome (CRS). It results from the release of significant amounts of pro-inflammatory cytokines by immune and non-immune effector cells and appears to contribute to inflammation and extensive lung injury [18]. The presence of immunocompetent cells, proinflammatory cytokines and viral antigen in the intestine can maintain the state of the inflammatory process [19].

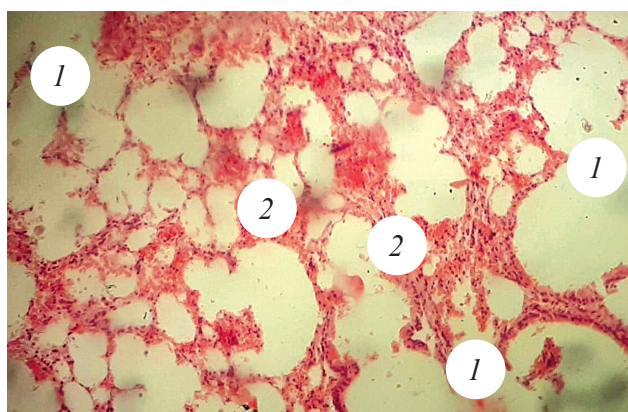


Рис. 3. Легкие контрольной группы на 6-е сутки после заражения. Окраска гематоксилин-эозином: 1 – зона эмфиземы; 2 – утолщение межалвеолярных перегородок. $\times 100$

Fig. 3. Lungs of the control group, 6 days after the infection. Hematoxylin-eosin staining: 1 – zone of emphysema; 2 – thickening of the interalveolar septa. $\times 100$

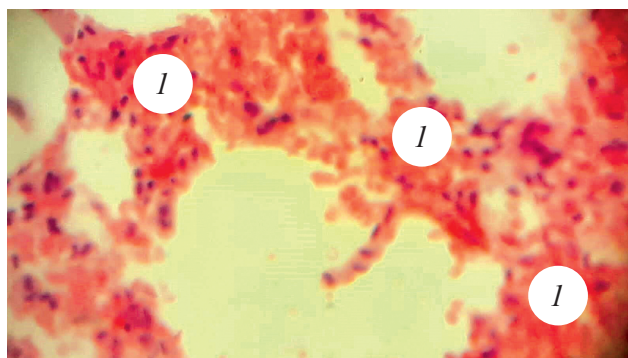


Рис. 4. Легкие контрольной группы на 6-е сутки после заражения: 1 – сосудистая гиперемия и утолщение межалвеолярных перегородок. Окраска гематоксилин-эозином. $\times 400$

Fig. 4. Lungs of the control group, 6 days after the infection: 1 – vascular hyperemia and thickening of the interalveolar septa. Hematoxylin-eosin staining. $\times 400$

Inflammatory changes were significantly less pronounced in the animals of the 1st experimental group receiving Argosil preparation. However, the presence of lymphoid-macrophage, peribronchial infiltrates should be noted (see Fig. 5–7).

The severity of peribronchial infiltrates in the animals of the 2nd experimental group receiving Argovit-Maxi preparation was significantly less than in the animals of the control and 1st experimental groups.

In general, the data of histological studies do not contradict the results of PCR testing of lung tissues for the presence of genomic RNA of Newcastle disease virus. Absence of viral RNA in the animals of experimental groups is naturally accompanied by the absence of vascular hyperemia.

The presence of lymphocytic infiltrates in the animals treated with Argosil may be due to absorption of the preparation and its accumulation in the lungs.

CONCLUSIONS

1. Absence of genomic RNA of the ND virus in the lungs of animals treated with Argosil

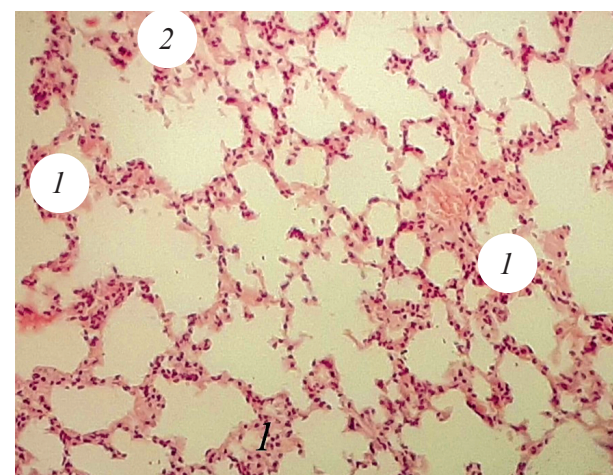


Рис. 5. Легкие животных 1-й опытной группы (Аргосил): 1 – утолщение межалвеолярных перегородок; 2 – гиалиновые тромбы. Окраска гематоксилин-эозином $\times 200$

Fig. 5. Lungs of the animals of the 1st experimental group (Argosil): 1 – thickening of the interalveolar septa; 2 – hyaline thrombi. Hematoxylin-eosin staining. $\times 200$

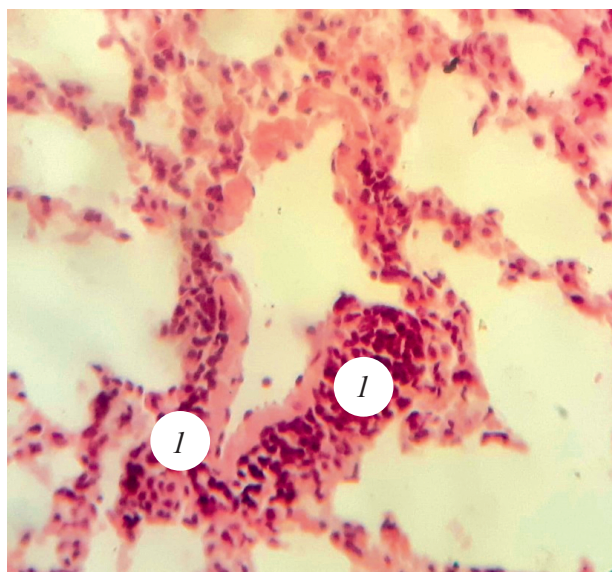


Рис. 6. Лимфомакрофагальная воспалительная инфильтрация у животных 1-й опытной группы (Аргосил):

I – воспалительный инфильтрат. Окраска гематоксилин-эозином × 400

Fig. 6. Lymphomacrophage inflammatory infiltration of the 1st experimental group (Argosil):

I – inflammatory infiltrate. Hematoxylin-eosin staining. × 400

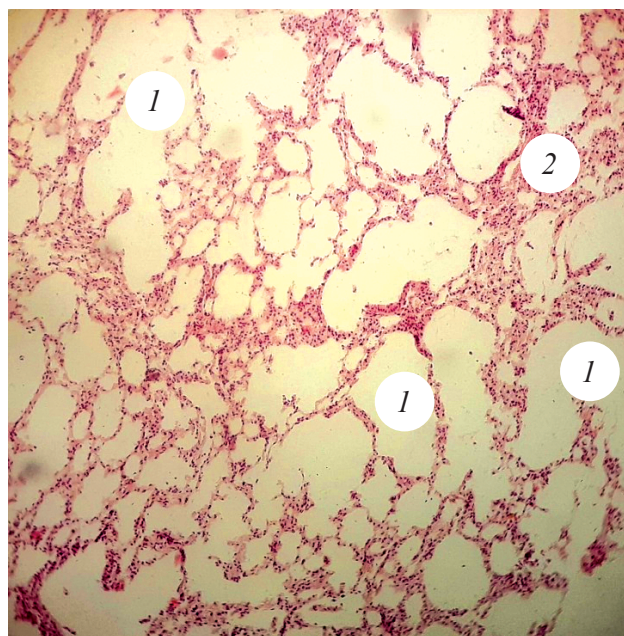


Рис. 7. Легкие у животных 2-й опытной группы (Арговит):

1 – зона эмфиземы; *2* – очаговое интерстициальное воспаление. Окраска гематоксилин-эозином × 200

Fig. 7. Lungs of the animals of the 2nd experimental group (Argovit):

1 – zone of the emphysema; *2* – focal interstitial inflammation. Hematoxylin-eosin staining. × 200

and Argovit-Maxi allows considering the use of virocidal agents based on nanosilver as a treatment for the Newcastle disease.

2. Less pronounced inflammatory changes in the lung tissues of the mice of the experimental groups compared to the animals of the control group testify to the possibility of using antiviral agents based on silver nanoparticles and organic silver molecules.

3. The use of virocidal agents based on nano- and organic silver in the period preceding the formation of postvaccinal immunity seems promising for the pharmacoprophylaxis of the Newcastle disease.

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ИНФОРМАЦИЯ ОБ АВТОРАХ

Сумарокова А.Д., аспирант

✉ **Афонюшкин В.Н.**, кандидат биологических наук, ведущий научный сотрудник; **адрес для переписки:** Россия, 630501, Новосибирская область, р.п. Краснообск, а/я 463; e-mail: lisocim@mail.ru

Миронова Т.Е., младший научный сотрудник

Черепушкина В.С., младший научный сотрудник

Афонюшкин А.В., студент

Стацевич Л.Н., кандидат биологических наук, доцент

Сильников В.Н., доктор химических наук, заведующий лабораторией

AUTHOR INFORMATION

Anastasia D. Sumarokova, Post-graduate Student

✉ **Vasily N. Afonyushkin**, Candidate of Science in Biology, Lead Researcher; **address:** PO Box 463, Krasnoobsk, Novosibirsk Region, 630501, Russia; e-mail: lisocim@mail.ru

Tatyana E. Mironova, Junior Researcher

Victoria S. Cherepushkina, Junior Researcher

Artem V. Afonyushkin, Student

Lyudmila N. Stastevich, Candidate of Science in Biology, Associate Professor

Vladimir N. Silnikov, Doctor of Science in Chemistry, Laboratory Head

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Изменение физических свойств залежных земель при их восстановлении

✉ Яковлев Н.С., Рассомахин Г.К., Иванников А.Б., Чернышов А.П.

Сибирский федеральный научный центр агробиотехнологий Российской академии наук

Новосибирская область, р.п. Краснообск, Россия

✉ e-mail: yakovlev-46@inbox.ru

Изучено изменение физико-механических свойств почвы в зависимости от способов ее обработки. Эксперименты проведены в Новосибирской области с апреля по сентябрь 2023 г. Для изучения структуры почвы выполнен почвенный разрез на глубину 0,7 м. Определено, что почва на участках опыта серая лесная, толщина дернового слоя в среднем 10 см, глубина залегания гумусового горизонта 25–27 см, под гумусовым слоем виден слой супеси. Обработку залежной почвы проводили почвообрабатывающим агрегатом АКП-2,5Н с трактором МТЗ-80Л, ширина захвата 1,8 м. Рабочий орган АКП-2,5Н выполнен в виде прямой стойки с лапой размером 410 мм, кроме этого на стойку устанавливали небольшой отвал. На агрегате предусмотрена установка катков диаметром 600 мм. Для определения режимов работы агрегата проведены исследования в почвенном канале. Установлено, что рабочая скорость агрегата с отвалами должна быть не более 2,22 м/с, или 8 км/ч. Условия проведения эксперимента: почва серая лесная, температура воздуха не ниже 10 °С, влажность воздуха не более 70%, относительная влажность не ниже 18%, ветер не выше 2 м/с, средняя длина гона не менее 70 м, отсутствие засоренности поля камнями. Установлено, что наиболее рациональный способ введения залежных серых лесных почв в сельскохозяйственный оборот является их обработка агрегатами АКП-2,5Н с рабочими органами, оснащенными отвалами. После трех обработок содержание частиц почвы менее 10 мм составляет до 93,1%, почва быстрее впитывает влагу и снижает твердость до 15 кг/см², что соответствует твердости почвы, находящегося в обороте поля. Получены уравнения закономерности изменения фракционного состава почвы размером менее 10 мм и более 50 мм в зависимости от сроков и количества обработок.

Ключевые слова: почвообрабатывающий агрегат АКП-2,5Н, культиватор, кольцевой каток, залежная земля, влажность, твердость почвы

Changes in the physical properties of fallow lands during their regeneration

✉ Yakovlev N.S., Rassomakhin G.K., Ivannikov A.B., Chernyshov A.P.

Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences

Krasnoobsk, Novosibirsk region, Russia

✉ e-mail: yakovlev-46@inbox.ru

The change of physical and mechanical properties of soil depending on the methods of its cultivation has been studied. The experiments were carried out in the Novosibirsk region from April to September 2023. To study the structure of the soil, a soil section was made to a depth of 0.7 meters. It was determined that the soil at the experiment plots was gray forest, the thickness of the turf layer was on average 10 cm, the depth of the humus horizon 25–27 cm, a layer of sandy loam was observed under the humus layer. Fallow land cultivation was carried out by the tillage combine AKP-2.5N with MTP-80L tractor and the working width of 1.8 meters. The working body of the AKP-2.5N was made in a form of a straight rack with a blade measuring 410 mm, in addition, a small screen was installed

on the rack. The unit provides for the installation of the rollers with a size of 600 mm. To determine the operating modes of the unit, studies were carried out in the soil channel. It was found that the operating speed of the unit with installed screen should be no more than 2.22 m/s or 8 km/h. The conditions of the experiment: gray forest soil, air temperature not lower than 10 °C; air humidity no more than 70%; relative humidity of at least 18%, wind speed not higher than 2 m/s; the average length of the rut is not less than 70 m and without stones on the field. It has been concluded that the most rational way to introduce fallow gray forest soils into agricultural circulation is to treat them with AKP-2.5N units with working bodies equipped with blades. After three treatments, the content of soil particles less than 10 mm is up to 93.1%, the soil absorbs moisture faster and reduces the hardness to 15 kg/cm², which corresponds to the hardness of the soil of the field in rotation. Equations of regularity of changes in the fractional composition of soil with a size of less than 10 mm and more than 50 mm depending on the timing and number of treatments have been obtained.

Keywords: tillage combine AKP-2.5N, cultivator, ring roller, fallow lands, humidity, soil hardness

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Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

According to the Ministry of Agriculture, about 44 million hectares of agricultural land in the Russian Federation are not used, of which arable land accounts for about 20 million hectares, or 11.5% of the total area¹. In recent years, uncontrolled burning of dry grass on fallow lands has led to negative environmental and social consequences. Of all unused agricultural land, fallow land accounts for about 10%, or 4.4 million hectares. In the context of economic sanctions, the development of such a large amount of fallow land will contribute to increasing the country's food independence^{2, 3}.

The maximum growth of fallow lands occurred in 2004, and in 2005–2006 their area continued to increase [1]. In total, 853.9 thousand hectares of abandoned land are registered in the Novosibirsk Region as of 2023. Only in 2022

16,200 hectares of agricultural land fell out of use.

In 2021, the Russian Federation approved a state program for the return of agricultural land to agricultural use and the development of land reclamation complex with a 10-year implementation period. During this time, it is planned to return 13 million hectares of land to rotation. It is assumed that more than 754 billion rubles will be spent on this, including 538 billion rubles allocated from the federal budget until 2031, and another part of the funds will be provided by the regions. It is also planned to carry out land surveying when introducing fallow lands into rotation by means of photo and video recording of individual plots through the use of unmanned aerial vehicles with geolocation reference⁴ [2].

Many scientific institutions are engaged in the problem of return of fallow lands to agricultural rotation. The expediency of further

¹Russia in figures. 2019: brief. stat. coll. / Rosstat. Moscow, 2019, 317 p.

²Problems of degradation and restoration of productivity of agricultural land in Russia / ed. by Acad. RAAS A.V. Gordeev, G.A. Romanenko. Moscow: Rosinformagroteh, 2008, 67 p.

³Smolin N.V., Bochkarev D.V., Zaichikova T.F. et al. Effect of different doses of Roundup on suppression of dominant species of fallow land weeds // Achievements of science and technology of AIC, 2008, N 2, pp. 37–38.

⁴Golubev I.G., Kudryavtsev A.V., Tumanov I.V. et al. Digital technology for monitoring landscapes // Proceedings of the scientific-practical conference XII Intern. scientific-practical Internetconf. Moscow: Rosinformagroteh, 2020, N 1, pp. 254–258.

use of fallow lands withdrawn from rotation in agriculture depending on the age of the fallow was established in the All-Russian Scientific Research Institute of Hydraulic Engineering and Land Reclamation named after A.N. Kostyakov based on the studies of fallow lands transformation [3]. Studies to identify effective methods of fallow land development were conducted at the All-Russian Research Institute of Agriculture and Soil Protection from Erosion. It has been established that soil treatment with disk harrow BDT-3 leads to an increase in weeding, thinning of crops, their weaker development and, as a result, to a decrease in yield compared to plowing⁵. The Institute of Agroengineering and Environmental Problems of Agricultural Production (branch of FSAC VIM) is conducting research on the development of technologies and technical means with new working bodies for the restoration of fallow lands in the North-West region of the Russian Federation, including for the conditions of organic farming. Weed control in organic farming means the use of such cultivation methods that allow controlling rhizomes, bringing them out of the ground to the surface, where they wither and dry up [1, 4–6].

The Institute of Soil Science and Agrochemistry of the Siberian Branch of the Russian Academy of Sciences conducted studies to determine the vegetation cover of middle-aged fallow lands in the forest-steppe zone of the Novosibirsk region [7]. It was noted that it is quite difficult, and often impossible, to find fallow areas of the same age in the same conditions when identifying different-aged fallow areas. In addition, haying and grass fires block the succession development, returning it to the previous stages of overgrowth [8]. Back in 1919 in his book “General Agriculture” academician V.R. Williams described the change of natural vegetation from weedy overgrowth through rhizomatous (wheatgrass) phase and the stage of hard overgrowth to the

restoration of typical zonal vegetation⁶. Thus, all overgrown fields are conditionally divided into four main groups according to the length of time elapsed since the cessation of use: the first (the beginning of overgrowth) – 1–5 years, the second – 5–10 years, the third – 10–15 years, the fourth – dense young forest, the approximate age of which is 15–20 years⁷[9].

The purpose of the research is to study the changes in physical and mechanical properties of soil depending on the methods of its cultivation.

Objectives of the study are:

- to investigate the change of soil fractional composition depending on the number and time of treatments;
- to determine changes in moisture and hardness of fallow soil during the summer period depending on its tillage.

MATERIAL AND METHODS

Field experiments were conducted in the Novosibirsk region from April to September 2023. To study the soil structure, a soil transect to a depth of 0.7 m was made. It was determined that the soil is gray forest, the thickness of the sod layer is an average of 10 cm, the depth of the humus horizon is 25–27 cm, under the humus layer is a layer of sandy loam. Ap horizon (10–27 cm) is dark gray, lumpy-powdery, semi-loam, compacted. The presence of sparse roots is noted, the transition is wavy in color, noticeable in density. Horizon AB (28–45 cm) is light with grayish tint, semi-loam, moistened, compacted, there are pockets with gray-colored tones, inclusions of single charcoals, alfalfa roots are present, extending to the depth.

Tillage of fallow soil was carried out by tillage unit AKP-2,5H. The machine is adapted to work with MTZ-80, MTZ-82 and MTZ-1221 tractors. Working width can vary from 1.8 to 2.5 m depending on the tractor pulling power.

⁵*Cherkasov G.N., Sosov N.A.* Effectiveness of the development of fallow land for grain crops on the slopes of the Central-Chernozem Zone // *Achievements of science and technology of AIC*, 2016, vol. 30, N 2, pp. 35–37.

⁶*Methodology of effective development of different-age fallow lands on the basis of multivariant technologies for pastures and hayfields and the order of their return to arable land in the Non-Chernozem zone of the Russian Federation / V.R. Williams* All-Russian Research Institute of Forages. Moscow: OOO “Ugreshskaya typography”, 2017, 64 p.

⁷*Kudryavtsev A.V., Golubev V.V., Kopaev E.V.* Technical means of land reclamation works: textbook. Tver: Tver State Agricultural Academy, 2017, 131 p.

The working device AKP-2,5H is made in the form of a standard straight stand with a tine of 410 mm, in addition, a small moldboard can be mounted on the stand (see Fig. 1). [10]. The machine is provided for installation of rollers of 500- or 600-mm diameter with the working width of 1.8 and 2.5 m. In order to choose the most acceptable version of the working body, studies were conducted in the soil channel. As a result of the experiment, it was determined that the working speed of the machine with installed moldboards should be no more than 2.22 m/s, or 8 km/h. Further it is confirmed by studies in the field during fallow land cultivation: with the increase of the machine speed more than 8 km/h the movement of the cut layer of turf increases, which complicates cultivation. Conditions of experimental studies: gray forest soil, air temperature not less than 10 °C, air humidity not more than 70%, relative humidity not less than 18%, wind not higher than 2 m/s, average length of the chase 70 m, no littering of the field with stones.

Two plots were selected for the experiment: at plot No. 1 the cultivator without moldboard and ring roller was used for treatment to a depth of 10 cm, the following ones - at the same depth - with a cultivator with moldboards and ring roller with a ring diameter of 600 mm; at plot No. 2 the first treatment was carried out to a depth of 10 cm with a cultivator with a working tool equipped with a moldboard, but without a ring roller. Subsequent tillage until complete restoration of arable land was carried out by a cultivator with working bodies equipped with moldboards and a ring roller with a ring diameter of 600 mm. In accordance with the program and the methodology of research, the necessary measurements of soil hardness were carried out by a penetrometer SC-900, determination of soil moisture, degree of loosening, depth of tillage were carried out in accordance with standard methods⁸. Experimental data were processed using standard programs⁹.



Рис. 1. Трактор МТЗ-80Л с почвообрабатывающим агрегатом АКП-2,5Н (а) и стойка, оснащенная отвалом (б)

Fig. 1. MTP-80L tractor with a tillage combine AKP-2.5N (a) and a rack equipped with a blade (b)

RESULTS AND DISCUSSION

At the first cultivation of the deposit on May 29, 2023, soil moisture at a depth of 10 cm was 10%, density 1.24 g/cm³, and hardness reached 42.5 kg/cm². With increasing depth, the moisture content increased to 15%, and the density increased to 1.33 g/m³. The highest hardness (over 40 kg/cm²) was observed at low moisture content (10–13%) within the A horizon, where the humus layer is located. Soil hardness decreased to 23–16 kg/cm² with immersion of the hardness tester plunger into the loam layer, where moisture content was within 14–15%.

⁸GOST 20915-2011. Methods for determining test conditions. Moscow: Standardinform, 2013, 18 p.

⁹Valge A.M., Dzhabborov N.I., Eviev V.A. Basics of statistical processing of the experimental data at carrying out researches on mechanization of agricultural production with examples on STATGRAPHICS and EXCEL. SPb. – Elista, 2015, 140 p.

The presence of roots in the layer 0–10 cm was 7.6 kg/m², 10–20 cm – 0.6 kg/m². The average thickness of the turf layer was 80–100 mm, the degree of sodding was 24.36 g/dm², and the specific tensile strength of the turf was 1.18 N/cm².

Fig. 2 shows the diagram of soil fractional composition change at plot No. 1. It can be noted that treatment, which was carried out on June 16 by aggregate AKP-2,5H, allowed obtaining up to 65.5% of soil particles smaller than 10 mm. The next treatment on June 19 was carried out with ring harrow. At the same time, the number of particles smaller than 10 mm increased to 88.6%. After 20 days, weeds appeared on the field and rains occurred, the soil compacted. Therefore, after the ring harrow treatment on July 12, the number of particles smaller than 10 mm decreased to 79.9% and the number of particles larger than 50 mm increased to 10.5%.

The first treatment of the fallow land, which was carried out on May 29, 2023, is not indicated in the diagrams of Fig. 2, because the fractional composition after the first treatment was not determined. The regularity of changes in the fractional composition of soil with the size less

than 10 mm at plot No. 1 depending on the terms of treatments and their number is presented in Fig. 3 and is expressed by the equation

$$y = -4,5725x^2 + 32,345x + 25,952, \quad (1)$$

where y – amount of soil particles smaller than 10 mm in the total volume, %; x – number of treatments after the first loosening of the fallow land.

The regularity of changes in the fractional composition of soil with the size more than 50 mm depending on the terms of tillage and their number is presented in Fig. 4 and is expressed by the equation

$$y = 5,9475x^2 - 39,053x + 70,993, \quad (2)$$

where y – amount of soil particles larger than 50 mm in total volume, %; x – number of treatments after the first loosening of the fallow land.

The essence of cultivation of gray forest soils is to separate the turf layer from the soil. The working tool should loosen the sod as much as possible without disturbing its integrity. The

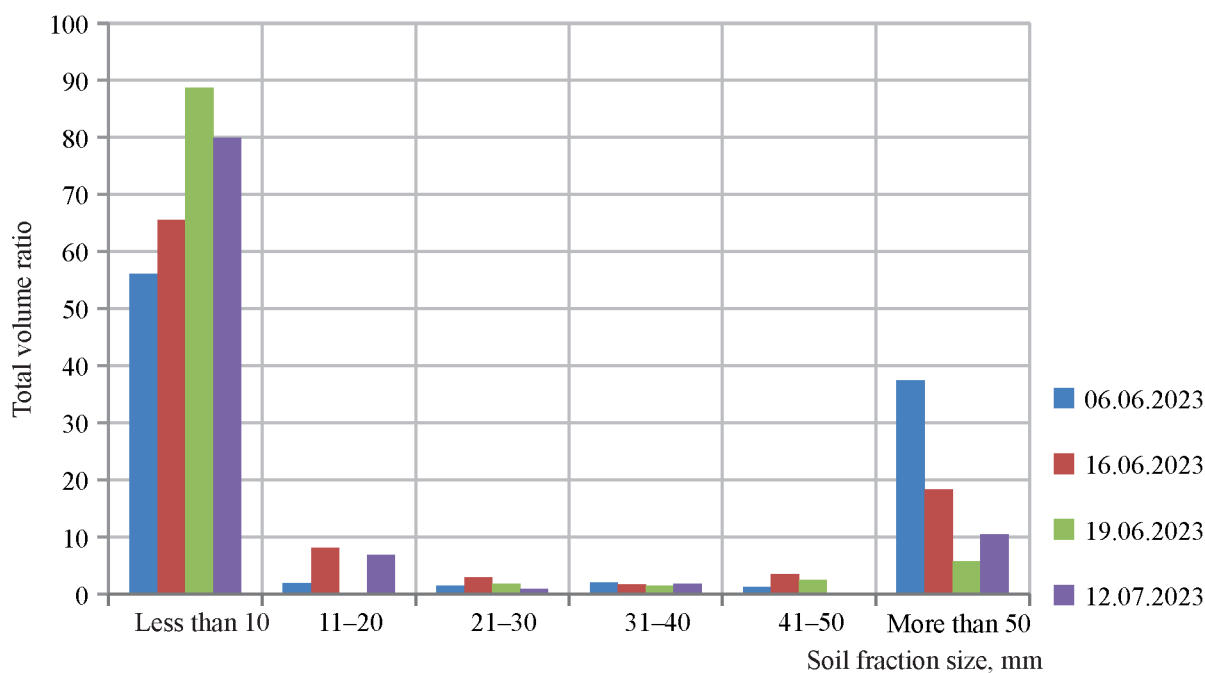


Рис. 2. Изменение фракционного состава почвы на участке № 1 в зависимости от времени обработки и зарастания сорняками

Fig. 2. Change in the fractional composition of the soil at the site No.1 depending on the time of treatment and overgrowth with weeds

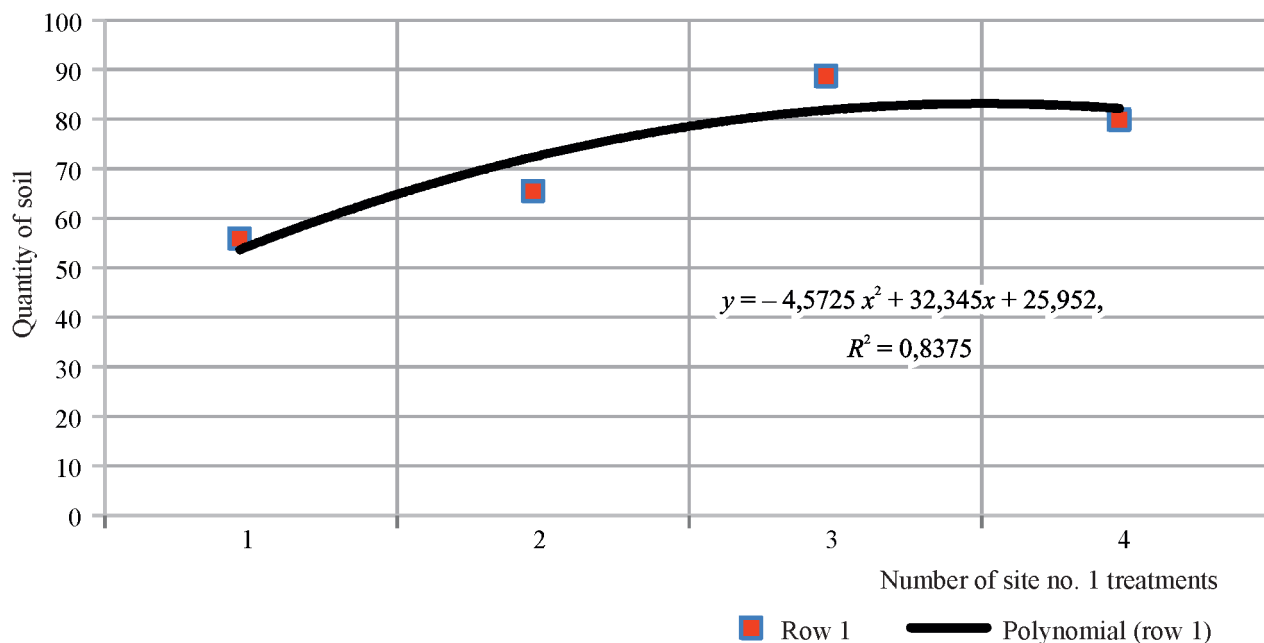


Рис. 3. Изменение количества частиц почвы размером менее 10 мм

Fig. 3. Change in the number of soil particles smaller than 10 mm

analysis of graphs and the obtained equations shows that the fallow land treatment with the aggregate AKP-2,5H without equipping the working bodies with moldboards does not provide quality soil treatment. The largest amount of soil particles with the size less than 10 mm (88.6%) is obtained only after the fourth cultivation with the use of moldboards. Subsequent tillage of the developed fallow land is carried out as necessary

to get rid of the newly grown weeds, so there is no increase in the fine fraction, as the soil has time to compact between the treatments.

Fig. 5 shows the diagram of changes in the fractional composition of the soil on the plot No. 2 depending on the method of treatment and time of weed overgrowth. Experimental data allow us to conclude that the third treatment, conducted on June 16 by the aggregate AKP-2,5H,

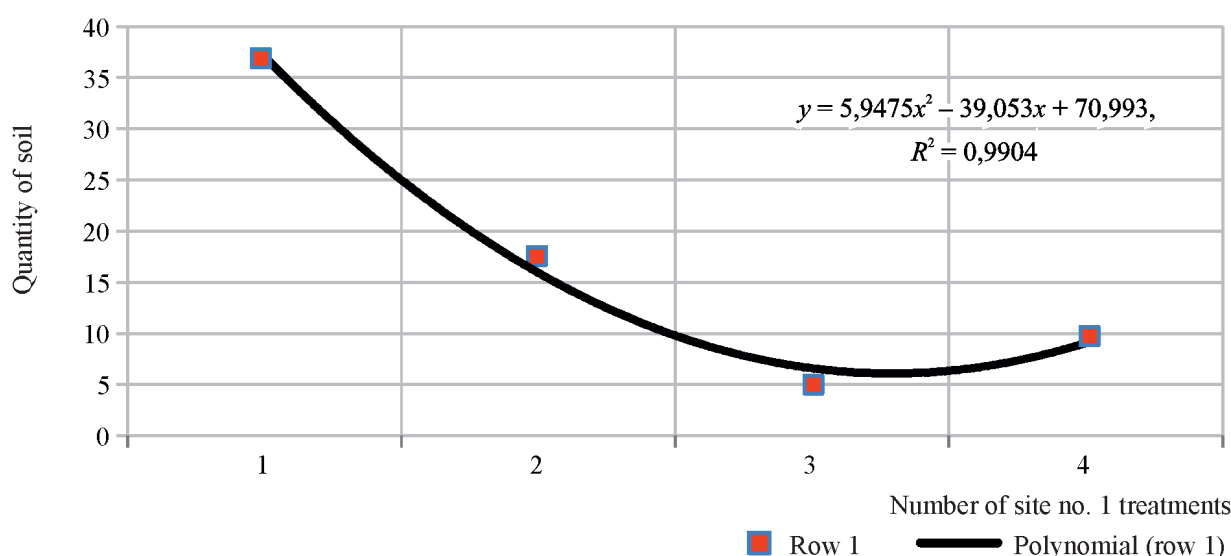


Рис. 4. Изменение количества частиц почвы размером более 50 мм

Fig. 4. Change in the number of soil particles larger than 50 mm

the working bodies of which are equipped with moldboards, allowed to obtain the highest content of particles less than 10 mm (93.1%). Measurement of soil fractional composition at plot 2 after 3 days showed that the number of particles smaller than 10 mm decreased to 88.75%. This can be explained by the fact that on June 16-18 precipitation occurred, soil moisture increased and the soil compacted.

The regularity of changes in the fractional composition of soil size less than 10 mm at plot no. 2 depending on the terms of tillage and their number is presented in Fig. 6 and is expressed by the equation

$$y = 4,1467x^3 - 38,5x^2 + 110,98x - 8,04, \quad (3)$$

where y – amount of soil particles smaller than 10 mm in the total volume, %; x – number of treatments after the first loosening of the fallow land.

The regularity of changes in the fractional composition of soil with the size more than 50 mm depending on the terms of tillage and their number is presented in Fig. 7 and is expressed by the equation

$$y_1 = -5,0217x^3 + 45,125x^2 - 127x + 115,04, \quad (4)$$

where y_1 – amount of soil particles larger than 50 mm in total volume, %; x – number of treatments after the first loosening of the fallow land.

From the analysis of Fig. 3, 4 and 6, 7 it is clear that installation of moldboards on the working bodies of the machine AKP-2,5H allows to reduce the number of cultivations of fallow soils, therefore, to save fuel and reduce labor costs.

At cultivation of fallow gray forest soil with an interval of less than 10 days it is possible to reduce the number of clods of fraction more than 50 mm and increase the composition of fraction less than 10 mm. When increasing the interval between the treatments for more than 10 days, the number of soil lumps less than 10 mm decreases, more than 50 mm it increases due to natural soil compaction and appearance of weed vegetation. The longer the time interval between the treatments, the smaller the number of soil lumps smaller than 10 mm and larger than 50 mm. In the presence of precipitation, the interval is reduced, in their absence increases. Timing and methods of cultivation of fallow lands large-

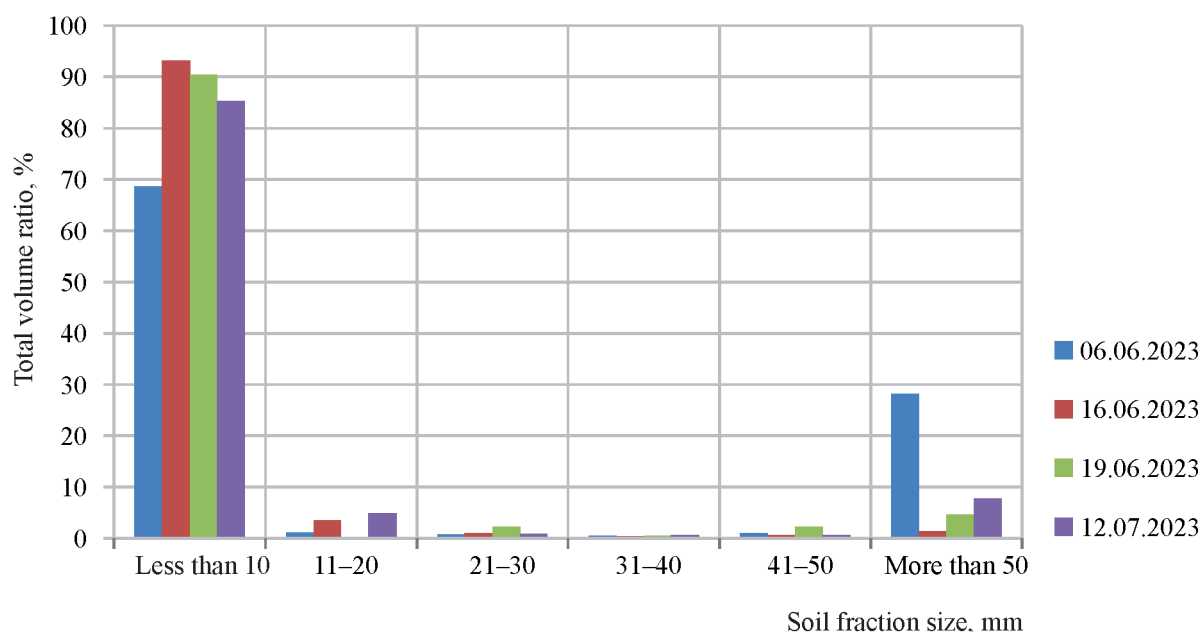


Рис. 5. Изменение фракционного состава почвы на участке № 2 в зависимости от времени обработки и зарастания сорняками

Fig. 5. Changes in the fractional composition of the soil at site No. 2 depending on the time of treatment and overgrowth with weeds

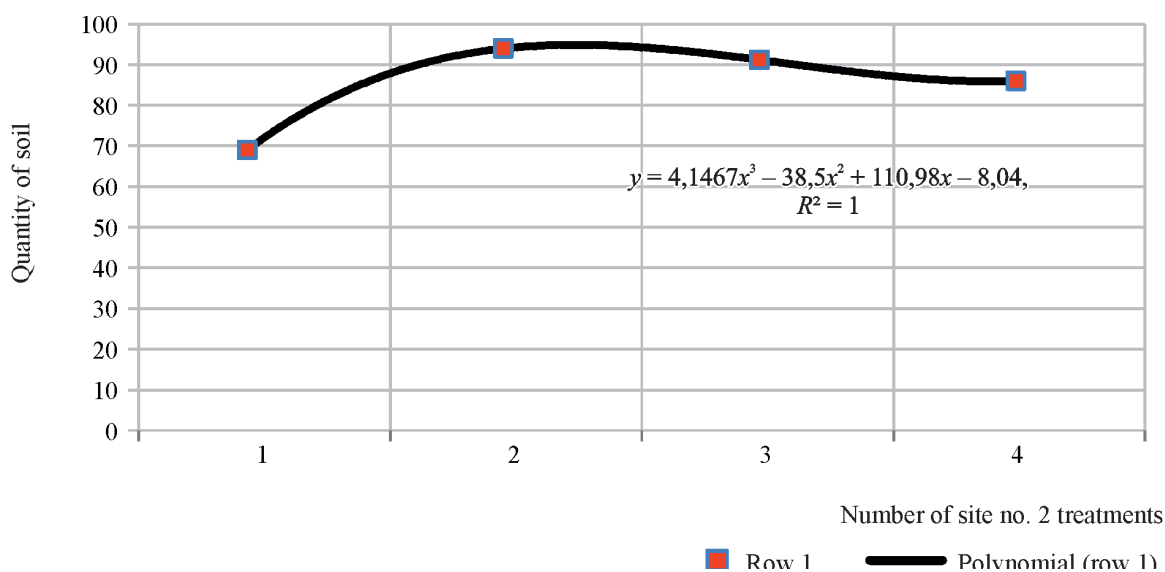


Рис. 6. Изменение количества частиц почвы размером менее 10 мм

Fig. 6. Change in the number of soil particles smaller than 10 mm

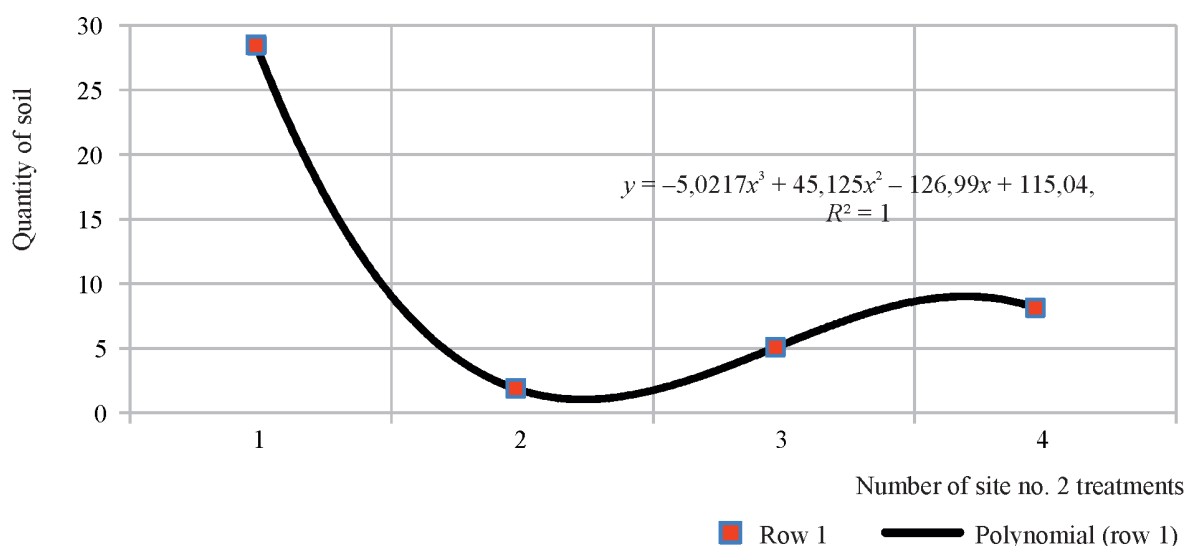


Рис. 7. Изменение количества частиц почвы размером более 50 мм

Fig. 7. Change in the number of soil particles larger than 50 mm

ly depend on the weather in this period. In 2023 in spring and in the first half of summer there was practically no precipitation. Precipitation that occurred during this period had no effect on soil moisture.

According to the data of the weather station “Ogurtsovo”, the average precipitation rate by months of grain crops vegetation in the Novosibirsk District of the Novosibirsk Region for 1991–2021 was 39 mm in May, 55 mm in June, 68 mm in July, 58 mm in August, and 46 mm in

September. In 2023 only 16 mm of precipitation fell in May, the first rains were on June 28 and 30, but they did not wet the soil (see the table). The moisture content of the cultivated soil increased after the July rains, on fallow land it increased by the end of August.

The change in soil moisture influenced its hardness. At the time of the beginning of fallow land cultivation, soil hardness at a depth of 15 cm at a moisture content of about 13% was 44 kg/cm². At the beginning of July, the mois-

ture content decreased to 10%, the soil hardness was 49 kg/cm², and when the moisture content decreased to 8.55%, the hardness increased to 62 kg/cm². The same was observed on the treated soil: at moisture content of 13–14% the hardness was within 25 kg/cm², when moisture content decreased to 10.5% the hardness increased up to 39 kg/cm². In the middle of September, soil moisture at the depth of 10–20 cm increased to 19–21%, and soil hardness changed accordingly.

At the depth of 15 cm, soil hardness decreased to 14.4 kg/cm², and at the untreated soil – to 19.5 kg/cm² (see Fig. 8).

It should be noted that the restored fallow gray forest soil fills with moisture faster and acquires hardness at the level of the soil in rotation of 15 kg/cm² (see Fig. 8). The untreated fallow land under the same conditions has humidity 2% lower than the treated one and hardness up to 19.5 kg/cm². In addition, at a depth of more than

Изменение влажности почвы в течение летнего периода, %
Changes in soil moisture during the summer period, %

Condition of the site	Date of soil sample collection	Depth of soil moisture determination, cm				
		5	10	20	30	40
Fallow land	10.05.2023		20,77	19,84		
Virgin fallow land		10,05	10,43	13,23	15,16	14,39
Tilled fallow land	29.05.2023	5,72	11,79	13,30	13,15	12,50
Virgin fallow land		11,49	10,18	10,38	11,58	12,96
Tilled fallow land	07.06.2023	2,63	12,69	14,04	15,58	15,68
Virgin fallow land		14,54	9,98	8,62	8,82	9,03
Tilled fallow land	05.07.2023	17,20	10,30	10,85	11,15	11,52
Virgin fallow land		10,04	10,06	9,43	10,49	11,40
Tilled fallow land	08.08.2023	5,48	19,19	16,98	12,98	11,49
Virgin fallow land		24,35	21,62	20,50	17,83	11,03
Tilled fallow land	24.08.2023	22,07	25,00	22,20	21,52	18,03
Virgin fallow land		21,24	19,13	19,46	18,95	17,07
Tilled fallow land	14.09.2023	23,71	21,00	21,07	18,79	17,89

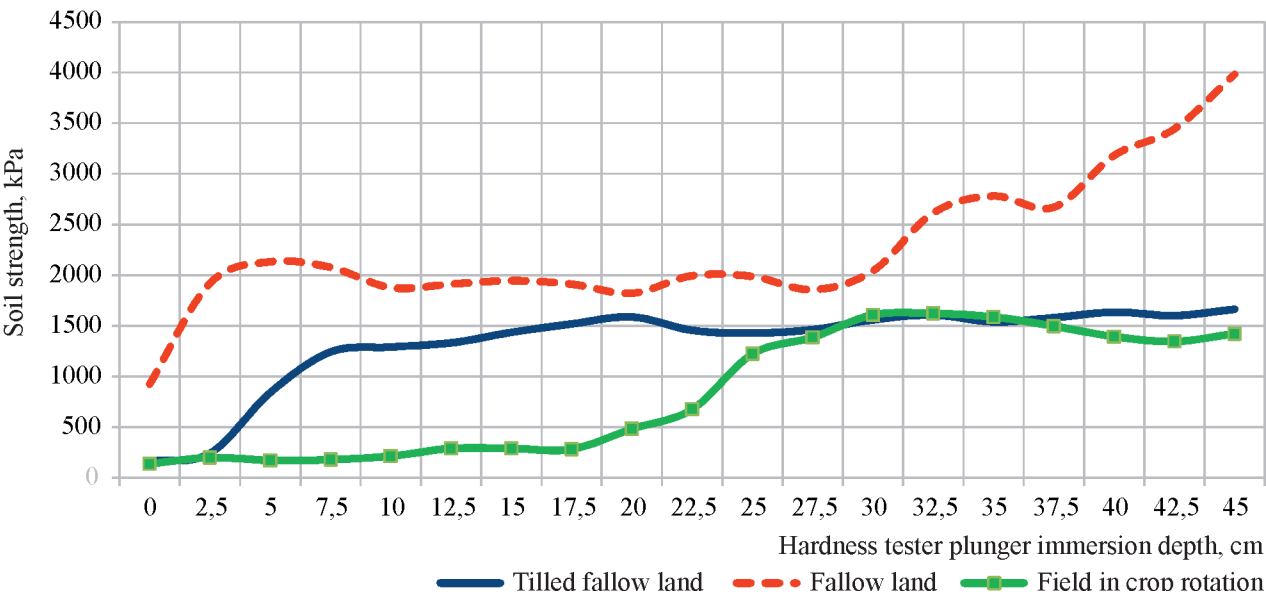


Рис. 8. Твердость восстановленной и залежной почвы на 14.09.2023

Fig. 8. Hardness of regenerated and fallow soil as of 14.09.2023

30 cm the soil hardness starts to increase and reaches 38.9 kg/cm² at a depth of 45 cm. Hardness of the sod layer at moisture content of 21% reaches 21.3 kg/cm².

CONCLUSIONS

1. The most rational way of introducing fallow gray forest soils into agricultural rotation is their treatment with AKP-2,5H aggregates with working bodies equipped with moldboards. After three treatments the content of soil particles less than 10 mm is up to 93,1%.

2. The restored fallow gray forest soil absorbs moisture faster and acquires hardness within 15 kg/cm², which corresponds to the hardness of the soil of the field in rotation.

3. The equations of regularity of changes in the fractional composition of soil with the size less than 10 mm and more than 50 mm depending on the timing and number of fallow fields treatments were obtained.

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ИНФОРМАЦИЯ ОБ АВТОРАХ

✉ **Яковлев Н.С.**, доктор технических наук, главный научный сотрудник; **адрес для переписки:** Россия, 630501, Новосибирская область, р.п. Краснообск, а/я 463; e-mail: yakovlev-46@inbox.ru

Рассомахин Г.К., кандидат технических наук, ведущий научный сотрудник

Иванников А.Б., кандидат технических наук, ведущий научный сотрудник

Чернышов А.П., старший научный сотрудник

AUTHOR INFORMATION

✉ **Nikolay S. Yakovlev**, Doctor of Science in Engineering, Head Researcher; **address:** PO Box 463, Krasnoobsk, Novosibirsk Region, 630501, Russia; e-mail: yakovlev-46@inbox.ru

Gennady K. Rassomakhin, Candidate of Science in Engineering, Lead Researcher

Alexei B. Ivannikov, Candidate of Science in Engineering, Lead Researcher

Alexander P. Chernyshev, Senior Researcher

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О необходимости трансформации парадигмы научных исследований в области земледелия (*сообщение первое*)

✉ Каличкин В.К.

Сибирский федеральный научный центр агробиотехнологий Российской академии наук

Новосибирская область, р.п. Краснообск, Россия

✉ e-mail: vk.kalichkin@gmail.com

Представлен анализ направлений научных исследований в области земледелия, связанных с преобладающей современной парадигмой. С опорой на теорию Т. Куна описано понятие «парадигма», которая, согласно представлениям ученого, формирует мировоззрение исследователей в определенной предметной области, является основой для выбора подходов и методов научных исследований в любой научной дисциплине. Показаны методологические основания изучения систем земледелия, подчеркнута зависимость агрономических исследований от логического позитивизма и инструментализма с редукционистским подходом. Обосновано применение системного мышления при разработке программ исследований в области земледелия, анализе и интерпретации результатов полевых экспериментов, в том числе с использованием искусственного интеллекта. Подчеркнута необходимость развития исследований по географии систем земледелия и их масштабированию в пространстве и во времени с помощью формирования архетипов на основе результатов полевых опытов научных и учебных учреждений, полученных на «небольших участках». С целью развития подходов к масштабированию архетипов систем земледелия предложено использовать концепцию «геонов» (геонов) как одного из перспективных направлений в геоинформатике, а также материалов дистанционного зондирования. Для преодоления негативного воздействия на природу химико-техногенной интенсификации одним из основных подходов может быть увеличение биоразнообразия, в частности диверсификация. Стратегии диверсификации систем земледелия реализуются за счет севооборотов, ассоциированных видов растений (покровные культуры, культуры-ловушки, культуры-репелленты, буферные культуры), смеси сортов и культур, агролесомелиорации и формирования неоднородности агроландшафтов. В рамках адаптации систем земледелия к возможному изменению климата целесообразно интегрировать знания, полученные из количественных климатических моделей и моделей архетипов систем земледелия, для использования их в цифровых системах управления земледелием «на местах». Следует направить усилия на развитие имитационного моделирования. Механистические модели продукционного процесса сельскохозяйственных культур, разработанные для однородной единицы в определенной точке пространства, необходимо масштабировать для различных сценариев окружающей среды.

Ключевые слова: парадигма, системный подход, архетипы систем земледелия, агрогеография, масштабирование, диверсификация, адаптация, имитационное моделирование

On the need to transform the paradigm of scientific research in agriculture (*the first message*)

✉ Kalichkin V.K.

Siberian Federal Scientific Centre of AgroBioTechnologies of the Russian Academy of Sciences

Krasnoobsk, Novosibirsk region, Russia

✉ e-mail: vk.kalichkin@gmail.com

Analysis of the directions of scientific research in the field of agriculture related to the prevailing modern paradigm is presented. Based on the theory of T. Kuhn, the concept of "paradigm" is

described, which, according to the scientist's ideas, forms the worldview of researchers in a certain subject area and serves as the basis for choosing approaches and methods of scientific research in any scientific discipline. The methodological foundations of the study of farming systems are shown, and the dependence of agronomic research on logical positivism and instrumentalism with a reductionist approach is emphasized. The application of systematic thinking in the development of research programs in the field of farming, analysis and interpretation of the results of field experiments, including the use of artificial intelligence is substantiated. The need to develop research on the geography of farming systems and their scaling in space and time through the formation of archetypes based on the results of field experiments of scientific and educational institutions obtained on "small plots" is emphasized. In order to develop approaches to scaling the archetypes of farming systems, it is proposed to use the concept of "geons" as one of the promising trends in geoinformatics, as well as remote sensing materials. Increasing biodiversity, in particular diversification, may be one of the main approaches to overcome the negative impacts of chemical-technogenic intensification on nature. Strategies for diversifying cropping systems are implemented through crop rotations, associated plant species (cover crops, trap crops, repellent crops, buffer crops), mixture of varieties and crops, agroforestry and formation of agro-landscape heterogeneity. As part of the adaptation of farming systems to potential climate change, it is useful to integrate knowledge from quantitative climate models and farming system archetype models for use in digital farming management systems "on the ground". Efforts should be directed towards the development of simulation modeling. Mechanistic models of crop production process developed for a homogeneous unit at a particular point in space need to be scaled for different environmental scenarios.

Keywords: paradigm, systemic approach, archetypes of farming systems, agrogeography, scaling, diversification, adaptation, simulation modeling

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Conflict of interest

The author declares no conflict of interest.

In modern scientific literature on agriculture, the concept of “paradigm” is found in various contexts and semantic applications, such as “paradigm of agricultural nature management” [1], “bioenergetic, ecological and socio-economic paradigms”¹, “soil-saving farming paradigm” [2], “agrogeography paradigm” [3], “precision agriculture as a new paradigm of crop production”², paradigm of landscape management” [4], etc.

The concept of “paradigm” became widespread after the publication in 1962 of the book by the American historian of science T. Kuhn³. According to T. Kuhn, a paradigm sets a certain vision of the world and outlines the range of the problems that make sense and have a solution in this paradigm. T. Kuhn also introduced the concept of disciplinary matrix, which includes elements of three types: symbolic generaliza-

¹Zhuchenko A.A. Challenges of the XXI century of the world and domestic food security // Agro-food Policy in Russia, 2012, N 1, pp. 6–9.

²Uskov I.B., Yakushev V.P., Chesnokov Yu.V. Management of agrobiological systems – physical-agronomic and genetic and breeding aspects (to the 85th anniversary of the Agrophysical Research Institute) // Agricultural Biology, 2017, vol. 52, N 3, pp. 429–436.

³Kuhn T. The Structure of Scientific Revolutions: transl. from English. V.Yu. Kuznetsov. Moscow, 2003, 605 p.

tions, or laws; models and ontological interpretations; samples of problem solving. Symbolic generalizations and their ontological interpretations define the world, which is investigated by the supporter of this paradigm. Ontological interpretation defines those entities to which the laws of the theory refer. Problem-solving patterns are essentially recommendations formed from the generalization of empirical research. The Philosophical Dictionary interprets paradigm as “a set of theoretical and methodological assumptions embodied in scientific practice at a given stage, defining particular scientific research”⁴.

A paradigm can also be understood as a set of scientific achievements in a certain subject area, recognized by the entire scientific community in a particular period of time and serving as a basis for new scientific research. Everything that does not belong to this circle will be outside the sphere of scientific interests of the supporters of a certain paradigm. In addition, the paradigm establishes acceptable methods of solving problems in a given subject area and therefore actually determines the type of facts obtained in the process of empirical research. Thus, a paradigm is also the basis of a certain scientific tradition. T. Kuhn's theory shows that almost every significant breakthrough in scientific development is, first of all, a break with tradition, with old ways of thinking, with old paradigms.

The modern paradigm of farming includes industrial agro-technologies, as well as green, agrochemical, transgenic and informatization “revolutions” [5]. It is realized through the design and development of on-farm adaptive-landscape farming systems.

The methodological basis for the study of farming systems should be the understanding

that they are characterized by states far from equilibrium, co-evolution of system components, self-organization properties, nonlinear dynamics, multidimensional structure, high level of uncertainty, limited control of factors and inter-scale interrelationships in time and space. As a complex system, agriculture is an expression of certain human-environment interactions in a dynamic process shaped by uncertainty, error and adaptation. The need to rely on a systems approach was formulated decades ago⁵, but agronomic science still maintains the perception of human capacity to fully control nature, which is the main reason for the vulnerability of human society due to the manifestation of “anthropocentric arrogance” [6]. To add, in cropping systems, uncertainty arising from human intervention is often higher than uncertainty due to nature.

It can be said that agronomic science, analogous to physics, is heavily dependent on logical positivism and instrumentalism. In logical positivism, atomistic or branch-based, reductionist thinking dominates over holistic thinking and favors experimental approaches over abstract laws and fundamental principles to support scientific claims⁶. This way of thinking also proves to be an obstacle to overcoming the limitations of causal analysis. The limitations are further aggravated by the narrowness of the methodology used to justify scientific statements. This, incidentally, shows the lag of agronomic science behind the development of science in general, which is currently characterized as “post non-classical rationality”, the essence of which is the study of complex self-organizing systems⁷.

In agronomy, conclusions about the state of systems are based on the results of testing various hypotheses in controlled field trials aimed

⁴Philosophical Dictionary / ed. by I.T. Frolov. Moscow: Respublika, 2001, 720 p.

⁵Obraztsov A.S. System method: application in farming. Moscow: Agropromizdat, 1990, 304 p.

⁶Arkhereev N.L. Logical positivism and modern formal philosophy of science // Manuscript, 2017, N 12–2 (86), pp. 22–26.

⁷Stepin V.S. Features of scientific cognition and criteria of the types of scientific rationality // Epistemology and Philosophy of Science, 2013, vol. 36, N 2, pp. 78–91.

at determining the effectiveness of individual practices and system elements. This is why they favor private approaches to data interpretation. The benefits of process analysis for explaining the state of systems are overlooked, and the analytical tools provided by the methods based on machine learning and artificial intelligence (including Explainable artificial intelligence) are ignored.

Most research in the field of agriculture is still focused on short-term optimization and improving the efficiency of individual blocks (elements) of the system, rather than on its ability to form long-term production and economic sustainability (stability). Although the term “sustainability” does not have an adequate functional definition, there is a general consensus that the goal of achieving sustainability is to develop land use systems so that they fully meet the needs of society indefinitely. The stability space for any such system has n number of dimensions defined by a set of boundaries that represent the limits of acceptable conditions for the system. Consequently, stability can also be defined as a measure of the extent to which changes over time move the components of the system inside or outside the non-static stability space.

It is widely recognized in systems theory that if each element of a system, considered in isolation, is made to work as efficiently as possible, the system as a whole will not work as efficiently as possible⁸. Therefore, the performance of the system depends more on how its parts interact than on how they act independently of each other. Consequently, it is the whole of a system, not the individual elements, that is important for optimizing the performance of the systems.

It should also be noted that any object or system, regardless of its nature, has an infinite set of properties and characteristics. Taking them all into account makes the solution of

the problem of describing the object or system practically impossible. “Scientific method” circumvents this problem by assuming that many properties of the object do not affect or weakly affect the problem under consideration and they can be disregarded (“One should not multiply things unnecessarily” - Occam's razor). Therefore, the classical “scientific method” never considers the object under study directly, but always deals with some simplified reflection of it in the human mind (image). This simplification is otherwise called a model, which specifies a set of properties and characteristics of the system, which will be taken into account in the future.

Thus, there are fundamental differences between an analytical-reductionist approach and systems thinking. Farming systems are characterized by complexity and variability. The complexity arises from inherently complex processes in plants, soils and surface air, combined in an almost infinite set of combinations related to biotic and abiotic factors that are inherently variable in both space and time. Therefore, systems thinking (systems analysis) should not just be applied as a separate part of the research program, it should be considered as a basis, a starting point for a holistic study and analysis of the problem to be solved. A holistic approach to the farming system implies studying the complexity of interactions in two aspects: within a “hard” system (biological and technological components are modeled) and within a “soft” system (biological and technological components have a common meaning and context). The emphasis on understanding the interrelationships and multiple causes of a phenomenon distinguishes farming systems from those approaches in agronomy that focus on technological solutions. This approach is exemplified by so-called precision farming, which predominantly addresses current crop productivity management problems.

⁸Ackoff R. The Art of Problem Solving: transl. from Engl. Moscow, 1982, 224 p.

In fact, precision farming implements some methods of agrotechnics of crop cultivation (in the discourse of precision farming – agrotechnologies), but using the capabilities of modern information systems (GLONASS/GPS, GIS, remote sensing, yield estimation technology, variable rationing, Internet of Things). However, agro-technologies themselves are only the final stage in the realization of farming systems and their connecting link [5]. In fact, the farming system is an emergent property of material conditions as well as of social construction, motivation and behavior. Therefore, farming system design involves the integration of several spatial and temporal levels, requiring a combination of extensive data sets, simulation models and expert knowledge, including “local” knowledge.

Sources of knowledge in agriculture, as mentioned above, are based on the results of inductive analysis of the experiments conducted on the experimental fields of scientific and educational institutions in a limited geographical space, and agronomic recommendations are general in nature and are implemented over large areas. However, the results obtained in a single point of space (in experiments on “small plots”) are not representative for heterogeneous production fields located in different natural conditions, even in one soil-climatic province or agro-ecological group of lands. The heterogeneity of natural conditions and socio-economic statuses of land use requires locally adapted solutions and “most adequate” approaches. Before making recommendations on the application of control actions, it is necessary to know the frequency and dimensionality of response to various interventions in the life cycles of biological objects not only in time, but also in space (“control zone”). The search for methods of intra-field allocation of “control zones” in the implementation of precision farming technologies has been actively developed recently [7, 8].

Unfortunately, relatively little effort in agronomic science has been spent on the formulation of acceptable hypotheses and theories related to the agronomic effects of the implementation of the farming systems in different spatial (geographical) conditions (land group, agrolandscape region, soil-climatic province). It should be noted that in the domestic scientific discourse the problems of “agrogeography” are discussed. However, the main subjects of this direction are the study of the peculiarities of the territorial organization of agriculture and the identification of regularities of the functioning of spatial agricultural systems, their relationships under the influence of external factors for the adoption of management decisions, mainly organizational and economic [9]. The direction called “landscape agronomy” is developing abroad [10]. But these studies are focused, as a rule, on a limited spatial object – agrolandscape (as in the interpretation of the subject of agrogeography by D.A. Ivanov [3]). The subject of “biogeography” is basically the classification of the regions in terms of their biota, which serves as a key to understanding the environmental and historical factors affecting the distribution of species and how they respond to past or current physical and biological determinants [11].

From our point of view, it is necessary to develop research on geography of the farming systems (GeoFarmSyst), the main objective of which would be to scale up the archetypes (prototypes) of the farming systems developed in a particular point of geographical space by scientific and educational institutions, in order to realize them on the “field” in the context of smart farming. Given the increasing availability of geographic information systems (GIS) and spatial data, there is a need for greater use of digital maps and geo-referencing of data analysis. Such use of geo-information modeling capabilities would be reflected in a better understanding of the influence of biotic and edaphic environmental factors on the response

of cultivated crops and would contribute to a more adequate interpretation of the quantitative results of the scientific experiments.

The archetype of the farming system is understood as a model of agricultural land use of a certain agro-ecological group with an ecologically and economically determined set of cultivated crops and appropriate methods of control actions (crop rotation, soil treatment, fertilizers, plant protection) [12].

Scaling of archetypes of the farming systems from “small plots” to the regional level or other taxonomic unit involves linking different spatial and temporal scales and will pose practical and theoretical challenges. First, high-performance solutions that integrate advanced GIS tools with remote sensing and machine learning, as well as an advanced computing infrastructure, will be required. Secondly, integration of spatially heterogeneous data on climate, relief, soil and management will inevitably lead to aggregation errors, spatial and temporal distortions in modeling. Therefore, it is necessary to pre-test different approaches for spatial object classification. For example, stratification, an approach used within spatial classification to identify archetypal patterns of agro-ecological land potential based on clustering of variables using machine learning on bioclimatic conditions, soil characteristics and topographical parameters [13], or the delineation of agro-ecological zones taking into account topography, soil cover and agrometeorological resources to create maps of land suitability for cultivation of certain crops [14].

In our opinion, a promising area of research to develop approaches to scaling archetypes of farming systems could be the application of the concept of “geons”⁹. This concept is used in geoinformatics as a strategy to represent and analyze hidden spatial processes at different geographic scales (local and regional) for territory zoning. Geons are geographical units,

homogeneous in terms of various spatial and temporal phenomena. The main purpose of creating geons is to create digital maps of spatial objects with the appropriate geodatabase relevant to economic use. The geon model works as a two-step process, where the first step of classification uses expert knowledge specific to a particular subject area, and the second step is based on semi-automatic zoning through segmentation and classification of remotely sensed images. The relevance of this approach is justified by the fact that it provides an opportunity to apply machine learning algorithms for automated classification of remotely sensed images. Remote sensing, in turn, is considered by us as the most promising tool for land typing and scaling of archetypes of the farming systems.

Closely related to the issues of the farming systems scaling are the problems of their adaptation to the natural and production conditions of a particular land use. The problems of adaptation of the farming systems are not new and have been discussed in various contexts [15, 16]. However, we would like to draw attention to the fact that these problems are discussed within the framework of the so-called “productivist” model of agriculture (deliberate unlimited increase in the production and consumption of agricultural products), which was significantly developed after World War II. This model is based on the use of “off-the-shelf” technologies (anthropogenic resources and genetics) in an attempt to overcome the heterogeneity of the environment through the achievements of crop breeding and the use of chemical synthetics (“green revolution” or chemical-technogenic intensification). Within the “war on hunger” paradigm, agriculture was seen as a “machine” that could be made to work better by adjusting the “nuts and bolts”, i.e. fertilizers, pesticides, seeds, irrigation, and thus provide a sustained effect in increasing productivity. In developed countries, this model has promoted the special-

⁹Lang S., Kienberger S., Tiede D., Hagenlocher M., Pernkopf L. Geons – domain-specific regionalization of space // Cartography and Geographic Information Science, 2014, vol. 41, N 3, pp. 214–226.

ization of the areas based on their suitability for specific land uses, which has led to the standardization of production methods and, consequently, to a reduction in the geographical cognitive resources required for their implementation¹⁰. Since the 1980s, there has been a realization of the negative impacts of this model of agricultural production on biodiversity, ecosystem functioning and climate change, as well as on product quality, human health and the growing scarcity of fossil resources and water (see footnote 1) [17].

In this regard, the dominant paradigm of agricultural intensification is questioned and new ways of building sustainable agro-ecosystems are sought. The concept of increasing biodiversity, in particular diversification, can help to overcome the negative impact on nature of the “productivist” model. Diversified farming systems are believed to contribute more to the maintenance of the following elements than uniform systems: biodiversity, soil quality, carbon sequestration and soil water holding capacity, energy efficiency, and climate change resilience [18, 19]. There are different types of cropping system diversification strategies: crop rotation, associated plant species (cover crops, trap crops, repellent crops and buffer crops), mixtures of varieties and crops, agroforestry, shaping landscape heterogeneity.

However, the meta-analysis published in [20] showed a high variability of approaches to crop diversification and the lack of a unified theoretical concept. For better comparability and the possibility of generalizing the results of different primary studies, the authors proposed a conceptual framework consisting of the following elements (finalized by us): 1) characterization of the basic farming system to be diversified; 2) determination of the scale and target land-use area; 3) development of the experiment plan and target variables, taking into account the specialization of land use; 4) deter-

mination (modeling) of the expected effect of the experiment. Application of this framework will help to define the limits of diversification and its possible benefits. A complete land-use transformation towards highly diversified farming systems is likely to be infeasible, but adopting selected elements of diversification may provide a realistic approach to improving farming sustainability.

At present, the problem of implementation of the farming systems “without pesticides but with the use of fertilizers” is also being discussed [21]. Let us call them “intermediate” between chemical-technogenic (conventional) and organic systems. Compared to organic farming, pesticide-free production technologies are more flexible and involve fewer barriers to implementation, as well as lower yield losses. However, there are various barriers to their implementation, so it is necessary to study all the positive and negative effects of these systems.

Adaptation of cropping systems to possible climate change is also considered an important aspect of adaptation. However, deciding how and when to adapt to climate change is a complex task involving many challenging issues, deep uncertainties and controversial objectives. Numerous decision-making strategies have been developed to reduce uncertainty, adaptation options have been evaluated under multiple future scenarios, and decision pathways for climate change adaptation have been created, but none of this has overcome the barriers that prevent adaptation decisions from being a “rational” process [22].

In addition, the distinction between feasible, possible, plausible and probable climate change scenarios is not always clear [23]. This is largely because anthropogenic climate change affects systems that are emergent and rapidly changing in nonlinear ways that are outside the ranges for which reliable scientific knowledge exists. In addition, climate science has a lim-

¹⁰Duru M., Therond O., Fares M. Designing agroecological transitions: a review // *Agronomy for sustainable development*, 2015, vol. 35, pp. 1237–1257.

ited ability to predict low-probability events, and does not offer ways to assess the effects of specific decisions and thus the response of climate systems to anthropogenic interventions. In turn, many adaptation decisions depend on the context, which limits the ability to make generalizations based on climate models on spatial and temporal scales [24]. Nevertheless, the development of the methods (ways, techniques) for adapting cropping systems to potential climate change requires the integration of knowledge from quantitative climate models and cropping system archetype models for use in digital farming management systems.

In order to develop digital farming management systems, more attention should be paid to simulation modeling in scientific research. Models are needed to answer a specific question of a subject area, are created for this purpose and come in different forms. Statistical (or empirical) models use the mathematical relationship between different variables. A fundamental disadvantage of statistical models is that they are developed from data and are ill-suited for use in applications that have not participated in the parameterization and development of the model. They also cannot predict values in an uncertain context (e.g., the effect of climate change on crop growth). In contrast, mechanistic models (also called process-based or biophysical models) are based on modeling biophysical processes. They use mathematical equations that describe these processes, rather than the equations that simply link two variables, as in statistical modeling. They can be derived in the absence of any real data, if the process is described. Mechanistic models can be deterministic, i.e., without random variation within the model and equations, so that for a given set of input data, the result will always be the same. Mechanistic models can also be stochastic, i.e. the models and equations include random effects, so

the results will vary even if the inputs remain constant. Most crop models are a combination of process and empirical models, resulting in mechanistic deterministic models¹¹.

The models take into account the relationship between crop growth, agro-ecological conditions and control actions. They are therefore, by definition, systemic, and the goal here is to simulate soil-plant-atmosphere interactions. In order to achieve this goal, interdisciplinary approaches are used that take into account biological, physiological, ecological, physical or economic components. The integration of these components has led to the development of well-known crop production models such as APSIM, DSSAT, STICS, WOFOST, CropSyst or AGROTOOL. Sometimes called “crop models”, they are interpreted as explanatory tools that are commonly used in testing different approaches to crop productivity management.

Most biophysical models have limitations, namely they are “point models”. They are designed to simulate crop growth and development for a homogeneous unit at a specific point in space. In addition, biophysical models require a large amount of input data. For example, the program WOFOST requires data on about 40 input parameters, for AGROTOOL – on more than 190. Mechanistic models are unable to simulate yield loss due to weeds, pests and diseases, as well as the damage caused by extreme weather events such as hail or high winds. Applications of such models are best suited for field experiments, forecasting and analyzing crop behavior under different environmental scenarios.

Mechanistic models are also expedient to use in complex with simulation modeling. Simulation is a descriptive tool that is used: 1) to describe the currently existing system; 2) study of a hypothetical system; 3) refinement and expansion of the existing system. The role of a simulation model is to create a “virtual world”

¹¹Antle J.M., Jones J.W., Rosenzweig C.E. Next generation agricultural system data, models and knowledge products: Introduction// Agricultural systems, 2017, vol. 155, pp. 186–190.

in which experiments can be conducted to facilitate the study of the system in question. Simulation modeling is expedient to apply in solving problems of crop yield planning and control actions in desk conditions. Based on the results of simulation modeling, an appropriate field research program is developed.

It should be noted that the application of mechanistic models on a spatial scale in a heterogeneous real-world situation is limited. In this context, remote sensing techniques can complement mechanistic models, in particular by generating missing spatial information for a modeling unit. Although these two technologies have developed independently, they can now be used synergistically at different spatial and temporal scales for the overall development of digital farming systems management and their implementation “on the ground”.

CONCLUSION

A paradigm shapes the worldview of researchers in a particular subject area and is the basis for choosing approaches and methods of the research process in any scientific discipline.

The methodological basis for the study of the farming systems lies in their complexity, variability and uncertainty (more precisely – underdetermination). Therefore, cognitive problems of farming cannot be solved using the philosophy of logical positivism and instrumentalism with reductionist approach. It is necessary to apply system thinking in developing research programs, analyzing and interpreting the results of field experiments, including the use of artificial intelligence.

To transform the modern farming paradigm in order to actualize it, it is advisable to pay attention to solving the following issues:

- research on the geography of cropping systems and their scaling in space and time should be based on the identification of the archetypes and taking into account the results of field experiments of scientific and educational institutions on “small plots”;
- in order to develop approaches to scal-

ing the archetypes of the farming systems, it is necessary to use the achievements of modern geoinformatics integrated with remotely sensed data;

- in order to overcome the negative impact of chemical-technogenic intensification (“production” model) on nature, it is necessary to study the limits of diversification of the farming systems, which can be realized through crop rotations, associated plant species, mixtures of varieties and crops, etc.;

- In order to develop scenarios for adaptation of the farming systems to possible climate change, it is advisable to integrate the knowledge obtained from quantitative climate models and models of farming system archetypes for their use in digital farming management systems “on the ground”;

- mechanistic models of the crop production process developed for a homogeneous unit at a specific point in space need to be scaled for different environmental scenarios and spatial objects, and used in integration with simulation modeling.

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✉ **Каличкин В.К.**, доктор сельскохозяйственных наук, профессор, главный научный сотрудник; **адрес для переписки:** Россия, 630501, Новосибирская область, р.п. Краснообск, а/я 463; e-mail: vk.kalichkin@gmail.com

AUTHOR INFORMATION

✉ **Vladimir K. Kalichkin**, Doctor of Science in Agriculture, Professor, Head Researcher; **address:** PO Box 463, Krasnoobsk, Novosibirsk Region, 630501, Russia; e-mail: vk.kalichkin@gmail.com

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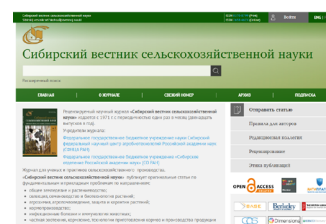
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