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СИБИРСКИЙ ВЕСТНИК СЕЛЬСКОХОЗЯЙСТВЕННОЙ НАУКИ

SIBIRSKII VESTNIK SEL'SKOKHOZYAISTVENNOI NAUKI

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

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ЭФФЕКТИВНОСТЬ УДОБРЕНИЙ НА ПОСЕВАХ ПШЕНИЦЫ В СЕВЕРО-ЗАПАДНОЙ ЗОНЕ КУРГАНСКОЙ ОБЛАСТИ

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Представлены результаты длительного (1968–2021 гг.) эксперимента по применению удобрений за 10-ю и 11-ю ротации зернопарового севооборота на опытном поле Курганской области. Севооборот включал пар и три пшеницы. Эффективность удобрения различалась в зависимости от комбинации элементов питания, места пшеницы в севообороте и условий увлажнения периода вегетации. На тяжелосуглинистом выщелоченном черноземе опытного поля в этих ротациях проявилось умеренное действие фосфорного удобрения и высокое – азотного на посевах, удаленных от пара. Сочетание азотного и фосфорного удобрений давало более высокую прибавку урожайности. Азотное удобрение оказывало положительное влияние и на качество пшеницы, повышая содержание клейковины и массу 1000 зерен. С увеличением накопления клейковины в зерне пшеницы на фоне азотного удобрения повышалась повторяемость соответствия качества пшеницы требованиям к 3-му классу зерна. Проявилось действие удобрений и длительности их применения на агрохимические свойства почвы. Заметнее с применением удобрений повышалось содержание подвижных питательных веществ в почве, гумуса, общего содержания азота и фосфора, но при этом снизилось значение $pH_{сол}$. Высокая экономическая эффективность относилась к азотному удобрению, вносимому на второй и третьей пшенице после пара с окупаемостью 1 кг азота 12–19 кг зерна. Действие фосфорного удобрения было умеренным, поскольку содержание подвижного P_2O_5 в пахотном слое почвы оставалось высоким. Сильнее применение аммофоса влияло на урожайность пшеницы при хорошей обеспеченности растений азотом на первом посеве по пару.

Ключевые слова: северо-западная зона Курганской области, выщелоченный чернозем, состав удобрения, зернопаровой севооборот, урожайность пшеницы, качество зерна

FERTILIZER EFFICIENCY ON WHEAT CROPS IN THE NORTHWESTERN ZONE OF THE KURGAN REGION

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The results of long-term (1968-2021) experiment on the use of fertilizers for the 10th and 11th rotations of grain and fallow crop rotation in the experimental field of the Kurgan region are presented. Crop rotation included fallow and three crops of wheat. Fertilizer efficiency varied depending on the combination of the nutrients, the place of wheat in the rotation, and the moisture conditions of the growing season. Moderate effect of phosphorus fertilizer and high effect of nitrogen fertilizer on heavy loamy leached chernozem of the experimental field in these rotations was observed on the crops distant from the fallow. The combination of nitrogen and phosphorus fertilizers gave a higher yield increase. Nitrogen fertilizer also had a positive effect on the quality of wheat, increasing the gluten content and the thousand-kernel weight. With the increase of gluten accumulation in wheat grain against the background of nitrogen fertilizer, the repeatability of wheat quality compliance with the requirements for the 3rd class of grain increased. The effect of fertilizers and the duration of their application on the agrochemical properties of soil became visible. The content of mobile nutrients, humus, total nitrogen and

phosphorus increased more noticeably with the use of fertilizers, but the pH_{salt} value decreased. High economic efficiency related to nitrogen fertilizer applied on the second and third wheat after fallow with a payback of 1 kg of nitrogen 12-19 kg of grain. The effect of phosphorus fertilizer was moderate, since the content of mobile P_2O_5 in the topsoil remained high. The use of ammophos had a stronger effect on the yield of wheat when the plants were well supplied with nitrogen in the first fallow crops.

Keywords: northwestern zone of the Kurgan region, leached chernozem, fertilizer composition, grain fallow crop rotation, wheat yield, grain quality

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INTROUCTION

Spring soft wheat is the main crop in the agriculture of the Kurgan region. Most of its plantings in the region are located on leached chernozem (black earth) and ordinary solonized soils. In chernozem soils, unlike other soil types, more nitrates accumulate, providing a favorable nitrogen regime for spring wheat. Among the two subtypes of chernozem, more nitrates form in ordinary solonized compared to the leached one.

With prolonged use of nitrogen fertilizers, not only does the amount of mobile nitrogen compounds in the soil increase, but the content of total nitrogen also changes, increasing by 4-16% [1]. The importance of clarifying the optimal doses of nitrogen fertilizer is justified by eliminating or reducing nitrogen losses through leaching into soil layers below the root-inhabited horizon. The action of nitrogen and phosphorus is closely linked. Adequate phosphorus supply in plants enhances the positive effect of nitrogen fertilizer [2–4].

In the Ural region, 50-60% of the soils in arable lands have a low content of mobile phosphorus [5, 6], necessitating the combined application of nitrogen and phosphorus fertilizers in such conditions. There is a sufficient amount of mobile potassium in the soils of the Kurgan region, but against the background of systematic application of nitrogen and phosphorus, the addition of potassium fertilizer brings a small additional increase in crop yields, especially in tilled crops. The efficiency of even optimal doses of fertilizers largely varies depending on the prevailing meteorological conditions[1–3] [7]. As noted by O.V. Melnikov and T.M. Mazhu-

[1]*Fatykhov I.Sh., Kolesnikova V.G., Korepanova E.V., Islamova C.M.* Environmental problems in agronomy // Modern agroindustrial complex - effective technologies: proceedings of the international scientific-practical conference dedicated to the 90th anniversary of V.M. Makarova (December 11-14, 2018). Izhevsk: Izhevsk State Agricultural Academy, 2019, Vol. 1, pp. 445-447.

[2]*Volkova L.V.* Yield of spring soft wheat and its relationship with the elements of productivity in different meteorological years // Agricultural Science Euro-North-East, 2016, No. 6, pp. 9-15.

[3]*Melnikov O.V., Mazhugo T.M.* Yield and grain quality of spring soft wheat varieties depending on growing conditions // Bulletin of the Kursk State Agricultural Academy, 2015, No 8, pp. 123-125.

go (see footnote 3), "crop yield is a result of a compromise between plant productivity and its resilience to adverse environmental conditions." By shifting the sowing date, there is an opportunity to adjust crop yields considering the distribution of precipitation and variability of other weather indicators based on long-term climatic data. There are instances when, under conditions of reduced solar activity, early sowing dates for wheat were advantageous, and during increased solar activity, late sowing[4] was beneficial.

Wheat grain yield and quality also vary in relation to other agronomic elements: selection of intensive type varieties [8], sowing of valuable or strong wheat [9], the place in the crop rotation, and the type of soil treatment. Regarding the influence on wheat yield, no-till and traditional farming converge in the steppe zones of many regions[5]. Fertilizers increase the amount of primary production and the total sum of plant residues, gradually increasing the humus content[6] due to this. Under the influence of fertilizers, the content of mobile nutrients in the soil increases, significantly improving plant nutrition conditions[7] [10].

MATERIAL AND METHODS

A long-term experiment was conducted at the experimental field of the Kurgan Agricultural Research Institute in the village of Maltsevo (Kurgan region) in three setups starting from 1968, 1969, and 1971. Initially, this department was known as the Shadrinsk Experimental Station, led by T.S. Maltsev for 35 years, followed by V.B. Sobyannin. Since 2010, the station has been annexed to the Kurgan Agricultural Research Institute, operating as the T.S. Maltsev Laboratory. For most of the years, the experiments were conducted by B.N. Sobyanin, P.Z. Sobyanina, V.B. Sobyanin, and O.B. Sobyanina, and from 2011 onwards by N.V. Ionina. From 2011, A.N. Kopylov led the research. The analysis of this experiment was performed by the authors of this article.

The experimental data studying fertilizers were published in 2019 in the "Agricultural chemistry" journal, where a summary of the results of the experiments with fertilizers from 1968 to 2017 was made [11]. The present article discusses the data obtained during the 10th and 11th rotations (2014-2021).

The soil type is heavy loamy leached chernozem. The crop rotation is expanded both spatially and temporally, meaning records were kept for the first to third wheat after fallow in three experimental fields. The agrochemical properties of the soil in the initial years of the experiment were as follows: humus across the three plots – 6.18-6.48-6.33%, total nitrogen – 0.308-0.314-0.339%, gross phosphorus – 0.145-0.118-0.153%, pH_{KCl} – 5.8-6.2, mobile P_2O_5 and K_2O according to Chirikov – 54-61 and 159-196 mg/kg of soil. The content of mobile phosphorus in the control began to increase from the 7th rotation due to systematic soil cultivation across plots, although each plot had a protective zone of 2.11 m on both sides. In the control during the 4th rotation, this indicator was maintained at the initial level of 54 mg/kg; in the 7th rotation (1999-2005) it equaled 74 mg/kg, and by 2011, it reached 93 mg/kg. Even against the backdrop of nitrogen-potassium fertilization, this value for the mentioned rotations changed from 43 to 60 mg/kg. Consequently, the usually well-manifested effect of fertilizers in the PK combination on wheat sowing after fallow, ranging from 2 to 5 centners of grain per hectare, was observed only in the 1st to 5th rotations. In the 6th and 8th rotations, the yield increase from PK on the first wheat decreased to 1.1-1.3 c/ha,

[4] *Vasilevsky V.D.* Response of soft spring wheat of different ripeness groups to sowing time in the southern forest-steppe of Western Siberia depending on solar // Modern agro-industrial complex - effective technologies: materials of the international scientific-practical conference dedicated to the 90th anniversary of V.M. Makarova (December 11-14, 2018). Izhevsk: Izhevsk State Agricultural Academy, 2019, Vol. 1, pp. 90-94.

[5] *Pasynkov A.V., Pasynkova E.N.* Method of tentative determination of crude gluten content in wheat grain// Modern agro-industrial complex - effective technologies: materials of the international scientific and practical conference dedicated to the 90th anniversary of V.M. Makarova (December 11-14, 2018). Izhevsk: Izhevsk State Agricultural Academy, 2019, Vol. 1, pp. 348-352.

[6] *Karpukhin M.Y., Grinets L.V.* Resource-saving technologies in the steppe zone of Northern Kazakhstan and their advantages and problems // Agrarian Bulletin of the Urals, 2016, No. 4, (146), pp. 13-17.

[7] *Sharkov I.N.* Humus and soil fertility management // Agrarian sector, 2016, No. 4 (38), pp. 126-135.

and in the 7th rotation, there was no addition. It was decided to suspend the use of phosphorus fertilizer for 8 years (2003-2010). After the hiatus, from 2011, phosphorus was applied locally with the SZ-3.6 seeder before sowing, unlike the previously used scattered uniform method. With localized application of phosphorus fertilizer in the 10th rotation, the yield increase from P_{20} on wheat after fallow amounted to 2.6 c/ha.

In the initial years, the crop rotation was five-field: fallow, two wheat crops, corn (oats since 1997), and wheat. From 2011, it became a four-field rotation: fallow and three wheat crops. The main soil treatment in the initial rotations was plowing, and from 2011, it became superficial. The plot area was 221 m² (34 × 6.5), with a registration plot of 68.4 m² (30 × 2.28), and the repetition of the variants was done four times.

The doses of all the nutrients varied. The tables show their average amount for 53 years of the experiment. The action of fertilizers was studied using the scheme: control (without fertilization), PK, NK, NPK. Nitrogen was applied in the form of ammonium nitrate, and phosphorus in the form of superphosphate. Potassium chloride was used in the experiment for 32 years (up to 2000). Afterwards, potassium had only a slight residual effect, as the K_2O content in the soil of the plot was high - 172-200 mg/kg.

In the 10th and 11th rotations, wheat varieties "Iset 45" and "Raduga" were sown. Sowing was carried out using the "Kuzbass" sowing complex to a depth of 6 cm at a rate of 4 million germinated grains per hectare. Sowing was done between May 25 and June 3, as the heavy loamy soil reached physical maturity and the air temperature rose to 15-17°C. The soil was rolled on the day of the sowing.

For plant care, a tank mixture of Explorer was used, l/ha: Oprichnik (0.4), Toptun (0.6), and the insecticide Aivengo (0.1). In the years of stem rust spread, the crop was sprayed with the fungicide Falcon. The harvest was collected directly using the Sampo-500 combine with a sample of grain taken to account for bunker mass moisture and impurity content.

In the grain-fallow crop rotation with plowing, droughts occurred 10 times over 24-26 years of wheat plantings. Over 7-8 years of grain-fallow crop rotation with surface treatment, it occurred once in 2021. The total precipitation for May-August during the analyzed period (2014-2021) averaged 192 mm, with fluctuations between 36 and 281 mm.

The purpose of the research was to continue studying the effects of fertilizer composition under changed agronomic and agrochemical conditions of wheat cultivation.

RESULTS AND DISCUSSION

Effect of fertilizers on wheat yield. The weather conditions in the 10th and 11th rotations for six sowings of the first wheat after fallow favored the formation of high yields five times. The exception was 2021 with a severe drought that lasted in May, June, and early July, which led to a decline in the yield of both unfertilized and fertilized wheat, previously ranging from 26-35 to 8-9 centners per hectare, respectively. Nitrogen was not applied to the first wheat, but its use in the following crop rotation fields had an aftereffect, which was positive only in 2019, explained by the heat deficiency in the previous year during fallow and also in May and June 2019. On the fertilized wheat after fallow, significant effects on yield were observed with the phosphorus-potassium and complete mineral fertilizer variants, with yield increases of 1.6 and 2.0 centners per hectare (see Table 1). The phosphorus action was low due to the aforementioned gradual increase in mobile P_2O_5 (according to Chirikov) on the experimental site. By 2011, it reached 93 mg/kg in the control, 62 mg/kg in the $N_{54}K_{16}$ variant, and 108 and 118 mg/kg in the phosphorus-fertilized backgrounds.

The yield of the second wheat after fallow decreased to 10-13 centners per hectare in some years, averaging 14.8 centners per hectare over 5 years of the 10th and 11th rotations. Yield improvement in this crop rotation field was ensured by nitrogen fertilizer and its combination with phosphorus, where the yield reached the level of the first wheat after fallow. In the final crop rotation field due to the drought of 2021, the lowest grain harvest was achieved - 5-12 centners per hectare. On average, over 5 years in the control, 13.4 centners per hectare were harvested. Nitrogen fertilizer had the strongest effect on yield in

this field. However, increased weed infestation at the end of the rotation, even with fertilization, limited grain yield to 21.8 centners per hectare on the $N_{54}K_{16}$ background and 23.4 centners per hectare with the application of full mineral fertilizer (see Table 1).

Comparing the effectiveness of fertilizers over two experimental periods with different soil treatments showed that the pattern of the effect of different fertilizer compositions was consistent. For example, in the first wheat after fallow in the variants 1-4 (see variant names in Table 1), the yield during plowing was 21.0; 23.5; 21.8, and 23.0 c/ha, during the years with superficial treatment, it was 25.4; 27.4; 26.1, and 28.0 c/ha. For the second wheat, the yields were 11.5; 11.8; 16.1; 17.7 and 14.2; 16.2; 24.9; 27.8 c/ha, respectively. The yield and its increase were lower during the plowing years, as the first experiment period had more drought-affected years.

Effect of fertilizers on grain quality. The fertilizer had a positive effect on the quality of wheat grain. Without fertilization, in the conditions of the northwestern zone, it is not always possible to simultaneously increase both the yield of wheat and the protein content in the grain. Thus, in the 10th and 11th rotations, even for the first wheat after fallow, the grain quality met the requirements for the 3rd class in terms of gluten content only in 50% of the years. The nitrogen-potassium background in the first sowing after fallow increased the repeatability of the 3rd class to 67% of years. In the second and third sowings after fallow, without fertilization, the gluten content in wheat grain was significantly lower, but with the addition of nitrogen,

Табл. 1. Урожайность первой – третьей пшеницы после пара в 10–11-й ротациях, ц/га
Table 1. Yield of the first - third wheat after fallow in 10-11th rotations, c/ha

Year	Option				
	Control	$P_{27}K_{16}$	$A*N_{54}K_{16}$	$AN_{54}P_{27}K_{16}$	LSD_{05}, c/ha
First wheat after fallow					
2014	31,3	33,2	30,0	34,0	0,9
2015	32,9	34,8	30,2	34,8	2,2
2017	30,5	32,2	29,9	32,0	1,3
2018	28,0	30,0	28,4	30,3	1,1
2019	26,5	27,0	28,2	30,3	0,7
2021	8,1	9,4	8,0	8,1	1,5
Average	26,2	27,8	25,8	28,2	
+– to the control	–	1,6	–0,4	2,0	
Second wheat after fallow					
2015	20,1	23,8	31,4	32,4	2,1
2016	19,5	21,0	31,0	36,2	3,0
2018	10,4	10,7	15,9	17,8	2,7
2019	13,0	15,5	28,3	33,6	3,1
2020	11,0	11,1	18,9	19,3	4,2
Average	14,8	16,4	25,1	27,9	
+– to the control	–	1,6	10,3	13,1	
Third wheat after fallow					
2016	18,6	20,0	29,8	28,7	2,7
2017	16,9	18,0	27,6	29,6	2,5
2018	14,5	16,1	22,1	23,9	2,1
2020	11,6	11,0	19,3	22,2	2,9
2021	5,7	5,6	10,4	12,5	1,7
Average	13,4	14,1	21,8	23,4	
+– to the control	–	0,7	8,4	10,0	

Note. Nitrogen fertilizers were not applied to the first wheat, but their application in subsequent fields of the crop rotation had an aftereffect. Here and in Tables 2 and 6 A - aftereffect.

it increased by 5–11% in absolute terms. Phosphorus-potassium fertilizer slightly changed the gluten content in the grain (see Table 2).

For the unfertilized third wheat, only 2 out of 5 years marked a gluten level of no less than 23%. Against the background of fertilization, including nitrogen, a significant increase in gluten was detected for three years. The average increase compared to the control was 5-6% in absolute terms. The decrease in gluten content in the grain in 2016 and 2017 was due to achieving a sufficiently high yield. The plants' affliction with stem rust also mattered.

Another important quality trait of wheat is grain plumpness (weight of 1000 grains). Under the conditions of the experiment, this indicator varied by year and option from 24.4 to 42.7 g. The use of fertilizers had a positive effect on the weight of 1000 grains mainly in options with nitrogen, especially against the background of a complete mineral fertilizer $N_{54}P_{27}K_{16}$, by which the value increased by 2-4-6 g for the second and third wheat after fallow.

The impact of fertilizers on the agrochemical properties of the soil. The effect of fertilizers on many soil properties occurs slowly and gradually, so we should refer to the initial soil analysis results in the 1st rotation and compare them with the data obtained 30 years later in the 6th rotation. Even for such slowly changing soil properties as humus, the total of absorbed bases, gross nitrogen, and phosphorus content, the fertilizers had an impact. Over 30 years, the amount of mobile phosphorus increased noticeably, and soil acidity also increased (see Table 3).

The relationship between the variability of wheat yield for the 1st to 6th rotations and the humus content in each subsequent rotation is of interest. The sum of plant residues is directly determined by the yield level of crop rotation crops; we considered wheat yield. Straw has been left in the field since 1978 (with the introduction of

Табл. 2. Содержание клейковины в зерне первой – третьей пшеницы после пара в 10–11-й ротациях, %

Table 2. Gluten content in the grain of the first - third wheat after fallow in the 10th-11th rotations, %

Option	Year						Average	3rd grain class, % of years
	2014	2015	2017	2018	2019	2021		
First wheat after fallow								
Control	26,7	18,7	20,7	24,3	17,9	29,1	22,9	50
$P_{27}K_{16}$	27,0	19,5	20,0	24,5	17,4	28,9	22,9	50
$AN_{54}K_{16}$	28,0	19,0	23,0	23,0	19,6	28,8	23,6	67
$AN_{54}P_{27}K_{16}$	28,0	19,0	24,5	22,2	20,6	29,0	23,9	50
LSD_{05}, %							1,44	
Second wheat after fallow								
Option	2015	2016	2018	2019	2020			
Control	13,2	15,2	24,5	19,9	22,6		19,1	40
$P_{27}K_{16}$	14,0	14,0	24,5	22,3	20,0		19,0	20
$N_{54}K_{16}$	16,0	16,5	30,0	31,4	27,3		24,2	60
$N_{54}P_{27}K_{16}$	14,0	16,5	32,0	30,0	30,6		24,6	60
LSD_{05}, %							3,32	
Third wheat after fallow								
Option	2016	2017	2018	2020	2021			
Control	15,5	21,5	26,1	21,0	28,3		22,5	40
$P_{27}K_{16}$	16,0	22,0	29,4	23,2	26,0		23,3	60
$N_{54}K_{16}$	17,0	21,5	41,0	34,2	29,0		28,5	60
$N_{54}P_{27}K_{16}$	17,0	22,0	36,4	31,3	32,0		27,7	60
LSD_{05}, %							4,63	

the Sampo-500 combine). Soil analysis was conducted at the beginning of the rotation for each experimental setup. In this complex relationship, there isn't a complete match, but in most comparisons, an increase in humus content was found after the rotations with higher yields (see Table 4).

The calculations are made on average for three experimental setups. It is clear that after achieving yields within 18-22 tons/ha in the 1st rotation, the humus content in the 2nd was higher than in the 3rd after 16-20 tons/ha in the 2nd. The humus content increased even more significantly in the 4th rotation due to a larger amount of plant residues at a yield of 17-27 tons/ha. A decrease in productivity in the 4th rotation to 12-18 tons/ha led to a reduction in humus in the 5th rotation to 5.63-6.61% (see Table 4).

Even without considering the expected plant residues in the forecrop wheat field based on

Табл. 3. Изменение агрохимических показателей выщелоченного чернозема за 30 лет опыта в с. Мальцево (среднее по трем закладкам)

Table 3. Changes in agrochemical indicators of leached chernozem over 30 years of experience in the village of Maltsevo (average of three establishments)

Option	Humus, %	pH_{wat}	pH_{KCl}	Total nitrogen, %	Total phosphorus, %	Ca + Mg, mg-eq./100 g	P_2O_5, mg/100 g	K_2O, mg/100 g
1st rotation								
$N_0P_0K_0$	6,30	6,6	6,1	0,288	0,134	36,4	0,175	13,8
PK	6,57	6,6	6,0	0,292	0,135	36,4	0,177	13,8
NK	6,66	6,5	6,2	0,321	0,138	37,2	0,176	13,3
NPK	6,68	6,5	6,2	0,321	0,139	37,2	0,176	13,3
After 30 years, 6th rotation								
$N_0P_0K_0$	6,43	6,3	5,2	0,290	0,148	38,4	0,645	13,6
PK	7,28	6,2	5,2	0,346	0,170	39,0	1,456	13,9
NK	7,41	6,2	5,2	0,321	0,161	38,6	0,469	14,0
NPK	7,34	6,2	5,2	0,310	0,179	37,2	1,954	13,0

Note. P_2O_5 - according to Franceson, K_2O - according to Brovkina.

Табл. 4. Влияние колебаний продуктивности пшеницы по ротациям севооборота на изменчивость содержания гумуса в слое почвы 0–20 см

Table 4. The effect of fluctuations in wheat productivity by rotation of crop rotation on the variability of humus content in the soil layer 0-20 cm

Option	Rotation, years					
	1st	2nd	3rd	4th	5th	6th
	1968–1975	1974–1980	1979–1985	1984–1990	1989–1995	1994–2000
Wheat yield, c/ha						
Control	18,6	16,0	17,4	12,9	10,3	13,1
PK	19,6	17,2	18,7	14,2	12,1	13,9
NK	21,2	17,4	24,5	16,2	14,1	17,6
NPK	22,6	20,0	27,6	18,0	16,0	19,0
Humus content, %						
Option	2nd 1974–1977	3rd 1979–1981	4th 1984–1987	5th 1989–1992	6th 1994–1997	9th 2011
Control	6,72	6,24	6,55	5,63	6,43	6,90
PK	7,21	6,81	7,39	6,43	7,28	7,10
NK	7,12	6,72	7,84	6,61	7,41	7,10
NPK	6,86	6,85	7,39	6,30	7,34	7,33

the yield, the discussed relationship is evident. Since 1997, the yield of oats, which averaged 9-22-25 tons/ha in the 6th-8th rotations based on three experimental setups, has been significant for the sum of residues, so elevated values were noted in the 9th rotation in 2011.

The experiment extensively studied the content of mobile P_2O_5 in the soil using the Francesson method, which changed both over time and under the influence of fertilizers. These data are presented in Table 5 for the 1968 setup. The materials obtained annually for 37 years are divided into seven periods, with an average calculated for 2 years.

Annual application of phosphate fertilizer significantly enriched the soil with mobile phosphorus. Its content also increased in the variants without phosphorus, explained by the transfer of soil from one area to the adjacent ones during processing at the experimental site across the variants. Until 2011, autumn plowing, spring harrowing, and pre-sowing cultivation were carried out.

Economic efficiency of different fertilizer compositions. Are fertilizers profitable in the new agrotechnical and agrochemical conditions of the experiment? The payback of nitrogen and phosphorus should be at least 8-10 kg/kg. According to Table 6, phosphate feed efficiency with grain additions is below the norm. In contrast, the nitrogen payback significantly exceeded it and equaled 16-19 kg/kg for the second wheat after fallow and 12-15 for the third.

Calculations of payback in rubles also showed that the most profitable was the use of nitrogen fertilizer. In 2020, 2021, the price of 1 centner of nitrate was 1800 rubles, 3rd class grain 1600 rubles/ centner; the dose of N_{54} in the form of ammonium nitrate - 2772 rubles/ha, with the cost of application and harvesting of additional yield 4822 rubles/ha. Addition from nitrogen 8-10 c/ha at a price adjusted on the basis of repeatability of obtaining 3rd class grain costs 12,480-15,600 rubles/ha, i.e. high profit is obvious.

Regarding ammophos, it is important to decide whether to introduce it under wheat after fallow in the conditions that have developed in the experiment: a high content of mobile P_2O_5 and a small average grain increment - 1.6 c/ha. Currently, 1 centner of ammophos costs 5400-5700 rubles, the P_{27} dose is 2916-3078 rubles/ha, with costs for the application and harvesting of grain increment - 3966-4063 rubles/ha. An increase of 1.6 c/ha with a repeatability of 3rd class grain for 50% of the years is worth 2480 rubles/ha. Expenses for the purchase and application of fertilizer are not covered by the increase in the yield value. The best increment from phosphorus added to nitrogen (2.8 c/ha) is valued at 4368 rubles/ha, but this slightly exceeds the cost of ammophos. Consequently, as long as the elevated content of mobile phosphorus in the soil is maintained, the grain and fallow crop rotation can be satisfied with the use of only nitrogen fertilizers. When the content of mobile phosphorus decreases to 40-60 mg/kg of soil, it is necessary to apply expensive ammophos.

When considering the effects of phosphorus on the first wheat, a significant increment was noted: 11 times in 26 years of plowing (2-3 c/ha) and 6 times in the following 7 years with surface soil treatment (2-7 c/ha). When adding phosphorus to nitrogen on the second and third sowings after fallow, increments of 2-7 c/ha were noted 8 times during plowing years. After an 8-year

Табл. 5. Изменчивость содержания P_2O_5 по Францесону в слое почвы 0–20 см в течение 37 лет опыта, мг/100 г

Table 5. Variability of the content of P_2O_5 according to Franceson in the soil layer of 0-20 cm during 37 years of experience, mg/100 g

Option	Years						
	1969, 1970	1974, 1975	1979, 1980	1987, 1988	1993, 1994	1998, 1999	2003, 2005
Control	0,136	0,151	0,270	0,368	0,482	0,672	0,545
PK	0,170	0,314	0,492	0,815	1,137	1,703	1,186
NK	0,164	0,165	0,244	0,275	0,272	0,442	0,485
NPK	0,222	0,314	0,634	0,722	1,446	1,641	1,396
LSD_{05}				0,27			

Табл. 6. Окупаемость азота и фосфора по посевам яровой пшеницы в зернопаровом севообороте в 10-й и 11-й ротациях, кг/кг

Table 6. Nitrogen and phosphorus profitableness for spring wheat in the grain and fallow crop rotation in the 10th and 11th rotations, kg/kg

Wheat after fallow					
first		second		third	
Control	–	Control	–	Control	–
P_{27}АК	5,9	P_{27}АК	6,7	P_{27}АК	2,6
AN_{54}АК	–	N_{54}АК	19,4	N_{54}АК	15,6
$AN_{54}P_{27}$АК	2,4	$N_{54}P_{27}$АК	16,4	$N_{54}P_{27}$АК	12,3

break in the application of phosphorus, when it was introduced during the years of surface soil treatment, a yield increase of 2-5 tons/ha was obtained on the second crop 4 times in 7 years and 5 times in 8 years - 2-3 c/ha on the third. Considering the manifestation of higher increments than the average effects, you can switch to the application of a smaller dose (P_{15}) and introduce it during sowing, which will increase the increment and payback of phosphorus.

CONCLUSION

Studying the effectiveness of different fertilizer compositions on wheat sowing in a grain-fallow rotation in the 10th and 11th rotations on heavy loamy leached chernozem, rich in mobile phosphorus, in the northwestern zone of the Kurgan region showed that the primary factor in improving plant nutrition was the application of nitrogen fertilizer. The same trend characterized the action of different compositions earlier, on average, in the 1st-9th rotations of the grain-fallow rotation during the years of plowing. In the 10th and 11th rotations, nitrogen provided high increments on wheat sowings, distant from fallow – 8-10 and 10-13 c/ha in combination with phosphorus, respectively. The average effect of nitrogen for the 1st-9th rotations is lower - 6-7 c/ha, possibly due to the improvement of nutrition conditions directly from plowing, as well as the influence of frequent droughts. The yield increment from the application of phosphorus in the first sowing after fallow was low - 1.6 c/ha, but in the initial period of the experiment, while the soil was poorer in phosphorus, in some years there was a very high effect of phosphorus fertilizer with obtaining increments of wheat after fallow up to 7 c/ha. Later, both with plowing and surface soil treatment, the yield increment from phosphorus was limited on average to 2 c/ha, which meant a low payback of expensive phosphorus fertilizer. Considering the higher effects obtained from phosphorus in some years, you can switch to the application of a smaller dose (P_{15}) and introduce it during sowing. This can increase the increment and ensure a decent payback of phosphorus fertilizer. In the following fields, an increment from phosphorus was more often noted only against the background of nitrogen fertilizer.

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АДАПТИВНОСТЬ И ЭКОЛОГИЧЕСКАЯ ПЛАСТИЧНОСТЬ ЯЧМЕНЯ В УСЛОВИЯХ ЛЕСОСТЕПИ КРАСНОЯРСКОГО КРАЯ

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Представлены результаты оценки ярового ячменя в питомнике конкурсного сортоиспытания по параметрам адаптивности и экологической пластичности в условиях Красноярской лесостепи. Объектами исследования, проводившегося в 2020–2022 гг., являлись районированные сорта и линии местной селекции. В качестве стандарта принят сорт Ача. Почва опытного поля – обыкновенный маломощный чернозем. Повторность четырехкратная, метод сравнения парный. Посев проведен в оптимальные сроки – 20–25 мая, норма высева – 5,5 млн всхожих семян/га. По режиму увлажнения 2020 и 2021 гг. были избыточно влажными (ГТК = 1,84–1,89), при этом 2021 г. оказался достаточно увлажненным. В 2022 г. наблюдалась майская засуха (ГТК = 0,27). По итогам проведенных исследований выделен ценный селекционный материал. Наибольшей продуктивностью (43,2 ц/га) по отношению к стандарту отличалась линия Д-7-7057 (Л-11-38 × Буян). Сорта Ача, Красноярский 80, линия Д-7-7057 по экологической пластичности были отнесены к интенсивному типу (b_i = 1,17–1,21), сорт Кедр меньше всего реагировал на улучшение условий выращивания (b_i = 0,86). Селекционная линия В-56-6885 (Биом × Сибиряк) оказалась самой стабильной, отличалась повышенными показателями средней урожайности (41,3 ц/га), экологической стабильности (S_i^2 = 417,1, SF = 2,82), селекционной ценности генотипа (S_c = 6,73), имела среднюю экологическую пластичность (b_i = 1,01). Среди сортов интенсивного типа наибольший интерес представляет линия Д-7-7057 (Л-11-38 × Буян) с самой высокой урожайностью (43,2 ц/га), средними параметрами стабильности (S_i^2 = 723,9, SF = 4,02) и повышенной пластичностью (b_i = 1,17). В ходе эксперимента установлено, что основной вклад в формирование урожая вносят селекционные признаки, связанные с плотностью посева (число растений перед уборкой, продуктивный стеблестой и кущение) и продуктивностью отдельного растения (масса зерна с одного растения, масса 1 тыс. зерен).

Ключевые слова: ячмень, сорт, селекционная линия, урожайность, экологическая пластичность, стабильность, селекционная ценность

ADAPTABILITY AND ECOLOGICAL PLASTICITY OF BARLEY UNDER FOREST-STEPPE CONDITIONS OF THE KRASNOYARSK TERRITORY

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The results of spring barley assessment by the parameters of adaptability and ecological plasticity in the Krasnoyarsk forest-steppe conditions are presented. The objects of the study, conducted in 2020-2022, were the released varieties and lines of local breeding. The Acha variety was adopted as the

standard. The soil of the experimental field is ordinary low-power chernozem. Repetition is fourfold, and the comparison method is paired. Sowing was carried out in optimal time - May 20-25, the seeding rate - 5.5 million germinated seeds/ha. In terms of moisture regime, 2020 and 2021 were excessively wet (HTC = 1.84-1.89), while 2021 was sufficiently wetted. May drought was observed in 2022 (HTC = 0.27). As a result of the research, valuable breeding material was selected. The highest productivity (43.2 c/ha) in relation to the standard showed the line D-7-7057 (L-11-38 × Buyan). The varieties Acha, Krasnoyarsk 80, line D-7-7057 on environmental plasticity were attributed to the intensive type (b_i = 1,17-1,21), the variety Kedr reacted the least to improvement of the growing conditions (b_i = 0,86). The breeding line B-56-6885 (Biom × Sibiryak) was the most stable, characterized by high indices of average yield (41.3 c/ha), environmental stability (S_i^2 = 417,1, *SF* = 2,82), breeding value of the genotype (S_c = 6.73), and had average environmental plasticity (b_i = 1.01). Among the varieties of the intensive type, the line D-7-7057 (L-11-38 × Buyan) with the highest yield (43.2 c/ha), medium stability parameters (S_i^2 = 723,9, *SF* = 4,02) and increased plasticity (b_i = 1.17) is of greatest interest. During the experiment it was found that the main contribution to the formation of the yield is made by the breeding traits associated with crop density (the number of plants before harvesting, productive stem and tillering) and the productivity of individual plants (grain weight per plant, thousand-kernel weight).

Keywords: barley, variety, line, yield, ecological plasticity, stability, selection value

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INTRODUCTION

Spring barley is the most in-demand and widespread crop in the Krasnoyarsk Territory. In 2020-2022, the area of spring barley cultivation in the region amounted to about 160 thousand hectares. Barley is widely used as both fodder and cereal crop. It is characterized by higher yields and a shorter growing season compared to wheat and oats.

Currently, cultivating varieties adapted to local conditions and having high yields is becoming increasingly relevant [1–3]. The complexity of addressing this issue is related to the region's low bioclimatic potential. For instance, while this indicator is 1.0 for Russia as a whole, it stands at 0.52-0.54 for Eastern Siberia, and 0.46-0.48[1] for areas like Transbaikal, Khakassia, and Tyva. Under these conditions, choosing a particular variety becomes a critical task. As N.A. Rodina[2] believes, any farming system starts with a variety, and essentially, a variety serves as the biological foundation of the yield. According to A.A. Zhuchenko[3], P.L. Goncharov (see footnote 1), N.A. Rodina (see footnote 2), the contribution of the variety to increasing the yield amounts to 50-70%.

[1]*Goncharov P.L.* Methodology of selection of forage grasses in Siberia. Novosibirsk, 2003, 396 p.
[2]*Rodina N.A.* Barley breeding in the North-East of the Non-Black Earth Region. Kirov, 2006, 486 p.
[3]*Zhuchenko A.A.* Adaptive potential of cultivated plants and problems of agrosphere. Moscow, 2004, Vol. 1, pp. 49-63.

In breeding for productivity, it's essential to achieve a positive combination of high yield, its stability, and the responsiveness of plants to an intensive background [4, 5]. Given the climate peculiarities of the Krasnoyarsk Territory, new varieties should simultaneously possess good resistance to external environmental stress factors, high grain yield, and quality [6].

During the research, it was determined that the potential productivity and ecological resilience of plants are controlled by different sets of genes. Thus, there is a genuine possibility of combining these characteristics in one variety. It is acknowledged that breeding is the primary method for enhancing plant adaptability and crop quality [7].

Assessing ecological adaptability based on productivity parameters allows for more targeted use of the initial material and efficiently selecting varieties for different soil and climatic conditions to maximize their potential yield.

The purpose of the study is to assess barley varieties and breeding lines in terms of yield and adaptability indicators in the conditions of the Krasnoyarsk forest-steppe.

MATERIAL AND METHODS

The research was conducted from 2020 to 2022 in the open forest steppe of the Krasnoyarsk Territory. The soil of the experimental site is typical light chernozem. The forecrop was complete fallow. The humus content in the plowing horizon ranged from 4.2% to 7.0%. The nitrate nitrogen ($N\text{-}NO_3$) content was 6.8-13.4 mg/kg of soil, phosphorus content was 17.5-22.2 mg/100g of soil, and potassium was 12.3-19.0 mg/100g of soil. The soil solution reaction (pH_{wat}) ranged from 6.1 to 6.6.

The weather conditions during the barley growing season varied in terms of average daily air temperature and the amount of precipitation from the average long-term values (see Table 1). In May and August of 2020, with elevated average daily temperatures, excessive moisture was recorded, leading to lodging of crops before harvest. In 2021, July was excessively humid, while August was warm and moderately humid. In 2020 and 2021, the hydrothermal coefficient (HTC) was 1.84-1.89, with 2021 being characterized as sufficiently humid. In 2022, May and June were warm, with June experiencing heavy rainfall.

The registration area of plots in the competitive variety test was 37-40 m^2. There was a fourfold repetition, and the comparison method was pairwise. The standard variety was "Acha". Sowing was done in optimal times, from 20th to 25th of May, with a seeding rate of 5.5 million germinated seeds per hectare.

Statistical data processing was performed according to B.A. Dospekhov [8]. To characterize adaptive potential, we calculated the ecological plasticity index (b_i) and stability (S_i^2) according to S.A. Eberhart and W.A. Russel, as presented by V.Z. Pakudin[4]. Genetic flexibility of the variety (GF) was determined according to A.A. Goncharenko[5], homeostasis (*Hom*) was determined using the methodology of V.V. Khangildin and S.V. Biryukov[6], the phenotypic variability indicator (*SF*) was based on D. Lewis[7], and the breeding value of genotypes (S_c) was as per A.V. Kilchevsky and L.V. Khotyleva[8].

RESULTS AND DISCUSSION

The yield of the varieties usually consists of individual productivity elements that mutually influence each other [9].

One of the essential factors associated with high yields is the duration of vegetation. Based on this parameter, all the varieties and lines discussed in this article were similar to the standard and were classified as medium-maturing, except

[4]*Pakudin V.Z.* Parameters for assessing the ecological plasticity of varieties and hybrids: the theory of selection in plant populations. Novosibirsk, 1976, 189 p.

[5]*Goncharenko A.A.* On adaptability and ecological stability of grain crop varieties // Bulletin of the Russian Academy of Agricultural Sciences, 2005, No. 6, pp. 49-53.

[6]*Khangildin V.V., Biryukov S.V.* The problem of homeostasis in genetic and breeding studies // Genetic and cytological aspects in agricultural plant breeding. 1984, No. 1, pp. 67-76.

[7]*Lewis D.* Gene-environment interaction: a relationship between dominance, heterosis, phenotypic stability and variability // Heredity. 1954. Vol. 8. P. 333–356.

[8]*Kilchevsky A.V., Khotyleva L.V.* Genotype and environment in plant breeding. Minsk: Science and Technology, 1989, 191 p.

Табл. 1. Агрометеорологические условия в период проведения опыта
Table 1. Agrometeorological conditions during the experiment

Indicator	2020					2021					2022					Annual average value				
	May	June	July	August	For the growing season	May	June	July	August	For the growing season	May	June	July	August	For the growing season	May	June	July	August	For the growing season
Average air temperature, °C	14,0	15,7	18,9	17,4	16,5	9,8	15,5	19,7	17,4	15,6	13,8	17,0	17,6	14,9	15,8	10,1	15,0	19,3	16,2	15,2
Precipitation amount, mm	44,9	96,0	109,0	79,0	328,9	30,3	121,8	48,0	63,0	263,1	15,1	75,0	49,0	65,1	204,2	29,0	44,0	65,0	61,0	199,0
HTC	1,30	2,80	1,83	1,63	1,89	2,77	2,63	0,80	1,17	1,84	0,27	1,80	0,90	1,57	1,14	1,47	1,07	1,37	1,20	1,28

for the “Takmak” variety, which practically matured 1-4 days later than other varieties (see Table 2).

The number of plants before harvest for the studied varieties was the same as for the standard “Acha” variety or lower. The maximum productive tillering (1.63-1.67 units) was observed in the “Olenek” variety and the D-7-7057 line, developed under the adaptive breeding program, as well as the breeding line D-39-7318. The highest number of productive stems (39-48 stems/m^2 more than the standard) was identified in the breeding lines D-7-7057 and D-39-7318. In terms of the number of grains per ear, the “Buyan” variety, identified by us as a donor in diallel crosses, as well as the varieties “Olenek” and “Takmak,” and the breeding lines B-56-6885 and D-39-7318, had an advantage of 1.3-3.8 grains.

The weight of 1,000 grains is a leading breeding trait, especially when grown in drought conditions, which is typically characteristic of early ripening varieties [10]. The “Kedr” and “Abalak” varieties and the breeding lines D-7-7057 and D-55-7455 had an advantage in the weight of 1,000 grains (+3.3-4.8 g).

In breeding to increase the productivity of grain crops, an important role is given to increasing productivity and the yield of grain from a single plant [11]. In terms of grain weight per plant, the “Buyan” variety and the breeding lines D-7-7057 and D-39-7318 showed an advantage over the standard (+0.15-0.20 g). The higher indicators of productive stem stand of the promising lines D-7-7057 and D-39-7318 had a positive impact on the yield size.

Based on the assessment of the adaptive potential, it was found that the “Takmak” variety and the D-7-7057 line have the highest genetic flexibility (GF = 40.4-42.2), indicating their ability to resist adverse factors while also positively responding to improved conditions. In optimal and limited conditions, these samples demonstrated the highest yield (41.5-43.2 c/ha). The combination of high genetic flexibility and a lower coefficient of variation (*CV*) indicates the real ability of the “Takmak” variety and the breeding lines D-7-7057 and D-39-7318 to produce higher yields (see Table 3).

Табл. 2. Вегетационный период и элементы продуктивности сортов и селекционных линий ячменя, участвовавших в конкурсном сортоиспытании (среднее за 2020–2022 гг.)

Table 2. Growing season and productivity elements of barley varieties and breeding lines that participated in competitive variety trials (average for 2020-2022)

Variety, line	Growing period, days		Number of plants before harvesting, pcs./m²		Productive tillering, pcs.		Productive plant stand, pcs./m²		Number of grains in an ear, pcs.		Weight of 1 thousand grains, g		Grain weight per plant, g	
	$\bar{X}$	*CV*, %	$\bar{X}$	*CV*, %	$\bar{X}$	*CV*, %	$\bar{X}$	*CV*, %	$\bar{X}$	*CV*, %	$\bar{X}$	*CV*, %	$\bar{X}$	*CV*, %
Acha	77	9,8	419	11,5	1,40	7,1	585	15,9	18,4	17,4	39,9	9,3	1,05	70,5
K-80	78	9,2	343	18,2	1,57	18,4	542	12,2	18,8	16,9	42,7	10,4	1,09	64,0
Kedr	79	8,7	320	12,8	1,60	12,5	510	7,6	18,0	24,4	43,9	7,2	0,97	69,8
Bakhus	78	10,0	348	9,1	1,60	25,0	547	22,8	18,0	23,3	42,9	7,5	0,95	65,3
Buyan	78	9,4	319	10,8	1,43	22,4	450	14,7	22,2	20,8	39,3	17,4	1,20	83,6
Olenek	79	9,6	306	20,8	1,67	25,0	479	10,2	19,7	23,3	39,5	7,4	0,91	69,3
Abalak	77	10,5	396	25,1	1,43	14,5	569	31,5	18,7	21,5	44,1	12,2	0,97	63,1
Takmak	80	10,5	367	10,0	1,40	7,1	551	10,8	21,0	18,1	40,6	8,4	1,03	53,1
B-56-6885	78	9,0	394	13,5	1,37	15,2	524	4,1	20,6	23,2	41,9	13,3	1,00	61,2
D-7-7057	77	9,4	395	24,9	1,63	27,6	633	21,1	17,9	16,6	44,7	10,1	1,25	86,5
D-39-7318	77	11,5	394	31,9	1,63	19,7	624	20,3	20,5	18,4	38,9	17,8	1,23	95,2
D-55-7455	76	9,8	404	11,7	1,50	13,3	596	3,3	18,2	19,4	43,2	10,3	1,04	68,5
LSD_{05}	1		46		0,20		47		0,5		3,0		0,10	

In terms of ecological plasticity, the varieties Acha, Krasnoyarsky 80, and the line D-7-7057 were classified by us as of the intensive type. This means that in favorable years, these varieties can yield the maximum harvest, but under stress conditions, they might yield lower than other varieties. The "Kedr" variety showed a weak response to varying growing conditions, as evidenced by its low ecological plasticity value (b_i = 0.86), yield variation coefficient (*CV* = 52.3%), and the highest phenotypic stability (S_i^2 = 285.8). The varieties "Bakhus", "Buyan", "Olenek", "Abalak", and the lines D-39-7318 and D-55-7455 had a medium level of ecological plasticity (b_i = 0.92–1.10) and showed better adaptability to environmental factors with yields at the standard level.

In breeding for stable productivity, the line B-56-6885 is of particular practical interest, combining a higher average yield (41.3 c/ha), ecological stability (S_i^2 = 417.1, *SF* = 2.82), semi-intensive response to the optimal background (b_i = 1.01), and an increased breeding value of the genotype (*Sc* = 6.73). For the creation of intensive-type varieties, it's crucial for them to have, above all, high yields, a medium level of ecological stability, and a high response level to an intensive background. The D-7-7057 line meets these criteria, combining a high yield (43.2 c/ha) and medium stability (S_i^2 = 723.9, SF = 4.02). This line is promising and is planned for further study and propagation.

To determine the influence of individual breeding characteristics on the formation of the yield of the studied varieties and breeding lines, the varimax rotation method was used based on the Statistica program[9]. As a result of the analysis, considering the mutual influence of individ-

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

Табл. 3. Показатели адаптивности перспективных сортов и линий ярового ячменя в условиях Красноярской лесостепи
Table 3. Indicators of adaptability of the promising varieties and lines of spring barley in the conditions of the Krasnoyarsk forest-steppe

Variety, line	Origin	Yield, c/ha				Adaptability indicators						
		2020	2021	2022	$\bar{X}$	*CV*, %	ГГ	b_i	S_i^2	*Hom*	*SF*	S_c
Acha	(Paragon × Christina) × (Jet × Obskoj) × (Novosibirsky 1 × Viner)	41,3	14,2	60,2	38,6	60,0	37,2	1,21	908,9	1,7	4,24	5,45
K-80	C-80 × Una	32,8	14,7	58,6	35,4	62,4	36,7	1,17	693,1	1,6	3,99	5,53
Kedr	Viner × Birgitta	34,6	13,9	46,7	31,7	52,3	30,3	0,86	285,8	1,9	3,36	4,94
Bakhus	(Viner × Donetsky 650) × (Viner × Krasnoufimsky 95)	43,6	19,9	55,5	39,7	45,7	37,7	1,02	398,0	2,2	2,79	6,50
Buyan	Kedr × Jo 1345	33,9	16,7	56,7	35,8	56,1	36,7	1,10	581,8	1,8	3,40	5,91
Olenek	[(Viner × Krasnoufimsky 95) × (Viner × Donetsky 650)] × Acha	34,0	18,9	49,0	34,0	44,3	34,0	0,98	558,1	2,3	2,59	5,81
Abalak	(Krasnoyarsky 80 × Drop (France)) × Ca 46925 (Denmark)	38,7	19,9	52,2	36,9	43,9	36,1	0,96	540,7	2,3	2,62	6,18
Takmak	Priazovsky 9 × U-20-706	40,2	24,2	60,1	41,5	43,3	42,2	1,05	681,8	2,3	2,48	7,24
B-56-6885	Biom × Sibiryak	47,2	20,1	56,6	41,3	45,9	38,4	1,01	417,1	2,2	2,82	6,73
D-7-7057	L-11-38 × Buyan	48,8	16,1	64,7	43,2	57,4	40,4	1,17	723,9	1,7	4,02	6,17
D-39-7318	Sv.66905 × Buyan	40,1	20,7	53,3	38,0	43,1	37,0	0,92	578,3	2,3	2,57	6,37
D-55-7455	Abalak × K-22092	40,9	20,6	55,7	39,1	45,1	38,2	0,93	619,9	2,2	2,70	6,52
LSD_{05}		5,0	2,7	2,4	3,5							

ual traits for the vegetation period and six yield structure elements, two factors were obtained for each research year. These mainly included productive tillering, productive stem stand, the number of grains in the main ear, and grain weight per plant. Their influence accounted for a significant value – 32.62% and 31.18% in 2020, 32.21% and 31.34% in 2021, 42.80% and 30.16% in 2022 (see Table 4).

In 2020, the first factor included the traits that positively correlated with yield, such as the number of grains in the main ear (r = 0.880) and the grain weight from a single plant (r = 0.724), while productive tillering showed a reverse dependency (r = −0.896). The second factor comprised the number of plants before harvesting (r = 0.818) and the productive plant stand (r = 0.813), which determine sowing density. In unfavorable conditions of 2021, the positive effects on productivity were given by the first factor's traits – productive tillering (r = 0.726), the number of grains in the main ear (r = 0.742), and the grain weight from a single plant (r = 0.922). The second factor included the number of the plants before harvesting (r = 0.874) and the productive plant stand (r = 0.837). The correlations of individual productivity elements noticeably differed in 2022. The first factor was made up of the productive plant stand (r = 0.813), the weight of 1,000 grains (r = 0.719), with a negative impact noted for the vegetation period (r = −0.891). The second factor predominantly consisted of productive tillering (r = 0.896) and the grain weight from a single plant (r = 0.738).

Thus, the dominant breeding traits affecting barley yield in the conditions of the Krasnoyarsk forest-steppe are productivity elements related to sowing density and the productivity of individual plants.

CONCLUSIONS

1. The evaluation of the studied barley varieties and lines in the competitive variety testing for productivity and adaptability parameters allowed us to highlight valuable breeding material.

2. During the trials in the conditions of the Krasnoyarsk forest-steppe, the highest average yield (41.3-43.2 c/ha) was obtained from the "Takmak" variety, and the breeding lines B-56-

Табл. 4. Матрица факторных нагрузок (вращение варимакс) для изученных переменных у сортов и линий ячменя

Table 4. Factor load matrix (varimax rotation) for the studied variables in barley varieties and lines

Selection trait	2020		2021		2022	
	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2
Duration of the growing season	−0,035	−0,622	0,400	−0,677	−0,891*	0,087
Number of plants before harvesting	0,324	0,818*	−0,034	0,874*	0,401	−0,854
Productive tillering	−0,896*	0,0001	0,726*	0,170	0,142	0,896*
Productive plant stand	−0,020	0,813*	0,375	0,837*	0,813*	0,064
Number of grains in the main ear	0,880*	0,011	0,742*	0,243	−0,907*	0,095
Weight of 1 thousand grains	−0,276	0,583	−0,155	−0,418	0,719*	0,117
Grain weight per plant	0,724*	0,352	0,922*	−0,084	0,147	0,738*
Factor contribution, %	32,62	31,18	32,21	31,34	42,80	30,16

*$p > 0{,}700$.

6885 and D-7-7057. As a result, the varieties Acha, Krasnoyarsky 80, and the line D-7-7057 were also classified as of the intensive type (b_i = 1.17–1.21), while the early-bred "Kedr" variety was of the extensive type (b_i = 0.86).

3. In breeding for stable productivity, the line B-56-6885 of the semi-intensive type is of particular interest, combining a higher average yield (41.3 c/ha), ecological stability (S_i^2 = 417.1, *SF* = 2.82), an average response to the optimal background (b_i = 1.01), and an increased breeding value of the genotype (*Sc* = 6.73).

4. For breeding varieties responsive to improved conditions, the promising line is D-7-7057 with high yield (43.2 c/ha) and medium stability parameters (S_i^2 = 723.9, *SF* = 4.02).

5. The leading breeding traits during the research years were yield structure elements responsible for forming the sowing density and productivity of individual plants.

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ИЗУЧЕНИЕ ИСХОДНОГО МАТЕРИАЛА ОЗИМОЙ МЯГКОЙ ПШЕНИЦЫ ДЛЯ СЕЛЕКЦИИ НА КАЧЕСТВО ЗЕРНА

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Представлены источники ценных признаков для целенаправленного использования в селекции новых сортов озимой пшеницы с улучшенными признаками качества. Приведены результаты оценки исходного материала по выраженности хозяйственно ценных признаков у коллекционных образцов озимой мягкой пшеницы. В работе представлены данные по 31 сорту различного эколого-географического происхождения. Полевые опыты проводили в 2018–2020 гг. в селекционном севообороте в условиях южной зоны Ростовской области. Показатели качества сортов: массу 1000 зерен, содержание белка, количество и качество клейковины в зерне, натуру зерна, общую стекловидность, хлебопекарные свойства – определяли по стандартным методикам и ГОСТам. В результате проведенной кластеризации сортов показано, что селекционная программа по созданию адаптивных сортов с высоким качеством зерна должна включать в качестве базового исходного материала сорта, входящие в 5-й и 6-й кластеры, – Л-19578 (Россия), Этана (Германия), Warwick (Канада), Akter (Германия), MV-15-09 (Венгрия), Симонида (Сербия), GK Hollo (Венгрия), Webster (Канада), Wisdom (Канада), № 42 CIMMYT (США) и KS 96 WGRC 37 (США). Данные сорта показали хорошие результаты в условиях южной зоны Ростовской области. Остальные сорта коллекционного питомника рекомендуем включать в селекционную работу в соответствии с принципом комплементарности, как взаимно дополняющие сорта по выраженности того или иного признака или свойства.

Ключевые слова: озимая пшеница, массовая доля белка, клейковина, натура зерна, стекловидность, масса 1000 зерен

STUDY OF THE PARENT MATERIAL OF SOFT WINTER WHEAT FOR BREEDING FOR GRAIN QUALITY

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The sources of valuable traits for targeted use in the breeding of new winter wheat varieties with improved quality traits are presented. The results of the evaluation of the parent material on the expression of economically valuable features in the collection samples of soft winter wheat are presented. The paper presents data on 31 varieties of different ecological and geographical origin. Field experiments were conducted in 2018-2020 in the breeding rotation under the conditions of the southern zone of the Rostov region. Quality indicators of the varieties: thousand grain weight, protein content, quantity and quality of gluten in the grain, grain unit, total vitreousness, baking properties were determined by standard methods and GOSTs. As a result of the clustering of varieties, it is shown that the breeding program to create adaptive varieties with high grain quality should include as basic parent material the varieties which are included in the 5th and 6th clusters - L-19578 (Russia), Etana (Germany), Warwick (Canada), Akter (Germany), MV-15-09 (Hungary), Simonida (Serbia), GK Hollo (Hungary), Webster (Canada), Wisdom (Canada), No. 42 CIMMYT (USA), and KS 96 WGRC 37 (USA). These varieties showed good results in the southern zone of the Rostov region. The other varieties of the collection nursery are recommended to be included in the breeding work in accordance with the principle of complementarity, as mutually complementary varieties in the expression of a particular trait or property.

Keywords: winter wheat, mass fraction of protein, gluten, grain unit, vitreousness, thousand grain weight

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The authors declare no conflict of interest.

INTRODUCTION

Winter soft wheat is a crop with a high biological potential for productivity and grain quality in the southern zone of the Rostov region [1, 2]. Creating new varieties of winter soft wheat largely depends on the proper selection of starting material as an initial and crucial stage of the breeding process [3–6]. For successful wheat breeding, it's essential to identify and comprehensively study genetic sources and donors of valuable traits directly in the breeding regions [7, 8].

The purpose of the study is to identify the sources of valuable traits for targeted use in breeding new varieties with improved quality characteristics.

The research objectives are:

– selection of the most productive samples from the collection nursery for comprehensive study of grain and flour quality;

– carrying out variance and cluster analyses of experimental data;

– selection of the best varieties that significantly exceed the standard by the studied traits and properties for use in crossbreeding to create new genotypes with high grain quality.

MATERIAL AND METHODS

The study of collection varieties took place in field conditions from 2018 to 2020 at the laboratory of selection and seed production of intensive-type winter wheat and in the biochemical, technological, and agrochemical assessment laboratory of the Agrarian Scientific Center "Donskoy" (ASC "Donskoy").

The research object for determining the technological properties of grain and flour was 31 varieties of winter wheat of various ecological-geographical origins. The Ermak variety was used as a standard. The plot area was 3 m^2, with a two-time repetition, and the forecrop was autumn fallow. The test field soil was a powerful carbonated heavy loamy chernozem.

In the 2017/18 agricultural year, drought was noted during the active vegetation period of wheat (April - June). Precipitation during this period was 25.9 mm compared to the long-term norm of 165.3 mm. Daily average air temperatures exceeded long-term values in April by 0.8 °C, in May by 2.7 °C, and in June by 3.4 °C.

In the 2018/19 agricultural year, quality formation occurred under conditions of insufficient moisture, especially in June (10.8 mm, standard - 71.3 mm), and elevated temperatures (in May by 2.5 °C, in June by 4.7 °C). Moreover, a shortage of precipitation was noted in June compared to the long-term average by 100.3; 61.5, and 32.5 mm, respectively.

The grain quality formation period in the 2019/20 agricultural year was characterized by a large amount of precipitation in May (155.7% of the standard) and an optimal temperature (15.4 °C). It was favorable for the growth and development of soft winter wheat, despite the precipitation shortage (54.4% of the standard) and an elevated temperature regime (by 2.6 °C) in June.

The main quality characteristics of grain and flour were determined in the biochemical assessment laboratory of breeding material and grain quality of ASC "Donskoy". Grain nature was studied in accordance with GOST 10840–2017[1], overall grain vitreousness – according to GOST R 70629–2023[2]. The protein mass fraction in grain was determined using the infrared ana-

[1]GOST 10840-2017 Grain. Method for determining the natural weight. Moscow: Standardinform, 2019, 19 p.
[2]GOST R 70629-2023 Wheat. Determination of vitreousness by the optical-computer method. Moscow: Standardinform, 2023, 5 p.

lyzer SpektraStar 2200, the quantity and quality of gluten in the grain – according to GOST R 54478-2011[3], the falling number – in accordance with GOST 27676-88[4]. A trial laboratory baking was carried out using the remix method with re-kneading. Bread quality was assessed according to the methodological guidelines of the state commission for crop variety testing[5]. Data mathematical processing and cluster analysis were carried out using Microsoft Office Excel and Statistica 10 software. Euclidean distance was used as a similarity measure.

RESULTS AND DISCUSSION

The weight of 1000 grains is an essential element of productivity and a significant selection trait for yield selection. It also significantly affects the grain's appearance and milling properties. Breeders pay attention to this trait as it allows them to select not only sources of large grains but also varieties well-adapted to specific soil and climatic conditions; moreover, this trait is inherited well [9, 10]. It was found that, on average, over the years of study, the weight of 1000 grains ranged from 33.2 g (GK Hollo, Hungary) to 44.8 g (Eistanzuelo Benteveo, Uruguay), which according to the CMEA[6] classifier, characterizes varieties from small-grained to large-grained. Varieties like Eistanzuelo Benteveo (Uruguay) (44.8 g), Ling Xing 99 (China) (44.7), and Akter (Germany) (44.7 g) showed high values of this trait on average over 3 years of study, significantly exceeding the standard LSD_{05} = 1.5 g (see Table 1).

These samples are recommended to be used as sources of large grains.

In determining the quality of wheat grain, vitreousness is one of the most critical class-forming indicators, also characterizing its milling properties. The higher the grain's vitreousness, the higher its technological properties [11]. The overall vitreousness of the studied varieties ranged from 50% (Bombus, France) to 74%

Табл. 1. Показатели качества зерна сортов озимой мягкой в пшеницы в коллекционном питомнике, 2018–2020 гг.

Table 1. Grain quality indicators of soft winter wheat varieties in the collection nursery, 2018-2020

Variety	Origin	Weight of 1000 grains, g	Vitreousness, %	Grain unit, g/l
Ermak, standard	Russia	42,8	57	804
L-19578	»	42,0	57	799
Vinnichanka	Ukraine	38,5	58	815
Shestopalivka	»	41,0	53	805
Slavna	»	40,3	73	814
Chornyava	»	41,1	73	810
Simonida	Serbia	38,0	66	824
Zlatka	»	37,2	72	835
NS 405/00	»	35,8	54	786
№ 42 CIMMYT	USA	37,6	74	809
KS 96 WGRC 37	»	34,8	68	816
Warwick	Canada	37,3	51	817
Webster	»	36,1	55	811
Wisdom	»	33,7	52	807
Zhong Ping 1597	China	41,8	57	812
Fuimai 5	»	41,5	55	797
Ling Xing 99	»	44,7	74	809
Akter	Germany	44,7	57	814
Etana	»	36,6	58	786
Cubus	»	35,0	63	785
MV-15-04	Hungary	39,8	63	823
GK Cipo	»	39,7	63	818
GK Hollo	»	33,2	55	830
№ 71 CIMMYT	Romania	40,6	56	809
Fidelius	Austria	38,6	57	801
Tatsitus	»	37,4	62	804
CO 911	France	36,7	59	794
Seilor	»	38,3	74	811
Bombus	»	35,6	50	759
Dagmar	»	39,9	57	822
Eistanzuelo Benteveo	Uruguay	44,8	55	809
LSD_{05}	–	1,5	7	13

[3]GOST R 54478-2011 Grain. Methods for determining the quantity and quality of gluten in wheat. Moscow: Standardinform, 2012, 23 p.

[4]GOST 27676-88 Grain and products of its processing. Method for determining the fall number. Moscow: Standardinform, 2009, 5 p.

[5]Methodology of the state variety testing of agricultural crops. Technological evaluation of grain, groat and leguminous crops. Under the general editorship of M.A. Fedin. Moscow, 1988, 121 p.

[6]International CMEA Classifier of the genus Triticum L. L., 1984, 86 p.

(Sailor, France), (No. 42 CIMMYT, USA), and (Ling Xing 99, China). The maximum expression of the trait (> 70%) was noted for the following varieties: Slavna, Chornyava (Ukraine) (73%), Zlatka (Serbia) (72%), No. 42 CIMMYT (USA) (74%), Ling Xing 99 (China) (74%), Sailor (France) (74%). The selected varieties for grain vitreousness exceeded the Ermak variety (LSD_{05} = 7%) and can be used in breeding to improve this trait.

Grain nature is also an indicator of grain size and plumpness. The values of the nature of the studied varieties were established from 759 g/l (Bombus, France) to 835 g/l (Zlatka, Serbia). On average, over the years of the study, all studied varieties were characterized by high nature values and corresponded to the 1st quality class according to the GOST for wheat. The maximum values, which significantly exceeded the standard (LSD_{05} = 13 g/l) for this trait, were noted in the varieties, g/l: Warwick (Canada) (817), GK Cipo (Hungary) (818), Dagmar (France) (822), MV-15-04 (Hungary) (823), Simonida (Serbia) (824), GK Hollo (Hungary) (830), and Zlatka (Serbia) (835). These varieties are recommended for use as sources to improve the "natural weight" trait.

The problem of protein content in wheat grain as a breeding trait is complicated by the negative correlation with grain yield, making it challenging to select for both traits simultaneously. The protein content in the grain significantly influences baking properties, the biological value of the grain, and processed products [12, 13]. The average protein mass fraction in grain over the research years varied from 12.66% (Bombus, France) to 15.05% (L-19578, Russia) (see Table 2).

According to GOST 9353-2016[7], strong wheats are varieties with protein content not less than 14%. Based on this criterion, the following samples stood out significantly (LSD_{05} = 0.52%), %: L-19578 (Russia) (15.15), Zhong Ping 1597 (China) (14.48), Akter (Germany) (14.28), Etana (Germany) (14.16), Sailor (France) (14.24), No. 42 CIMMYT (USA) (14.15), KS 96 WGRC 37 (USA) (14.01), and Zlatka (Serbia) (14.08).

Табл. 2. Качество клейковинно-белкового комплекса и хлебопекарные свойства муки из сортов озимой мягкой пшеницы в коллекционном питомнике, 2018–2020 гг.

Table 2. The quality of the gluten-protein complex and the baking properties of flour from soft winter wheat varieties in the collection nursery, 2018-2020

Variety	Protein mass fraction, %	Gluten content, %	Gluten quality, GDI device units	VB, ml	TBS, score
Ermak, standard	13,88	24,7	71	600	3,8
L-19578	15,05	31,6	76	670	4,1
Vinnichanka	13,76	26,6	84	593	3,6
Shestopalivka	13,71	26,5	81	610	3,7
Slavna	13,75	24,2	81	613	3,7
Chornyava	13,43	24,4	81	583	3,5
Simonida	13,57	29,1	86	687	4,4
Zlatka	14,08	26,7	84	607	3,8
NS 405/00	13,46	22,5	69	563	3,3
№ 42 CIMMYT	14,15	30,8	90	693	4,2
KS 96 WGRC 37	14,01	30,0	85	693	4,3
Warwick	13,28	25,6	88	657	4,1
Webster	13,09	22,9	87	690	4,2
Wisdom	13,24	23,9	84	673	4,1
Zhong Ping 1597	14,48	30,9	105	600	3,4
Fuimai 5	12,69	22,8	79	593	3,5
Ling Xing 99	13,93	28,6	99	620	3,7
Akter	14,28	27,6	87	643	4,1
Etana	14,16	25,1	89	670	4,1
Cubus	13,61	24,4	84	563	3,1
MV-15-04	13,64	25,5	84	647	3,8
GK Cipo	13,54	27,8	81	630	3,8
GK Hollo	13,60	30,4	87	683	4,1
№ 71 CIMMIT	13,91	25,7	81	610	3,6
Fidelius	13,29	23,4	68	590	3,6
Tatsitus	13,76	25,2	73	530	3,0
CO 911	13,54	24,1	84	617	3,8
Seilor	14,24	27,9	82	587	3,4
Bombus	12,66	25,1	79	637	3,9
Eistanzuelo Benteveo	13,22	25,3	87	610	3,4
Dagmar	13,30	24,5	75	613	3,6
LSD_{05}	0,52	1,1	5	25	0,1

Note. VB - volumetric yield of bread, ml; TBS - total baking score, score.

[7]GOST 9353-2016 Wheat. Technical conditions. Moscow: Standardinform, 2019,12 p.

These samples can be used as parental forms for crossbreeding.

Seven varieties were characterized by maximum gluten content in grain, meeting the requirements for the 2nd quality class (not less than 28.0%). The varieties with the highest values of this trait (> 30%) were, %: L-19578 (Russia) (31.6), No. 42 CIMMYT (USA) (30.8), Zhong Ping 1597 (China) (30.9), and GK Hollo (Hungary) (30.4). These varieties significantly exceeded the standard (LSD_{05} = 1.1%). These collection samples are recommended for use as sources to improve the "amount of gluten in grain" trait.

The Gluten Deformation Index (GDI) describes physical and rheological properties of gluten (elasticity, stretchability). Among the studied varieties in the collection nursery, GDI values varied widely – from 68 units (Fidelius, Austria) to 105 units (Zhong Ping 1597, China). This corresponded to the 1st-3rd quality groups. For producing quality bread products, the optimal gluten quality in grain for baking is 70-90 GDI units, i.e., the satisfactory upper range of the 1st group and the lower range of the 2nd group [14, 15].

Conducting trial laboratory baking is the final stage in determining the baking properties of winter soft wheat varieties. Based on the conducted studies, varieties have been identified that have fully realized baking properties and were characterized by the maximum volumetric yield of bread and overall bread rating, ml, score: L-19578 (Russia) (670, 4.1), Simonida (Serbia) (687, 4.4), No. 42 CIMMYT (USA) (693, 4.2), KS 96 WGRC 37 (USA) (693, 4.3), Webster (Canada) (690, 4.2), Wisdom (Canada) (673, 4.1), Etana (Germany) (670, 4.1), and GK Hollo (Hungary) (683, 4.1). These standout samples are recommended for use as parental forms for creating baking-type varieties.

To identify the genotypes possessing a combination of economically valuable traits affecting baking properties, with their subsequent inclusion in hybridization, cluster analysis of winter soft wheat collection samples was conducted. It was based on yield, grain weight, vitreousness, weight of 1000 grains, protein content, quantity and quality of gluten, bread volume yield, and overall bread baking assessment.

As a result of the analysis, a dendrogram was constructed with the distribution of samples into 7 clusters (see the figure, Table 3).

The first cluster included 6 varieties characterized by large grain (44.0 g), high grain density (808 g/l), GDI of 78 device units (1st group). However, their baking properties were marked at the level of valuable wheat (see table 3).

The second cluster represented 7 samples characterized by large grains (weight of 1000 grains 44.5 g), high grain density (810 g/l), and high gluten content (25.4%). The Gluten Deformation Index for this group of the varieties was 82 device units (2nd group), which influenced the increased bread volume yield (615 ml) (see Table 4).

The third cluster consisted of 3 varieties, which formed maximum values for weight of 1000 grains (45.7 g), grain density (818 g/l), protein content (14.16%), and gluten content in grain (28.7%). These samples can be used for hybridization as sources to improve the gluten-protein complex.

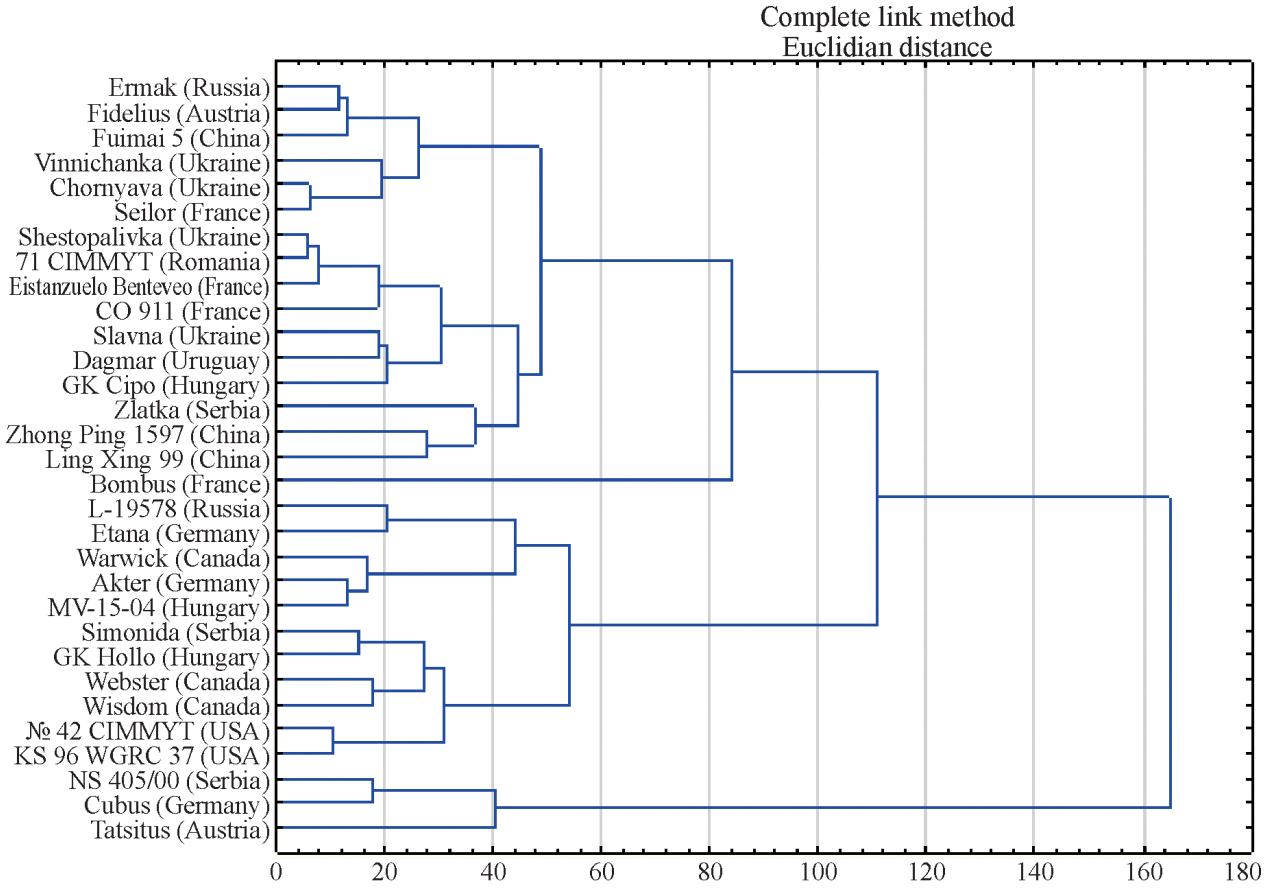
The fourth cluster was represented by one variety, Bombus (France), which had high yield (12.2 t/ha) but low protein content (12.66%) and the following physical quality traits: grain density of 759 g/l, vitreousness of 57%, and the weight of 1000 grains of 38.2 g.

The fifth cluster included 5 varieties with the weight of 1000 grains (44.3 g), high grain density (808 g/l), maximum protein content (14.08%), high gluten content in grain (27.1%), and good baking properties (bread volume yield of 657 ml and overall bread rating of 4.0 points).

The sixth cluster included 6 varieties, where all the studied traits and properties were best expressed, affecting bread quality.

The seventh cluster consisted of 3 varieties with a low gluten content (24.0%). The Gluten Deformation Index was 75 device units, resulting in a low bread volume (552 ml) and an overall score of 3.2 points.

The varieties of the collection nursery, included in the 5th and 6th clusters, are of greatest interest for the development of baking varieties.



Распределение сортов озимой мягкой пшеницы на кластеры по урожайности и комплексу признаков, характеризующих качество, 2018–2020 гг.

Distribution of soft winter wheat varieties into clusters according to productivity and a set of traits which characterize quality, 2018-2020

Табл. 3. Распределение сортов коллекции по кластерам

Table 3. Distribution of soft winter wheat varieties according to clusters

Cluster	Variety
1st	Ermak (Russia), Fidelius (Austria), Fuimai 5 (China), Vinnichanka (Ukraine), Chornyava (Ukraine), Seilor (France)
2nd	Shestopalivka (Ukraine), 71 CIMMYT (Romania), Eistanzuelo Benteveo (France), CO 911 (France), Slavna (Ukraine), Dagmar (Uruguay), GK Cipo (Hungary)
3rd	Zlatka (Serbia), Zhong Ping 1597 (China), Ling Xing 99 (China)
4th	Bombus (France)
5th	L-19578 (Russia), Etana (Germany), Warwick (Canada), Akter (Germany), MV-15-04 (Hungary)
6th	Simonida (Serbia), GK Hollo (Hungary), Webster (Canada), Wisdom (Canada), № 42 CIMMYT (USA), KS 96 WGRC 37 (USA), KS 96 WGRC 37 (USA)
7th	NS 405/00 (Serbia), Cubus (Germany), Tatsitus (Austria)

CONCLUSION

When creating varieties of winter soft wheat adapted to the climatic conditions of the southern zone of the Rostov region, an important step is the most comprehensive study of the sources of useful traits and properties for use as starting material. As a result of the cluster analysis, it is believed that the breeding program for creating adaptive varieties with high grain quality should include the varieties from the 5th and 6th clusters as the basic starting material. These are L-19578 (Russia), Etana (Germany), Warwick (Canada), Akter (Germany), MV-15-09 (Hungary), Simonida (Serbia), GK Hollo (Hungary),

Табл. 4. Характеристика кластеров по урожайности и качеству зерна
Table 4. Characteristics of clusters according to productivity and grain quality

Trait	Cluster						
	1st	2nd	3rd	4th	5th	6th	7th
Grain unit weight, g/l	806	810	818	759	808	816	792
Vitreousness, %	62	59	68	50	57	62	60
Weight of 1000 grains, g	44,0	44,5	45,7	38,2	44,3	37,5	38,8
Protein mass fraction, %	13,55	13,57	14,16	12,66	14,08	13,61	13,61
Gluten content, %	25,0	25,4	28,7	25,1	27,1	27,8	24,0
Gluten deformation index, units of the device	78	82	96	79	85	86	75
Volumetric yield of bread, ml	591	615	609	637	657	687	552
Total baking score, score	3,6	3,6	3,6	3,9	4,0	4,2	3,2
Yield, t/ha	11,2	11,5	10,1	12,2	11,5	11,1	11,5

Webster (Canada), Wisdom (Canada), No. 42 CIMMYT (USA), and KS 96 WGRC 37 (USA). These varieties have shown the highest results in the conditions of the southern zone of the Rostov region. Other varieties from the collection nursery are recommended to be included in the breeding work according to the principle of complementarity, complementing the basic varieties by expressing a particular trait or property.

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АНАЛИЗ АКТИВНОСТИ ОКИСЛИТЕЛЬНЫХ ФЕРМЕНТОВ МЕТОДОМ МНОГОМЕРНОЙ РЕГРЕССИИ В ПРИСУТСТВИИ MG^{2+} МИЦЕЛИЯ ГРИБА ВЕШЕНКА

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Проведены исследования по оптимизации процесса глубинного культивирования мицелия гриба вешенка. Усовершенствован процесс получения мицелия как посевного материала для выращивания плодовых тел грибов. Изучено влияние различных концентраций карбоната магния (Magnesium carbonates) на ростовые характеристики мицелия гриба *Pleurotus ostreatus* при глубинном культивировании. Выявлена зависимость активности ферментов от концентрации металла в питательной среде прорастания мицелия вешенки. Адаптирована методика определения активности каталазы спектрофотометрическим методом для изучаемых объектов. Впервые получены данные активности ферментов каталазы и супероксиддисмутазы мицелия в присутствии добавки карбоната магния. Установлено, что применение карбоната магния в малых концентрациях положительно влияет на рост биомассы мицелия гриба *Pleurotus ostreatus,* поскольку с увеличением концентрации Mg^{2+} отмечено уменьшение скорости роста биомассы и активности каталазы, предположительно, за счет участия магния в создании определенной ионной концентрации, при которой начинается инактивация каталазы. Изучена возможность применения метода многомерной регрессии в виде метода главных компонент (МГК). Проведен анализ редокс-состояния культуры *Pleurotus ostreatus* на уровне ферментных компонентов системы антиоксидантной защиты при погруженном культивировании базидомицетов, который показал, как взаимосвязаны между собой полученные переменные с разными единицами измерений. Графики счетов также наглядно указывают на зависимость роста мицелия от концентрации применяемой добавки. Введение предложенных в работе условий культивирования в практику грибоводства потенциально способствует более успешному противостоянию макромицетов биотическому и абиотическому стрессу. Результаты исследований актуальны для развития фундаментальных основ науки о грибах.

Ключевые слова: мицелий, каталаза, супероксиддисмутаза, активность ферментов, ионы, магний, гриб вешенка

ANALYSIS OF THE ACTIVITY OF OXIDATIVE ENZYMES BY MULTIVARIATE REGRESSION IN THE PRESENCE OF MG^{2+} OYSTER MUSHROOM MYCELIUM

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Studies have been conducted to optimize the process of deep cultivation of the Oyster mushroom mycelium. The process of obtaining mycelium as a seed for cultivation of fruiting bodies of mushrooms has been improved. The effect of different concentrations of magnesium carbonate (Magnesium carbonates) on the growth characteristics of mycelium of the fungus *Pleurotus ostreatus* during deep cultivation has been studied. The dependence of enzyme activity on the concentration of metal in the nutrient medium of germinating mycelium of oyster mushrooms has been revealed. The method for determining the activity of catalase by spectrophotometric method has been adapted for the studied objects. For the first time the data on the activity of mycelium catalase and superoxide dismutase

enzymes in the presence of magnesium carbonate additive have been obtained. It has been found that the application of magnesium carbonate in low concentrations has a positive effect on the growth of mycelial biomass of the fungus *Pleurotus ostreatus*, since with increasing concentration (Mg2+) a decrease in biomass growth rate and catalase activity has been observed, presumably due to the participation of magnesium in creating a certain ionic concentration at which catalase inactivation begins. The possibility of applying the method of multivariate regression in the form of the principal components analysis (PCA) has been studied. The redox state of *Pleurotus ostreatus* culture at the level of enzyme components of the antioxidant defense system during submerged cultivation of basidomycetes has been analyzed, which showed how the obtained variables with different measurement units are interconnected. The account graphs also clearly indicate the dependence of mycelial growth on the concentration of the additive used. The introduction of the cultivation conditions proposed in this work in the practice of mushroom production potentially contributes to a more successful resistance of macromycetes to biotic and abiotic stress. The results of the research are relevant to the development of the fundamentals of the science of fungi.

Keywords: mycelium, catalase, superoxide dismutase, enzyme activity, ions, magnesium, oyster mushroom

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INTRODUCTION

The question of the possibility of artificial cultivation of edible and medicinal mushrooms has occupied mankind for over two millennia. More than 100,000 species are subjects of scientific research worldwide. The functional importance of fungi in various biogeocenoses is well-known, where, due to their wide range of enzymes, they actively participate in the processes of organic matter destruction and mineralization [1]. Although fungi are a very intriguing group of living organisms, both theoretically and practically, they remain relatively under-researched to date. Macromycetes produce biologically active substances, such as polysaccharides, glycoproteins, terpenes, sterols, and carotenoid pigments, which can demonstrate antibacterial, antiviral, anticancer, antiparasitic, and immunomodulatory properties.

Significant research into the physiology of higher fungi began between the 1980s and 2020s. The complex physiological and biochemical processes occurring during the growth and development of a fungal organism, their intensity, determined by the hereditary and potential qualities of the organism itself and external environment factors, require further study [2]. The study of basidiomycete growth in liquid environments focuses on understanding the nutritional needs and physiology of the species in pure culture and developing submerged mycelium cultivation techniques to obtain feed and food biomass. Deep cultivation is also proposed as a quick and effective method for producing seeding material for mushroom cultivation. Significantly fewer works focus on the biochemistry of deep cultivation, its relationship with the physiology of growth and development of the fungal organism in submerged culture. In particular, the antimicrobial activity of higher fungi is clearly understudied, and only a few studies address this activity in relation to physiological aspects, mushroom morphogenesis issues [3-

15]. Research aimed at creating growing conditions for basidiomycetes, to achieve maximum biomass yield, reduce cultivation time, reduce seeding material, etc., is actively developing. Analyzing the change in the enzymatic activity of basidiomycetes during varying cultivation conditions is one of the main effective indicators of the competitiveness of mycelial biomass growth [16].

In the world of higher plants, enzymes act as antioxidants, protecting cellular components from oxidation by reactive oxygen species (ROS). Primarily, these include the enzyme superoxide dismutase (SOD), catalase, and glutathione peroxidase. Superoxide is one of the most common ROS produced by mitochondria, while SOD converts superoxide anions into hydrogen peroxide, thus serving as a central regulator of ROS levels. The enzyme catalase is a hemin enzyme. The biological role of catalase is to catalyze the decomposition of hydrogen peroxide. *In vivo* (in the cell), most enzymes are spatially organized into so-called "multienzyme systems." They are either associated with cellular structures or are free in various cell organelles.

The practice of adding nutrient supplements for mushroom cultivation during spawning or casing to maximize yield emerged in the 1960s [17] and has been widely recognized and disseminated, but its use may be limited in some sectors due to technical and economic factors. Additives, as a nutrient substance, are defatted plant flour obtained from soybean meal and also bran, which is an organic source of protein enriched with minerals or vitamins, often used for growing *Agaricus* and *Pleurotus* species.

Higher fungi's growth and development are favorably influenced by trace elements in small quantities. Absence of trace elements causes various developmental disturbances in the organism. At specific concentrations of zinc, iron, manganese, copper, calcium, and some other trace elements, there is a stimulation of mycelium formation and growth. For nutrition, i.e., for the main metabolism of fungi, about 17-18 elements are needed, including nitrogen, carbon, oxygen, hydrogen, sulfur, phosphorus, potassium, magnesium, iron, copper, zinc, manganese, molybdenum, calcium. Fungi require the following main elements in large amounts: nitrogen, carbon, oxygen, hydrogen, phosphorus, potassium, sulfur, and magnesium. Therefore, nutrient media with sufficient trace elements, in addition to sources of nitrogen and carbon, add potassium and magnesium. Magnesium plays a significant role in carbohydrate metabolism and all syntheses based on the use of phosphorus bond energy. About 50 enzymatic reactions in fungi involve magnesium.

The purpose of the research is to analyze the redox state of the mycelium of the *Pleurotus ostreatus* culture at the level of enzymatic components of the antioxidant defense system during cultivation with different concentrations of magnesium carbonate $MgCO_3$ using multivariate regression and to determine the activity of catalase and superoxide dismutase in extracts from mycelial biomass.

MATERIAL AND METHODS

The chosen strain for the research was *Pleurotus ostreatus* strain NK-35 from the collection of the agrochemical laboratory of TRPC "Agrocenter" of the Vavilov University. This strain has the following characteristics: during maturation, fruiting waves are roughly uniform - 10-12% for the first wave, 7-10% for the second, and 5-7% for the third. The optimal growing parameters are temperature of 16-17°C; humidity at the time of primordia formation is 90%, after massive formation it decreases to 88%, and during fruiting it is maintained at 85-87%; the level of carbon dioxide should not exceed 850 ppm.

Magnesium carbonate is used as a food additive E 504. In Russia, additive E 504 is permitted for the production of cocoa and chocolate products, cheeses, and other products according to the technical requirements of production. Magnesium is an element required for oxidation processes, which does not form stable organic compounds in mushroom mycelium.

In Russia, the largest share in the range of magnesium fertilizers is attributed to lime-magnesium and potassium-magnesium fertilizers.

The use of organic fertilizers, the chemical composition of which contains magnesium within 0.01-0.09% (according to GOST R 58658-2019 Agricultural products, raw materials, and food with improved environmental characteristics), is notable (see Table 1).

Cultivation was performed periodically using a deep method at a temperature of (28 ± 1)°C from 6 to 14 days with continuous stirring (rotation frequency of 200 rpm) in the dark on a shaker-incubator in flasks with a capacity of 750-1000 ml. Cultivation was carried out in liquid nutrient media containing different concentrations of magnesium carbonate, in a 2% solution of first-grade flour. The nutrient media were autoclaved at 1.2 atm for 0.5 hours.

Total activity of superoxide dismutase was determined by the enzyme's ability to inhibit the photochemical reduction of nitro blue tetrazolium (NBT), according to Giannopolitis and Ries[1], with some modifications as described by O.G. Poleskaya et al.[2] The amount of soluble protein in the supernatant was determined by the Bradford method. Superoxide dismutase activity was expressed in arbitrary units per milligram of protein. The activity of catalase in liquid samples was measured by the decrease in the concentration of H_2O_2 upon contact with protein extracts from the mycelium. Catalase activity was determined by the spectrophotometric method at a wavelength of 240 nm. The amount of soluble protein in the supernatant was determined by the Bradford method[3]. Catalase activity was expressed in units of $mM \cdot min^{-1} \cdot mg^{-1}$ of protein. The analysis of the kinetic curves of catalase activity was carried out using the UVWin5 program. Growth characteristics (growth rate) during deep cultivation were determined in accordance with the recommendations[4] based on the accumulation of dry biomass per unit of time depending on the duration of cultivation.

Biomass measurement experiments were conducted in 5-10 repetitions, all others in 3 repetitions. For quantitative data processing, the principal component analysis (PCA) method was used, with particular attention paid to score plots. On the score plot, each sample is depicted in coordinates (t_1, t_2), denoted by GC1 and GC2. An essential property of PCA is the orthogonality (independence) of the principal components. The proximity of two points indicates their similarity, i.e., a positive correlation. The dependence of the average value of the quantity on some other quantity or several other quantities is considered. Unlike the purely functional dependence $y = f(x)$, where each value of the independent variable x corresponds to one specific value of the dependent variable y, with regression linkage, the same value of the independent variable (factor) x can correspond to different values of the dependent variable (response) y depending on the specific case. If at each value $x = x_i$ there are ni values of y_{ij}; $j = 1, n_i$, then the dependence of arithmetic mean values: $y_i = \frac{1}{n_i} \sum_{j=1}^{n_i} y_{ij}$ on x_i

Табл. 1. Дизайн эксперимента
Table 1. Experiment design

No	Group	Initial concentration of $MgCO_3$ in nutrient medium, mol/l	Designation color
1	Control	–	Green©
2	1st	$1 \cdot 10^{-6}$	Lilac©
3	2nd	$1 \cdot 10^{-5}$	Red©
4	3rd	$1 \cdot 10^{-4}$	Yellow©
5	4th	$1 \cdot 10^{-3}$	Blue©

[1]*Giannopolitis C. N., Ries S.K.* Superoxide Dismutases: I. Occurrence in Higher Plants // Plant Physiology. 1977, Vol. 59, pp. 309–314.

[2]*Polesskaya, O.G., Kashirina, E.I., Alekhina, N.D.* Changes in the activity of antioxidant enzymes in wheat leaves and roots depending on the form and dose of nitrogen in the medium // Plant Physiology. 2004, No. 5, P. 686–691.

[3]*Bradford* GPM.1.2.3.0012.15. Determination of protein, GENERAL PHARMACOPEIAN MORNING, Instead of Art. GF XII, part 1.

[4]*Dudka I.A., Vasser S.P., Ellanskaya I.A. and others.* Methods of experimental mycology: a Handbook // Pod. ed. IN AND. Bilay. Kyiv: Naukova Dumka, 1982. 549 p.

and is regression in the statistical sense of the term[5, 6].

RESULTS AND DISCUSSION

To determine the possibility of using the principal component method for processing data on the activity of the enzyme catalase and superoxide dismutase, experimental studies were conducted on the cultivation of mycelium in the media containing different concentrations of magnesium carbonate, as indicated in Table 1, in a 2% solution of first-grade flour. The nutrient media were autoclaved at 1.2 atm for 0.5 hours.

Figure 1 shows score plots based on catalase activity data with several variables, including mass (m) of protein in mg, Σ (total protein mass in the sample); catalase activity per milligram of protein (cat/mg protein); catalase activity per microgram of protein (cat/μg protein); error for activity per 1 mg of protein; error for activity per 1 μg protein; ΔD/min – measurement weight errors). The data obtained by the spectrophotometric method at a wavelength of 240 nm for catalase activity, for *V* sample – 2 ml; ε – molar extinction coefficient of H_2O_2 – 0.039 mol^{-1}; *l* – optical path length – 1 cm; *t* – 1 min.

The obtained data are well modeled by the PCA method with two main components. In this analysis, the indicator of the sample and variable dependencies, representing catalase activity and its spectral range, is essential. Analysis of the score plots in Figure 1 shows a clear dependence of catalase activity on the concentration of magnesium carbonate in the nutrient medium. The proximity of the points highlighted in red (with $MgCO_3$ in the nutrient medium of $1 \cdot 10^{-5}$ mol/l) and purple ($1 \cdot 10^{-6}$ mol/l) demonstrates rapid mycelial biomass growth and a high catalase activity indicator compared to the green points (control). When constructing regression dependence by the least squares method (LSM), it is required that the sum of the squares of the experimental values deviations from those calculated by the approximating dependence be minimal.

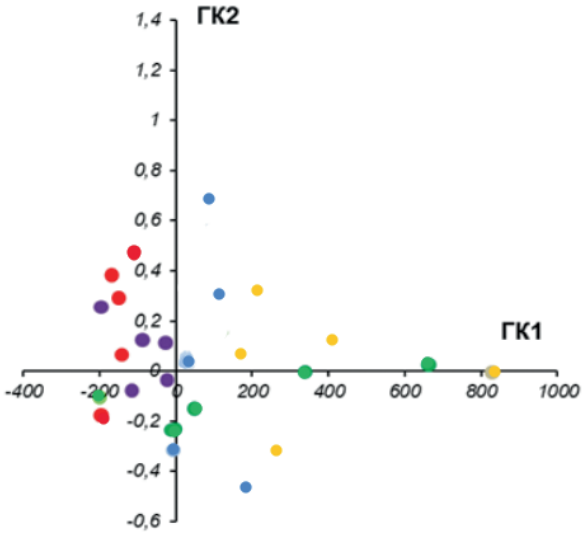

Рис. 1. Графики счетов (ГК1 и ГК2) по активности каталазы mM· мин$^{-1}$ · мг$^{-1}$ белка (контроль – зеленый©; $1 \cdot 10^{-6}$ – сиреневый©; $1 \cdot 10^{-5}$ – красный©; $1 \cdot 10^{-4}$ – желтый©;$1 \cdot 10^{-3}$ – синий©)

Fig. 1. Score plots (GS1 and GS2) for catalase activity mM·min–1·mg–1 of the protein (control-green©; $1 \cdot 10^{-6}$ – lilac©; $1 \cdot 10^{-5}$ – red©; $1 \cdot 10^{-4}$ – yellow©; $1 \cdot 10^{-3}$ – blue©)

Hence, it is clear how the points highlighted in yellow and blue are scattered, with higher magnesium concentrations in the nutrient medium (from $1 \cdot 10^{-4}$ to $1 \cdot 10^{-3}$ mol/l). This indicates a decrease in catalase activity and mycelial mass growth, which may be caused by damage to the enzyme structure or disruption of the catalase biosynthesis pathway in the presence of a high magnesium concentration. Toxins entering plant cells can bind to -SH, -NH_2, -COOH groups of amino acids that are part of the enzyme, which can lead to the suppression of enzyme activity. The concept of the coordinated action of active forms of oxygen (AFO) and metabolites essential for regulating growth, development, and stress tolerance of plant organisms is well known [18-20]. AFOs are multifunctional signaling molecules that contribute to adaptability, and the effect of any compound - a pronounced antioxidant - leads to weak oxidative stress development. Likely, counteracting AFO, agents

[5] *Pomerantsev A.L.* Chemometrics in Excel: textbook. Tomsk, TPU Press. 2014, 435 p.

[6] *Pomerantsev A.L.* Chemometrics in Excel, John Wiley and Sons, 2014, 336 p.

with antioxidant properties – metal-containing additives – influenced the biochemical processes of macromycetes, could be one of the reasons for the decrease in growth indicators due to the absence of stress-dependent activation of some antioxidant enzymes in fungi. Moreover, catalase is a chromoprotein and has an oxidized heme as a non-protein group. One catalase molecule can cause the decomposition of 6 × 106 molecules of H_2O_2 per second. However, catalase has low affinity for hydrogen peroxide, so it starts to function only at its high content in the cell. Increasing the concentration of catalase in cells enhances the decomposition of hydrogen peroxide, which, in turn, positively affects the speed of redox reactions. Possibly, the increase in enzyme activity accelerates cell metabolism processes, affecting growth rate. Therefore, an increase in magnesium concentration leads to a decrease in the growth rate of biomass and catalase activity due to the cells' response at the level of enzyme components of the antioxidant defense system during mushroom cultivation.

Key antioxidant enzymes in cells are SOD, catalase, and peroxidase. SOD provides the "first line" of cell protection against AFOs, catalyzing the dismutation reaction of the superoxide radical in various cell compartments. The hydrogen peroxide formed as a result of superoxide reduction, whose molecule also belongs to AFOs, is neutralized in turn by catalase and PO. It is known from the literature that plants resistant to various adverse environmental factors are characterized by higher antioxidant enzyme activity compared to susceptible ones [20, 21]. In our studies, the determination of superoxide dismutase activity was carried out by the spectrophotometric method at a wavelength of 560 nm; to plot scores based on SOD activity (c.u./mg protein), the above variables were also involved.

The significant increase in SOD activity observed at magnesium concentrations in the nutrient medium (from $1 \cdot 10^{-6}$ to $1 \cdot 10^{-5}$ mol/l), marked on the graph in purple and red points, obviously provides protection of cells from the increasing amount of superoxide radicals. The analysis results in Figure 2 indicate that different concentrations of magnesium carbonate differently affect the protein concentration during the cultivation of the *Pleurotus ostreatus* fungus.

From the score plots, it's evident that concentrations of $1 \cdot 10^{-4}$ and $1 \cdot 10^{-3}$ had a negative impact on the superoxide dismutase (SOD) activity of the mycelium of the fungus *Pleurotus ostreatus*. A low level of SOD when increasing the magnesium concentration in the nutrient solution indicates that the intensification of oxidative processes in their cells doesn't occur. Presumably, the reduction in the intensity of the SOD enzyme and biomass growth in this case may be associated with a decrease in the number of active forms of oxygen (AFO). This, on the one hand, is related to the interaction of metal ions with SH-groups of membrane proteins, causing a change in their properties and, on the other hand, with the ability of the metal to indirectly influence the generation of excessive amounts of AFO.

Analysis of the biomass growth of basidiomycetes, cultivated by immersion in the presence of magnesium carbonate at different concentrations 14 days after sowing nutrient media, revealed a noticeable increase in growth at concentrations of $1 \cdot 10^{-6}$ and $1 \cdot 10^{-5}$ of magnesium carbonate, amounting to 120.5% and 112.9%, respectively, compared to control indicators (see Table 2).

However, higher concentrations, on the contrary, showed a decrease in biomass in percentage terms compared to the control. It's known that increasing the content of metals in nutrient media leads to inhibition of physiological processes, and the degree of inhibition largely depends on the metal resistance of the species [20, 21].

The conducted research showed that different concentrations of magnesium differently affect the protein concentration of this type of fungus. Analysis of the results indicates that antioxidant enzymes play an important role in accelerating the growth of *Pleurotus ostreatus* mycelium biomass when using magnesium carbonate in the nutrient solution at concentrations of $1 \cdot 10^{-6}$

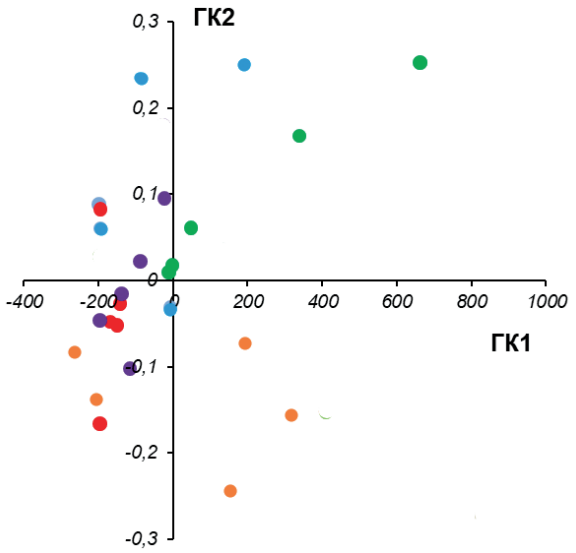

Рис. 2. Графики счетов (ГК1 и ГК2) по активности СОД, усл. ед. /мг белка (контроль – зеленый©; $1{\cdot}10^{-6}$ – сиреневый©; $1{\cdot}10^{-5}$ – красный©; $1{\cdot}10^{-4}$ – желтый©; $1{\cdot}10^{-3}$ – синий©)

Fig. 2. Score plots (GS1 and GS2) by SOD activity, c. u. per mg of protein (control-green©; $1{\cdot}10^{-6}$ – lilac©; $1{\cdot}10^{-5}$ – red©; $1{\cdot}10^{-4}$ – yellow©; $1{\cdot}10^{-3}$ – blue©)

and $1{\cdot}10^{-5}$. Their activity is well modeled by the multivariate regression method.

The data obtained show that the increase in enzyme activity under the influence of metal ions, in particular, in our study of magnesium carbonate can occur in the following ways:

– metal ions directly constitute the active center of the enzyme (catalase, peroxidase);

– metal ions participate in the formation of the enzyme-substrate complex (alcohol dehydrogenase);

– metal ions contribute to maintaining the specific catalytically active conformation of the enzyme molecule, primarily its active center, etc. Specificity is explained by the correspondence of the structure of the enzyme's active center and the substrate.

Thus, for the first time, we processed absorption spectrum data for catalase and superoxide dismutase activity using multivariate regression, depending on the growth factor of mycelial biomass. As the results of this study show, a different metabolic status of the studied magnesium concentrations is formed at the earliest stages of ontogenesis, and this is expressed in different values of enzyme activity indicators and different directions of metabolic strategies. Changes in the activity of catalase, as an important enzyme involved in forming donor-acceptor relationships, also reflect the different metabolic growth status of the fungus mycelium. The results provide a basis for considering the multivariate regression method as a promising approach for the rapid assessment of spectrophotometric data.

Табл. 2. Биомасса мицелия *Pleurotus ostreatus*, культивируемого в присутствии $MgCO_3$

Table 2. Biomass of mycelium *Pleurotus ostreatus* cultivated in the presence of $MgCO_3$

Concentration in the nutrient medium (*C*), mol/l	Biomass, mg	Biomass, % to the control*
Control*	836,6	100
$1{\cdot}10^{-6}$	1008,4	120,5
$1{\cdot}10^{-5}$	944,7	112,9
$1{\cdot}10^{-4}$	825,1	98,6
$1{\cdot}10^{-3}$	785,9	93,9

*Absence of $MgCO_3$ in the nutrient medium.

CONCLUSIONS

1. Based on the conducted research, it can be concluded that the use of magnesium carbonate in the nutrient medium at concentrations of $1{\cdot}10^{-5}$ and $1{\cdot}10^{-6}$ not only influences the enzymatic activity of the basidiomycete *Pleurotus ostreatus*, but also the growth characteristics, as well as the protein concentration in mycelial cells.

2. The use of multivariate regression shows the interrelationships of the obtained variables. Score plots clearly indicate the dependence of mycelium growth on the concentration of the applied additive.

3. Introducing the cultivation conditions proposed in this work into mushroom cultivation practice could potentially lead to more successful resistance of basidiomycetes to biotic and abiotic stress and make a significant contribution to the development of the fundamental basics of mycology. Cultivated higher fungi are

known as a natural biofactory of biologically active compounds, including antioxidant compositions. The research shows the possibility of increasing the yield of basidiomycete biomass by changing their cultivation conditions.

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ВЕТЕРИНАРНОЕ ОБЕСПЕЧЕНИЕ ТАБУННОГО КОНЕВОДСТВА: ПРОБЛЕМЫ И ПУТИ РЕШЕНИЯ

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Представлены разработанные иммунобиологические препараты для профилактики инфекционных болезней лошадей табунного содержания. Инфекционные болезни лошадей регистрируют почти во всех странах Азии, Европы и Америки. В России, Казахстане, Киргизии и Монголии наиболее распространенными болезнями являются мыт, ринопневмония и сальмонеллезный аборт, которые наносят значительный экономический ущерб табунному коневодству. В зарубежных странах разрабатывают и производят различные моновакцины, большинство из них применения в России не имеют. Нами установлено одновременное заболевание кобыл ринопневмонией и сальмонеллезом, а также молодняка лошадей ринопневмонией, сальмонеллезом и мытом. В связи с этим актуальной проблемой становится разработка моновакцин и комбинированных иммунобиологических препаратов. Иммуногенность инфекционных вакцин следует усиливать иммуномодуляторами, особенно в экстремальных условиях ведения табунного коневодства. В период проблемы появления антибиотикорезистентных штаммов микроорганизмов следует разрабатывать альтернативные антибактериальные средства: пробиотики и бактериофаги. Выделены, идентифицированы и депонированы во всероссийских коллекциях восемь новых штаммов микроорганизмов. Разработан пробиотик Сахабактисубтил, который используют для профилактики и лечения дисбактериозов, микотоксикозов, мыта, лептоспироза, обеззараживания навоза. Разработаны новые эффективные вакцинные препараты и закваска «Якутская кумысная», которые можно успешно использовать для повышения продуктивности коневодства в других субъектах Российской Федерации и за рубежом. Подготовлена научно-техническая документация на инактивированную вакцину против ринопневмонии, комбинированные двух- и трехвалентные вакцины. Разработанные иммунобиологические препараты защищены 48 патентами на изобретение и могут быть использованы в других странах.

Ключевые слова: лошади, вакцина, пробиотик, кумыс, бактериофаги

VETERINARY SUPPORT OF THE HERD HORSE BREEDING: PROBLEMS AND SOLUTIONS

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Developed immunobiological preparations for the prevention of infectious diseases in herd horses are presented. Infectious diseases of horses are registered in almost all countries in Asia, Europe and America. In Russia, Kazakhstan, Kyrgyzstan, and Mongolia, the most common diseases are strangles

of horses, rhinopneumonia, and salmonella abortion, which cause significant economic damage to herd horse breeding. Various monovaccines are developed and produced in foreign countries, most of them have no use in Russia. We have found a simultaneous disease of mares with rhinopneumonia and salmonellosis, as well as young horses with rhinopneumonia, salmonellosis and strangles. In this regard, the development of monovaccines and combined immunobiological preparations is becoming an urgent problem. Immunogenicity of infectious vaccines should be enhanced by immunomodulators, especially in the extreme conditions of herd horse breeding. At a time when antibiotic-resistant strains of microorganisms are a problem, alternative antibacterial agents should be developed: probiotics and bacteriophages. Eight new microbial strains have been isolated, identified, and deposited in all-Russian collections. Sahabaktisubtil probiotic has been developed, which is used to prevent and treat dysbacteriosis, mycotoxicosis, strangles, leptospirosis, decontamination of manure. New effective vaccine preparations and "Yakutskaya Koumissnaya" starter culture have been developed that can be successfully used to increase the productivity of horse breeding in other regions of the Russian Federation and abroad. Scientific and technical documentation was prepared for inactivated vaccine against rhinopneumonia, combined bivalent and trivalent vaccines. The developed immunobiological preparations are protected by 48 patents for invention and can be used in other countries.

Keywords: horses, vaccine, probiotic, koumiss, bacteriophages

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In Asian and African countries, Europe, the USA [1, 2], the Russian Federation, the Republic of Kazakhstan, Kyrgyzstan and Mongolia [3, 4], the prevention of some mass infectious diseases, including rhinopneumonia (equine viral abortion), salmonella abortion and horse strangles, remains an unsolved problem of herd horse breeding. As a result of these diseases, the yield of foals per 100 breeding mares decreases to 45% [4]. However, in Russia and global practice, there are few effective immunobiological preparations for the prevention and treatment of infectious diseases.

For the prevention of equine rhinopneumonitis, a live virus vaccine and an inactivated one with an immunomodulator have been developed [4]. In various countries, live and inactivated monovaccines against strangles are developed and applied [5-7].

As our research and other authors' results show, mares often simultaneously suffer from rhinopneumonitis and salmonella abortion. It is known that about 20-30% of mares are carriers of the strangles-causing streptococcus. They serve as sources of infection and facilitate the spread of strangles among foals [8, 9]. Among young horses, there are instances of simultaneous illness from rhinopneumonitis, salmonellosis, and strangles. With such complications, mortality can reach up to 22% [3].

The purpose of the study is to introduce the developed immunobiological preparations for the prevention of infectious diseases in horses of herd breeding.

The genus and species identification of microorganisms were conducted according to the "Reference for Microbiological and Virological Studies" (1982), the "Identifier of Zoopathogenic Microorganisms" (1995), and the "Bergey's Manual of Determinative Bacteriology" (1997). The survivability of infectious disease pathogens was studied according to commonly accepted veterinary sanitation methods.

Preclinical and clinical trials, and the development of dossiers were conducted according to the Federal Law of 12.04.2010 (№ 61-FL),

orders of the Ministry of Agriculture of the Russian Federation from 06.03.2018 (№ 101), from 22.08.2017 (№ 430). The strains are deposited in the Russian State Center for Animal Feed and Drug Standardization and Quality (VGNKI).

To study the antagonistic properties of bacteria, passported strains were tested: *Staphylococcus aureus* (strain 209 R) obtained in the VGNKI, *Staphylococcus equi* H-34, *Salmonella abortus equi* BN-12 - YSRIA, *Escherichia coli* (strain 1257) - ARRIVSHE; *Salmonella pullorum* (strain 10b), *Brucella abortus* (in-82) - ARRIEVM, as well as local strains: *St. aureus* K-1, *Sal. typhymurium, Sal. dublin, Pseudomones, Micobacterium, Rajendra soloni, Streptomyces, Fusarium.*

We have isolated, identified, and deposited the following strains in the All-Russian State Collection of Strains of Microorganisms used in Veterinary Medicine and Animal Husbandry (VGNKI): *Sal. abortus*. equi BN-12, *Str. equi* H 5/1, *Bacillus subtilis* TNP-3, *Bacillus subtilis* TNP-5.

Deposits have been made in the State Collection of Microorganisms of Normal Microflora (GKNM) " MRIEM " named after G.N. Gabrichevsky of the Russian Consumer Protection Agency: *Lactobacillus acidophilus* K 1901, *L. acidophilus* K 1902, *L. delbrueckii* subsp. *Bulgaricus* K 1903. The strain *Clavispora lusitaniae* 1D (U-4861) is deposited in the Bioresource Center of the All-Russian Collection of Industrial Microorganisms (BRC ARCIM), SRC "Kurchatov Institute" (GosNIIGenetika). Molecular-genetic identification of microorganisms was carried out by SKC "Genomics" and VGNKI [3].

The studies conducted showed that the survival rates of some microorganisms on external environment objects in permafrost conditions are 2-3 times longer than the life preservation periods of similar microorganisms in the southern and European territories of Russia and abroad. During the study of microbial contamination and survival rates of microorganisms, a significant content of aerobic spore-forming bacteria (more than 2 × 106 CFU/g) was found in the permafrost soils of Central Yakutia. The isolation of viable *Bacillus* bacteria from the representatives of mammoth fauna preserved in permafrost soils (aged 30-40 thousand years) proves the role of permafrost in preserving Pleistocene-era bacteria. Permafrost contributes to the prolonged preservation of foci and transmission factors of infectious disease agents. The isolation of pathogens from glacier surfaces and from wild animals indicates the danger of food contamination during storage and consumption. The circulation of viral disease agents among northern reindeer and horses suggests the role of migratory birds in spreading infectious diseases. The study of epizootology of anthrax remains relevant. Knowledge of microorganism survival rates in extreme conditions of the Far North and the study of the microbiota of wild animals and migratory birds is essential for optimizing anti-epizootic and epidemiological measures to ensure biological safety. The problem is of global significance.

The strain of bacteria *B. subtilis* TNP-3 has more pronounced antagonistic activity against pathogenic microorganisms for humans and animals, *B. subtilis* TNP-5 – against plant disease agents (rhizoctonia, fusarium, and potato scab). Bacterial strains do not have pathogenic properties for laboratory and agricultural animals.

As a result of the studies conducted, the probiotic Sahabactisubtil has been developed and introduced for the prevention of dysbiosis, increasing the immunobiological reactivity of agricultural animals. Instructions for use have been approved (from 06.06.2012). The drug has been registered (71-111.12-0850 № SLA-1.6/01632).

It has been found that in the conditions of Yakutia, composting of poultry litter, manure with various substrates, sawdust, sapropel, peat, straw, zeolite does not always produce a positive sterilization result. The most reliable sterilization method is adding an antagonist microbe *B. subtilis* TNP-3 in the form of a 1 billion suspension or B. subtilis adsorbed on zeolite (0.5% of the compost mass) with an exposure of 80 days during the summer period.

Studies of the gut microbiota of young horses showed a decrease in the content of lactobacilli, bifidobacteria, lactopositive Escherichia, and fungi in the winter period (December – March). During this period, an increase in the number of opportunistic microflora – lactose-negative

Escherichia and staphylococci was noted. The results obtained indicate the development of dysbiosis in young horses. As is known, when the ratio of opportunistic and normal microbiota is disturbed, the digestibility of feeds and the immunobiological reactivity of the body decrease.

It should be noted that the intestines of young horses are colonized by spore-forming aerobic bacteria from the first days of life. The dominance of these microorganisms in the gut microbiota of horses persisted throughout the study period. The obtained data confirm the results of previous studies showing that during the formation of the normal flora of foals, calves, piglets, birds, and cell animals, spore-forming aerobic bacteria perform an active protective function against pathogenic and opportunistic microorganisms and are representatives of the normal microbiota of the animal's body in the conditions of the Far North.

The development of intestinal dysbiosis, reduced immunobiological reactivity of the body, and the spread of helminthiasis, rhinopneumonia, strangles, and salmonellosis are facilitated by weaning foals from their mothers, inadequate and insufficient feeding, prolonged low temperatures (–43 … 45 °C), and absence of planned preventive measures.

We have found that the use of the probiotic Sahabactisubtil with zeolite when feeding young horses in winter corrects the disturbed gut microbiota, stimulates immunobiological reactivity, and increases average daily gains. The positive effect of the probiotic on the body of the young is explained by the ability of bacterial strains *B. subtilis* TNP-3 and *B. subtilis* TNP-5 to stimulate the development of normal microflora, suppress the development of toxin-producing mold fungi, produce enzymes. Proteolytic, gelatinase, amylolytic, cellulolytic, β-glucanase, fructosyltransferase, and xylanase activity of bacterial strains contributes to increased digestibility and assimilation of nutrients.

Dehelminthization of young animals of 8-9 months of age after weaning from their mothers, practiced in almost all horse breeding farms of the Republic of Sakha (Yakutia), exacerbates the phenomenon of dysbiosis, leading to decreased growth and development rates. The drug Sahabactisubtil should be prescribed for the treatment and prevention of parasitic diseases of horses with any anthelmintic drugs.

Feed supplement based on local raw materials with the drug Sahabactisubtil, when fed to in-foal mares, increases the digestibility of dry matter by 5.14%, organic matter by 2.29%, raw protein by 26.05%, raw fiber by 3.95%, and raw fat by 4.74%. The metabolic energy level of the mares in the control group was lower by 6.30 MJ or 6.54%. The probiotic also has a positive effect on the business output of foals compared to the control group of animals (increased by 10%).

According to the instructions, when leptospirosis is detected, infected animals are isolated and treated with antibiotics, and then vaccinated. However, it is known that the use of antibiotics causes intestinal dysbiosis, decreases immunobiological reactivity and vaccine immunogenicity, and promotes the emergence of antibiotic-resistant strains of leptospira. We have found that the drug Sahabactisubtil in laboratory conditions causes lysis of leptospires serogroups *Pomona, Tarassovi, Grippotyphosa, Hebdomadis, Sejroe, Icterohaemorrhagiae, Canicola.* Laboratory studies have shown the resistance of bacterial strains *B. subtilis* TNP-3 and *B. subtilis* TNP-5 to the effects of a wide range of antibiotics (kanamycin, rifampicin, levomycetin, furadoxin, ampicillin, neomycin, eryprim, and kinoex), low resistance to cefuroxime, cefatoxin, ciroperazine, gentamycin, sensitivity to ciprofloxacin. The probiotic Sahabactisubtil is recommended to be used in combination with antibiotics to suppress the causative agent of leptospirosis, increase immunobiological reactivity, eliminate dysbiosis, and disinfect the external environment.

One of the promising measures to combat mycotoxicosis is considered to be the biological method using aerobic spore-forming bacteria of the genus *Bacillus*. We have found that bacterial strains *B. subtilis* TNP-3 and *B. subtilis* TNP-5 have a pronounced fungicidal effect against microscopic fungi *Aspergillus niger, Mucor ramosissimus, Candida albicans, Fusarium semitectum*. The probiotic Sahabactisubtil, adsorbed on oats, can be used as a remedy to combat mold fungi in feeds. Treating oats with the Sahabactisubtil probiotic reduces the number of mold fun-

gi by 40 times, normalizes intestinal microbiocenosis, stimulates immunobiological activity, and increases the live weight of the young.

In the system of measures for the treatment and prevention of strangles in horses, conducting therapeutic measures is of great importance. In laboratory conditions, a pronounced antagonistic activity of the *B. subtilis* TNP-3 strain against the causative agent of horse strangles was established. The possibility of using a suspension of the *B. subtilis* TNP-3 bacterial strain for the treatment of horse strangles has been proven, with its relatively high therapeutic effectiveness, especially in mixed viral-bacterial diseases (strangles and rhinopneumonia). Adding strains of bacteria *B. subtilis* TNP-3 to the composition of inactivated vaccines against strangles and salmonella abortion in horses enhances their immunogenicity. The immunomodulatory ability is due to the immune-stimulating and interferon-inducing activity of bacterial strains *B. subtilis* TNP-3 and *B. subtilis* TNP-5.

For the specific prevention of salmonella abortion in horses, an inactivated vaccine has been developed from the *Sal. abortus equi* BN-12 strain with the fugate of the *B. subtilis* TNP-3 strain as an immunomodulator. Preclinical trials were conducted on laboratory white mice, clinical trials on horses. The absence of toxicity of the drug was established. The immunogenicity in white mice was 90%, in mares - 100%. Production tests of the vaccine showed that after immunization, the business yield of foals increased by 13.8%. The economic effectiveness of using the vaccine with the fugate of the *B. subtilis* TNP-3 strain for every 1 ruble of costs amounted to 14.1 rubles. Instructions for the use of the vaccine were approved and a registration certificate was obtained (71-1-10.19-4495 No. SLA -1-1.6/01631 dated 10.06.2019).

We have developed a new inactivated vaccine against horse strangles with an immunomodulator made from the bacterial strain *Str. equi* H-5/1 with the fugate of the bacterial strain *B. subtilis* TNP-3 added as an immunomodulator. Preclinical trials on laboratory animals (white mice, rabbits) showed that the vaccine protects against experimental infection with a pathogenic strain of the strangles streptococcus in up to 90% of white mice and does not have a toxic effect on the organism of laboratory animals.

Clinical trials were conducted on 6-8-month-old foals. The effectiveness of immunization is 97.6%. The economic effect per head amounted to 3.99 thousand rubles, and the profit for every 1 ruble of costs was 6.65 rubles. The vaccine is registered in the registry of medicinal products for veterinary use (Rosselkhoznadzor RF) under the registration number 71-1-27.21-4828 No. SLA -1-27.21/03691 dated 08.12.2021.

The combined vaccine against rhinopneumonia and strangles in young horses is made from inactivated strains of the rhinopneumonia virus CV/69, the bacteria *Str. equi* H-5/1, and an immunomodulator from the strain of bacteria *B. subtilis* TNP-3. Preclinical testing showed no acute toxicity, allergenic, or pyrogenic properties. The combined vaccine protects against experimental infection by the rhinopneumonia virus in 75% of vaccinated animals, and against the strangles agent in 80%. Production trials confirmed the results of preclinical research.

Preclinical and clinical trials of the inactivated vaccine against rhinopneumonia have been completed. The protective effect from experimental VGL-1 infection regarding morbidity in linear mice with one and two administrations of the vaccine was 60%, and regarding mortality was 100%. The inactivated vaccine against rhinopneumonia, with the culture fluid of the bacterial strain *B. subtilis* TNP-3, is as effective as the live virus vaccine with a single administration. Immunizing breeding mares in areas affected by rhinopneumonia increases the business yield of foals by 10.9-33.3%.

The combined vaccine is made from the CV/69 strain of the rhinopneumonia virus and the bacterial strain *Sal. abortus equi* BN-12, with the addition of an immunomodulator – a culture fluid (fugate) from the bacterial strain *B. subtilis* TNP-3. The vaccine protects against experimental infection by the rhinopneumonia virus in 87.5% of vaccinated horses and from salmonella abortion infection in 100%. Immunization with the vaccine in affected areas increases the business yield of young horses up to 24.1%.

We have developed a trivalent vaccine, made from the CV/69 strain of the rhinopneumonia virus (ARRIEVM), strains of bacteria *Sal. abortus equi* BN-12 causing salmonella abortion, and *Str. equi* H-34. The drug protects against experimental infection with the rhinopneumonia virus in 88.8% of laboratory mice, and against salmonella abortion and strangles in 100%.

The trivalent vaccine stimulates immunobiological reactivity, induces the synthesis of specific antibodies in high titers, and increases the business yield of foals from 18 to 38%. Clinical trials of the combined trivalent vaccine in young horses (657 heads) demonstrated high effectiveness: it protects 94-100% of the animals vaccinated from the disease.

The developed vaccines in terms of immunogenicity, harmlessness, and eco-friendliness not only match but also surpass known global vaccines [2, 10]. It should be noted that antibiotics in the composition of the vaccine disrupt the development of humoral immunity [11].

High efficacy of the inactivated vaccines can be explained by the antigenic activity of the vaccine strains and the immunomodulatory component – the culture fluid (fugate) of the bacterial strain *B. subtilis* TNP-3. According to our previous research results, it can induce interferon synthesis and stimulate the immunobiological reactivity of the organism, enhancing the immunogenicity of inactivated bacterial and viral vaccines [3, 4].

Kumys – a traditional fermented milk product of the Turkic peoples – has been known since ancient times. However, in the production of kumys, as in any fermented milk products, a starter culture is necessary. For the first time in Yakutia, we developed a starter culture called "Yakut Kumys" using epy strains of bacteria *Lactobacillus acidophilus* K 1901, *L. acidophilus* K 1902, L. *delbrueckii subsp. bulgaricus* K 1903, and the yeast culture *Clavispora lusitaniae* 1 D, intended for mass production.

The search for new strains of microorganisms - producers of biologically active substances used in the development of immunobiological preparations continues. As an alternative to antibiotics, new probiotic preparations and bacteriophages are being developed.

To commercialize the developments, a licensed enterprise "Khoto-Bakt" Scientific Production Center was established and operates. Vaccines are marketed in the regions of Russia and Kazakhstan. The plan includes entering the Mongolian market.

CONCLUSIONS

1. Eight new strains of microorganisms have been isolated, identified, and deposited in the all-Russian collections. The long survivability of microorganisms, conditioned by the permafrost of the region, complicates the epidemiological and epizootic situation, but it is of interest to microbiologists.
2. A probiotic called "Sahabaktisubtil" has been developed, which is used for the prevention and treatment of dysbacteriosis, mycotoxicosis, strangles, leptospirosis, and for disinfecting manure.
3. New effective vaccine preparations and the "Yakut Kumys" starter culture have been developed, which can successfully be used to increase horse breeding productivity in other regions of the Russian Federation and abroad. The scientific novelty of the developments is confirmed by 48 invention patents.

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МИРОВЫЕ ДОСТИЖЕНИЯ ГЕНОМНОГО РЕДАКТИРОВАНИЯ В ОБЛАСТИ СВИНОВОДСТВА

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Представлен обзор основных мировых достижений редактирования генома свиней с использованием системы CRISPR/Cas9, в частности модификации генов (MSTN, IGF2, ZBED6, UCP1, LGALS12, APOE, vWF), для повышения продуктивных характеристик и хозяйственно полезных свойств, а также генов устойчивости животных к заболеваниям (APN, CD163, SRCR5, RSAD2). Большой интерес представляет изучение опыта применения этого инновационного инструмента для получения свиней с заданными признаками. Развитие молекулярно-генетических исследований, открытие взаимосвязей ген – фенотип обеспечило платформу, необходимую для модификации конкретных генов, чтобы значительно сократить репродуктивные циклы и повысить эффективность разведения свиней. Появившаяся относительно недавно система CRISPR/Cas9 уже нашла применение во многих передовых областях исследований, однако в задачах развития свиноводства, в том числе за счет получения трансгенных пород свиней, применение этой технологии ограничено. Это связано с тем, что существуют этические вопросы и проблемы нормативно-правового урегулирования, связанные с генно-отредактированными продуктами и потенциальными нецелевыми эффектами CRISPR/Cas9, которые необходимо исследовать. Технология геномного редактирования активно развивается в мире. В России реализуется программа развития генетических технологий, рассчитанная на 2019–2027 гг. Основная цель программы состоит в комплексном решении задач ускоренного развития генетических технологий, в том числе технологий генетического редактирования. Получение результатов посредством геномного редактирования линий сельскохозяйственных животных с новыми улучшенными свойствами – один из целевых индикаторов программы. С использованием CRISPR/Cas9 могут быть улучшены такие продуктивные характеристики свиней, как устойчивость к болезням, терморегуляция, повышение выхода и качества мяса.

Ключевые слова: CRISPR/Cas9, редактирование генома, ген, мутация, свиньи

GLOBAL ADVANCES IN GENOMIC EDITING IN PIG BREEDING

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An overview of the main world advances in editing the pig genome using the CRISPR/Cas9 system, in particular the modification of the genes (MSTN, IGF2, ZBED6, UCP1, LGALS12, APOE, vWF) to improve productivity and economic properties as well as the disease resistance genes (APN, CD163, SRCR5, RSAD2) in pigs is presented. It is of great interest to study the experience of using this innovative tool to produce pigs with specified traits. The development of molecular genetic research and the discovery of gene-phenotype relationships has provided the platform needed to modify specific genes to significantly shorten the reproductive cycles and improve the efficiency of pig breeding. The relatively recent CRISP/Cas9 system has already found use in many advanced fields of research, but its application is limited in the challenges of pig breeding, including the production of transgenic pigs. It is due to the fact that there are ethical and regulatory issues associated with genetically-edited

products and the potential non-target effects of CRISPR/Cas9 that need to be investigated. Genomic editing technology is actively developing worldwide. Russia is implementing the 2019-2027 genetic technology development program. The main goal of the program is to comprehensively address the problems of accelerated development of genetic technologies, including genetic editing technologies. Obtaining results through genomic editing of farm animal lines with new, improved properties is one of the program's target indicators. CRISPR/Cas9 can be used to improve pig performance characteristics such as resistance to disease, thermoregulation, improved meat yield and quality.

Keywords: CRISPR/Cas9, genome editing, gene, mutation, pigs

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Using selective breeding, people have developed breeds of pigs with beneficial characteristics for agriculture, although traditional selection is a lengthy process. However, this process can now be accelerated through genetic modification, including random transgenesis, gene knockouts, and knock-ins [1, 2]. Enhancing productivity traits and the quality of the products contributes to the efficient development of pig farming. Yet, alongside this, there are significant challenges related to pigs' susceptibility to diseases. Commercial pig farming has suffered massive economic losses due to various diseases such as African swine fever, classical swine fever, porcine reproductive and respiratory syndrome, among others. Modern molecular-genetic technologies allow us to identify specific causes that significantly contribute to the health and productivity traits of farm animals. One of the approaches for further use of this data is local DNA-level changes - genome editing. The ability to generate specific changes in the genome enables researchers to pose fundamental questions about gene functions, transfer allele variants between breeds or species, or create new phenotypes. Current achievements in this area show promising results related to enhancing productivity traits [3]. Moreover, it is believed that genome editing is one of the effective solutions to counter infectious diseases and reduce the heavy reliance on pharmaceutical drugs for treating pigs [4, 5].

The purpose of this article is to review the main global achievements in pig genome editing using the CRISPR/Cas9 system.

CRISPR/Cas9 is a component of the adaptive immunity of bacteria against phages and other invasive nucleic acids. The RNA-guided CRISPR/Cas system consists of a CRISPR repeat-spacer array and the Cas nuclease, which cleaves foreign viral DNA. The Cas9 nuclease, together with a single guide RNA (sgRNA), induces targeted and efficient double-strand breaks (DSBs) in the DNA. CRISPR/Cas9 is a relatively inexpensive system and offers means for broad application in various fields due to its simplicity and efficiency [6]. Mammalian cells were first subjected to gene editing using CRISPR/Cas9 in 2013, and by 2014 the technology was applied to pigs. Since then, CRISPR/Cas9 has found applications in livestock research, including in pigs [7].

Modification of specific genes to enhance the productive characteristics and economically beneficial properties of pigs. The demand for high-quality, low-fat pork is growing worldwide. The CRISPR/Cas9 system serves as a valuable tool for improving the quality of pork through gene manipulations aimed at increasing muscle mass and reducing fat tissue in commercial pigs. One of the achievements in molecular breeding

is pigs with a knockout of the myostatin (MSTN) gene. The MSTN gene inhibits the development of skeletal muscles, making it a suitable target to increase the muscle mass of livestock. Numerous studies have documented an increase in muscle mass with a reduction in fat tissue in pigs with the MSTN gene knockout, resulting in high-quality lean pork. However, a problem encountered with European commercial breed pigs with the MSTN knockout was the low survival rate of piglets after birth. In contrast, Chinese pig breeds carrying homozygous MSTN gene mutations exhibited good survivability. The second obstacle to creating transgenic pigs with a deficiency of the MSTN gene was the biological risks associated with selectable marker genes, such as the green fluorescent protein (EGFP) gene. Chinese scientists hypothesized that modifying the non-coding regions of the MSTN gene could be beneficial in promoting muscle development without significantly affecting the expression of MSTN and its related biological functions [8].

The insulin-like growth factor 2 (IGF2) gene has been successfully used as a regulator of muscle development in Chinese pig breeds [9, 10]. This gene activates a cascade of signaling pathways that regulate cellular proliferation, differentiation, and apoptosis during both intrauterine and postnatal growth. The transcription and expression of the IGF2 gene are suppressed by the ZBED6 protein, which contains a BED domain with zinc fingers. ZBED6 is a transcription factor in mammals that can combine with the IGF2 gene, increasing its expression level, thereby reducing subcutaneous fat deposition [11]. It's shown that this transcription factor is closely associated with muscle growth and development and can inhibit the formation of muscle tubes during cell differentiation. Xiang G. et al. [9] were the first to demonstrate the improvement of the economic traits of livestock by genetically modifying non-coding regions in the genome. Mutations in the intron of the IGF2 gene significantly improved the meat productivity of the Bama pig breed [10].

Pigs are susceptible to various diseases in cold weather. Throughout evolution, these animals have almost lost the key element of non-shivering thermogenesis - the thermogenin protein (UCP1). Rodent studies have shown that mice have the UCP1 protein, and they use brown fat to maintain internal body temperature through non-shivering thermogenesis [12]. A group of Chinese scientists led by Q. Zheng demonstrated the possibility of creating a UCP1 gene knockout in pigs via CRISPR/Cas9-mediated insertion of mouse UCP1 into the pig's endogenous locus [13]. Mating of the male obtained in this way with wild-type females confirmed the Mendelian segregation rule of transgenes among the F_1 offspring and also showed no impact of CRISPR/Cas9 elements on fertility. The resulting pigs exhibited improved thermoregulation and a reduction in the deposition of white adipose tissue, a priority in some countries' pig breeding programs. It's also reported that a total of 2,553 cloned embryos were transferred to the oviducts of 13 surrogate recipients. Three pregnancies were established, which reached term. Twelve male piglets were born naturally from three litters [14].

Adipose tissue performs various physiological functions, including storing excess energy as fat, protecting internal organs from physical impact, retaining heat, and secreting adipokines. Due to their well-developed adipose tissue, pigs are considered an ideal model for studying adipogenesis. A group of scientists has presented new data on fat deposition and a fat tissue-specific promoter element in genetically modified pigs. The galectin 12 gene (LGALS12) showed the highest specificity in pig adipose tissue. However, literature on the pig LGALS12 gene is scarce. According to bioinformatic analysis, five truncated fragments of the LGALS12 promoter were cloned. A 4 bp fragment (L-4 bp) exhibited promoter activity specific to adipose tissue. In these studies, it was shown that L-4 bp could control the expression of the apolipoprotein E (APOE) gene to perform its function in adipocytes. This data confirms the idea that LGALS12 is a candidate gene for genetic improvement of obesity-related traits in pigs [15].

Chinese scientists have used the CRISPR/Cas9 technology to create pigs with a knockout of the von Willebrand factor (vWF) gene. In humans, mutations in this gene cause Willebrand's

disease, which is characterized by spontaneous bleeding. To endow pigs with an economically beneficial trait, which entails active bleeding of the animal after slaughter, the authors introduced genetic constructs using cytoplasmic injection of CAS9 mRNA and shRNA (small hairpin RNA) into zygotes. This was followed by transplantation to surrogate sows, leading to the desired deletion in the vWF gene area in 62% of the piglets born. From a perspective of creating a large animal model for studying human genetic diseases, this research is useful and promising. However, from a food safety perspective, a problem arises: out of 76 embryos injected into five surrogate sows, only three pregnancies were successful. Only 16 piglets were born (2 of which died after birth), and only 10 had the economically valuable gene deletion [15]. It seems that these animals would have required special care, which would increase the cost of their maintenance, casting doubt on the profitability of the obtained beneficial trait.

Modification of specific genes to enhance pig resistance to infectious diseases. Susceptibility to infectious diseases in animals is one of the most serious problems in livestock farming. Many viral infections are associated with secondary bacterial infections, significantly contributing to the use of antimicrobial drugs in agriculture. The use of CRISPR/Cas9 is crucial for producing pigs resistant to coronaviruses. Coronaviruses are single-stranded RNA viruses found worldwide. They include viruses such as transmissible gastroenteritis (TGEV), porcine epidemic diarrhea virus (PEDV), and porcine deltacoronavirus (PDCoV) [16]. These coronaviruses cause significant losses in pig farming, as they result in high mortality rates in piglets due to malabsorptive diarrhea and dehydration. Research using CRISPR/Cas9 has confirmed that the aminopeptidase protein N (APN), present on the surface of intestinal villi, is the primary receptor for establishing a transmissible gastroenteritis infection in pigs. Newborn piglets with an APN deficiency are resistant to TGEV infection. However, an APN deficiency does not provide protection against PEDV infection [17]. Thus, there's an urgent need to identify the recognizing receptor for PEDV.

One of the essential receptors for infecting with the porcine reproductive and respiratory syndrome virus (PRRSV) is the cluster of differentiation antigen 163 (CD163). The CD163 protein performs several critical biological functions, including the recycling of hemoglobin/haptoglobin. CD163 has nine extracellular domains on the surface of monocytes and macrophages, and the virus specifically interacts with the fifth domain. By deleting exon 7, which encodes the entire fifth domain, it was possible to obtain expressing a modified protein CD163 that retains these functions. Pigs with knockout of the CD163 gene proved to be resistant to the PRRS virus [18]. However, the PRRSV virus has two forms: PRRSV-1 (European) and PRRSV-2 (Asian). PRRSV-1 and PRRSV-2 CD163 use different CD163 sites, so further research is needed.

Researchers aim at producing pigs with multiple resistances to viral pathogens. Oh J. et al. [19] developed a multi-resistance strategy for pseudorabies and PRRS using CRISPR/Cas9-mediated deletion of the CD163 gene and the integration of a small hairpin shRNA in pig fibroblasts. The integrated shRNA targets genes of the pseudorabies virus and PRRSV. However, pigs with dual resistance to the pseudorabies virus and PRRSV still need testing, as further *in vivo* studies are required.

Guo C. et al. [20] performed a specific deletion of a fragment from 41 amino acids containing a lipopolysaccharide-binding protein (LBP) in the cysteine-rich area phagocytic receptor 5 (SRCR5) CD163 in two breeds of pigs (small spotted Liang-Guang and Large White pigs). Then, the Large White pigs with modified genes in the F_0 generation were used for virus infection. These pigs with an edited genome were resistant to the porcine reproductive respiratory syndrome virus 2 (PRRSV 2).

Classical swine fever (CSF) is a viral disease in pigs characterized by fever, damage to blood vessels and hematopoietic organs, and diphtheritic inflammation of the mucous membranes of the colon. It causes tremendous economic damage to farms, with a mortality rate of 80-100%. The CSF virus induces immunosuppression, predisposing domestic and wild boars to sec-

ondary opportunistic infections of the gastrointestinal and respiratory systems. The use of CRISPR/Cas9 combined with RNA interference resulted in transgenic pigs resistant to the CSF virus. Through a CRISPR/Cas9 knock-in strategy, a specific antiviral shRNA was inserted into the Rosa26 locus of the pig to degrade the RNA of the CSF virus. Infection results in these pigs showed a significant reduction in CSF replication, clinical symptoms, mortality, and the transmission of CSF resistance to the first-generation piglets [21]. The Radical S-adenosylmethionine domain-containing protein 2 (RSAD2) is a cellular protein that exhibits broad antiviral activity against DNA and RNA viruses. Due to the broad antiviral activity exhibited by the RSAD2 gene, it was considered a potential candidate for CRISPR/Cas9 knock-in for developing virus-resistant transgenic pigs. The specific introduction of the RSAD2 gene into the pig's ROSA26 locus allowed for the creation of transgenic pigs, which exhibited a reduction in ASF and pseudorabies virus (PRV) upon infection [21]. Consequently, using several critical genes may lead to the emergence of multi-resistant pigs. However, limited knowledge of the interaction of these genes with receptors in many viral diseases may partially hinder the widespread adoption of this strategy.

Consideration of off-target effects. The off-target effect, which represents unintended DNA changes in non-target gene sites, poses a major problem for CRISPR/Cas9-mediated formation of genetically modified organisms (GMOs). Adverse changes can affect not only the phenotype of the parent animal but also the phenotype of subsequent generations. Off-target effects can be assessed by genome sequencing.

CONCLUSION

CRISPR/Cas9 generates significant public interest within the global community, but there are opposing views that will likely vary considerably depending on societal perspectives, including wealth, age, and religion of people. This affects the development and speed of implementation of these innovations in the agriculture of individual countries. Currently, China is the leader in the development of genome editing in the field of pig breeding. In Russia, a genetic technology development program is being implemented, scheduled for 2019-2027. The primary goal of the program is a comprehensive solution to the challenges of accelerated development of genetic technologies, including genetic editing technologies. In the near future, we can expect the emergence of the promising Russian developments in genome editing of various farm animals, including pigs. It should be acknowledged that gene editing can also cause unexpected side effects. Therefore, researchers must plan their experiments carefully. However, overall, the CRISPR/Cas9 system is being refined, becoming more accessible for use, offering unlimited possibilities and prospects for broader application in the future.

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СОВЕРШЕНСТВОВАНИЕ КРАСНОГО СТЕПНОГО СКОТА ГЕНОФОНДОМ ГОЛШТИНСКОЙ ПОРОДЫ

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Представлены результаты сравнительной оценки продуктивности, воспроизводительной способности и рентабельности производства молока при использовании коров красной степной породы и помесей разной кровности по голштинской породе красно-пестрой масти. Исследования хозяйственно полезных признаков и рентабельности проводились в 2019–2022 гг. Объектом исследований являлись представительницы красной степной породы (контроль), помеси с 50% (1-я опытная группа) и 75% крови голштинов красно-пестрой масти (2-я опытная группа). По величине удоя установлено превосходство помесных первотелок над сверстницами красной степной породы, которое за 1-ю лактацию составило 605–673 кг ($p > 0,999$), за 2-ю – 714–788 кг ($p > 0,999$), за 3-ю – 817–868 кг ($p > 0,999$). Наибольшим коэффициентом молочности характеризовались голштинские помеси F_1 и F_2 (9,4–9,7 кг), преимущество которых в среднем за все лактации варьировало в пределах 0,9–1,2 кг ($p > 0,95–0,99$). Во все анализируемые сервис-периоды наибольшую оплодотворяемость после первого осеменения демонстрировали животные красной степной породы, в результате чего затраты семени в их случае оказались в среднем на 0,2–0,5 доз ниже, чем у помесей разной кровности по голштинам. Самый высокий коэффициент воспроизводительной способности имели коровы красной степной породы – 0,98–1,01 ед. против 0,85–0,95 ед. у помесей. Анализ оплаты корма молоком свидетельствует о меньших затратах на производство единицы продукции коровами первого и второго поколений, у которых они составили 0,95–0,98 ЭКЕ, что ниже, чем у сверстниц красной степной породы, на 1,11–1,12 ЭКЕ. Более рентабельным оказалось производство молока полукровными помесями – 30,8–32,9% при несущественных различиях между красными степными и высококровными по голштинам особями.

Ключевые слова: коровы, красная степная, голштинская порода, помеси, молочная продуктивность, воспроизводительная способность, рентабельность

IMPROVEMENT OF THE RED STEPPE CATTLE BY THE HOLSTEIN BREED GENE POOL

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The results of the comparative assessment of productivity, reproductive ability and profitability of milk production when using cows of the Red Steppe breed and the crossbreeds of different blood

relationship by the Holstein breed of the Red-and-White color type are presented. The studies of economically useful traits and profitability were conducted in 2019-2022. The objects of the research were representatives of the Red Steppe breed (control), mixtures with 50% (1st experimental group) and 75% of the blood of the Holstein Red-and-White color type (2nd experimental group). The superiority of the crossbred heifers over their herd mates of the Red Steppe breed in terms of milk yield was established: for the 1st lactation it was 605-673 kg ($p > 0.999$), for the 2nd lactation it was 714-788 kg ($p > 0.999$), for the 3rd lactation it was 817-868 kg ($p > 0.999$). The highest coefficient of the milk yield was observed in Holstein F_1 and F_2 crossbreeds (9.4-9.7 kg), whose average advantage during all lactations ranged from 0.9-1.2 kg ($p > 0.95$-0.99). In all analyzed service-periods, the highest fertilization rate after the first insemination was demonstrated by the Red Steppe breed animals; as a result, their semen consumption was on average 0.2-0.5 doses lower than that of the Holstein crossbreeds of different blood relationship. Cows of the Red Steppe breed had the highest reproductive ability coefficient - 0.98-1.01 units vs. 0.85-0.95 units for crossbred cows. The analysis of the feed efficiency shows lower costs per unit production by cows of the first and second generations, in which they were 0.95-0.98 EFU, which is lower than in the Red Steppe breed peers, by 1.11-1.12 EFU. Milk production by half-blooded crossbreeds was more profitable - 30.8-32.9% with no significant differences between the Red Steppe and high-blooded Holstein individuals.

Keywords: cows, Red Steppe, Holstein, crossbreeds, milk productivity, reproductive capacity, profitability

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INTRODUCTION

The Red Steppe breed was one of the most widespread and adapted to natural-climatic, fodder and technological conditions in the southern regions of our country before the beginning of mass Holsteinization of the Russian breeds of dairy cattle. Despite a significant reduction in the specific weight of animals of this breed, at present the work on improvement of its breeding and productive qualities with the use of gene pool of improving breeds - Holstein Red-and-White, Angler and Danish Red continues. The change in the breed composition towards the increase of highly productive herds of dairy cattle in most cases has led to a decrease in productive longevity and reproduction at the expense of local genetic resources, which ultimately reduced the profitability of the dairy cattle breeding industry.

Improvement of the Red Steppe breed, aimed at the combination of high milk yields with fat and protein-milk yield, allowed to create the Kulunda type in Western Siberia, the representatives of which surpass the animals of the parent breed by 0.37-0.43% by the main distinguishing feature - fat-milk yield [1]. Along with high milk yields, this type is characterized by excellent reproductive functions: 86 calves can be obtained from 100 cows, which is 11 calves more than from the representatives of the Kuban type, but lower than the level of the Siberian type - 95 calves from 100 cows[1].

In the Rostov region the use of the Holstein Red-and-White and the Ayrshire bulls' semen provided the first-generation littermates with 449.7-518.1 kg increase in milk productivity in comparison with their counterparts of Red Steppe breed in the 1st lactation, with insignificant differences in the 2nd lactation. Milk quali-

[1]*Knyazeva T., Tyurikov V.* Exterior features of the types of the Red Steppe breed of cattle // Dairy and Beef Cattle Farming, 2012, No. 2, pp. 14-16.

ty parameters also had no significant intergroup differences [2].

Application of the semen of the Russian and German stud bulls in the herd consisting of the animals of the Siberian type of the Red Steppe breed provided production of the daughters with duration of economic use of 36,25-38,2 months, which is by 3,0-6,4 months more than the peers obtained from the bulls of Canadian and Danish origin. In the Red Steppe herds of the Omsk region, the best indicators were demonstrated by the daughters of the Angler breed bulls - their period of economic use was 0.29-0.50 lactations longer in comparison with the descendants of the Danish Red and Swedish Red breeds. Although the profitability of the Swedish Red and Danish Red bull daughters was higher by 8.5-10.1% [3].

In the Kabardino-Balkar Republic, F_1 crossbred cows, obtained as a result of crossing the breeding stock of the Red Steppe breed with the Holstein Red-and-White cows, were superior to purebred Red Steppe cows in terms of milk productivity, udder morphofunctional properties and milk feed conversion. The advantage in the milk yield was 465 kg, milk flow rate - 3.6%, feed costs for the production of 1 kg of milk - 0.15 EFU (energy feed units) [4].

Evaluation of stud bulls on the quality of the progeny (comparing the productivity of daughters with their mothers and with their peers) has shown the inexpediency of using purebred Red-and-White Holstein bulls to improve the domestic Red Steppe breed in the farms with average herd milk yield up to 5000 kg per cow per year. The use of the Angler breed bulls gene pool, except for Dax 21699, is also of no breeding interest neither on productive qualities, nor on the type of the progeny physique. The use of crossbred stud bulls of the Red-and-White Holstein breed proved to be a more effective technique [5].

The most suitable for breeding in the conditions of the plains zone of the Kabardino-Balkar Republic are three-breed crosses obtained by crossing half-breed Holstein-Red Steppe cows with the Angler breed bulls. The superiority of such cows in milk yield over purebred Red Steppe cows and half-bloods of the genotypes "Red Steppe × Angler", "Red Steppe × Red Estonian" and "Red Steppe × Holstein" averaged 6.6-20.4% [6].

A single use of the Holsteins on the breeding stock of the Red Steppe breed contributed to the production of the daughters exceeding purebred peers of the Red Steppe breed in milk yield for the 1st lactation by 568 kg, for the 2nd lactation - by 710 kg with lower fat content in milk by 0.05 and 0.04 abs.%, respectively [7].

The effectiveness of Holsteinization of the Red Steppe cattle under creation of proper environmental conditions is evidenced by the studies conducted in different regions of our country[2] [8-10].

The use of bulls of the Swedish Red breed in the herds of the Red Steppe cattle allowed to increase the milk yield of their daughters in comparison with their peers from producers of the Danish Red and Angler breeds by 219 and 569 kg, respectively, to increase the fat content in milk by 0.03 and 0.25 abs.%, protein - by 0.07 and 0.25 abs.%, to improve reproductive functions and udder health, which had a positive effect on the profitability of dairy cattle breeding [11].

The need for selection and appropriate matching of production types of cows to increase the economically useful traits of the Red Steppe cattle is noted by many domestic scientists, but on the Red Steppe breed such studies are extremely limited[3, 4] [12].

The study of the possibility of further increase in the volume of milk produced in the conditions of the south of our country is topical and of great national and economic importance.

For the first time in the Kabardino-Balkar Republic in the framework of industrial production

[2]*Ulimbashev M.B.* Features of Holsteinized Red Steppe cattle of Kabardino-Balkaria // Agrarnaya Rossiya, 2010, No. 3, pp. 23-24.

[3]*Ulimbashev M.B.* Productive and ethological features of cows of different production types // Reports of the Russian Academy of Agricultural Sciences, 2007, No. 5, pp. 35-36.

[4]*Pisarenko A.V.* Economically useful traits of the Red Steppe cows of different constitutional and production types in the conditions of gene pool conservation // Scientific support of livestock breeding in Siberia: Proceedings of the III International Scientific and Practical Conference (Krasnoyarsk, May 16-17, 2019). Krasnoyarsk, 2019, pp. 209-213.

comparative data on economically useful traits and efficiency of milk production using the Red Steppe and Holsteinized cattle of different generations have been obtained.

The purpose of the research is a comparative assessment of productivity, reproductive ability and profitability of milk production when using cows of the Red Steppe breed and the crossbreds of different bloodlines on the Holstein Red-and-White breed.

MATERIAL AND METHODS

The study of economically useful traits and profitability of milk production was conducted in 2019-2022. The object of research were cows of Red Steppe breed (control), crossbreds with 50% (1st experimental group) and 75% (2nd experimental group) blood of the Holstein Red-and-White cows. Formation of the experimental groups of first heifers was carried out taking into account the origin, age, live weight and physiological condition of animals. Each group included 30 heifers.

All groups were in the same conditions of care, housing and feed supply. The structure of the diet of the experimental herd in winter was as follows: roughage - 18%, haylage - 22, silage - 25, concentrated fodder - 35%. The technology of dairy herd maintenance is stall-pasture. In the pasture period green conveyor was used with the use of village pastures.

Cows were milked in the milk pipe using ADM 8 unit, control milking was carried out once a month. Milk quality parameters were determined using analyzer "Lactan 1 4M". Milk yield (milk protein and milk fat) and milking capacity coefficient were calculated according to the formulas generally accepted in zootechnical practice. Live weight of animals was determined according to the Kluver-Strauch table, for which the following body measurements were taken: chest circumference behind the shoulder blades and oblique body length.

Reproductive ability of experimental stock was studied on the basis of zootechnical and veterinary records on such indicators as fertilization rate after insemination, insemination frequency, duration of service and inter-mating periods. The reproductive capacity coefficient was calculated as the ratio of days in a calendar year to the duration of the inter-breeding interval.

The amount of feed eaten was determined as a group by the difference between the amount of feed given and the uneaten residues. Costs for production of 1 kg of milk were calculated as the ratio of milk yield to the volume of feed consumed.

Biometric processing of the obtained data was carried out by methods of variation statistics, the reliability of intergroup differences on the analyzed indicators was determined by the Student's criterion at three levels of reliability of difference.

RESULTS AND DISCUSSION

Productive qualities of cows of different genotypes during the first three lactations are presented in Table 1.

The superiority of crossbred first calvers in terms of milk yield over their peers of the Red Steppe breed was established, which amounted to 605-673 kg ($p > 0.999$) in the 1st lactation, 714-788 kg ($p > 0.999$) in the 2nd lactation, and 817-868 kg ($p > 0.999$) in the 3rd lactation. The greatest growth of milk yield with age (752 kg) was observed in half-blooded littermates, which is probably due to the effect of heterosis. Increasing the bloodlines of Red-and-White Holstein breed up to 75% did not have such a significant effect on milk yield compared to the indicators of half-blooded stock. If milk yields of 3/4 Holstein-blooded crossbreds in the first two lactations tended to be superior to half-blooded animals, then in the 3rd lactation the picture was the opposite.

Regardless of the blood on Holsteins, the litters of both groups were inferior to the cows of the Red Steppe breed on the content of the main components in milk - fat and protein. Despite this, due to significant superiority in milk yield, the highest yield of milk fat and protein was characterized by the groups of Holsteinized cows, whose advantage in the 1st lactation was 35.6-37.7 kg ($p > 0.99$), in the 2nd lactation - 41.6-42.9 kg ($p > 0.99$), in the 3rd lactation - 43.7-51.5 kg ($p > 0.99$-0.999).

As a result of calculating the ratio of the milk yield to the live weight, it was found that Hol-

Табл. 1. Изменение продуктивных особенностей красного степного скота разного генотипа с возрастом (по данным трех лактаций)

Table 1. Changes in productive characteristics of the Red Steppe cattle of different genotypes with age (based on three lactations)

Lactation	Group		
	control	1st experimental	2nd experimental
Number of cows, heads			
1st	30	30	30
2nd	29	27	26
3rd	27	25	23
Milk yield for 305 days, kg			
1st	3856 ± 96	4461 ± 124***	4529 ± 131***
2nd	4079 ± 119	4793 ± 144***	4867 ± 156***
3rd	4345 ± 128	5213 ± 163***	5162 ± 174***
Fat mass fraction, %			
1st	3,83 ± 0,02	3,74 ± 0,03*	3,71 ± 0,03**
2nd	3,88 ± 0,02	3,77 ± 0,03**	3,73 ± 0,04***
3rd	3,90 ± 0,02	3,78 ± 0,04**	3,75 ± 0,04***
Protein mass fraction, %			
1st	3,31 ± 0,02	3,23 ± 0,03	3,20 ± 0,03
2nd	3,35 ± 0,02	3,25 ± 0,03	3,21 ± 0,03
3rd	3,35 ± 0,02	3,25 ± 0,03	3,20 ± 0,03
Total yield of milk fat and milk protein, kg			
1st	275,3 ± 6,6	310,9 ± 8,3**	313,0 ± 8,9**
2nd	294,9 ± 8,2	336,5 ± 9,7**	337,8 ± 10,4**
3rd	315,0 ± 8,7	366,5 ± 10,8***	358,7 ± 11,5**
Live weight at 2-3 months, kg			
1st	456,0 ± 3,7	476,0 ± 3,5***	481,0 ± 3,2***
2nd	482,0 ± 4,0	510,0 ± 3,7***	518,0 ± 3,5***
3rd	509,0 ± 4,4	537,0 ± 4,1***	549,0 ± 4,0
Milk yield ratio			
1st	8,4 ± 0,20	9,4 ± 0,25**	9,4 ± 0,27**
2nd	8,4 ± 0,24	9,4 ± 0,27**	9,4 ± 0,29**
3rd	8,5 ± 0,23	9,7 ± 0,28**	9,4 ± 0,30*

Note. Here and in Table 2:
*$p > 0,95$; **$p > 0,99$; ***$p > 0,999$.

stein F_1 and F_2 littermates had the highest milk yield ratio (9.4-9.7 kg), the advantage of which varied between 0.9-1.2 kg on average over all lactations ($p > 0.95$-0.99).

The results of evaluation of the reproductive qualities of experimental stock are presented in Table 2.

In all the analyzed service-periods, the greatest fertilization after the first insemination was demonstrated by the cows of the Red Steppe breed, as a result of which their semen expenditure was on average 0.2-0.5 doses lower than that of the Holstein littermates of different bloodlines.

Longer period from calving to fruitful insemination was characterized by crossbred animals, in which it exceeded 100 days and after the third calving reached 127-144 days, which is more than the values obtained for the cows of the Red Steppe breed on average by 35-52 days ($p > 0.999$).

In all the periods compared, the longer inter-breeding interval was characterized by the cows of 3/4 blooded Holstein Red-and-White cows - 392-426 days, which is higher than the values of the Red Steppe cows on average by 31, 50 ($p > 0.95$) and 53 days ($p > 0.95$), respectively.

During the study, the maximum values of the reproductive ability coefficient were recorded in the Red Steppe cows - 0.98-1.01 units against 0.85-0.95 units in the crossbreds.

The efficiency of milk production by the Red Steppe cows of different origins can be judged by the materials presented in Table 3.

Analysis of the milk feed conversion indicates lower costs per unit of production by cows of the first and second generations, in which they amounted to 0.95-0.98 EFU, which is lower than the values obtained for peers of the Red Steppe breed - 1.11-1.12 EFU.

Taking into account the actual costs of milk production and the revenue received from its realization, the most profitable was the exploitation of crossbreds of the genotype “1/2 Red Steppe + 1/2 Red-and-White Holstein”. In this connection, milk production by half-blooded littermates can be considered more profitable - 30.8-32.9% with insignificant differences between the Red Steppe and high-blooded Holstein animals. Also, the age-related decrease of milk production profitability values in all groups of cows should be noted.

CONCLUSION

The greatest increase in milk productivity and profitability of milk production at the lowest feed costs are characterized by the first-generation littermates, obtained as a result of using the gene pool of the Holstein breed of the Red-and-White breed on the mother stock of the Red Steppe cattle, while the coefficients of reproductive ability in this case are practically at the same level with the representatives of the

Табл. 2. Воспроизводительные качества подопытных групп животных
Table 2. Reproductive qualities of the experimental groups of animals

Period	Group		
	control	1st experimental	2nd experimental
Fertilization rate after the first insemination, %			
After the 1st calving	66,7	60,0	56,7
After the 2nd calving	62,1	55,6	53,8
After the 3rd calving	59,3	52,0	47,8
Insemination index, doses			
After the 1st calving	1,6 ± 0,03	1,8 ± 0,05**	1,9 ± 0,07***
After the 2nd calving	1,9 ± 0,04	2,2 ± 0,07***	2,3 ± 0,10***
After the 3rd calving	2,2 ± 0,05	2,5 ± 0,09**	2,7 ± 0,12***
Service period duration, days			
After the 1st calving	82,0 ± 2,7	103,0 ± 4,0***	112,0 ± 4,9***
After the 2nd calving	85,0 ± 3,0	118,0 ± 5,2***	133,0 ± 6,8***
After the 3rd calving	92,0 ± 3,4	127,0 ± 5,5***	144,0 ± 7,4***
Duration of the calving interval, days			
Between the 1st and the 2nd calvings	361,0 ± 12,1	383,0 ± 15,0	392,0 ± 16,4
Between the 2nd and the 3rd calvings	365,0 ± 12,8	400,0 ± 16,3	415,0 ± 18,7*
Between the 3rd and the 4th calvings	373,0 ± 14,2	410,0 ± 19,4	426,0 ± 22,0*
Reproductive capacity ratio			
Between the 1st and the 2nd calvings	1,01 ± 0,032	0,95 ± 0,036	0,93 ± 0,038
Between the 2nd and the 3rd calvings	1,00 ± 0,034	0,91 ± 0,037	0,88 ± 0,039*
Between the 3rd and the 4th calvings	0,98 ± 0,037	0,89 ± 0,040	0,85 ± 0,042*

Red Steppe breed and littermates of the second generation. Increase of blood on Holsteins up to the second generation is inexpedient, as in these animals productive qualities and efficiency of milk production in comparison with half-blood stock increase insignificantly, and the indicators of fertility and qualitative composition of milk are much lower than in the purebred Red Steppe and F1 litters. Based on the results obtained, the use of the seed of Holstein bulls of the Red-and-White breed for obtaining the first generation of litters can be considered as an effective method of improving herds of the Red Steppe breed.

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Табл. 3. Эффективность производства молока коровами разного происхождения (по данным трех лактаций)

Table 3. Efficiency of milk production by cows of different origin (based on three lactations)

Lactation	Group		
	control	1st experimental	2nd experimental
Milk yield for 305 days, kg			
1st	3856	4461	4529
2nd	4079	4793	4867
3rd	4345	5213	5162
Volume of energy feed unit consumption			
1st	4289	4361	4450
2nd	4568	4684	4745
3rd	4872	4950	4936
Energy feed unit inputs for production of 1 kg of milk			
1st	1,11	0,98	0,98
2nd	1,12	0,98	0,97
3rd	1,12	0,95	0,95
Cost of 1 kg of milk, rubles			
1st	20,34	19,20	19,56
2nd	22,53	20,89	21,44
3rd	23,79	22,31	22,58
Production costs, rubles			
1st	78 431,04	85 651,20	88 587,24
2nd	91 899,87	100 125,77	104 348,48
3rd	103 367,55	116 302,03	116 557,96
Cost of sales of 1 kg of milk, rubles			
1st	26	26	26
2nd	28	28	28
3rd	29	29	29
Revenue from milk sales, rubles			
1st	112 944	127 582	128 492
2nd	130 340	148 792	149 492
3rd	144 536	168 055	165 097
Profit (+) / loss (-), rubles			
1st	34 512,96	41 930,80	39 904,76
2nd	38 440,13	48 666,23	45 143,52
3rd	41 168,45	51 752,97	48 539,04
Profitability, %			
1st	30,5	32,9	31,1
2nd	29,5	32,7	30,2
3rd	28,5	30,8	29,4

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РЕЗУЛЬТАТЫ РЕАЛИЗАЦИИ ОЗДОРОВИТЕЛЬНЫХ МЕРОПРИЯТИЙ В ХОЗЯЙСТВАХ, НЕБЛАГОПОЛУЧНЫХ ПО ЛЕЙКОЗУ КРУПНОГО РОГАТОГО СКОТА

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Изучена динамика проведения оздоровительной работы на примере двух аналогичных по экономическим и производственно-технологическим характеристикам хозяйств Новосибирской области. Приведены данные обстановки по лейкозу на момент начала активной оздоровительной работы и результаты через несколько лет. Проанализированы показатели инфицированности поголовья по разным возрастным группам и на разных отделениях изучаемых хозяйств за 2017–2022 гг. Уровень инфицированности коров в хозяйствах с 2017 по 2019 г. имел тенденцию к незначительному снижению и находился в диапазоне 8–4%. Уровень инфицированности телок составил 5–12%. Регистрация новых случаев реагирования по серологии в группе телят в хозяйстве № 1 снизилась от 9,9 до 4,9%, в хозяйстве № 2 – от 14,2 до 7,1%. Показана положительная динамика реализации плана по оздоровлению с применением для серологической диагностики иммуноферментного анализа (ИФА). После перехода с реакции иммуннодиффузии в геле агара (РИД) на ИФА и первого его применения число вновь выявленных животных увеличилось во всех возрастных группах в обоих хозяйствах по сравнению с предыдущим периодом. В последующих исследованиях процент новых случаев значительно снизился. Физическое разделение групп животных с разным статусом, размещение их на разных отделениях и четкий контроль с моментальным исключением из производственного процесса инфицированных животных привело к заметному улучшению эпизоотической ситуации в хозяйстве. Отмечены аспекты, вызывающие замедление оздоровительной работы, в частности, несвоевременное разделение животных на группы после проведения серологической диагностики и установления их статуса по инфекции. Проведение полной замены инфицированного крупного рогатого скота в неблагополучных стадах или отделениях группами животных, отрицательных по серологии, позволяет значительно сокращать сроки оздоровления, особенно на завершающем этапе.

Ключевые слова: лейкоз, крупный рогатый скот, оздоровительные мероприятия, ИФА, РИД, инфицированность

RESULTS OF THE IMPLEMENTATION OF SANITATION MEASURES IN THE FARMS UNFAVORABLE FOR BOVINE LEUKEMIA

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The dynamics of recuperation work on the example of two farms similar in economic and production and technological characteristics of the Novosibirsk region were studied. The data on leukemia at the time of the beginning of active recuperation work and the results after several years were presented. The infection rates of the livestock by different age groups and in different parts of the studied farms were analyzed for 2017-2022. The infection rate of cows on the farms tended to decrease slightly from 2017 to 2019 and was in the range of 8-4%. The infection rate of the heifers was 5-12%. Registration of new cases of serology response in the group of the calves in the farm No. 1 decreased from 9.9 to 4.9%, in the farm No. 2 - from 14.2 to 7.1%. The positive dynamics of implementation of the recovery plan using enzyme-linked immunosorbent assay (ELISA) for serological diagnosis was shown. After switching from the immunodiffusion in agar gel reaction (AGID) to ELISA and its first use, the number of newly detected animals increased in all age groups in both farms compared to the previous period. In subsequent studies, the percentage of new cases decreased significantly. Physical separation of the groups of animals with different statuses, placing them in different sections and clear control with the

immediate exclusion of infected animals from the production process led to a noticeable improvement in the epizootic situation on the farm. Aspects causing delay in sanitation work were noted, in particular, untimely separation of animals into groups after serological diagnosis and establishment of their infection status. Complete replacement of infected cattle in unhealthy herds or wards by groups of serology-negative animals can significantly reduce the recovery period, especially at the final stage.

Keywords: leukemia, cattle, recreational activities, ELISA, AGID, infection

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IUNTRODUCTION

Leukosis of cattle remains a pressing issue in a large part of the territory of the Russian Federation (RF), accounting for over 40% of the main infectious diseases in cattle. In 2021, 2070 unfavorable points were identified for leukosis in cattle, and 1398.704 thousand heads of cattle were examined (hematological test), revealing 15,096 positively responding heads, with 15,611 heads sent for slaughter[1]. The situation in the Siberian Federal District (SFD), particularly in the Novosibirsk region, remains steadily tense. The SFD ranks second in Russia in the number of unfavorable points [1, 2].

Currently, serological (AGID and ELISA), gene-molecular (PCR) [3] and hematological methods are mainly used for the diagnosis of cattle leukosis. In the absence of specific methods of treatment and prevention, timely diagnosis and removal from the herd of sick and infected animals are the only effective measure to improve the population from leukosis. Existing methods and techniques yield positive results when implementing health improvement measures [4–7].

In the farms conducting improvement, three groups of animals can be conditionally identified, usually related to separate farms or herds. The first one comprises healthy animals, negative according to serological studies. This group is usually replenished only by serologically negative young animals, typically obtained from healthy cows. The second one is at an intermediate stage of recovery, with most animals also being serologically negative (conditionally healthy), but there is a small proportion of responders. This is due to the need to maintain a certain number in the department for its normal functioning and the limitation of the reserve of young animals for replacement. This group is primarily replenished with healthy young stock, as far as the agricultural enterprise can afford. The terms of recovery often directly depend on these opportunities. The third group comprises the remaining responding (infected) herds, departments, flocks. They concentrate cattle from the first two groups, generally suitable, except for the presence of the leukemia virus, for further exploitation. This group is mainly replenished with infected young stock, and the recovery process in it will proceed only after the complete recovery of the first two.

An important characteristic of health improvement activities is the terms of herd (farm) recovery from infection. They can be very short with a radical way of recovery (complete or par-

[1]Epizootic situation in the Russian Federation 2022 (Quarter 1). URL: https://fsvps.gov.ru/sites/default/files/files/iac/o_31_03_2022_otchet_iac_1_kv.pdf.

[2]Order of the Ministry of Agriculture of Russia from 24.03.2021 № 156 "On Approval of Veterinary Rules for the implementation of preventive, diagnostic, restrictive and other measures, the establishment and lifting of quarantine and other restrictions aimed at preventing the spread and elimination of foci of bovine leukosis" https://fsvps.gov.ru/ru/fsvps/laws/150301.html.

tial replacement of the animal population with animals from favorable agricultural enterprises for leukosis), or they can last for years and even decades. The second variant of events has its reasons, which mainly consist of non-compliance with the regulations of prescribed measures for various reasons. A systematic, comprehensive approach helps increase the efficiency of anti-epizootic measures [8–10].

The purpose of the study is to examine the dynamics and analyze the effectiveness of health improvement measures in agricultural enterprises unfavorable for leukosis based on epizootological indicators.

MATERIAL AND METHODS

The study analyzed the experience of conducting health-improvement work for bovine leukosis in two commercial dairy farms with similar production and economic conditions. Farm No. 1 consists of two farms and six departments, while Farm No. 2 consists of two farms and five departments.

The study was conducted by the employees of the leukosis laboratory based at the Institute of Experimental Veterinary Medicine of Siberia and the Far East, and by the staff of the Siberian Research and Technological Design Institute of Animal Husbandry of the SFSCA RAS. The serological diagnosis was conducted using ELISA test systems to detect antibodies to the gp51 glycoprotein of bovine leukosis (IDEXX Leucosis Blocking Ab Test). In the first stage (2020), a diagnostic study in ELISA of the entire livestock older than 6 months was conducted, except for the departments with AGID-positive cows, which are examined only by hematological method twice a year, with the culling of sick animals.

Plans for carrying out health improvement measures were then developed, involving full coverage of the livestock with serological studies (in this variant - ELISA), dividing the herd into groups with conditionally healthy and infected animals, raising repair young stock free from the virus, and introducing them into the herd in groups. Strict control and registration for all animals was a mandatory condition.

RESULTS AND DISCUSSION

For a primary analysis of the epizootic situation, a comparison of veterinary reporting data for the three previous years (2017-2019), relative to the beginning of active health-improvement work, was conducted. The data are presented in Tables 1 and 2.

Given that the livestock population did not change significantly over the study period and the coverage of studies of different age groups in separate years was incomplete (see Tables 1 and 2), the situation with the registration of new cases of infection did not change fundamentally over the years.

The level of cow infection in Farm No. 1 slightly decreased during the study period and ranged from 6.6 to 4.3%; in Farm No. 2, it ranged from 8.4 to 6.4%. The level of infection of heifers in Farm No. 1 varied from 8.7 to 4.8%, while in Farm No. 2, a slight increase in newly identified responding animals was noted (from 9.4% in 2017 to 12.0% in 2019). The registration of new cases of serological response in the calf group in Farm No. 1 decreased from 9.9 to 4.9%, in Farm No. 2 – from 14.2 to 7.1%. Some

Табл. 1. Результаты серологических исследований в РИД в хозяйстве № 1 за 2017–2019 гг. и в ИФА в 2020 г.

Table 1. Results of serological studies in AGID in farm No. 1 for the period 2017-2019, and in ELISA in 2020

Year	Age groups								
	Cows			Heifers			Calves		
	Number of examined animals, heads	Number of reacting animals, heads	%	Number of examined animals, heads	Number of reacting animals, heads	%	Number of examined animals, heads	Number of reacting animals, heads	%
2017	2645	176	6,6	583	51	8,7	373	37	9,9
2018	4196	248	5,9	1046	74	7,1	885	105	11,8
2019	2784	120	4,3	1126	55	4,8	714	35	4,9
2020	2653	188	7,1	1209	73	6,0	902	87	9,6

Табл. 2. Результаты серологических исследований в РИД в хозяйстве № 2 за 2017–2019 гг. и в ИФА в 2020 г.

Table 2. Results of serological studies in AGID in farm No. 2 for the period 2017-2019, and in ELISA in 2020

Year	Age groups								
	Cows			Heifers			Calves		
	Number of examined animals, heads	Number of reacting animals, heads	%	Number of examined animals, heads	Number of reacting animals, heads	%	Number of examined animals, heads	Number of reacting animals, heads	%
2017	2234	189	8,4	689	65	9,4	190	27	14,2
2018	1890	155	8,2	810	91	11,2	358	30	8,3
2019	1703	109	6,4	583	70	12,0	212	15	7,1
2020	2465	204	8,2	775	109	14,1	437	90	20,6

increase in values in 2020 can be explained by the higher sensitivity of ELISA compared to AGID. A significant increase in the percentage of infected was noted only in the calf group in Farm No. 2. All positively responding calves were transferred to the fattening group, positive heifers, and cows - to groups for replenishing the herd with infected cows.

It is important to note that specific work towards health improvement was carried out in the farms. Over several years, "clean" groups, designated as AGID-negative animals, were formed on two departments in Farm No. 1 and one department in Farm No. 2 (see Tables 3, 4). These departments housed cows, and the heifers obtained from them mainly served as the replacement base for these herds. Heifers from the departments where both AGID-negative and positive cows were kept were also introduced. Since the percentage of responders was relatively low, they began to form new departments in addition to these improved ones, concentrating healthy animals from the herds where groups of animals responding in serology were identified. Positively responding animals were transferred to the second farms in the departments where only infected cows are kept, and also to the second stage departments, which were replaced by heifers after restoring the number of "clean" departments.

The physical separation of animal groups with different statuses, placing them in different departments, and strict control with the instant exclusion of infected animals from the production process led to a noticeable improvement in the epizootic situation in the farm.

By the beginning of 2023, the health improvement work in Farm No. 1 is being completed. Departments 3 and 4 have obtained the first fully negative results according to the serological

Табл. 3. Результаты серологических исследований в ИФА в хозяйстве № 1 «чистых» отделений (1, 2 и 5), и отделений второй очереди (3 и 4) за 2021–2022 гг.

Table 3. Results of serological tests in ELISA in farm No. 1 for the period 2021-2022 "clean" herds - 1, 2 and 5, and the herds of the second stage - 3 and 4

Department	Age groups								
	Cows			Heifers			Calves		
	Number of examined animals, heads	Number of reacting animals, heads	%	Number of examined animals, heads	Number of reacting animals, heads	%	Number of examined animals, heads	Number of reacting animals, heads	%
2021									
"Clean"	1613	2	0,12	720	3	0,4	536	6	1,2
Other	890	16	1,8	415	4	0,9	638	21	3,3
2022									
"Clean"	1804	0	0	693	1	0,1	204	0	0
Other	801	5	0,6	350	1	0,3	310	10	3,2

Табл. 4. Результаты серологических исследований в ИФА в хозяйстве № 2 «чистых» отделений (1 и 3) и отделения второй очереди (5) за 2021–2022 гг.

Table 4. Results of serological tests in ELISA in farm No. 2 for the period 2021-2022 "clean" herds - 1 and 3, and the herds of the second stage - 5

Departments by years	Age groups								
	Cows			Heifers			Calves		
	Number of examined animals, heads	Number of reacting animals, heads	%	Number of examined animals, heads	Number of reacting animals, heads	%	Number of examined animals, heads	Number of reacting animals, heads	%
				2021					
"Clean"	1127	20	1,7	487	5	1,0	302	2	0,7
Other	800	33	4,1	198	12	6,0	150	48	32,0
				2022					
"Clean"	1309	8	0,6	355	56	15,7	171	3	1,7
Other	652	15	2,4	220	27	12,3	113	23	20,3

study. In Department 6, where about 400 infected cows were kept, a one-time replacement of livestock with animals purchased from a healthy farm was carried out.

In the first stage, after a full examination using ELISA of the entire population and isolation of positively responding individuals, the epizootic picture in Farm No. 2 noticeably improved. However, while the recovery dynamics are positive in "clean" departments with cows, an increase in the number of infected animals is noted in the groups of heifers and calves. Upon detailed study, it was found that in the calf group, ELISA-negative animals were kept together with ELISA-positive ones for a long time after establishing the serological status for leukosis, and some seropositive calves remained in the group until the next study and were re-examined. A similar situation occurred with the heifer group – the studied and ELISA-negative heifers, formed into a group for sending to another department, remained in the former for several months. During this time, they were kept in one yard with ELISA-positive ones. From earlier studies, it is known that the joint maintenance and grazing of healthy and infected animals significantly affects the high indicator of infection among heifers [11].

CONCLUSION

Analyzing the epizootic dynamics in two farms with initially similar situations regarding bovine leukosis, it was found that strict adherence to all the points prescribed by the plan plays a significant role in successful health improvement. In Farm No. 1, all prescriptions were strictly followed, and the dynamics of eliminating the leukemia virus from the herd were pronounced and predictable. Visible results were achieved in relatively short terms. After carrying out a one-time replacement of the remaining infected cows in one department with a group of healthy animals regarding leukosis, they reached the final stage of improving the health of the farm as a whole. In Farm No. 2, the recovery was slow. The established dynamics contradicted expectations justified by the logic of the measures outlined in the plan. Upon additional analysis, violations of the execution of recommended measures were identified, which did not allow achieving the expected result.

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О РАЦИОНАЛЬНОМ ВЫБОРЕ ЗЕРНОУБОРОЧНОГО КОМБАЙНА И ЖАТКИ ДЛЯ УБОРКИ ЗЕРНОВЫХ В УСЛОВИЯХ СИБИРИ

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Рассмотрен вопрос производительности современных моделей зерноуборочных комбайнов производства ООО «Ростсельмаш» и ОАО «Гомсельмаш» в связке с номенклатурой поставляемых к ним жаток для прямого комбайнирования и в зависимости от урожайности зерновых культур, типичной для Сибирского региона. Для определения рационального состава уборочного агрегата из списка рассматриваемых моделей расчетно-графическим методом определены модели комбайнов, загрузка которых может быть обеспечена в Сибирском регионе на уровне, близком или равном максимальной производительности. Установлено, что при условии использования жаток шириной захвата 9,0 м с российскими моделями комбайнов и 9,2 м – с белорусскими для проведения уборочных работ рационально использовать Vector 410 при уровне урожайности 1,8–2,4 т/га, GS 10 PRO – 2,45–3,00 т/га. При этом может быть полностью реализован их технический потенциал и обеспечена максимальная производительность как по убранной площади, так и по намолоту зерна. Использование более производительных комбайнов на уборке зерновых прямым комбайнированием в Сибири не всегда оправдано, поскольку при существующем здесь в настоящее время уровне урожайности зерна их технический потенциал не может быть в полной мере реализован. На основе проведенных исследований получены диаграммы, с помощью которых можно провести подбор уборочного агрегата «комбайн + жатка», с учетом уровня урожайности и контурности полей в конкретном хозяйстве, варьируя шириной захвата жатки.

Ключевые слова: зерновые культуры, урожайность зерна, комбайн, производительность комбайна, ширина захвата жатки

ON THE RATIONAL CHOICE OF A COMBINE HARVESTER AND A REAPER FOR GRAIN HARVESTING IN CONDITIONS OF SIBERIA

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The issue of productivity of modern models of grain harvesters produced by OOO Rostselmash and OAO Gomselmash in connection with the nomenclature of reapers supplied to them for direct harvestering and depending on the grain crop yields typical for the Siberian region was considered. To determine the rational composition of the harvesting unit from the list of models under consideration, the models of combines, the loading of which can be provided in the Siberian region at a level close to or equal to the maximum productivity, were determined by calculation and graphical method. It was found that on condition of using 9,0 m wide reapers with Russian models of combine harvesters and 9,2 m with Byelorussian models, for harvesting works it is rational to use Vector 410 with the yield of 1,8-2,4 t/ha and GS 10 PRO with the yield of 2,45-3,00 t/ha. In this case, their technical potential can be fully realized and the maximum productivity in terms of both harvested area and threshed grain

can be ensured. The use of more productive combine harvesters for direct harvesters in Siberia is not always justified, because at the current level of grain yields here their technical potential cannot be fully realized. On the basis of the research, diagrams were obtained, which can be used to select the harvesting machine "combine harvester + reaper", taking into account the level of yield and the contour of fields in a particular farm, varying the coverage of the reaper.

Keywords: grain crops, grain yield, combine, combine performance, reaper coverage

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INTRODUCTION

The cultivation of cereal crops remains a fundamental and traditional activity in the agriculture of the Russian Federation. Many studies are dedicated to the development of cultivation and harvesting technologies for grains in Russia. The organization and technology of conducting harvesting operations hold a significant place in grain production technology [1–3]. They account for 25–45% of the direct technical costs associated with the entire technology of cereal crop production [4]. Therefore, the efficiency of investment in grain production by a farm is largely determined by the rational choice of a combine harvester and an accompanying reaper.

The question of rational choice of harvesting equipment is becoming especially relevant under conditions of its total reduction in the agricultural sector [5, 6]. Hence, the choice of the harvesting unit's composition (combine + reaper) for a specific agricultural producer should be justified and rational, taking into account the peculiarities of the cultivated crops and their yields in the farm over several past years.

Currently, most industries in Russia are under the conditions of sanction pressure. Agriculture is no exception. The purchase of foreign agricultural equipment has become impractical due to its unjustifiably high cost and the unpredictability of future deliveries of spare parts and consumables. Under the prevailing conditions of reducing the number and aging of the machine and tractor fleet, Russian agricultural producers are constrained to choose harvesting equipment primarily from the model range of the combines produced in the Russian Federation and the Republic of Belarus [7].

The purpose of the study is to determine the rational composition of the harvesting units, consisting of modern models of grain harvesters produced by LLC "Rostselmash" and JSC "Gomselmash" and accompanying direct combining reapers to them. With these, the maximum loading of the threshing and separating device and the maximum productivity per harvested area in the conditions of the Siberian region would be achieved.

To achieve the set goal, it is necessary to solve the following tasks:

1. Identify the component of the harvesting unit that limits its productivity at the yield of cereal crops typical for Siberia.
2. Based on the solution of the first task, determine the rational composition of the harvesting unit, which will ensure the maximum loading of the harvesting unit at the maximum productivity per the harvested area.

MATERIAL AND METHODS

Modern grain harvesters produced by LLC "Rostselmash" and JSC "Gomselmash" have been examined. Tables 1 and 2 present the performance indicators of the grain harvesters manufactured by these enterprises, the width of the reapers recommended for use with them, and the power of the installed engines.

Табл. 1. Характеристики основных моделей зерноуборочных комбайнов, производимых в Российской Федерации

Table 1. Characteristics of the main models of combine harvesters produced in the Russian Federation

Combine model	Maximum capacity, t/h	Width of the reaping machines used, m	Engine power, kW/hp.
Nova	10	4; 5; 6; 7	132/180
Vector 410	12	5; 6; 7; 9	154/210
Acros 550 (585)	25	5; 6; 7; 9	206/280 (221/300)
T-500	30	7; 9	264/360
RSM 161	36	7; 9	294/400
Torum 785	45	7; 9	383/520

Табл. 2. Характеристики основных моделей зерноуборочных комбайнов, производимых в Республике Беларусь

Table 2. Characteristics of the main models of combine harvesters produced in the Republic of Belarus

Combine model	Maximum capacity (determined at grain weight to straw weight ratio of 1.0 : 1.2), t/h	Width of the reaping machines used, m	Engine power, kW/hp.
GS 812 PRO	13,0	4; 5; 6; 7	169/230
GS 10 PRO	16,3	6; 7; 9,2	184/250
GS 12A1	19,6	6; 7; 9,2	243/330
GS 2124	26,2	9,2	390/530

The data in Tables 1 and 2 indicate that modern grain harvesters of domestic production and those produced in the Republic of Belarus have high productivity and engine power with a reaper width not exceeding 9.0–9.2 m. However, the characteristics of a combine's high productivity should not be dominant when a consumer chooses the harvesting equipment. In practice, it often happens that even the largest reaper width from the produced range, combined with the recommended speed of movement during harvesting and the ordinarily not high yield in local conditions, does not provide machine loading close to nominal. In this case, the efficiency of using a high-performance combine becomes lower than the efficiency of a less productive combine selected according to the criteria of ensuring optimal loading.

According to the Ministry of Agriculture and Food of the Omsk Region for 2020, 2021, and 9 months of 2022, agricultural organizations in the region purchased 619 units of various brands of grain harvesters. Among them, the most productive ones were Acros, of which 182 units (or 29.4%) were purchased. The study examined the question of their characteristics corresponding to the working conditions in Siberia.

In the Siberian Federal District, the highest yield of grain crops for the 2010s was obtained in 2021. In this year, the highest level of average grain yield was recorded in the Krasnoyarsk Territory - 2.88 t/ha. The lowest was 1.65 t/ha in the Republic of Altai. Based on these two boundary values, the choice of the reapers and combines from the assortment produced by LLC "Rostselmash" and JSC "Gomselmash" is determined by the criteria of loading close to optimal and high productivity per harvested area.

It is noted that the issue of the effective use of the fleet of grain harvesters and the formation of its optimal model composition in the economy has been worked out by a number of studies and has several solutions [1, 2] [8–14].

However, the use of most of the proposed methods is complicated in the conditions of farms due to the complexity of the calculations performed, which take into account a large number of criteria and factors, which can be quite challenging to consider and calculate in practice. When determining the advisability of applying a particular combine model, the calculations took the header width, yield, and maximum combine

[1] *Shchitov S.V., Kidyaeva N.P.* Selection of combines by importance coefficients // Technics and equipment for rural areas, 2014, No. 5, pp. 24–26.

[2] *Kidyaeva N.P., Shchitov S.V.* Optimization of the choice of combine harvesters by weather conditions // Mechanization and electrification of technological processes in agricultural production. Collection of scientific papers, Blagoveshchensk, 2013, pp. 80–87.

productivity declared by their manufacturers as the initial data. It was assumed that in the mode of optimal loading of the engine and threshing-separating device, the economic efficiency of using the combine would be a priori maximum, and losses - within permissible limits. Other operational characteristics were not considered in the calculations.

RESULTS AND DISCUSSION

The productivity of a combine harvester is conventionally measured by the amount of crop mass processed by the threshing-separating device per unit of time. The ratio of grain to straw in this crop mass can vary widely, depending on factors such as the cutting height, and the species and varietal characteristics of the harvested crops. For instance, this ratio can reach 1.0:1.2 for barley and 1:2 for winter rye. For most grain crop varieties cultivated in Siberia, the grain to straw mass ratio falls within this range.

In calculating the grain yield during the harvest, we used the formula:

$$H_з = \frac{V_р \times У \times B_к \times k_ш}{10},$$

where Vp is the working speed of the combine in km/h, $У$ is the yield per grain part in t/ha, Bк is the constructive cutting width of the reaper in meters, and kш is the coefficient accounting for the overlap between the adjacent reaper passes (taken as 0.95 for calculations).

Figures 1-4 show diagrams constructed for the mass of threshed grain per hour of pure combine operation at working speeds from 6 to 8 km/h, corresponding to the real operating conditions of grain harvesters in Siberia, at various reaper cutting widths in direct combining. The green shading on the diagrams marks the productivity interval falling within the range of the working speeds from 6 to 8 km/h and yields from 1.65 to 2.90 t/ha. The diagrams consider that under real field conditions, not all of the constructive cutting width of the reaper is used, but only about 0.95 of its size.

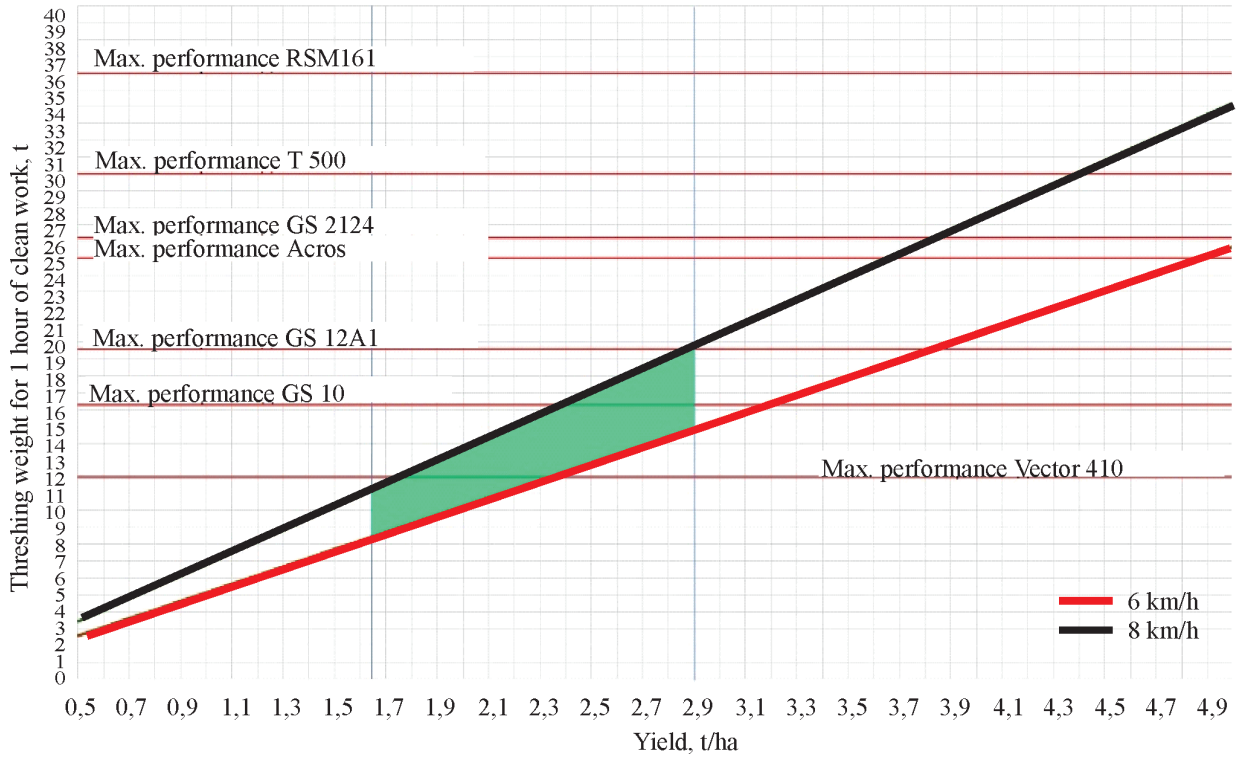

Рис. 1. Диаграмма для определения рационального состава уборочного агрегата при работе с жаткой шириной захвата 9 м в зависимости от урожайности и скорости движения комбайна

Fig. 1. Diagram for determining the rational composition of the harvesting unit when working with a reaper with a coverage of 9 m, depending on the yield and speed of the combine

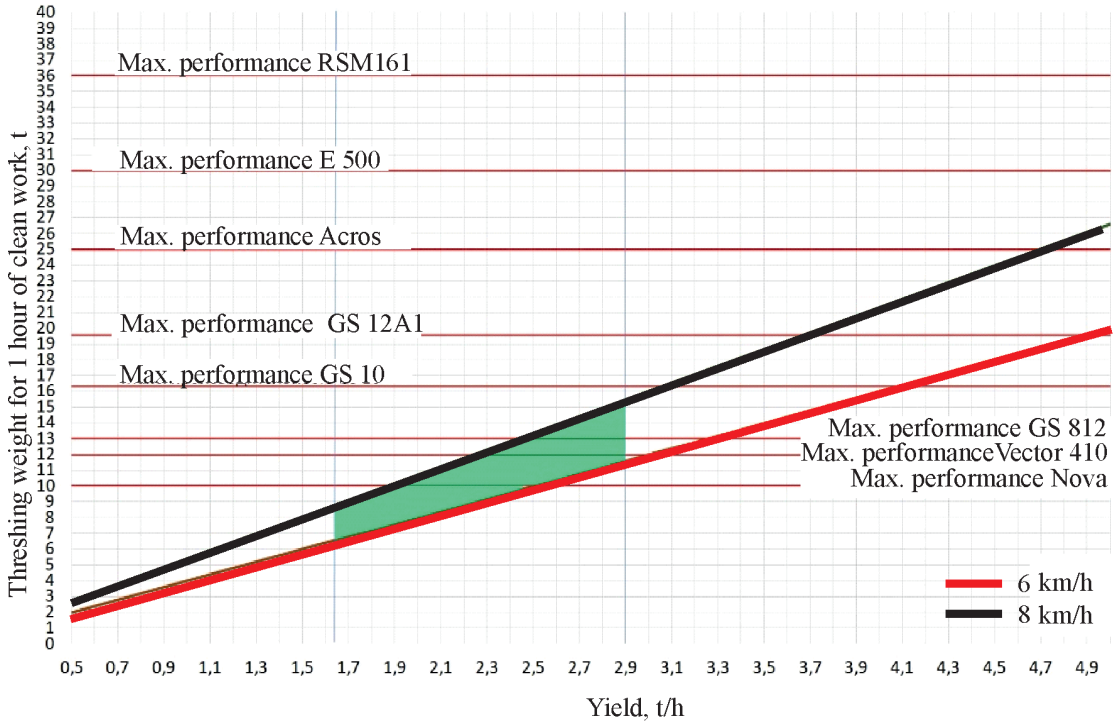

Рис. 2. Диаграмма для определения рационального состава уборочного агрегата при работе с жаткой шириной захвата 7 м в зависимости от урожайности и скорости движения комбайна

Fig. 2. Diagram for determining the rational composition of the harvesting unit when working with a reaper with a coverage of 7 m, depending on the yield and speed of the combine

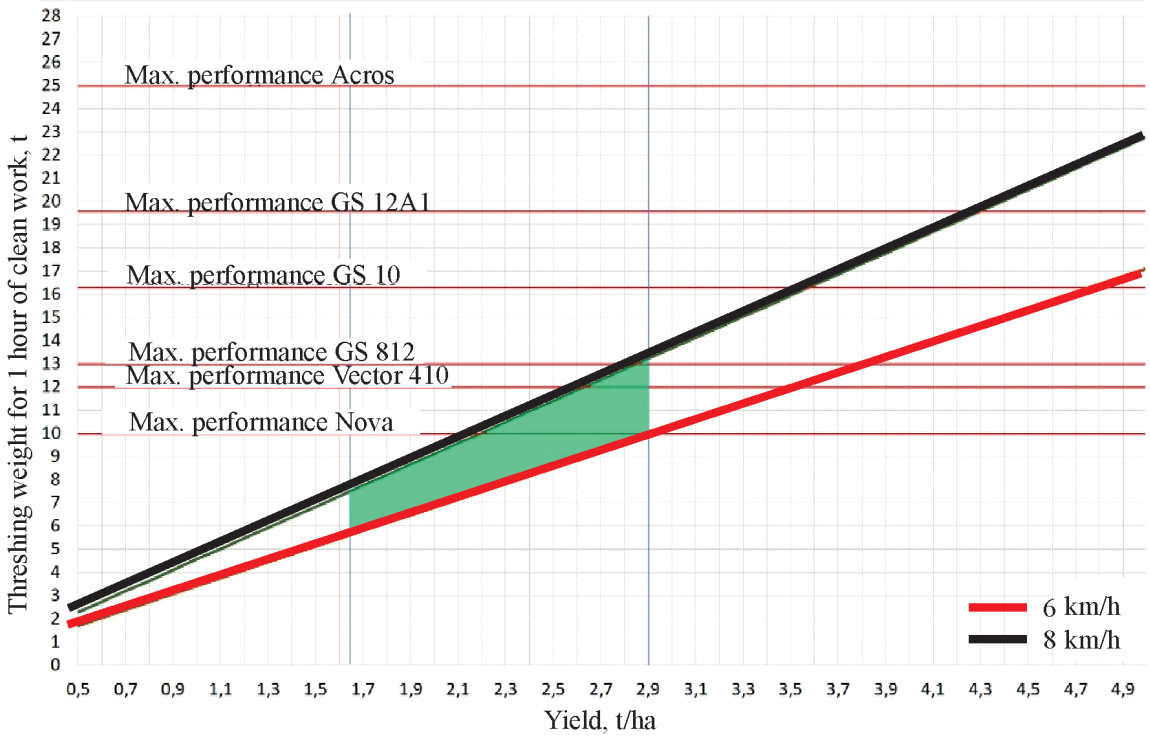

Рис. 3. Диаграмма для определения рационального состава уборочного агрегата при работе с жаткой шириной захвата 6 м в зависимости от урожайности и скорости движения комбайна

Fig. 3. Diagram for determining the rational composition of the harvesting unit when working with a reaper with a coverage of 6 m, depending on the yield and speed of the combine

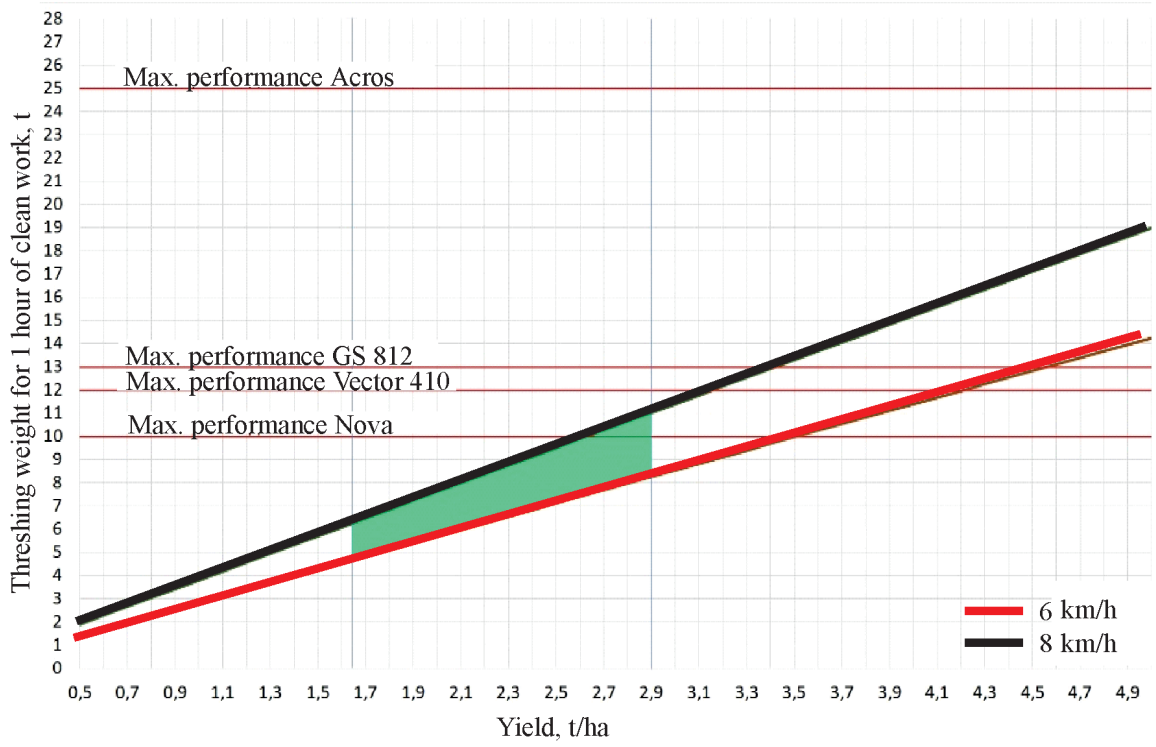

Рис. 4. Диаграмма для определения рационального состава уборочного агрегата при работе с жаткой шириной захвата 5 м в зависимости от урожайности и скорости движения комбайна

Fig. 4. Diagram for determining the rational composition of the harvesting unit when working with a reaper with a coverage of 5 m, depending on the yield and speed of the combine

For clarity, the diagrams are marked with horizontals corresponding to the maximum grain productivity for each of the considered combine models. Considering that it's advisable to start equipping the harvesting unit with the selection of the reaper with the maximum possible cutting width, the diagrams in the text are arranged in descending order from 9 to 5 meters.

The calculations assume a stand of crop without lodging, not requiring a reduction of the harvesting unit's working speed from nominal values.

Analysis of the presented diagrams shows that at a yield lower than 1.75 t/ha, it is impossible to ensure the loading of the combines from the considered list, even when using reapers with a cutting width of 9.0 and 9.2 m (see Fig. 1). For the harvest of grains with a yield from 1.75 to 2.88 t/ha, several models of modern combines can be used, whose optimal loading can be ensured by equipping them with the reapers of corresponding width: GS 12A1, GS 10 PRO - with a reaper cutting width of 9.2 m; Vector 410 - with a reaper cutting width of 9 m; GS 10 PRO, Vector 410, GS 812 PRO, and Nova - with reapers cutting width of 7 m; Vector 410, GS 812 PRO, and Nova - with reapers cutting width of 6 m. Clearly, to reduce the duration and cost of harvesting, it is rational to use combines with wider headers. Preference should be given to harvesting units with smaller cutting width only in cases where the use of wider machines is hampered by the terrain and field configuration.

It is impractical to use reapers with a 5m cutting width at the corresponding yield range as they are low-productive, lead to prolonged harvesting times, and require a larger number of harvesting units. In this case, even the least productive combine from the considered list (Nova) achieves loading only at speeds ranging from 7 to 8 km/h.

Reviewing the diagrams also allows for a graphical method to obtain data characterizing the optimal loading of various harvesting units for grain harvesting with a yield ranging from 0.5 to 5.0 t/ha. However, at a yield less than 1.75 t/ha and a speed up to 8 km/h, any of the consid-

ered harvesting units will operate under partial loading conditions.

The results of calculations to determine the rational composition of the harvesting unit at various yield levels are summarized in Table 3.

The results of the calculations presented in Table 3 indicate that in the conditions of the Siberian region, characterized by grain yields ranging from 1.65 to 2.9 t/ha, it is advisable to carry out the grain harvest with GS 10 PRO combines with a 9.2m cutting width and Vector 410 with a 9m cutting width. In this case, higher productivity will be ensured when using GS 10 PRO. More productive machines in this yield range will not receive loading close to the maximum.

Guided by the data in Table 3 on the "minimum-maximum yield" range and productivity per harvested area, a rational composition of the harvesting unit (combine + reaper) can be selected. In addition to the yield level, the features of the terrain and field configuration in a particular farm should be considered, which may require the use of reapers with a smaller cutting width and a less productive combine.

Табл. 3. Рациональные составы уборочных агрегатов при уборке зерновых с различной урожайностью прямым комбайнированием и соответствующая им производительность по убранной площади

Table 3. Rational compositions of harvesting units when harvesting grain crops with different yields by direct combining and the corresponding productivity for the harvested area

Combine model combine; reaping machine coverage	Minimal yield (harvesting at the speed of 8 km/h), t/ha	Maximum yield (harvesting at the speed of 6 km/h), t/ha	Maximum capacity of the harvested area, ha/h
Reaping machine with a coverage of 9,2 m			
GS 10 PRO	2,4	3	5,2–7,0
GS 12A1	2,85	3,8	5,2–7,0
GS 2124	3,85	5,0	5,2–7,0
Reaping machine with a coverage of 9 m			
Vector 410	1,75	2,35	5,1–6,8
Acros	3,65	4,85	5,1–6,8
Reaping machine with a coverage of 7 m			
Nova	1,9	2,5	4,0–5,3
Vector 410	2,25	3,0	4,0–5,3
GS 812 PRO	2,45	3,25	4,0–5,3
GS 10 PRO	3,1	4,1	4,0–5,3
GS 12A1	3,7	4,9	4,0–5,3
Reaping machine with a coverage of 6 m			
Nova	2,2	2,9	3,4–4,6
Vector 410	2,65	3,5	3,4–4,6
GS 812 PRO	2,85	3,8	3,4–4,6
GS 10 PRO	3,6	4,8	3,4–4,6
Reaping machine with a coverage of 5 m			
Nova	2,65	3,5	2,9–3,8
Vector 410	3,15	4,2	2,9–3,8
GS 812 PRO	3,4	4,6	2,9–3,8

CONCLUSION

In the conditions of Siberia, with the current level of grain yield, the factor limiting the use of high-performance grain harvesters is the cutting width of the reaper. For grain harvesting with a yield typical for Siberia (1.65–2.90 t/ha), considering the loading conditions of the combine's engine and threshing-separating device, it is advisable to use combines with a maximum productivity from 12 to 16 t/h and reapers with a cutting width of 9.0–9.2 m. The use of more productive combines under such conditions is economically unjustified since their technical potential under partial loading conditions of the main units remains unrealized. However, such machines can be used in farms where a higher level of applied technologies ensures a higher yield level, and also in the selection of paired rolls during two-phase harvesting.

It has been established that when using 9m cutting width reapers with Russian combine models and 9.2m with Belarusian ones for harvesting works on crops with a yield typical for Siberia, it is rational to use Vector 410 at a yield level of 1.8–2.4 t/ha, GS 812 PRO – 1.95–2.6 t/ha, GS 10 PRO – 2.45–3.0 t/ha.

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ИНФОРМАЦИЯ ОБ АВТОРАХ

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ВЛИЯНИЕ СООТНОШЕНИЯ ПОМОЛЬНОЙ СМЕСИ ЗЕРНА ПШЕНИЦЫ И АМАРАНТА НА ХИМИЧЕСКИЕ И ФИЗИКО-ХИМИЧЕСКИЕ ПОКАЗАТЕЛИ ПШЕНИЧНО-АМАРАНТОВОЙ МУКИ

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На российском рынке появился новый источник растительного сырья для пищевой промышленности – зерно амаранта и продукты его переработки, обладающие ценным химическим составом, высокой пищевой и биологической ценностью, содержащие широкий спектр физиологически функциональных пищевых веществ. Представлены исследования по влиянию различного соотношения помольной смеси зерна пшеницы и амаранта на химические и физико-химические свойства пшенично-амарантовой муки в результате их совместной переработки. Объектом исследования послужили зерно озимой пшеницы Немчиновская 85 и зерно амаранта Воронежский. Переработку контрольного образца мягкой пшеницы и помольных пшенично-амарантовых смесей различного процентного отношения проводили на мельницах лабораторного помола (МЛП-4) с нарезными (для драных систем) и гладкими микрошероховатыми вальцами (для размольных систем). Установлено, что в контрольном образце пшеничной муки средневзвешенное содержание жира и белка составило 1,12 и 11,57% соответственно, при добавлении 5% амаранта в помольную пшенично-амарантовую зерновую смесь средневзвешенное содержание жира в пшенично-амарантовой муке составило 2,47%, белка – 12,55%, при добавлении 10% амаранта – 3,13 и 12,66%, при добавлении 15% амаранта – 3,88 и 13,34%, при добавлении 20% амаранта – 4,29 и 13,78% соответственно. Выявлено, что добавление зерна амаранта в помольную пшенично-амарантовую смесь до 20% зерна амаранта существенно повышает выход пшенично-амарантовой муки. Установлено, что добавление в помольную зерновую смесь зерна амаранта позволяет повысить содержание жира в пшенично-амарантовой муке на 282,1% и на 18,4% содержание белка по сравнению с контрольной пшеничной мукой.

Ключевые слова: пшеница, амарант, помольная смесь, выход, пшенично-амарантовая мука, химические и физико-химические свойства

INFLUENCE OF WHEAT AND AMARANTH GRAIN MIXTURE RATIO ON CHEMICAL AND PHYSICOCHEMICAL PARAMETERS OF WHEAT-AMARANTH FLOUR

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A new source of vegetable raw materials for the food industry has appeared on the Russian market - amaranth grain and products of its processing, which have a valuable chemical composition, high nutritional and biological value, containing a wide range of physiologically functional nutrients. The studies on the effect of different ratios of the grinding mixture of wheat and amaranth grains on the chemical and physico-chemical properties of wheat-amaranth flour as a result of their joint processing are presented. The object of the study was the grain of winter wheat of the variety Nemchinovskaya

85 and the grain of amaranth of the variety Voronezhsky. Processing of the control sample of common wheat and milling wheat-amaranth mixtures of various ratios was carried out in the laboratory grinding mills (LGM-4) with threaded (for break systems) and smooth microroughened rollers (for grinding systems). It has been found that in the control sample of wheat flour, the weighted average content of fat and protein was 1.12% and 11.57%, respectively, with the addition of 5% amaranth to the grinding wheat-amaranth grain mixture, the weighted average fat content in wheat-amaranth flour was 2.47 %, and the protein content - 12.55%, with the addition of 10% amaranth to the grinding wheat-amaranth grain mixture, the weighted average fat content of wheat-amaranth flour was 3.13%, and the protein content - 12.66%, with the addition of 15% amaranth in the milled wheat-amaranth grain mixture, the weighted average fat content in wheat-amaranth flour was 3.88%, and the protein content was 13.34%, with the addition of 20% amaranth to the milled wheat-amaranth grain mixture, the weighted average fat content in wheat-amaranth flour was 4.29%, and the protein content was 13.78%, respectively. It has been found that the addition of amaranth grain to the milled wheat-amaranth mixture up to 20% of amaranth grain significantly increases the yield of wheat-amaranth flour. It has been established that the addition of amaranth grain to the grinding grain mixture makes it possible to increase the fat content in wheat-amaranth flour by 282.1% and the protein content by 18.4% compared to the control wheat flour.

Keywords: wheat, amaranth, grinding mixture, yield, wheat-amaranth flour, chemical and physicochemical properties

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INTRODUCTION

Over the last 30 years, there has been a reduction in the balanced animal proteins by 20-25%, overall caloric content of food products by 10-15%, animal fats by 65-70%, and high-protein plant-based foods by 25-30%[1] in the dietary structure of the population of the Russian Federation.

A relatively new source of plant raw materials for the food, oil extraction, and pharmaceutical industries has appeared on the global and Russian markets – amaranth grain and its processed products. They boast a valuable chemical composition, high food and biological value, containing a wide range of physiologically functional food substances, which defines the prospects of their use in food production technology[2] [1–3].

Amaranth grain surpasses many traditional crops, including wheat grain, in protein, amino acids, vitamins, macro and microelements, biologically active substances, and fat content [4–6]. Amaranth has a valuable chemical composition with an increased content of the essential limiting amino acid - lysine, high food and biological value, making it a promising raw material for use in the food and processing industry [7, 8]. Amaranth flour contains essential amino acids, insoluble dietary fibers, PP group vitamins, mineral substances, and is

[1]*Litvinova O.S.* Nutrition structure of the population of the Russian Federation. Hygienic assessment // Population health and habitat, 2016, No. 5 (278), pp. 11–14.

[2]*Medvedeva A.A., Nevskaya E.V.* Study of the influence of amaranth meal on the properties of dough and quality of bakery products from wheat flour // Scientific Works of the Kuban State Technological University: Electronic network polythematic journal, 2019, No. S9, pp. 406-413.

balanced in macroelement content of Ca and P[3] [9–11].

Analysis of various literary sources indicates the feasibility of using amaranth processing products as an enriching additive in various food products[4–8] [12–15].

Special mention should be made of the fact that amaranth meal includes a unique substance – squalene, which is a powerful (effective) antioxidant[9].

Studies to determine the milling and baking properties of wheat-amaranth grinding mix compared to the grinding mix from wheat grain have not been conducted either in Russia or abroad. In this regard, the composition of wheat-amaranth grinding mixes for obtaining wheat-amaranth flour of increased food and nutritional value is relevant.

The purpose of the study is to examine the influence of different ratios of grinding mix of wheat and amaranth grains on the chemical and physical-chemical properties of the streams of wheat-amaranth flour obtained as a result of their joint processing.

Research tasks are as follows:

– develop a laboratory technological scheme for processing the wheat-amaranth grinding mix;

– conduct laboratory grindings of a control sample of soft wheat, as well as grinding mixes of wheat and amaranth grains in a percentage ratio of 95:5, 90:10, 85:15, 80:20 according to the developed technological scheme;

– determine the influence of the amaranth content in the wheat-amaranth grinding mix on the chemical and physical-chemical properties of individual streams of wheat-amaranth flour and compare with control wheat flour obtained by all technological systems.

MATERIAL AND METHODS

The objects of the studies were winter wheat grain Nemchinovskaya 85 and amaranth Voronezhsky of domestic selection [3]. Table 1 presents a comparative characteristic of the chemical composition of amaranth and soft winter wheat grain.

The control sample of soft wheat and different ratios of wheat-amaranth grinding mixtures were processed on laboratory milling machines (MLP-4) with serrated (for break systems) and smooth micro-rough rolls (for reduction systems) [14].

The grinding parameters and modes on roller mills remained unchanged during the processing of all samples of wheat-amaranth grinding mixtures, including the control sample of wheat. Sifting and selection of intermediate grinding products of wheat-amaranth mixtures of different percentage ratios and flour milling were carried out on the sifters of MLP-4 mills, consisting of a set of three sieves, including two for groats and one for flour with a total sieving surface of 720 cm^2.

Chemical and physicochemical indicators of streams of wheat-amaranth flour and control wheat flour, obtained in all break and reduction systems, were determined on the SpectraStar 2500 XL infrared grain and flour analyzer (made in the USA).

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Табл. 1. Химический состав зерна амаранта и пшеницы, %

Table 1. Chemical composition of amaranth and wheat grains, %

Culture	Protein	Fats	Carbohydrates	Fiber	Ash	Water
Amaranth Voronezhsky	17,6	6,8	56,2	6,2	2,6	10,6
Wheat Nemchinovskaya 85	12,3	1,7	68,4	2,0	1,73	14

RESULTS AND DISCUSSION

In the first stage of the study, laboratory grindings of the control sample of soft wheat, as well as grinding mixtures of wheat and amaranth grain in a percentage ratio of 95:5, 90:10, 85:15, 80:20 were conducted according to the developed technological scheme. In total, 11 streams of wheat-amaranth and control wheat flour were obtained, including five from break systems and six from reduction systems.

The obtained results of laboratory grindings on the influence of the content of the amaranth grain in the wheat-amaranth grinding mixture on the yield of wheat-amaranth flour compared to the yield of control wheat flour are presented in Table 2.

It was found that the addition of amaranth grain to the grinding mix significantly increases the yield of wheat-amaranth flour. When adding 5% of amaranth grain to the grinding mixture, the yield of wheat-amaranth flour was 72.2%, 10% of amaranth grain - 73.7%, 15% of amaranth grain - 80.2%, 20% of amaranth grain - 82.7%, which is 8.4% higher compared to the flour yield from the control wheat sample. Thus, the highest yield of wheat-amaranth flour is obtained by grinding a mixture of wheat and amaranth grains in a percentage ratio of 80:20.

In the second stage of the study, the influence of amaranth content in the wheat-amaranth grinding mix on the chemical and physicochemical properties of individual streams of wheat-amaranth flour was determined, compared with control wheat flour obtained from all technological systems (see Table 3).

Taking into account the total yield of wheat flour, the average weighted fat content in all streams was 1.13%, protein - 11.61%. In the streams of wheat flour on break systems, the average weighted content of fat and protein was

Табл. 2. Выход со всех технологических систем пшенично-амарантовой муки различного соотношения и контрольной пшеничной муки, %

Table 2. Yield from all technological systems of wheat-amaranth flour of different ratios and control wheat flour, %

Technological system of the laboratory scheme	Wheat-amaranth flour yield				
	Wheat-amaranth milling mixture in percentages				Control sample of soft wheat grain
	95 : 5	90 : 10	85 : 15	80 : 20	
Break system:					
I	1,7	2,9	2,0	1,3	2,7
II	2,1	2,9	2,2	1,6	3,4
III	5,3	3,1	7,8	3,0	4,4
IV	2,1	2,3	2,6	1,7	2,6
V	0,7	0,8	0,7	0,9	1,3
Break system flour	11,9	12,0	15,2	8,5	14,4
Reduction system: 1st	19,2	20,7	25,6	22,7	25,6
2nd	14,2	17,8	19,4	20,1	15,9
3rd	11,7	10,7	12,8	14,1	8,2
4th	7,2	6,6	3,1	9,4	7,3
5th	4,9	2,5	2,2	5,5	1,5
6th	3,1	3,4	1,8	2,4	1,4
Reduction system flour	60,3	61,7	64,9	74,2	59,9
Total flour	72,2	73,7	80,2	82,7	74,3

1.14 and 11.94%, on reduction systems - 1.12 and 11.53% respectively.

The average weighted fat content in the streams of wheat-amaranth flour in a 95:5 percentage ratio, taking into account the total yield, was 2.47%, protein - 12.55%. The average weighted fat and protein content in the streams of wheat-amaranth flour in the break systems for this variant was 2.45% and 12.53%, in reduction systems - 2.48% and 12.56% respectively (see Table 4).

The average weighted fat content in the streams of wheat-amaranth flour in a 90:10 raw material ratio, taking into account the yield on break and reduction systems, was 3.12% and 3.14%, protein - 12.77% and 12.64% respectively. The average weighted fat and protein content in the streams of wheat-amaranth flour for all systems in this variant - 3.13% and 12.66% respectively (see Table 5).

The average weighted fat content in the streams of wheat-amaranth flour in an 85:15

Табл. 3. Химические и физико-химические показатели потоков контрольной пшеничной муки, полученных со всех технологических систем

Table 3. Chemical and physicochemical parameters of control wheat flour streams obtained from all technological systems

Flour indicator	Break system					Reduction system				
	I	II	III	IV	V	1st	2nd	3rd	4th	5th + 6th
Lipids, %	1,01	1,03	1,11	1,09	1,14	1,12	1,08	1,17	1,15	1,22
Ash content, %	0,58	0,56	0,57	0,65	0,67	0,50	0,52	0,60	0,71	0,90
Fiber, %	1,20	1,22	1,06	1,10	1,18	1,12	1,15	1,33	1,46	1,61
Protein, %	11,39	11,20	11,89	12,15	12,42	11,41	11,45	11,60	11,76	12,32
Moisture, %	13,54	13,21	14,21	14,05	13,75	13,94	13,33	12,84	12,17	11,99
Starch, %	64,62	64,43	63,64	63,22	62,20	64,65	65,30	65,24	65,55	64,42
Whiteness, device units	67,72	68,95	65,16	62,00	55,99	66,06	59,39	54,36	48,27	40,79
GDI, units	60,20	59,42	59,89	61,88	66,56	59,34	66,12	69,15	75,62	81,14
Gluten, %	24,39	22,19	26,52	27,32	28,23	25,52	25,35	25,10	24,87	25,25
General fibers, %	2,88	3,31	2,61	2,96	3,25	2,68	3,08	3,40	3,64	4,00
Falling number, s	310,5	292,5	316,8	307,1	299,8	317,9	303,3	305,2	299,7	283,6

Табл. 4. Химические и физико-химические показатели потоков пшенично-амарантовой муки в процентном отношении 95 : 5, полученных со всех технологических систем

Table 4. Chemical and physicochemical parameters of wheat-amaranth flour streams as a percentage of 95 : 5 obtained from all technological systems

Flour indicator	Break system					Flour indicator	Reduction system				
	I	II	III	IV	V		1st	2nd	3rd	4th	5th + 6th
Lipids, %	2,37	2,41	2,46	2,51	2,57	Fat, %	2,41	2,45	2,51	2,53	2,61
Ash content, %	0,73	0,89	0,9	1,0	1,02	Ash content, %	1,03	1,12	1,32	1,48	1,55
Fiber, %	1,51	1,66	1,45	1,58	1,57	Fiber, %	1,4	1,43	1,55	1,62	1,66
Protein, %	12,24	12,91	12,32	12,73	13,04	Protein, %	12,32	12,42	12,57	12,91	13,07
Moisture, %	12,28	12,24	12,33	12,11	12,15	Moisture, %	12,27	12,05	11,63	11,3	11,23
Starch, %	64,32	61,26	63,5	63,06	62,39	Starch, %	63,22	62,98	61,91	61,1	60,67
Whiteness, device units	49,21	41,66	42,1	7,73	36,99	Whiteness, device units	35,86	32,08	23,71	17,12	14,17
GDI, units	71,71	78,03	73,66	78,03	79,01	GDI, units	74,78	77,83	82,75	87,73	90,08
Gluten, %	25,58	27,58	24,91	25,65	26,22	Gluten, %	23,84	23,01	22,6	22,27	22,44
General fibers, %	3,95	4,02	3,81	4,04	4,19	General fibers, %	3,73	3,74	3,96	4,15	4,16
Falling number, s	293,28	279,66	298,93	281,79	275,95	Falling number, s	307,6	304,38	298,41	287,62	280,69

Табл. 5. Химические и физико-химические свойства потоков пшенично-амарантовой муки в процентном отношении 90 : 10, полученных со всех технологических систем

Table 5. Chemical and physicochemical properties of wheat-amaranth flour streams in the percentage ratio of 90 : 10 obtained from all technological systems

Flour indicator	Break system					Reduction system				
	I	II	III	IV	V	1st	2nd	3rd	4th	5th + 6th
Lipids, %	3,09	3,12	3,10	3,14	3,18	3,11	3,15	3,14	3,18	3,22
Ash content, %	1,27	0,87	0,9	0,98	1,04	1,05	1,14	1,29	1,41	1,56
Fiber, %	1,59	1,47	1,49	1,52	1,58	1,37	1,4	1,48	1,54	1,65
Protein, %	12,83	12,4	12,77	13,0	13,2	12,64	12,53	12,52	12,78	13,04
Moisture, %	11,75	12,3	12,39	12,4	12,3	12,51	12,18	11,74	11,47	11,21
Starch, %	61,7	63,7	63,1	62,4	61,3	61,67	61,57	61,64	61,15	60,12
Whiteness, device units	26,5	43,3	41,3	37,5	34,5	34,4	30,69	24,6	19,07	13,1
GDI, units	84,5	74,7	75,7	78,6	81,3	75,8	78,05	80,8	85,01	89,9
Gluten, %	24,0	25,1	26,3	27,1	27,7	24,7	23,57	22,6	22,4	22,5
General fibers, %	4,15	3,86	3,9	4,0	4,05	3,49	3,55	3,84	4,0	4,12
Falling number, s	277,4	291,2	285,0	276,5	273,0	305,0	304,4	304,3	298,2	287,5

Табл. 6. Химические и физико-химические свойства потоков пшенично-амарантовой муки в процентном отношении 85 : 15, полученных со всех технологических систем

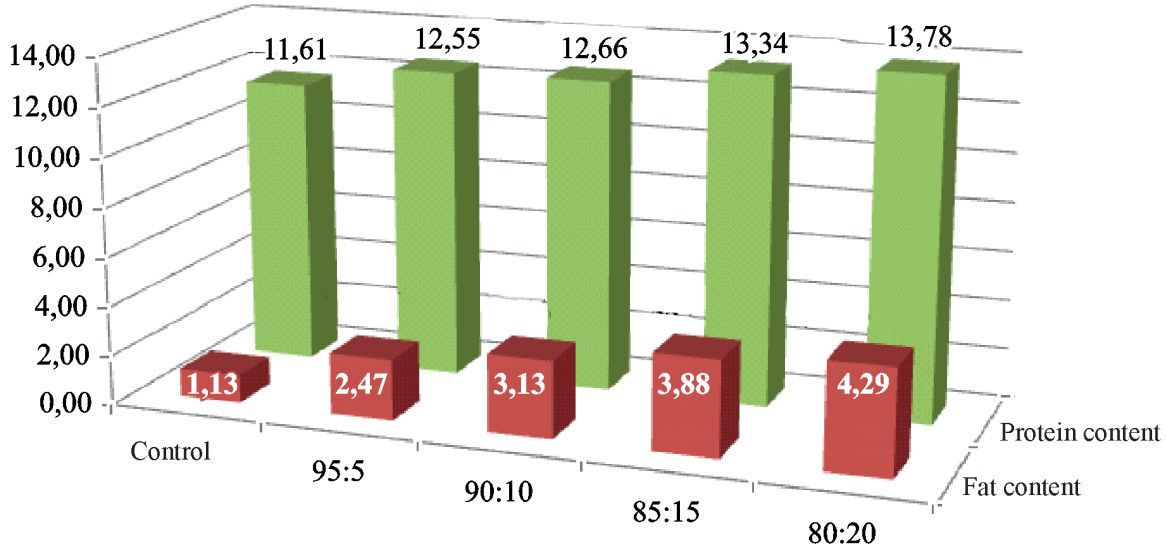
Table 6. Chemical and physicochemical properties of wheat-amaranth flour streams in the percentage ratio of 85 : 15 obtained from all technological systems

Flour indicator	Break system					Reduction system				
	I	II	III	IV	V	1st	2nd	3rd	4th	5th + 6th
Lipids, %	3,63	3,59	3,68	3,77	3,79	3,85	3,89	3,92	3,87	3,97
Ash content, %	1,14	1,07	1,15	1,25	1,31	1,46	1,53	1,64	1,74	1,95
Fiber, %	1,67	1,49	1,38	1,39	1,49	1,41	1,01	1,52	1,62	1,81
Protein, %	13,14	12,95	13,07	13,34	13,66	13,26	13,45	13,24	13,32	13,65
Moisture, %	11,28	12,13	12,52	12,55	12,26	11,89	11,26	11,21	10,76	10,15
Starch, %	62,2	62,89	61,06	59,77	59,45	60,88	61,99	61,04	61,28	61,35
Whiteness, device units	20,31	34,97	31,06	26,3	23,5	16,45	13,05	8,74	4,09	0,0
GDI, units	90,82	8/0,49	79,92	83,6	87,42	23,17	92,92	93,39	97,27	105,84
Gluten, %	23,62	24,43	25,09	25,79	26,45	23,17	22,13	21,66	21,08	20,8
General fibers, %	4,33	3,98	3,69	3,78	4,01	3,82	4,79	3,98	4,1	4,44
Falling number, s	265,4	273,7	282,3	270,4	259,5	276,7	271,1	278,4	274,8	260,2

Табл. 7. Химические и физико-химические свойства потоков пшенично-амарантовой муки в процентном отношении 80 : 20, полученных со всех технологических систем

Table 7. Chemical and physicochemical properties of wheat-amaranth flour streams in the percentage ratio of 80 : 20 obtained from all technological systems

Flour indicator	Break system					Reduction system				
	I	II	III	IV	V	1st	2nd	3rd	4th	5th + 6th
Lipids, %	4,07	4,17	4,21	4,35	4,47	4,12	4,29	4,32	4,41	4,58
Ash content, %	1,44	1,48	1,51	1,49	1,55	1,62	1,96	2,08	2,34	2,73
Fiber, %	1,67	1,5	1,49	1,58	1,69	1,55	1,64	1,8	1,91	2,15
Protein, %	12,51	12,54	13,02	13,44	13,81	13,46	13,79	13,70	14,21	14,26
Moisture, %	10,65	11,67	12,08	11,97	11,72	11,75	11,01	10,47	10,06	9,43
Starch, %	64,82	64,3	62,22	60,86	59,81	59,08	58,39	58,15	57,21	56,23
Whiteness, device units	18,35	34,27	32,32	25,04	17,51	11,0	10,0	0,0	0,0	0,0
GDI, units	94,95	83,04	81,98	87,24	93,15	90,4	99,52	102,8	110,4	124,4
Gluten, %	23,54	24,76	25,57	26,19	26,88	23,41	21,15	20,58	20,42	20,84
General fibers, %	4,62	4,26	4,11	4,21	4,39	3,97	4,2	4,21	4,35	4,81
Falling number, s	265,1	269,6	267,1	255,9	245,3	273,3	265,2	271,3	258,1	226,9



Зависимость содержания зерна амаранта в помольной смеси на количество жира и белка в пшенично-амарантовой муке различного процентного отношения в сравнении с контрольной пшеничной мукой, %

Dependence of amaranth grain content in the milling mixture on the amount of fat and protein in wheat-amaranth flour of different percentages compared with the control wheat flour, %

ratio, taking into account the yield, was 3.84%, protein - 13.30%. The average weighted fat and protein content in the streams of wheat-amaranth flour in the break systems - 3.71% and 13.22%, in reduction systems - 3.88% and 13.34% respectively (see Table 6).

The average weighted fat content in the streams of wheat-amaranth flour in an 80:20 ratio, taking into account the yield, was 4.28%, protein - 13.70%. The average weighted fat and protein content in the streams of wheat-amaranth flour in the break systems - 4.24% and 13.02%, in reduction systems - 4.29% and 13.78% respectively (see Table 7).

The figure shows the dependence of the amaranth grain content in the grinding mix on the fat and protein content in the wheat-amaranth flour of different ratios compared to the control wheat flour. The graph shows that adding amaranth grain to the grinding mix allows increasing the fat content in wheat-amaranth flour by 282.1% and the protein content by 18.4% compared to control wheat flour.

CONCLUSIONS

1. Adding amaranth grain to the grinding mix has a positive effect on the granulating ability and leads to an increase in the yield of wheat-amaranth flour. When adding 5% of amaranth grain to the wheat-amaranth grinding mix, the flour yield was 72.2%, 10% of amaranth grain - 73.7%, 15% of amaranth grain - 80.2%, 20% of amaranth grain - 82.7%. The highest yield of wheat-amaranth flour is obtained by grinding wheat and amaranth grain in a percentage ratio of 80:20, which is 8.4% higher compared to the flour yield from the control wheat sample.

2. Adding amaranth grain to the wheat-amaranth grinding mix increases the fat and protein content in all streams of wheat-amaranth flour obtained from both break and reduction systems. Compared to the control sample of wheat flour, the fat and protein content was 1.12% and 11.57% respectively; when adding 5% of amaranth, the average weighted fat content was 2.47%, protein - 12.55%; 10% of amaranth, the fat content - 3.13%, protein - 12.66%; 15% of amaranth, the fat content - 3.88%, protein - 13.34%; 20% of amaranth, the fat content - 4.29%, protein - 13.78%.

3. Adding amaranth grain to the grinding mix allows increasing the fat content in wheat-amaranth flour by 282.1%, protein - by 18.4% compared to control wheat flour.

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ОЦЕНКА ГЕНЕТИЧЕСКИХ РАЗЛИЧИЙ У ЖИВОТНЫХ НА ПРИМЕРЕ ПРЕДСТАВИТЕЛЕЙ РОДА *CAMELUS*

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Представлены данные о генетической изменчивости геномной ДНК двух видов верблюдов (дромедар и бактриан). Отмечено, что указанные виды имеют большое значение в ряде южных стран – используются как сельскохозяйственные, тягловые, верховые и спортивные животные. В настоящее время изучению верблюдов уделяется большое внимание с целью выявления их генетических особенностей, которые можно использовать в селекционной работе. Одним из методов исследования является мультилокусный анализ с применением меченых олигонуклеотидных зондов. Последние избирательно гибридизуются в отдельных участках геномной ДНК, приводя к формированию специфических генетических профилей, характерных для каждой особи. Мечение зонда дезоксигенином позволяет детектировать результаты гибридизации на фильтре. После проведения реакции молекулярной гибридизации зонда с геномной ДНК верблюдов было выявлено от 3 до 15 фрагментов ДНК, при этом картина гибридизации сильно отличалась у дромедаров и бактрианов, что свидетельствует о значительной генетической разнице в организации их геномов. Коэффициент сходства особей внутри популяции у бактрианов был существенно выше, чем у дромедаров (0,48 против 0,39), коэффициент межвидового сходства по этому параметру составил всего 0,13. Расчет генетического расстояния между популяциями дал довольно высокое значение – 0,305, что намного выше, чем ранее полученные данные по крупному рогатому скоту (от 0,05 до 0,10). Внутрипопуляционное генетическое разнообразие оценивали по критерию средней гетерозиготности. Расчеты показали большее генетическое разнообразие в популяции дромедаров (H = 0,72), что косвенно подтверждалось и более низким значением коэффициента сходства в этой группе животных.

Ключевые слова: бактриан, дромедар, генетическое разнообразие, олигонуклеотидный зонд

ASSESSMENT OF GENETIC DIFFERENCES IN ANIMALS AS EXEMPLIFIED BY REPRESENTATIVES OF THE GENUS *CAMELUS*

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Data on the genetic variability of genomic DNA from two species of camels (Dromedary and Bactrian) are presented. It is noted that these animal species are of great importance in a number of southern countries, they are used as farm animals (milk, meat, wool), as draft, riding and sports animals. At present, much attention is paid to the study of camels in order to identify their genetic characteristics that can be used in breeding work. One of the research methods is multilocus analysis using labeled oligonucleotide probes. The latter selectively hybridize in separate regions of genomic

DNA, leading to the appearance of specific genetic profiles characteristic of each individual. Labeling the probe with digoxigenin makes it possible to detect the results of hybridization on the filter. After the reaction of molecular hybridization of the probe with genomic DNA of camels, from 3 to 15 DNA fragments were detected, while the pattern of hybridization was very different in Dromedaries and Bactrians, which indicates a significant genetic difference in the organization of genomes. The coefficient of similarity of individuals in Bactrians was significantly higher than in Dromedaries (0.48 versus 0.39); interspecific similarity coefficient in this parameter was only 0.13. The calculation of the genetic distance between populations gave a rather high value of 0.305, which is significantly higher than the previously obtained data on cattle (from 0.05 to 0.10). Intrapopulation genetic diversity was assessed by the criterion of average heterozygosity. Calculations showed greater genetic diversity in the dromedary population (H = 0.72), which was indirectly confirmed by a lower similarity coefficient in this group of animals.

Keywords: Bactrian camel, Dromedary camel, genetic diversity, oligonucleotide probe

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INTRODUCTION

Currently, it is believed that there are three types of camels in nature - the single-humped (Dromedary), the double-humped (Bactrian), and the wild camel. The first two types are widely used in many southern countries, especially in Arab nations, for agricultural production (milk, meat, wool) and have significant social importance for the population [1, 2]. Shubat, a fermented milk beverage with many valuable properties, is made from camel milk. Unlike kumis, shubat is thicker and has a white color. Despite their scant diet, camels' milk productivity can reach 2000 liters per season [3]. Global interest in camel milk and its products is growing[1].

In modern animal husbandry, the achievements of molecular genetics are actively applied. Genomic selection, in particular, has been adopted in many countries. To date, phenotypic breed standards for camels have yet to be established [4]. This fact underscores the importance of implementing genetic approaches in studying these animals to lay the groundwork for further genomic selection. Research is being conducted on the influence of polymorphic variants of individual genes on various economically useful traits for application in breeding. Such genes include kappa-casein, diacylglycerol acyltransferase 1 (DGAT1), lactoglobulin, myostatin, etc[2]. For example, it has been established that

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[2] *Pauciullo A., Giambra I.J., Iannuzzi L., Erhardt G.* The β-casein in camels: molecular characterization of the CSN2 gene, promoter analysis and genetic variability // Gene. 2014. Vol. 547. N 1. P. 159–168.

the *CSN2* gene of kappa-casein in camels is the most polymorphic in the entire family of casein genes, having 91 variants [5]. In some cases, associations between genetic polymorphism in individual genes and economically useful traits are identified. Such works exist for variants of the kappa-casein gene and the *FGF5* gene, associated with the formation of hair length in camels. A single missense mutation (C > T substitution) led to a statistically significant change in hair length [6].

Special attention in animal husbandry is given to studying population genetic parameters to refine the history of breed creation and populations, reconstruct extinct breeds, determine the direction of current breeding work, and genetic diversity in populations for use in genome conservation programs [7, 8]. In some instances, clear genetic distinctiveness of camel populations is found depending on the country of breeding. As noted by M.A. Homas et al. [9], a multilocus approach revealed the differentiation of camel populations in Saudi Arabia compared to animals from other countries.

Genomic DNA is studied by various methods, including sequencing (whole-genome or specific regions) [10], using polymorphism in microsatellite DNA[3] [11], and chip technologies for screening the genome at many loci simultaneously (SNPs). DNA level polymorphism is well-studied, as revealed by point mutations in various genes. Much more useful for studying DNA sequence polymorphism at the population level are hypervariable regions of the genome, characterized by the presence of different allelic variants (high frequency of occurrence) in different individuals in the population and a significant mutation rate (see footnote 3).

Studies are conducted on polymorphism in mitochondrial DNA. In the Indian camel population, a high level of diversity of mitochondrial genome regions was found, exceeding the indicators of other populations [12].

The existence of different camel species raised questions about their genetic closeness. This issue can be resolved by genetic methods. It is known that the two-humped camel (Bactrian) and one-humped camel (Dromedary) are classified as different species, despite their ability to interbreed. Therefore, some researchers consider them representatives of one species but different breeds.

The purpose of the research is a comparative assessment of the genetic diversity of two camel species.

The tasks are:

1) collection of the biomaterial (blood) from camels of both species;

2) extraction of high-molecular-weight genomic DNA from available samples;

3) conducting a multilocus genetic analysis to calculate the basic population genetic parameters characterizing the experimental animal samples;

4) evaluation of the obtained results.

MATERIAL AND METHODS

The objects of the study are single-humped and double-humped camels (18 individuals in each group), bred at the "Daulet-Beket" farm, located in the Ilisky district of the Almaty region of the Republic of Kazakhstan. DNA was extracted from the venous blood of animals using standard methods, including the precipitation of the leukocyte fraction, cell lysis with detergent (sodium dodecyl sulfate), and phenolic deproteinization. DNA precipitation was performed with ethanol. The precipitate was washed again in 70% ethanol, dried, and dissolved in 400 µl of TE buffer (10 mM Tris + 1 mM EDTA, pH 8.0). The quantity and quality of DNA were assessed using a NanoDrop2000 spectrophotometer.

A labeled oligonucleotide (GTG)5 containing a digoxigenin mark was used as a molecular probe. Genomic DNA was cleaved with *Hae*III restriction endonuclease, electrophoresis was performed in tris-acetate buffer, and DNA fragments separated by size were transferred to a nylon filter. After fixing the DNA on the filter, it was placed in a tray for molecular hybridization. The DNA probe complementarily bound to corresponding sections of genomic DNA on

[3]*Kiseleva T.Yu., Kantanen J., Vorobyev N.I., Podoba B.E., Terletsky V.P.* Imbalance in the linkage disequilibrium of microsatellite loci in six local populations of cattle // Genetics, 2014, Vol. 50, No. 4, pp. 406-414.

the filter. After washing off the unincorporated label, a solution for immunohistochemical detection of digoxigenin was added to the tray. Developed DNA fragments with a label appearing as dark bands were visualized, and the number of common and differing bands (pairwise on all electrophoretic tracks) was counted. Population genetic parameters (heterozygosity, genetic distance, allele frequencies) were calculated using the GelStats computer program.

RESULTS AND DISCUSSION

During the experiment, after the molecular hybridization reaction, 5 to 12 DNA fragments were detected on the filter, the number and distribution of which are characteristic of each individual (see the figure). Tracks 2–11 and 13–20 are the results of analyzing Dromedary camels; 22–31 and 33–40 are Bactrian camels. On tracks 1, 12, 21, 32, and 41, a DNA fragment length marker is shown. The range of the marker DNA fragments lengths ranged from 500 to 23,000 base pairs of the DNA. It was found that a significantly larger number of DNA fragments were identified in the Bactrian group.

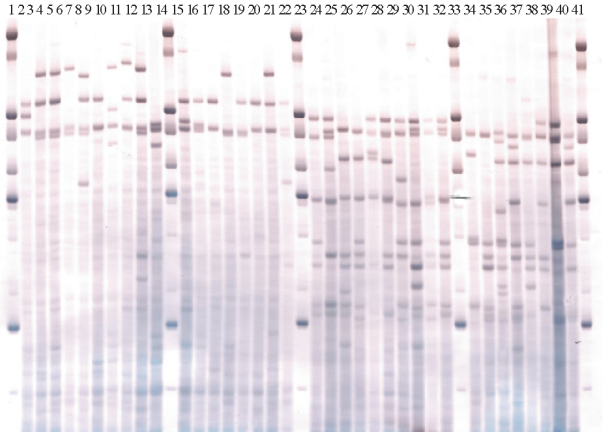
Pairwise comparison of the number of common DNA fragments between populations showed an extremely low value of the interpopulation similarity coefficient (0.13), while the intrapopulation similarity coefficient reached 0.39 for Dromedaries and 0.48 for Bactrians (see Table 1). The calculated genetic distance between the populations gave a rather high value – 0.305, which is much higher than the previously obtained indicators when comparing different breeds of cattle.

Табл. 1. Популяционно-генетические параметры исследуемых популяций верблюдов по данным ДНК-фингерпринтинга

Table 1. Population and genetic parameters of the studied camel populations according to DNA fingerprinting data

Type	*n*	Number of bands per one lane ($X \pm m$)	P	BS[1]	BS[2]	D
Dromedary camel	18	3,44 ± 0,27	$3{,}81\times10^{-2}$	0,39		
Bactrian camel	18	7,61 ± 0,34	$3{,}55\times10^{-3}$	0,48	0,13	0,305

Note. P - probability of occurrence of an identical set of all DNA fragments in the compared pairs of individuals; BS1 - intrapopulation similarity coefficient; BS2 - interpopulation similarity coefficient; D - genetic distance between populations.



ДНК-фингерпринтинг геномной ДНК верблюдов обеих групп

DNA fingerprinting of the genomic DNA of camels of two groups

The calculation of average heterozygosity showed greater genetic diversity in the Dromedary population (H = 0.72), which was indirectly confirmed by the low value of the similarity coefficient in this group of animals (see Table 2). Bactrians were characterized by greater homogeneity according to genetic parameters.

CONCLUSION

Thus, the obtained data show that the two compared camel populations are characterized by significant genetic differences. Single-humped camels have greater diversity by genetic criteria within their population. As we can see, DNA fingerprinting with a labeled DNA probe can be used to assess genetic diversity in camels.

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Табл. 2. Характеристика внутрипопуляционного генетического разнообразия верблюдов

Table 2. Characteristics of intra-population genetic diversity in camels

Type	*n*	Number of loci	Number of alleles	Number of polymorphic loci	Average heterozygosity
Dromedary camel	18	2,01	9,46	1,00	0,72
Bactrian camel	18	4,55	5,49	1,00	0,67

Animal Breeding. 2015. Vol. 58. N 2. P. 269–275. DOI: 10.5194/aab-58-269-2015.
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РАЗРАБОТКА АГРОТЕХНОЛОГИЧЕСКИХ ТРЕБОВАНИЙ ДЛЯ ПРОИЗВОДИТЕЛЕЙ ТЕХНИЧЕСКИХ СРЕДСТВ, ИСПОЛЬЗУЕМЫХ В ТОЧНОМ ЗЕМЛЕДЕЛИИ

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Приведены результаты исследования по разработке и формированию агротехнологических требований для производителей сельскохозяйственной продукции и технических средств, используемых в точном земледелии на территории Республики Казахстан. Существующие агротехнические требования не учитывают влияние систем точного земледелия на технологические параметры при выполнении технологических операций. В процессе проведения исследования сформированы базы данных по агротехнологическим параметрам технологических операций, а также машин и оборудования, используемых в системе точного земледелия. На основании сформированных баз данных сформулированы агротехнологические требования для производителей сельскохозяйственной продукции и технических средств системы точного земледелия. Агротехнологические требования к проведению машинной технологической операции состоят из следующих разделов: «Назначение», «Условия применения», «Предшественники», «Предшествующие и последующие операции», «Агротехнологические требования к качеству выполнения», «Агротехнические требования к технике». В первом разделе представлена информация, поясняющая, для чего предназначена данная технологическая операция; во втором – приводятся климатические и почвенные условия, влажность семян, удобрений, состояние убираемого материала; в третьем – различная необходимая информация; в четвертом – требования к качеству выполнения технологического процесса; в пятом – тип рабочего органа, рабочая скорость, коэффициент надежности технологического процесса, коэффициент использования времени смены, коэффициент готовности, точность вождения агрегата (отклонение от заданного направления движения) без средств навигации, системы параллельного и автоматического вождения с отклонением от заданного направления движения и другие системы точного земледелия для более качественного и эффективного выполнения технологического процесса, дорожный просвет, транспортная скорость движения и требования к конструктивному исполнению сельскохозяйственной машины (орудия).

Ключевые слова: агротехнологии, технологические параметры, точное земледелие, системы автоматического вождения, дистанционный мониторинг

DEVELOPMENT OF AGROTECHNOLOGICAL REQUIREMENTS FOR MANUFACTURERS OF TECHNICAL TOOLS AND AGRICULTURAL PRODUCTS USED IN PRECISION FARMING

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The results of research on the development and formation of agro-technological requirements for producers of agricultural products and technical means used in precision farming in the Republic of

Kazakhstan are presented. The existing agrotechnical requirements do not take into account the influence of precision farming systems on the technological parameters when performing technological operations. In the course of the research, databases were formed on agrotechnological parameters required for technological operations, as well as on the machines and equipment used in the precision farming system. Based on the generated databases, agrotechnological requirements were developed for the producers of agricultural products and technical means used in precision farming systems. Agrotechnological requirements for a machine technological operation consist of five sections: "Purpose", "Conditions of use", "Forecrops", "Previous and subsequent operations", "Agrotechnological requirements for the quality of performance", "Agrotechnological requirements for the equipment". The first section provides information explaining what this technological operation is intended for; the second section tells about climatic and soil conditions, moisture content of seeds, fertilizers, the condition of the material being harvested; the third section gives various necessary information; the fourth section presents the requirements for the quality of the technological process; the fifth section provides the following information: type of the working body, working speed, process reliability coefficients, shift time utilization coefficient, readiness coefficient, unit driving accuracy (deviation from a given direction of movement) without navigation aids, parallel and automatic driving systems with deviation from a given direction of movement and other precision farming systems for better and more efficient execution of the technological process, road clearance, the transport speed of movement and the requirements for the design of an agricultural machine (tool).

Keywords: agricultural technologies, technological parameters, precision farming, systems automatic driving, remote monitoring

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INTRODUCTION

Agrotechnological requirements for the technological process consist of a set of rules for the impact of agricultural machines on the environment being treated, aiming to produce a specified quality of products at the lowest costs. These requirements form the basis for developing a system of technologies and machines, initial requirements, and technical tasks in creating new equipment, technological maps, and other technological documentation.

In Kazakhstan, as part of the implementation of soil conservation technology, methodological recommendations and agronomic and soil conservation requirements for soil treatment have been prepared. The main task of mechanical soil treatment is to create optimal conditions within the treated layer for the normal growth, development, and formation of crops yield[1]. Considering the requirements for soil treatment quality, agrotechnical requirements have been formu-

[1]*Gossen E.F., Dvornikova T.N., Vogel V.T.* To the methodology of determining the parameters of soil tillage quality for specification of soil-protective technology of cultivation of field crops. Tselinograd, 1979. 45 p.

lated, and anti-erosion complex machines have been created[2, 3].

At the initial stage of economic reforms in the agricultural production of the republic, simplified cultivation technologies for grain and fodder crops were applied due to emerging economic difficulties. The traditional soil conservation technology reduced the number of mechanical treatments, and in minimal and zero technologies, only the most necessary technological operations remained.

Currently, there are no agrotechnological requirements for technological operations in the cultivation of agricultural crops of domestic development in the Republic of Kazakhstan. Existing agrotechnical requirements and initial requirements for basic machine technological operations in crop production are outdated both technically and technologically[4,5]. These regulatory documents were adopted in 2001 and 2005 respectively. Over the past 15–20 years, new crop cultivation technologies have been introduced in the agricultural sector of Kazakhstan, and modern high-performance agricultural machinery equipped with digital technologies and precision farming systems have been used. The use of new technologies and new equipment has contributed to improving the quality of work, productivity, and production efficiency.

The purpose of the study is to formulate agrotechnological requirements that meet modern realities for performing mechanized agricultural work, forming technological maps, and technical tasks in the field of designing agricultural machines.

The novelty of the conducted research lies in the fact that in formulating agrotechnological requirements for performing technological operations in the conditions of the northern region of the Republic of Kazakhstan, indicators of the technological process were used, taking into account the influence of precision farming systems.

MATERIAL AND METHODS

Parameters and agrotechnical requirements for technological processes in the cultivation of agricultural crops in the system of precision farming were established for three main technologies: soil conservation, minimal, and zero tillage. The requirements were compiled based on the recommendations of the Scientific Research Institute of Agriculture and experimental stations, data from monographs, and other materials[6-8] [1].

In addition, zonal characteristics of cultivating agricultural crops, as well as existing requirements and recommendations for the use of agricultural machinery in the northern region of Kazakhstan (see footnotes 2-5), were taken into account. When developing agrotechnical requirements for basic technological processes, features and advantages of using agricultural machinery in the system of precision farming were considered[9, 10] [2-6]. In particular, the ability to equip machinery with elements of the precision farming system: remote monitoring systems with GPS trackers installed on tractors, fuel consumption sensors, navigation systems, etc. [7, 8].

Requirements for each technological process should consist of the following sections:

[2]*Baraev A.I., Zaitseva A.A., Gossen E.F.* Agrotechnical requirements for a set of tillage implements and seeding machines for areas with soils unstable to wind erosion // Improvement of tillage machines, Moscow, 1963. pp. 34-54.

[3]*Gribanovsky A.P., Bidlingmeyer R.V., Revyakin E.P.* Complex of anti-erosion machines (device, adjustments, operation). Moscow: Agropromizdat, 1989. 152 p.

[4]*Aniskin V.I., Artyushin A.A.* Initial requirements for basic machine technological operations in crop production. Moscow, 2005. 270 p.

[5]Agrotechnical requirements for the main technological operations in adaptive technologies of cultivation of winter spikelets and corn, and new technical means for their implementation in the Krasnodar Territory: methodical instructions. Krasnodar: Agroprompolygraphist, 2001. 144 p.

[6]*Alabushev A.V.* State and ways of efficiency of crop production industry. Rostov-on-Don: Book, 2012. 384 p.

[7]*Bessonova E.A.* Energy and resource saving - the most important factor of agrotechnologies and soil fertility improvement // Bulletin of the Kursk State Agricultural Academy, 2010, No. 1, pp. 44-49.

[8]*Belyaeva B.I., Mandzhieva T.V.* Treatment of soils subject to wind erosion // Bulletin of the Institute for Integrated Research of Arid Territories, 2011, Vol. 2, No. 2, pp. 62-66.

[9]*Shpaara D., Zakharenko V., Yakusheva V.* Precision agriculture. St. Petersburg: Pushkin, 2009, 397 p.

[10]*Yakushev V.V.* Precision farming: theory and practice. St. Petersburg, 2016, 364 p.

1) a list of technological processes performed in the cultivation of basic agricultural crops for various soil treatment technologies;

2) technological parameters and special requirements for technological processes;

3) general requirements for the technological process and machinery;

4) timing of technological processes;

5) a list of technical means required for their implementation.

As practice has shown, the adoption of irrational decisions is often associated with the specialist lacking necessary information. The first step in updating agrotechnological requirements for manufacturers of technical means used in precision farming is the formation of a database of machines and equipment for the implementation of promising technologies.

The structural scheme of the database of agrotechnological parameters and requirements for the technological process is presented in Fig. 1.

A database is a collection of information (about real objects, processes, events, or phenomena) related to a specific topic or task, organized in such a way as to provide a convenient representation of this collection as a whole and in parts.

The process of developing a database consists of several formalized stages[11, 12]:

1) study of the subject area, object of activity, functions, the performance of which should be based on the materials of the base, determination of goals;

2) creation of the database structure based on the analysis of the subject area and relationships between information objects;

3) collection of factual material and filling the database;

4) information filtering, exclusion of unreliable data, filling gaps, evaluating informativeness.

The construction of the database is based on the application of a systematic approach, which

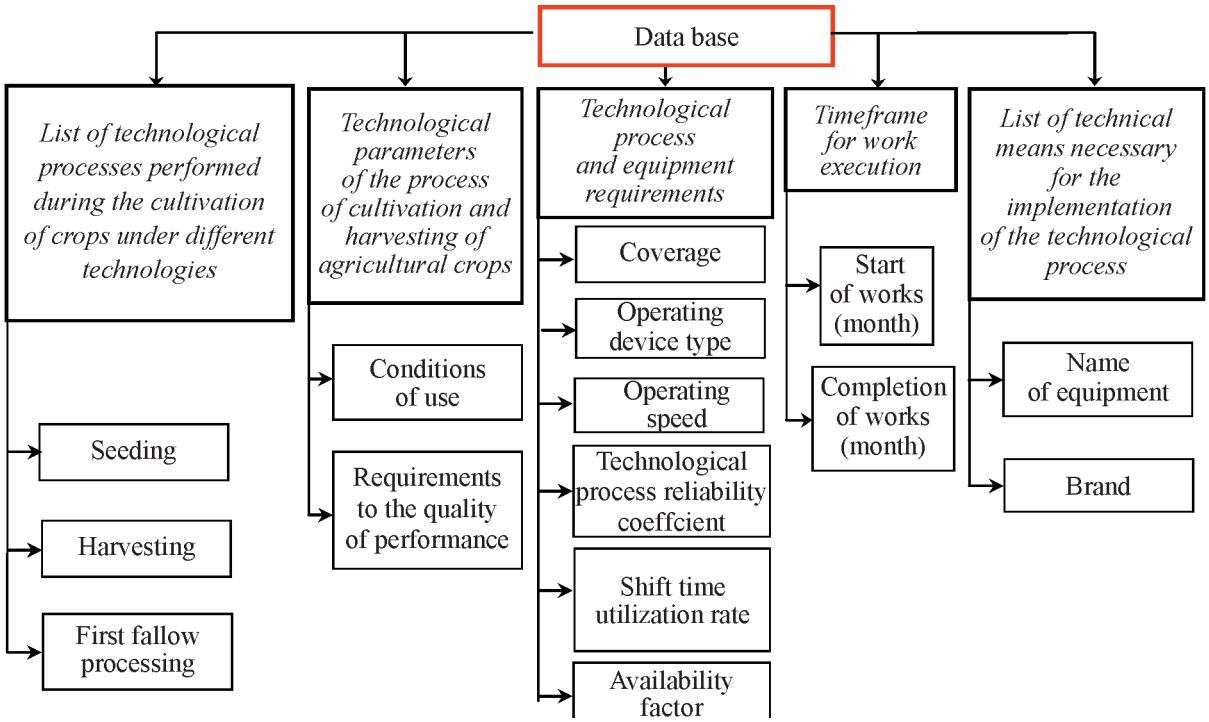

Рис. 1. Структурная схема базы данных агротехнологических параметров и требований к технологическому процессу

Fig. 1. Block diagram of the database of agrotechnological parameters and requirements for the technological process

[11] *Fufaev E.V.* Databases. Moscow: Academia Publishing Center, 2008. 320 p.

[12] *Fedorenko V.F., Buklagin D.S., Chavikin Y.I., Nino T.P.* Engineering and technical databases in the system of scientific and information support of innovative development of the agricultural complex. Moscow: Rosinformagroteh, 2013. 128 p.

involves considering the base as a large system consisting of a certain set of interconnected and interacting elements [9, 10].

The creation of the database is guided by the following rules:

1) taking into account the interests of all potential users;

2) modular principle of development - the independence of developing each module relative to others;

3) standardization of information support - maintaining the unity of terminology used in relation to machines and equipment.

One of the most energy-intensive stages of creating a database is filling it with relevant information. The search for information was carried out in materials presented by machine testing stations, in catalogs and reference books, scientific and technical literature, on the websites of equipment manufacturers.

The database of machines and equipment contains reference information about machinery and equipment used for the implementation of promising technologies for cultivating basic agricultural crops by the system of precision farming (see Fig. 2).

To accomplish the set task, it is logical to present the structure of the database in a form of a network data model. This model is a set of elements arranged in order from general to specific, forming a graph - a tree with a hierarchical structure. Each element can be connected with any other element in the base.

The database consists of three blocks:

1) technologies for cultivating basic agricultural crops;

2) machinery used for cultivation and harvesting of agricultural crops;

3) digital systems and equipment for precision farming.

Each of the blocks contains in its structure a number of modules, in which machines, equipment, and other components are grouped by functional purpose. Modules from different blocks and within one block can have a functional connection with another module.

Among the indicated information the following are presented: the name and brand of the

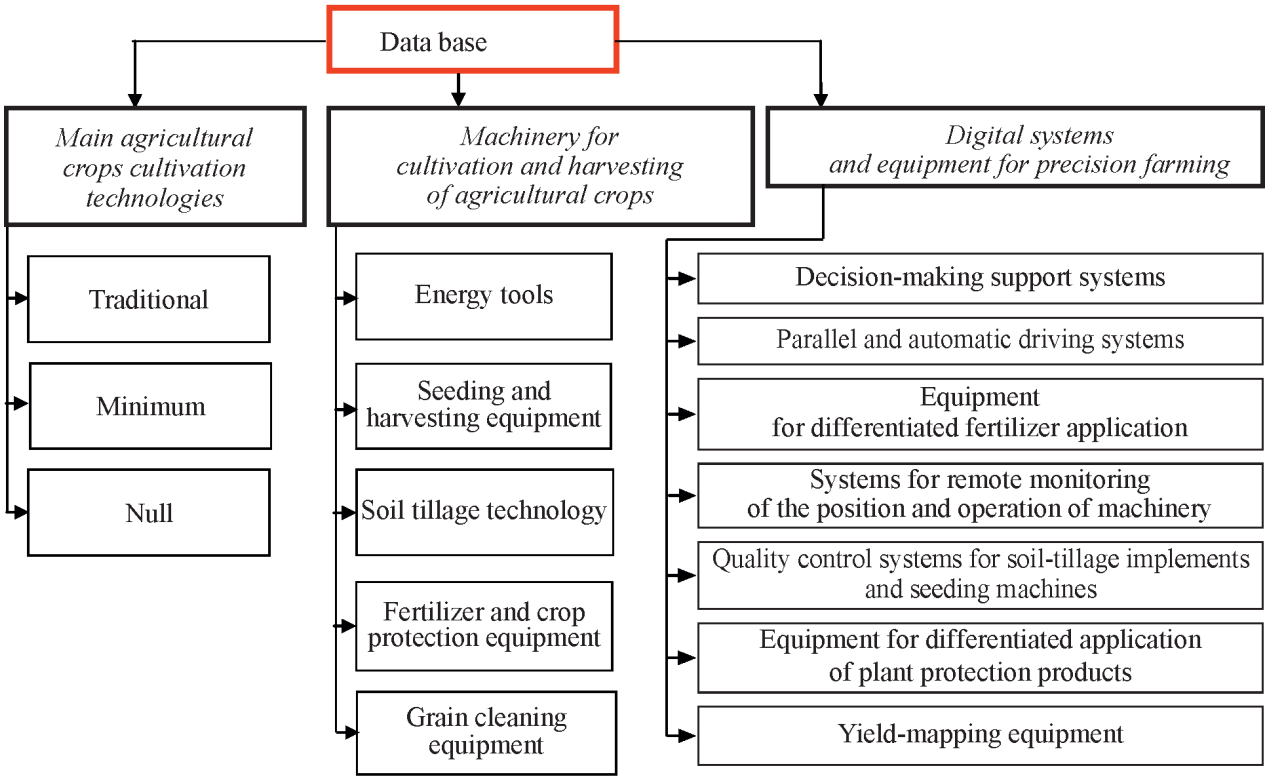

Рис. 2. Структурная схема базы данных машин и оборудования
Fig. 2. Block diagram of the machinery and equipment database

machine or equipment, photograph, description, technical specifications, type of aggregation, and manufacturer.

RESULTS AND DISCUSSION

In the course of the research, databases on agrotechnological parameters and requirements for the cultivation technologies of agricultural crops, as well as on agricultural machinery and equipment for precision farming, were formed using Microsoft Office Access.

Databases on agrotechnological parameters and requirements for the cultivation of wheat, barley, corn for silage, soy, sunflower, and flax using traditional, minimal, and zero tillage technologies have been compiled for all technological operations. Table 1 presents a fragment of the database on agrotechnological parameters and requirements for the "Early Spring Harrowing" technological process when cultivating soy using minimal technology.

A database has been developed for machines and equipment used in the precision farming system. The tractor database consists of 236 units, grain and forage harvesters with headers – 54 and 58 respectively, seeders and seeding complexes – 245, soil cultivation equipment – 599, plant protection and fertilizer application equipment – 223, grain cleaning equipment – 82, systems and equipment for precision farming – 84 units. Table 2 presents a fragment of the tractor database, and Table 3 presents a fragment of the systems and equipment used in the precision farming system.

In the process of research, agrotechnological requirements for manufacturers of technical means used in the precision farming system in the conditions of the Republic of Kazakhstan were developed. The creation of agrotechnological requirements was based on the database of agrotechnological parameters and requirements for the cultivation technologies of agricultural crops, as well as on the database of machines and equipment. In formulating agrotechnological requirements, agrotechnological parameters recommended by the Scientific Research Institute of Agriculture and experimental stations, published in the works of research and educational institutes, and obtained during the testing of machine-tractor units equipped with precision farming systems in the northern region of the Republic of Kazakhstan were used.

Agrotechnological requirements for machine technological operations in crop production have the following parts: title page, content, introduction, and the agrotechnological requirements themselves.

These requirements consist of five sections:

1) purpose – information explaining the intended use of a particular technological operation;

2) conditions of use – climatic and soil conditions, seed moisture, fertilizers, the state of harvested material;

3) forecrops, preceding and subsequent operations;

4) quality requirements for the performance of the technological process;

5) requirements for the technological process and machinery – the type of the working organ, working speed, reliability coefficient of the technological process, time utilization coefficient of the shift, readiness coefficient, driving accuracy of the unit (deviation from the specified direction of movement) without navigation means, parallel and automatic driving systems with deviation from the specified direction of movement, and other precision farming systems for more quality and efficient performance of the technological process, ground clearance, transport speed, and requirements for the design execution of agricultural machinery (implement).

CONCLUSIONS

1. An information database has been formed on agrotechnological parameters and requirements for the cultivation technologies of wheat, barley, corn for silage, soy, sunflower, and flax for all technological operations, as well as a database on agricultural machinery and equipment for precision farming (for tractors, grain and forage harvesters, headers, seeders, seeding complexes, soil cultivation equipment, plant protection and fertilizer application, grain cleaning equipment, systems and equipment used in precision farming).

2. Based on the indicated databases, agrotechnological requirements for manufacturers of

Табл. 1. Требования к технологическому процессу «Ранневесеннее боронование» при возделывании сои по минимальной технологии (фрагмент)
Table 1. Requirements for the technological process «Early spring harrowing» when cultivating soybeans using minimal technology (fragment)

Technological process	Technological parameters of the process (requirements to the quality of work)	Technical requirements	Timeframe	List of technical means
Early spring harrowing	*Conditions of use* Early spring harrowing is carried out on soil of different mechanical composition when it reaches physical ripeness (moisture up to 30%) on the fields with stubble of ear crops. The amount of the stubble - 250-300 pieces/m^2, height up to 20 cm *Requirements to the quality of performance* Depth of cultivation 4-5 cm. Deviation of the average depth of cultivation from the set depth should not exceed ± 1 cm. The processed layer of soil should have fine crumbling with at least 75-80% of clods of 1 to 25 mm in size. Clumps larger than 10 cm are not allowed. After tillage, at least 85% of the stubble should remain on the field surface compared to the initial amount. Overlap of passes - not more than 10-15 cm	Coverage 12-27 m; drawbar category of the tractor - 2-6 dc; type of the working tool - chain tooth, spiny; working speed 15-20 km/h; technological process reliability coefficient - 0,99; shift time utilization coefficient - 0,85	April-May	Harrows: a) BTSD-12; b) BZTS-12; c) Lira-XL-15; d) Kama-18; e) Kama-27; f) TPB-27 “Agristar”

Табл. 2. База данных по тракторам (фрагмент)
Table 2. Tractor database (fragment)

Make, model	Characteristics						
	Drawbar category	Operating weight, kg	Engine make	Engine power, kW (hp)	PTO shaft rotational speed, rpm	Load capacity of the suspension gear, kgf	Manufacturing plant
Belarus-1523/1523T1	2	6250	D-260.1 (ММЗ)	109 (148)	540/1000	6500	OJSC Minsk Tractor Plant, Republic of Belarus
Belarus -1523.3/1523T1.3	2	6250	D-260.1S2 (ММЗ)	111 (150)	540/1000	6500	

Табл. 3. База данных по системам и оборудованию для точного земледелия (система автоматического вождения, фрагмент)
Table 3. Database of the systems and equipment for precision agriculture (automatic driving system, fragment)

Name	Driving accuracy	Control device	Drive type of self-steering	Possibility of area measurement along the outline	Antenna used	Manufacturing plant
Automatic driving system EZ-Steer	CenterPoint RTK, CenterPoint VRS, CenterPoint RTX – up to 2,5 cm; OmniSTAR HP/XP – 5–10 cm; OmniSTAR – 8–10 cm; OmniSTAR VBS – more than 1 m; RangePoint RTX – up to 15 cm	TMX-2050 system display – 30.8 cm high-definition touch screen display; CFX-750 display – 20.3 cm high-definition touch screen display	Electric actuator with friction roller, mounted on the steering column of the machine	Exists	AG25	Trimble, California, USA

technical means used in precision farming have been developed.

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ПРАВИЛА ДЛЯ АВТОРОВ

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

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

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

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

Наименование рубрики	**Шифр и наименование научной специальности в соответствии с Номенклатурой научных специальностей, по которым присуждаются ученые степени**
Земледелие и химизация	4.1.1. Общее земледелие и растениеводство 4.1.3. Агрохимия, агропочвоведение, защита и карантин растений
Растениеводство и селекция	4.1.1. Общее земледелие и растениеводство 4.1.2. Селекция, семеноводство и биотехнология растений
Защита растений	4.1.3. Агрохимия, агропочвоведение, защита и карантин растений
Кормопроизводство	4.1.1. Общее земледелие и растениеводство 4.1.2. Селекция, семеноводство и биотехнология растений 4.1.3. Агрохимия, агропочвоведение, защита и карантин растений
Зоотехния и ветеринария	4.2.3. Инфекционные болезни и иммунология животных 4.2.4. Частная зоотехния, кормление, технологии приготовления кормов и производства продукции животноводства 4.2.5. Разведение, селекция, генетика и биотехнология животных
Механизация, автоматизация, моделирование и информационное обеспечение	4.3.1. Технологии, машины и оборудование для агропромышленного комплекса
Переработка сельскохозяйственной продукции	4.3.3. Пищевые системы
Проблемы. Суждения Научные связи Из истории сельскохозяйственной науки Краткие сообщения Из диссертационных работ	4.1.1. Общее земледелие и растениеводство 4.1.2. Селекция, семеноводство и биотехнология растений 4.1.3. Агрохимия, агропочвоведение, защита и карантин растений 4.2.3. Инфекционные болезни и иммунология животных 4.2.4. Частная зоотехния, кормление, технологии приготовления кормов и производства продукции животноводства 4.2.5. Разведение, селекция, генетика и биотехнология животных 4.3.1. Технологии, машины и оборудование для агропромышленного комплекса 4.3.3. Пищевые системы

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

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

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

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

Публикации для авторов **бесплатны**.

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

РЕКОМЕНДАЦИИ АВТОРУ ДО ПОДАЧИ СТАТЬИ

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

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

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

ПОРЯДОК НАПРАВЛЕНИЯ РУКОПИСЕЙ СТАТЕЙ

1. Отправка статьи осуществляется через электронную редакцию на сайте журнала **https://sibvest.elpub.ru/jour/index.** После предварительной регистрации автора в правом верхнем углу страницы выбрать опцию «Отправить рукопись». Затем загрузить рукопись статьи (в формате *.doc или *.docx) и сопроводительные документы к ней. После завершения загрузки материалов обязательно выбрать опцию «Отправить письмо», в этом случае редакция автоматически будет уведомлена о получении новой рукописи.

Сопроводительные документы к рукописи статьи:

- скан-копия письма от организации с подтверждением авторства и разрешением на публикацию (образец на **http://sibvest.elpub.ru/**);
- скан-копия авторской справки по представленной форме (образец на **http://sibvest.elpub.ru/**), в которой должно быть выражено согласие на открытое опубликование статьи в печатном варианте журнала и его электронной копии в сети Интернет;
- скан-копия рукописи с подписями авторов. Автор, подписывая рукопись и направляя ее в редакцию, тем самым передает авторские права на издание этой статьи СФНЦА РАН;
- анкеты авторов на русском и английском языках (образец на **http://sibvest.elpub.ru/**);
- скан-копия справки из аспирантуры (для очных аспирантов).

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

3. Нерецензируемые материалы (материалы научной хроники, рецензии, книжные обозрения, материалы по истории сельскохозяйственной науки и деятельности учреждений и ученых) направляются на e-mail: **sibvestnik@sfsca.ru** и регистрируются ответственным секретарем.

ПОРЯДОК ОФОРМЛЕНИЯ СТАТЬИ

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

Структура оформления статьи:

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

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

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

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

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

ВВЕДЕНИЕ (постановка проблемы, цели, задачи исследования)

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

РЕЗУЛЬТАТЫ И ОБСУЖДЕНИЕ

ЗАКЛЮЧЕНИЕ или **ВЫВОДЫ**

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

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

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

ПРИМЕРЫ ОФОРМЛЕНИЯ СПИСКА ЛИТЕРАТУРЫ, REFERENCES И СНОСОК

СПИСОК ЛИТЕРАТУРЫ:

Монография

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

Часть книги

Холмов В.Г. Минимальная обработка кулисного пара под яровую пшеницу при интенсификации земледелия в южной лесостепи Западной Сибири // Ресурсосберегающие системы обработки почвы. М.: Агропромиздат, 1990. С. 230–235.

Периодическое издание

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

REFERENCES:

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

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

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

Транслитерация авторов. Англоязычное название статьи

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

Транслитерация источника = Англоязычное название источника

Монография

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

Часть книги

Kholmov V.G. Minimum tillage of coulisse-strip fallow for spring wheat with intensification of arable agriculture in southern forest-steppe of Western Siberia. *Resource-saving tillage systems*, Moscow, Agropromizdat Publ., 1990, pp. 230–235. (In Russian).

Периодическое издание

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

СНОСКИ:

Цитируемый текст[1].

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

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

Пример:

Chu T., Starek M.J., Brewer M.J., Murray S.C., Pruter L.S. Assessing lodging severity over an experimental maize (Zea mays L.) field using UAS images // Remote Sensing. 2017. Vol. 9. P. 923. DOI: 10.3390/rs9090923.

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

РИСУНКИ, ТАБЛИЦЫ, СКРИНШОТЫ И ФОТОГРАФИИ

Рисунки должны быть хорошего качества, пригодные для печати. Все рисунки должны иметь подрисуночные подписи. Подрисуночную подпись необходимо перевести на английский язык. Рисунки нумеруются арабскими цифрами по порядку следования в тексте. Если рисунок в тексте один, то он не нумеруется. Отсылки на рисунки оформляются следующим образом: «На рис. 3 указано, что …» или «Указано, что … (см. рис. 3)». Подрисуночная подпись включает

порядковый номер рисунка и его название: «Рис. 2. Описание жизненно важных процессов». Перевод подрисуночной подписи следует располагать после подрисуночной подписи на русском языке.

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

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

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

ВЗАИМОДЕЙСТВИЕ МЕЖДУ ЖУРНАЛОМ И АВТОРОМ

Редакция просит авторов при подготовке статей руководствоваться изложенными выше правилами.

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

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

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

Все научные статьи, поступившие в редакцию журнала «Сибирский вестник сельскохозяйственной науки», проходят обязательное двухстороннее «слепое» рецензирование (double-blind – автор и рецензент не знают друг о друге). Рукописи направляются по профилю научного исследования на рецензию членам редакционной коллегии.

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

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

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

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

ПОРЯДОК ПЕРЕСМОТРА РЕШЕНИЙ РЕДАКТОРА/РЕЦЕНЗЕНТА

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

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

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

ДЕЙСТВИЯ РЕДАКЦИИ В СЛУЧАЕ ОБНАРУЖЕНИЯ ПЛАГИАТА, ФАБРИКАЦИИ ИЛИ ФАЛЬСИФИКАЦИИ ДАННЫХ

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

ИСПРАВЛЕНИЕ ОШИБОК И ОТЗЫВ СТАТЬИ

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

УВАЖАЕМЫЕ ПОДПИСЧИКИ!

Подписку на журнал «Сибирский вестник сельскохозяйственной науки»
(как на годовой комплект, так и на отдельные номера)
можно оформить одним из следующих способов:

– в агентстве подписки ГК «Урал-Пресс» по индексу 014973. Ссылка на издание https://www.ural-press.ru/catalog/97210/8707659/?sphrase_id=392975. В разделе контакты зайти по ссылке http://ural-press.ru/contact/, где можно выбрать филиал по месту жительства;
– в редакции журнала (телефон 7-383-348-37-62; e-mail: sibvestnik@sfsca.ru).

Полнотекстовая версия журнала
«Сибирский вестник сельскохозяйственной науки»
размещена на сайте Научной электронной библиотеки:
http://www.elibrary.ru.