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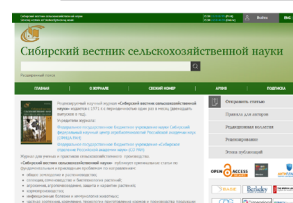
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Накопление криопротекторных сахаров и перезимовка озимой тритикале под влиянием ассоциативных ризобактерий

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В настоящее время актуальной задачей является разработка эффективных методов повышения устойчивости озимых зерновых к заболеваниям и стрессовым факторам среды с опорой на активацию собственных защитных механизмов растений. В статье представлены результаты полевых исследований, проводившихся в 2021–2024 гг. и посвященных оценке влияния предпосевной инокуляции семян микробными препаратами на адаптацию к низким температурам и зимостойкость озимой тритикале. Эксперимент проходил на опытных полях Ленинградского научно-исследовательского института сельского хозяйства «Белогорка». Объект исследования – сорт озимой тритикале Билинда. Полевой опыт включал семь вариантов: контроль и шесть вариантов с обработкой семян препаратами на основе ассоциативных ризобактерий: Агрофил (*Agrobacterium radiobacter*, штамм 10), Мизорин (*Arthrobacter mysorens*, штамм 7), Флавобактерин (*Flavobacterium* sp., штамм 30), Ризобакт марки РЖФ (*Corynebacterium* sp., штамм ПБТ 7), Ризобакт марки МЖФ (*Enterobacter* sp., штамм ПБТ 3), Ризобакт марки ФЖФ (*Pseudomonas* sp., штамм ПБТ 4). Изучали содержание растворимых углеводов (моносахаров и сахарозы) в узлах кушения в предзимний период (ноябрь – декабрь) и их взаимосвязь с поражением снежной плесенью (*Microdochium nivale*), а также сохранностью растений после перезимовки. Установлено, что обработка семян препаратами Ризобакт ФЖФ, Флавобактерин и Мизорин достоверно повышает накопление моносахаров и сахарозы в 1,45–1,55 раза относительно контроля. Также была выявлена устойчивая положительная корреляция между уровнем накопления сахарозы ($r = 0,96$) и моносахаров ($r = 0,93$) и густотой стояния растений после перезимовки. В вариантах с обработкой этими препаратами наблюдаются минимальное поражение снежной плесенью и максимальная прибавка по густоте стояния растений (31,5–47,0% по сравнению с контролем).

Ключевые слова: озимая тритикале, ассоциативные ризобактерии, узел кушения, растворимые сахара

Accumulation of cryoprotective sugars and overwintering of winter triticale under the influence of associative rhizobacteria

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Currently, the development of effective methods for increasing the resistance of winter cereals to diseases and environmental stress factors based on the activation of plants own protective mechanisms is an urgent task. The article presents the results of field studies (2021–2024) aimed at assessing the im-

pact of pre-sowing seed inoculation with microbial preparations on the adaptation to low temperatures and winter hardiness of winter triticale. The experiment was conducted on the experimental fields of the Leningrad Research Institute of Agriculture "Belogorka". The object of the study was the Bilinda variety of winter triticale. The field experiment included 7 variants: control and six variants involving seed treatment with the preparations based on the associative rhizobacteria: Agrophil (*Agrobacterium radiobacter*, strain 10), Mizorin (*Arthrobacter mysorens*, strain 7), Flavobacterin (*Flavobacterium* sp., strain 30), Rizobact brand RZhF (*Corynebacterium* sp., strain PBT 7), Rizobact brand MZhF (*Enterobacter* sp., strain PBT 3), Rizobact brand FZhF (*Pseudomonas* sp., strain PBT 4). The content of soluble carbohydrates (monosugars and sucrose) in tillering nodes was studied during the pre-winter period (November – December), and their relationship with snow mold damage and plant survival after overwintering. It has been established that seed treatment with the preparations Rizobact FZhF, Flavobacterin and Mizorin significantly increases the accumulation of monosaccharides and sucrose by 1.45–1.55 times relative to the control. A stable positive correlation has been found between the level of sucrose accumulation ($r = 0.96$) and monosaccharides ($r = 0.93$) and the plant density after overwintering. In the variants treated with these preparations, minimal damage by snow mold and maximum increase in plant density (31.5–47.0% compared to the control) are observed.

Keywords: winter triticale, associative rhizobacteria, tillering unit, soluble sugars

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The authors declare no conflict of interest.

INTRODUCTION

In recent years, there has been a consistent global trend towards reducing the use of mineral fertilizers and pesticides, as well as expanding the production of environmentally friendly products [1–4]. These changes stimulate the widespread introduction of microbial preparations in agriculture. One of the modern and effective ways to increase the yield of agricultural crops is the inclusion of microbiological preparations in the technology of their cultivation [5–8]. Such preparations have a positive effect on plant growth processes and contribute to their adaptation to various adverse factors without negatively affecting the environment¹ [9–11].

The effectiveness of biopreparations depends on their composition and method of application.

Thus, in various regions of the Russian Federation, the use of biological preparations in the cultivation of winter triticale has led to an increase in yield from 0.14 to 1.10 t/ha [12]. The presented data confirm the promising potential of using microbiological preparations in the technology of winter triticale cultivation, especially under the conditions of the Northwestern region.

An important problem in growing winter crops remains the increase of their frost resistance, winter hardiness, and disease resistance. The adaptive processes that occur in plants during the winter period are accompanied by significant changes in metabolism and depend on species and varietal characteristics.

It has been established that there is a positive correlation between the level of frost resistance

¹Maisak G.P., Startseva A.B. Science for production. Winter triticale for forage and grain // Multifunctional adaptive fodder: collection of scientific works. Moscow, 2023, Iss. 30 (78), pp. 92–97.

of winter crops and their sugar content. The main volume of soluble sugars (about 90%) is concentrated in the cytosol, vacuoles, and other cell organelles, and only about 10% is located in the intercellular space, which prevents the formation of intracellular ice and increases resistance to low temperatures².

The degree of accumulation of water-soluble carbohydrates in cells depends on the type of plant. Symplastic species are characterized by the transport of substances through the cytoplasm and high sensitivity to low temperatures, whereas apoplastic species have greater cold resistance due to the high sugar content in the intercellular space (see footnote 2).

In the formation of cold and frost resistance in plants, sugars not only play the role of osmotic regulators but also perform cryoprotective and protective functions. The formation of glycoprotein complexes prevents protein denaturation and the reduction of their activity, which contributes to an increase in the overall resistance of the cell. In addition, sugars serve as the main substrate for the synthesis of lipids and stress proteins necessary for carrying out adaptive processes and repairing cells after the cessation of exposure to low temperatures (see footnote 2) [13].

Among the lipid components that maintain the integrity of cell membranes under low temperature conditions, phytochelatins and digalactosyl-diacylglycerols occupy a special place, as they provide a lower membrane phase transition temperature.

Antifreeze proteins, which prevent the growth of ice crystals to sizes capable of causing cell death, are also of great importance. Antifreeze proteins have been found in the intercellular space of winter rye and some wheat varieties. Certain low-molecular-weight glycoproteins and galactose-specific lectins, whose accumulation is closely associated with plant resistance to low temperature exposure (see footnote 2), are also considered cryoprotectants [13].

Thus, the use of microbiological preparations aimed at activating the natural mechanisms of plant resistance opens up additional opportunities for increasing the productivity of winter crops in northern regions. Of particular interest in this context are associative rhizobacteria capable of influencing key adaptive processes, including the accumulation of cryoprotective sugars.

However, there is currently insufficient experimental data quantitatively confirming the direct connection between inoculation with specific strains of rhizobacteria, the dynamics of sugar accumulation, and the actual winter hardiness of winter triticale.

In this regard, the objectives of our study were to assess the effect of pre-sowing inoculation of winter triticale seeds with strains of associative rhizobacteria on the accumulation of cryoprotective sugars in the tillering nodes, as well as to establish the quantitative relationship of this indicator with plant density and the level of snow mold infestation (*Microdochium nivale*).

MATERIAL AND METHODS

The study was conducted on the experimental field of the Leningrad Research Institute of Agriculture "Belogorka" – Branch of the "Federal Potato Research Center named after A.G. Lorkh". The object of the study was the winter triticale variety Bilinda.

The soil of the experimental plots is sod-podzolic, light and medium loamy. The humus content in the arable layer is 2,60–2,80%, P₂O₅ – 202–208 mg/kg of soil, K₂O – 97–102 mg/kg, pHKCl = 4,7–5,2.

Pre-sowing treatment of seeds with microbial preparations was carried out on the day of sowing. The working suspension was prepared based on preparations with a titer of 5×10⁹ CFU/ml. The application rate of the preparation is 1 liter per 1 ton of seed (equivalent to 100 ml/ha at a

²Koshkin E.I. Physiology of the resistance of agricultural crops: a textbook for universities. Moscow, 2010, 640 p.

seeding rate of 300 kg/ha), the total application rate of the working fluid is 10 liters/t. The trial was conducted with a randomized plot layout. The experimental plot area was 10 m², and the trial was replicated four times.

Experimental design:

1. Control (treatment with water).
2. Agrophil (*Agrobacterium radiobacter*, strain 10).
3. Mizorin (*Arthrobacter mysorens*, strain 7).
4. Flavobacterin (*Flavobacterium* sp., strain 30).
5. Rizobact RZhF (*Corynebacterium* sp., strain PBT 7).
6. Rizobact MZhF (*Enterobacter* sp., strain PBT 3).
7. Rizobact FZhF (*Pseudomonas* sp., ИТАММ ИБТ 4).

Samples for sugar determination were collected in the first ten days of November and the first ten days of December. For biochemical analysis, plants were selected diagonally from each experimental plot. An average sample was formed for each experimental treatment. The total number of plants in each sample was 100–150 pcs.³ The tillering nodes were dried to a completely dry state and crushed. A 2-g sample was collected for analysis. The soluble sugar content of the tillering nodes was determined using the Bertrand method.

After the resumption of vegetation, the density of overwintered plants was counted and the crops were assessed for snow mold damage.

The degree of snow mold infestation was assessed on a four-point scale, where 0 – healthy plants; 1 – sporadic spots on the lower and upper leaves, total infection up to 10% of leaves; 2 – lower leaves completely affected, upper leaves have spots (2–3 per leaf), total infection up to 30% of all leaves; 3 – lower and upper leaves affected, side shoots dying, total infection up

to 70% of all leaves; 4 – all leaves and shoots affected, total infection 100%⁴ [14]. Statistical data processing was carried out using the analysis of variance method according to the field experiment methodology of B.A. Dospekhov⁵.

The analysis of weather conditions during the research period revealed significant interannual variability in both temperature patterns and precipitation levels, which substantially affected the overwintering conditions of winter triticale. During the experiments, weather conditions in the key period for plant adaptation varied significantly. In the 2021/22 season, November was wet (46.4 mm of precipitation) with a positive average air temperature of 3.5 °C, while December was cold (–13.2 °C). In the 2022/23 season, there was contrasting weather: a relatively dry November (21.6 mm) with a sharp cold spell at the end of the month (–5.8 °C). The most stressful conditions were observed in the 2023/24 season, when a warm (5.2 °C) and wet (29.5 mm) November was followed by a cold December (–12.1 °C) with a low moisture level (8.3 mm) (see Fig. 1).

RESULTS AND DISCUSSION

The research results showed that pre-sowing inoculation of winter triticale seeds with associative rhizobacteria significantly affects the intensity of accumulation of cryoprotective sugars in the tillering nodes during the period of active preparation for winter (see Table 1).

A general trend for all variants was an increase in the content of monosaccharides and sucrose, which depended on the microbial strain used and the conditions of the specific year.

Based on the stability and pronounced effect, all the studied drugs were divided into groups. The most effective included Rizobact FZhF, Flavobacterin, and Mizorin, which provided the

³Sapunko V.L., Solonkin A.V., Belyaev A.I., Pugacheva A.M., Guzenko A.Yu., Guzenko A.V. Recommendations for the organization of experimental plots of agricultural crops. Volgograd, 2022, 44 p.

⁴Methodical guidelines for registration testing of fungicides in agriculture. Nesvizh, 2007, 511 p.

⁵Dospekhov B.A. Methodology of field experience (with basics of statistical processing of research results). Moscow: Agropromizdat, 1985, 352 p.

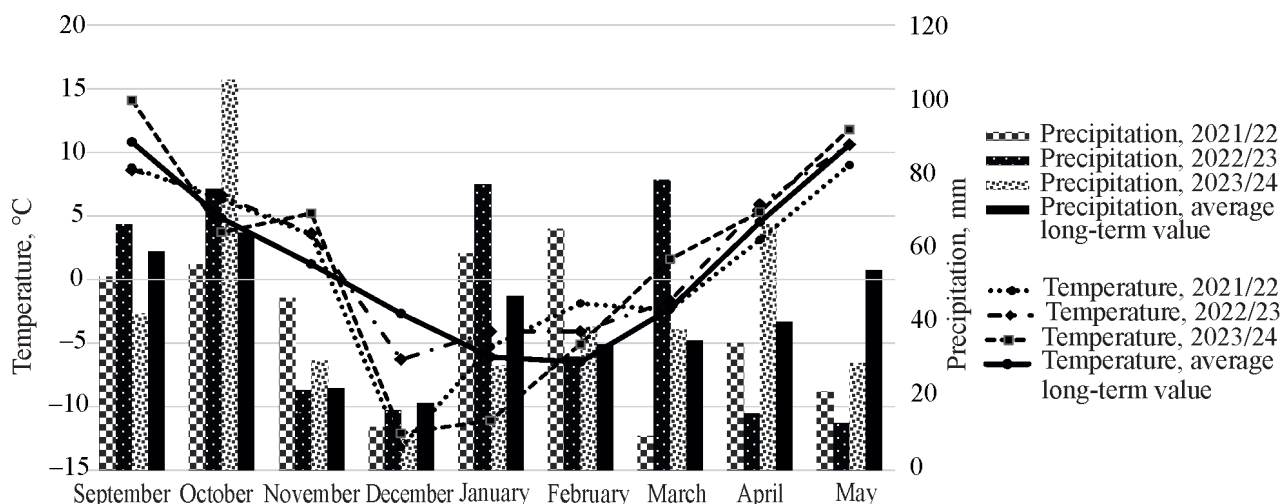


Рис. 1. Среднемесячная температура воздуха и распределение атмосферных осадков за вегетационный период озимой тритикале
Составлено на основе данных метеостанции д. Белогорка (Гатчинский район Ленинградской области)

Fig. 1. Average monthly air temperature and precipitation distribution for the growing season of winter triticale
Compiled on the basis of the data from the meteorological station Belogorka (Gatchina District of the Leningrad Region)

Табл. 1. Влияние микробных препаратов на содержание сахаров в узле кушения
Table 1. The effect of microbial preparations on the sugar content in the tillering node

Experiment option	Monosaccharides, %		Sucrose, %	
	November	December	November	December
2021				
Control (water)	13,6 ± 1,1	22,0 ± 0,9	8,8 ± 0,7	17,2 ± 1,2
Agrophil (<i>Agrobacterium</i>)	13,5 ± 0,8	24,5 ± 1,1	11,1 ± 0,6	19,1 ± 1,3
Mizorin (<i>Arthrobacter</i>)	24,0 ± 1,1	31,0 ± 0,7	20,1 ± 1,2	30,1 ± 1,2
Flavobacterin (<i>Flavobacterium</i>)	22,6 ± 1,3	32,8 ± 1,1	24,1 ± 1,2	26,2 ± 0,6
Rizobact RZhF (<i>Corynebacterium</i>)	21,9 ± 0,8	22,8 ± 1,1	22,6 ± 1,0	23,9 ± 1,0
Rizobact FZhF (<i>Pseudomonas</i>)	21,8 ± 1,4	31,7 ± 1,1	21,4 ± 1,2	27,3 ± 1,2
Rizobact MZhF (<i>Enterobacter</i>)	23,4 ± 1,1	27,9 ± 1,3	20,7 ± 0,8	24,4 ± 1,0
LSD ₀₅	1,5	2,2	1,0	2,7
2022				
Control (water)	13,7 ± 1,2	22,5 ± 1,0	7,4 ± 0,9	16,0 ± 1,0
Agrophil (<i>Agrobacterium</i>)	21,2 ± 1,4	25,2 ± 1,4	12,9 ± 1,0	17,8 ± 1,1
Mizorin (<i>Arthrobacter</i>)	25,5 ± 0,9	30,4 ± 1,4	23,3 ± 1,4	33,6 ± 1,1
Flavobacterin (<i>Flavobacterium</i>)	31,3 ± 0,8	32,4 ± 1,3	25,2 ± 1,0	27,3 ± 1,2
Rizobact RZhF (<i>Corynebacterium</i>)	24,4 ± 1,3	27,5 ± 1,0	21,2 ± 1,0	24,8 ± 1,3
Rizobact FZhF (<i>Pseudomonas</i>)	26,3 ± 1,1	33,0 ± 1,0	28,1 ± 1,2	30,2 ± 0,9
Rizobact MZhF (<i>Enterobacter</i>)	20,3 ± 1,4	26,9 ± 1,0	22,1 ± 0,9	26,3 ± 1,1
LSD ₀₅	1,8	1,5	2,4	2,1
2023				
Control (water)	16,4 ± 1,4	23,3 ± 1,2	10,4 ± 1,0	19,6 ± 1,2
Agrophil (<i>Agrobacterium</i>)	20,8 ± 1,3	26,4 ± 1,1	10,9 ± 1,0	19,8 ± 0,8
Mizorin (<i>Arthrobacter</i>)	30,0 ± 1,3	31,7 ± 1,4	21,8 ± 0,9	24,7 ± 1,3
Flavobacterin (<i>Flavobacterium</i>)	28,3 ± 1,0	31,8 ± 1,1	24,5 ± 1,4	25,5 ± 1,1
Rizobact RZhF (<i>Corynebacterium</i>)	25,7 ± 0,8	25,6 ± 1,2	21,6 ± 1,3	25,1 ± 1,4
Rizobact FZhF (<i>Pseudomonas</i>)	32,8 ± 1,3	34,7 ± 1,1	22,2 ± 1,0	27,7 ± 0,8
Rizobact MZhF (<i>Enterobacter</i>)	23,8 ± 1,0	28,0 ± 1,0	23,2 ± 1,2	24,3 ± 1,1
LSD ₀₅	2,0	1,7	2,3	2,6

maximum and stable accumulation levels of both sugar fractions. Rizobact FZhF increased the monosaccharide content by 1.49 times, and sucrose – by 1.41 times compared to the control variant. Flavobacterin was distinguished by exceptional stability, maintaining a high level of monosaccharides throughout all years of the study (up to 28.3–32.8%). Rizobact RZhF and Rizobact MZhF were classified into the group with a moderate but reliable effect. Their characteristic feature was a smooth dynamic, where the difference between the sugar content in November and December was often minimal, indicating an earlier and more gradual adaptation of the plants to low temperatures. Agrophil showed the least pronounced and unstable effect. Its key disadvantage was a weak influence on sucrose accumulation, the level of which in December 2023 was 19.8%, comparable to the control and 1.4 times lower than that of effective preparations.

A comparative year-by-year analysis revealed not only the stability of the action of effective drugs but also their critically important protective role in extreme conditions. Plants that had not been treated with microbial preparations demonstrated a basic sugar increase, whereas the most effective preparations contributed to an increase in monosaccharide and sucrose content by 1.45–1.55 times compared to the control. However, the most indicative year turned out to be 2022, which was stressful for the plants, as confirmed by the abnormally low initial sucrose level in the control in November (7.4%). By December, the level had risen to 16%, but it remained significantly lower than in other years. Under these conditions, the Rizobact FZhF and Mizorin treatments not only compensated for the stress but also ensured sucrose accumulation up to 30.2% and 33.6%, respectively, which is 1.7–2.1 times higher than the control level in December.

From a physiological point of view, the observed effects are explained by several interrelated mechanisms. Effective microbial prepara-

tions stimulate autumn photosynthetic activity and enhance the transport of assimilates to the tillering nodes. The ability of Flavobacterin and Rizobact FZhF to provide a high level of sugars in November indicates an earlier initiation of the plant adaptation process to low temperatures. Particular importance is attached to the targeted accumulation of sucrose, which acts not only as the main storage substance but also as an osmotic protector.

Thus, pre-sowing inoculation of seeds with microbial preparations is an effective method of biochemical modulation of the winter triticale condition, aimed at enhancing the natural mechanisms of adaptation to low temperatures.

The integral indicators of the effectiveness of pre-sowing seed inoculation were the preservation of plants after wintering and their resistance to snow mold. A visual scoring assessment conducted after the resumption of spring vegetation revealed clear differences between the variants. In the control, the plants exhibited the most pronounced symptoms of damage. While in the options with seed treatment using Mizorin, Flavobacterin, and Rizobact FZhF, minimal symptoms of infection were noted, indicating that these inoculants induce increased resistance to the pathogen (see Fig. 2).

Quantitative data on the standing density of surviving plants in spring fully confirmed visual observations. Compared to the control (190 pcs./m²), all the studied microbial preparations provided a significant increase. The most effective of them were Rizobact FZhF and Flavobacterin (+47.0 and 42.0%, respectively) (see Table 2).

Mizorin also showed a good result, increasing plant survival by 31.5%. The drugs Rizobact RZhF (+15.7%) and Rizobact MZhF (+10.5%) exhibited a moderate but statistically significant effect on plant survival. Agrophil demonstrated a slight positive effect (+7.8%).

Thus, the pre-sowing treatment of winter triticale seeds with preparations based on *Pseudomonas* (Rizobact FZhF), *Flavobacterium*

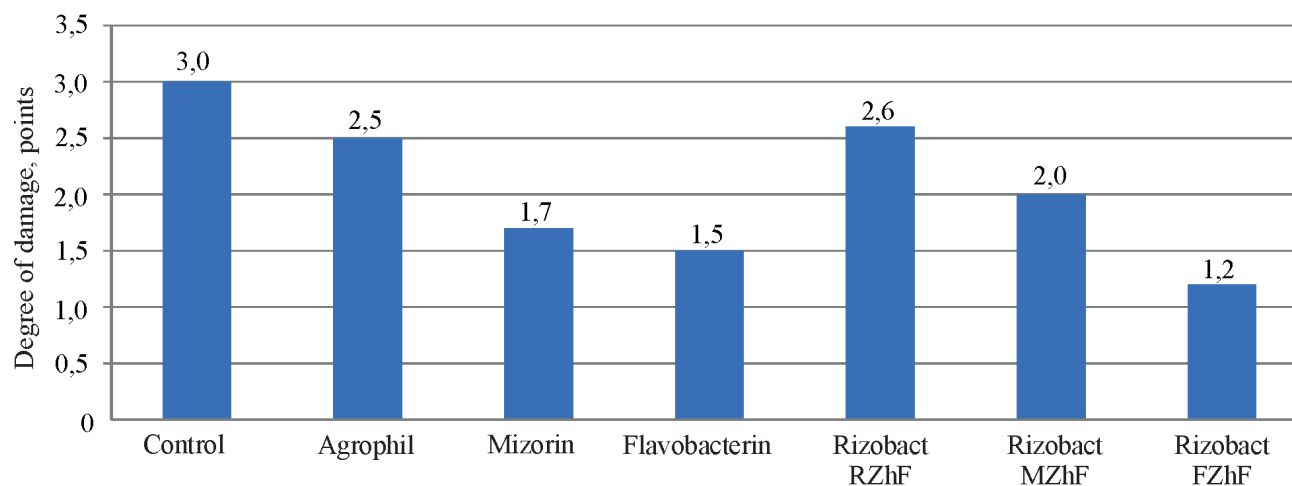


Рис. 2. Влияние микробных препаратов на поражение растений снежной плесенью

Fig. 2. The effect of microbial preparations on the damage of winter triticale plants by snow mold

(Flavobacterin) and *Arthrobacter* (Mizorin) is a highly effective method for enhancing cold adaptation. A key element in their mechanism of action is the induction of active accumulation of cryoprotective sugars in the tillering nodes.

The statistical confirmation of this causal relationship is provided by the identified strong positive correlations ($r = 0,93$, $r = 0,96$) between the content of soluble sugars (monosaccharides, sucrose) and the density of plant stands, as well as a strong negative correlation ($r = -0,9$) between the level of sucrose and the degree of snow mold damage. The accumulated reserve

of sugars provides osmotic protection for cells against freezing, serves as a resource for spring regeneration, and, consequently, determines the maximum increase in the preservation of productive stems (+31.5–47.0% relative to the control), which is a determining factor for yield formation.

The obtained data are in good agreement with the known mechanisms of interaction between associative bacteria and plants. The observed physiological effect is the result of the combined action of bacteria synthesizing phytohormones that stimulate the outflow of assimilates, the in-

Табл. 2. Влияние обработки семян микробными препаратами на густоту стояния растений (среднее за 2022–2024 гг.)

Table 2. The effect of seed treatment with microbial preparations on the density of winter triticale plants (average for 2022–2024)

Experiment option	Plant density, pcs/m ²	Gain	
		±	%
Control (water)	190	–	–
Agrophil (<i>Agrobacterium</i>)	205	15	7,8
Mizorin (<i>Arthrobacter</i>)	250	60	31,5
Flavobacterin (<i>Flavobacterium</i>)	270	80	42,0
Rizobact RZhF (<i>Corynebacterium</i>)	220	30	15,7
Rizobact FZhF (<i>Pseudomonas</i>)	210	20	10,5
Rizobact MZhF (<i>Enterobacter</i>)	280	90	47,0
LSD ₀₅	–	9,8	–

duction of systemic resistance leading to the accumulation of protective sugars, as well as the improvement of phosphorus and micronutrient nutrition due to the solubilizing activity of the bacteria.

CONCLUSION

During the conducted studies, it was established that pre-sowing treatment of winter triticale seeds with microbial preparations is an effective method for managing the adaptation process to low temperatures. The use of the preparations Rizobact FZhF (*Pseudomonas*), Flavobacterin (*Flavobacterium*) and Mizorin (*Arthrobacter*) contributes to a significant increase in the content of cryoprotective sugars. Variants with the highest sugar content showed the least damage from snow mold and the greatest preservation of plants after wintering, demonstrating an increase in stand density from 31.5 to 47.0%. In addition, strong positive correlations were identified ($r = 0,93$, $r = 0,96$) between the content of soluble sugars (monosaccharides, sucrose) and the density of plant stands, as well as a strong negative correlation ($r = -0,9$) between the level of sucrose and the degree of downy mildew infection.

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Влияние прямого посева и нормы высева на развитие симбиотического аппарата сои

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В статье приведены результаты исследования по оценке степени влияния технологии прямого посева и различных норм высева семян на общий симбиотический потенциал сои и массу клубеньков. Полевой опыт проводили в 2022–2024 гг. на территории Амурской области. Высеваемая культура – соя сорта Дебют. В рамках двухфакторного эксперимента изучали влияние двух технологий посева: без предварительной обработки почвы (прямой посев) и с обработкой (фактор А), а также четырех норм высева: 400, 500, 600 и 700 тыс. шт./га (фактор В). Полученные результаты показали, что в период от всходов до начала цветения растений посев без обработки почвы способствовал более активному развитию корневой системы и клубеньков. В период от начала цветения до образования бобов сухая масса корней оставалась существенно выше при прямом посеве (на 115 кг/га, или 11,1%). Развитие клубеньков мало различалось между технологиями посева. К фазе налива семян прямой посев ощутимо превосходил посев с обработкой почвы по сухой массе надземной части (на 502 кг/га, или 5,2%), корней (на 178 кг/га, или 16,0%) и клубеньков (на 27 кг/га, или 8,8%). За все время проведения исследования прямой посев сои показал себя эффективнее традиционной технологии в плане накопления массы клубеньков и общей продуктивности симбиотического аппарата. Оптимальной оказалась норма высева 500 тыс. шт./га, при которой был достигнут максимальный баланс между массой клубеньков и общим симбиотическим потенциалом. Корреляционный анализ показал, что в фазу начала цветения наблюдается отрицательная корреляция ($r = -0,36$, зависимость средняя), в фазу образования бобов – положительная ($r = 0,38$, зависимость средняя), а в фазу налива семян – положительная корреляция ($r = 0,125$) при слабой зависимости.

Ключевые слова: соя, прямой посев, норма высева, симбиотический аппарат, общий симбиотический потенциал

Influence of direct sowing and sowing rates on the development of the symbiotic apparatus of soybean

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The article presents the results of a study assessing the effect of direct seeding technology and different seeding rates on the overall symbiotic potential of soybeans and nodule mass. The field experiment was conducted in 2022–2024 in the Amur Region. The sown crop was the soybean variety Debut. In a two-factor experiment, the influence of two seeding technologies was studied: without preliminary soil cultivation (direct seeding) and with cultivation (factor A), as well as four seeding rates: 400, 500, 600 and 700 thousand units/ha (factor B). The results obtained showed that in the period from germination to the beginning of flowering of plants, sowing without tillage contributed to more active development of the root system and nodules. During the period from the beginning of flowering to the formation of beans, the dry mass of roots remained significantly higher with direct seeding (by 115 kg/ha, or 11.1%). Nodule development differed little between the sowing technologies. By the seed-filling stage, direct seeding significantly exceeded tillage seeding in terms of dry mass of the aboveground portion (by 502 kg/ha, or 5.2%), roots (by 178 kg/ha, or 16.0%), and nodules (by 27 kg/ha, or 8.8%). Over the entire period of the study, direct sowing of soybeans has proven to be more effective than traditional technology in terms of accumulation of nodule mass and overall productivity of the symbiotic apparatus. The optimal seeding rate turned out to be 500 thousand pieces/ha, which achieved the maximum balance between the mass of nodules and the overall symbiotic potential. The correlation analysis showed that in the early flowering phase there is a negative correlation ($r = -0.36$, average dependence), in the bean formation phase there is a positive correlation ($r = 0.38$, average dependence), and in the seed filling phase there is a positive correlation ($r = 0.125$) with a weak dependence.

Keywords: soybean, direct sowing, seeding rate, symbiotic apparatus, total symbiotic potential

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Conflict of interest

The authors declare no conflict of interest.

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INTRODUCTION

Nodular bacteria in symbiosis with leguminous plants are capable of fixing molecular nitrogen from the air and accumulating it in the arable layer. In terms of the ability to accumulate nitrogen, soybeans occupy one of the leading positions among leguminous crops: they can accumulate from 40 to 180 kg/ha of nitrogen, and their potential nitrogen fixation productivity is 390 kg/ha. After harvest, 19–63 kg/ha of nitrogen remains in the stubble and root residues and can be used by subsequent crops in the crop rotation [1].

The effectiveness of nitrogen fixation depends on soil and climatic conditions, agricultural practices, and the genetic characteristics of the variety and strain of rhizobia. Currently, scientists are conducting studies on the impact of inoculants [2–8], fertilizers [9–12], as well as their combined use [13–15] on the number and mass of nodules, and the overall and active symbiotic potential. However, against the backdrop of the introduction of new soybean cultivation technologies, the question of their impact on the indicators of symbiotic activity of this crop remains poorly studied.

In connection with the above, the purpose of our study is to assess the impact of direct sowing and seeding rate on the development of the soybean symbiotic apparatus and the overall symbiotic potential.

The research objectives are:

- 1) to study the effect of soybean cultivation technology at different seeding rates on the fresh and dry mass of nodules during vegetation;
- 2) to conduct correlation and regression analyses to determine the relationship between the mass of nodules on a single plant at different stages of development and soybean yield;
- 3) to determine the optimal agricultural techniques (seeding rate, sowing technology) to increase the symbiotic potential of soybeans.

MATERIAL AND METHODS

Field trials were conducted in 2022–2024 in the Amur Region at the experimental plot of the peasant farm “Serdyukov A.N.”. The trial design involved the use of various cultivation technologies, as well as different seeding rates:

- 1) direct sowing (without preliminary soil treatment) and traditional technology (with soil treatment) (factor A);
- 2) seeding rates: 400, 500, 600, and 700 thousand pcs./ha (factor B).

The sown crop is soybean of the Debut variety. Grain corn was used as the forecrop. The soil of the plot is meadow chernozem-like. The humus content in the arable layer is average (4.15%), available phosphorus elements are low (33.0 mg/kg of soil), and available potassium compounds are high (250.5 mg/kg).

The traditional technology included spring double disking to a depth of 16–18 and 6–8 cm.

The evaluation of the soybean symbiotic apparatus was carried out according to the method of G.S. Posypanov* based on the following indicators: fresh and dry mass of the nodules, and the total symbiotic potential. Fresh and dry mass of the nodules was determined at three stages – beginning of flowering, pod formation, and seed filling. The total symbiotic potential was determined by calculation.

Mathematical processing of the data was carried out using the analysis of variance with the Microsoft Excel program, and the calculation of the correlation of soybean yield was performed using the Statistical correlation coefficient calculator program.

RESULTS AND DISCUSSION

During the years of the study, the meteorological conditions during the soybean growing season differed from the long-term average data for the Amur region. In 2022, the total precipitation for the entire growing season was 38.1 mm lower, and in 2023 – 3.8 mm higher than the long-term average data. The average daily air temperature exceeded the long-term average by 0.8 °C.

In the specified years, the average mass of the nodules on a single soybean plant over the entire growing season was higher with direct sowing than with the use of traditional technology: in 2022 – by 0.12 g (8.2%), in 2023 – by 0.08 g (9,1%).

The maximum deviation in precipitation was observed in 2024: only 401.9 mm fell during the year (80.7% of the long-term average), and during the entire soybean growing season – 281.7 mm (65.5%). The average daily air temperature during the growing season exceeded the long-term average by 0.9 °C, and for the calendar year – by 3.3 °C. Thus, 2024 was characterized by the most difficult meteorological conditions of all the years under study due to the precipitation deficit.

This affected the development of the nodules. In 2024, their average fresh mass was lower than the indicators of 2022 and 2023 by 0.56 and 0.25 g/plant, respectively. The recommended soybean cultivation technology (with soil treatment) and direct sowing in the dry 2024 had an equivalent impact on the fresh and dry mass of nodules on a single plant (on average over the entire growing period).

On average for 2022–2024, at the first time of the tuber mass determination (flowering initiation stage), direct sowing and traditional technology had a proportionate effect on the fresh mass of the tubers per plant (see Table 1). At the same time, the dry mass of the tubers was higher with direct sowing (by 0.03 g/plant, LSD₀₅ = 0.01). The value of this indicator at a sowing rate of 400 and 500 thousand pcs./ha exceeded the options with a rate of 600 and 700 thousand pcs./ha. The maximum fresh mass was observed at a sowing rate of 400 thousand pcs./ha (0.50 g/plant). In the options with a sowing rate of 500 and 700 thousand pcs./ha, it decreased, amounting to 0.45 and 0.46 g/plant, respective-

Табл. 1. Сырая и сухая масса клубеньков (фаза начала цветения, 2022–2024 гг.), г/раст.
Table 1. Fresh and dry weight of nodules (beginning of the flowering phase, 2022–2024), g/plant

Factor A (soil treatment)	Factor B (seeding rate, thousand pcs./ha)				Average by factor A
	400	500	600	700	
No treatment					
With treatment	<u>0,50</u> 0,28	<u>0,42</u> 0,28	<u>0,41</u> 0,28	<u>0,47</u> 0,27	<u>0,45</u> 0,28
Average by factor B	<u>0,50</u> 0,29	<u>0,47</u> 0,28	<u>0,37</u> 0,22	<u>0,44</u> 0,21	<u>0,44</u> 0,25
Среднее по фактору В	<u>0,50</u> 0,29	<u>0,45</u> 0,28	<u>0,39</u> 0,25	<u>0,46</u> 0,24	<u>0,45</u> 0,27

Wet weight: LSD₀₅ A = $F_v < F_{05(v)}$, LSD₀₅ B = 0,03, LSD₀₅ = 0,04 (for quotient differences)
Dry weight: LSD₀₅ A = 0,01, LSD₀₅ B = 0,02, LSD₀₅ = 0,02 (for quotient differences)

Note. In tables 1–3: the numerator is the wet weight; the denominator is the dry weight.в знаменателе – сухая.

*Posypanov G.S. Methods for studying biological nitrogen fixation in air: reference manual. Moscow: Agropromizdat, 1991, 299 p.

ly. At a sowing rate of 600 thousand pcs./ha, the fresh mass was the lowest – 0.39 g/plant.

It should be noted that at a seeding rate of 500,000 pcs/ha, the greatest differences in the fresh mass of the tubercles were observed in favor of the soil treatment option. At the same time, the dry mass did not differ significantly between the sowing technologies. With seeding rates of 600,000 and 700,000 pcs/ha, the difference was more significant: with direct sowing, both fresh and dry mass were higher than with the traditional technology.

At the pod formation stage, the average raw mass of nodules per soybean plant increased from 0.47 to 0.70 g, and the dry mass from 0.27 to 0.34 g. At the same time, the raw mass was greater with direct sowing, and the dry mass was greater with soil cultivation (see Table 2).

With a seeding rate of 500 thousand pcs/ha, the most favorable conditions for nodule development are created, since maximum indicators of fresh and dry mass were obtained at this rate, particularly in the soil treatment variant. However, increasing the seeding rate to 600 and 700 thousand pcs/ha using the same technology led to a significant decrease in fresh (to 0.61 and 0.38 g/plant, respectively) and dry mass (to 0.26 and 0.18 g/plant).

Табл. 2. Сырая и сухая масса клубеньков (фаза образования бобов, 2022–2024 гг.), г/раст.

Table 2. Fresh and dry weight of nodules (bean formation phase, 2022–2024), g/plant

Factor A (soil treatment)	Factor B (seeding rate, thousand pcs./ha)				Average by factor A
No treatment	400	500	600	700	
With treatment	<u>0.74</u> 0,32	<u>0.70</u> 0,28	<u>0.69</u> 0,32	<u>0.78</u> 0,39	<u>0.73</u> 0,33
Average by factor B	<u>0.75</u> 0,40	<u>0.90</u> 0,56	<u>0.61</u> 0,26	<u>0.38</u> 0,18	<u>0.66</u> 0,35
Average by factor B	<u>0.75</u> 0,36	<u>0.80</u> 0,42	<u>0.65</u> 0,29	<u>0.58</u> 0,29	<u>0.70</u> 0,34

Wet weight: LSD₀₅ A = 0,03, LSD₀₅ B = 0,04,
LSD₀₅ = 0,06 (for quotient differences)

Dry weight: LSD₀₅ A = 0,02, LSD₀₅ B = 0,02, LSD₀₅ =
0,03 (for quotient differences)

It should be noted that during the pod formation phase, when sown using the traditional technology with a seeding rate of 700 thousand units/ha, the indicators of raw and dry nodule mass decreased by 0.06 and 0.03 g/plant, respectively, compared to the data from the beginning of flowering phase.

By the stage of seed filling, the raw and dry mass of tubers increased 2-fold and on average per the experiment amounted to 1.47 and 0.62 g/plant, respectively (see Table 3). In the variant with soil treatment, the highest tuber mass was observed only at the seeding rate of 400 thousand pcs/ha.

Further increasing the seeding rate led to a significant decrease in the raw and dry mass of the nodules. These indicators were best when soybeans were grown using the no-till technology in all variants. They reached maximum values at a rate of 400 and 500 thousand units/ha, significantly surpassing the other variants. At the same time, the best development of nodules was observed in the variant with a seeding rate of 500 thousand units/ha. The increase in dry mass during the period from the beginning of flowering to seed filling was the greatest at a seeding rate of 500 thousand units/ha

Табл. 3. Сырая и сухая масса клубеньков (фаза налива семян, 2022–2024 гг.), г/раст.

Table 3. Fresh and dry weight of nodules (seed filling phase, 2022–2024), g/plant

Factor A (soil treatment)	Factor B (seeding rate, thousand pcs./ha)				Average by factor A
No treatment	400	500	600	700	
With treatment	<u>1.66</u> 0,70	<u>1.65</u> 0,67	<u>1.43</u> 0,66	<u>1.34</u> 0,55	<u>1.52</u> 0,64
Average by factor B	<u>1.60</u> 0,66	<u>1.39</u> 0,53	<u>1.37</u> 0,62	<u>1.27</u> 0,55	<u>1.41</u> 0,59
Average by factor B	<u>1.63</u> 0,68	<u>1.52</u> 0,59	<u>1.40</u> 0,64	<u>1.31</u> 0,55	<u>1.47</u> 0,62

Wet weight: LSD₀₅ A = 0,03, LSD₀₅ B = 0,04,
LSD₀₅ = 0,06 (for quotient differences)

Dry weight: LSD₀₅ A = 0,02, LSD₀₅ B = 0,03, LSD₀₅ =
0,04 (for quotient differences)

(1.23 g/plant), whereas in the variant with a seeding rate of 400 thousand units/ha it was 1.16 g/plant.

Observing the development of the entire soybean plant at various stages, it should be noted that before the beginning of flowering, direct sowing and soil cultivation had an equivalent effect on the development of the above-ground part of the plant ($F_v < F_{05(v)}$). However, the root system and nodules developed better in the direct sowing variant, since in this case their mass was significantly higher than in the variant with soil treatment: dry root mass – by 26 kg/ha ($LSD_{05} = 18$), dry mass of the tubers – 17 kg/ha ($LSD_{05} = 7$).

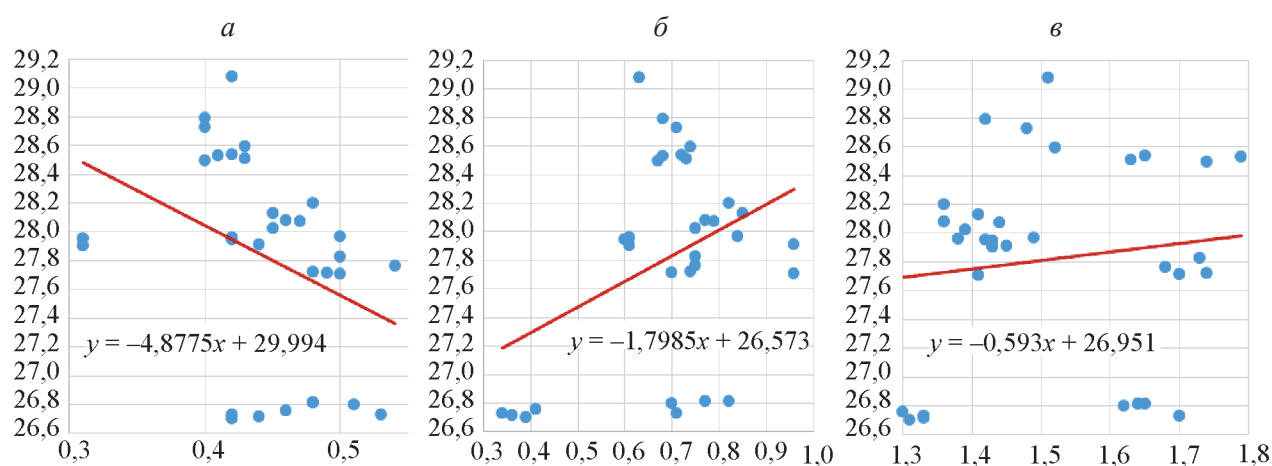
By the pod formation phase, a noticeable influence of the sowing technology on the development of the aboveground part of soybean plants was recorded. The increase in the aboveground part with direct seeding was 6316 kg/ha, whereas with the use of traditional technology – 6688 kg/ha, i.e., soil cultivation provided more intensive growth of the aboveground biomass during the period from the beginning of flowering to pod formation. However, the root system developed better with direct sowing, as the increase in root dry mass in this option was 762 kg/ha, compared to 673 kg/ha in the soil cultivation option. No

significant differences were found in the development of the nodules ($F_v < F_{05(v)}$).

At the seed filling stage, the dry matter indicators of all parts of the plants were significantly higher under direct sowing, since the amount of aboveground dry matter exceeded the soil treatment option by 502 kg/ha ($LSD_{05} = 282$), root dry matter by 178 kg/ha ($LSD_{05} = 40$), and nodule dry matter by 27 kg/ha ($LSD_{05} = 10$).

Correlation and regression analyses showed the relationship between the mass of nodules on a single plant at different stages of development and yield (see the figure).

At the beginning of the flowering phase, a negative correlation is observed ($r = -0.36$, moderate relationship). At the same time, the p -value is below the conventional significance threshold ($p = 0.0207$), which provides grounds to reject the null hypothesis and recognize the presence of a significant negative correlation. The negative slope of the straight line (-4.8685) confirms the inverse relationship between nodule mass and yield. Therefore, an increase in the tuber mass is associated with a decrease in the yield, but the relationship is average. The coefficient of determination R^2 is 0.1308, so only 13.08% of the yield variation is due to fluctuations in tuber mass, with other factors having a greater influence.



Взаимосвязь между массой клубеньков на одном растении и урожайностью семян сои (по фазам развития):

a – начало цветения; *б* – образование бобов; *в* – налив семян

Relationship between the mass of nodules on a single plant and the yield of soybean seeds (by development phases):

a – beginning of flowering; *б* – formation of beans; *в* – seed filling

Табл. 4. Общий симбиотический потенциал сои за вегетацию (среднее за 2022–2024 гг.), кг×дней/га
Table 4. Total symbiotic potential during soybean vegetation (average for 2022–2024), kg×days/ha

Factor A (soil treatment)	Factor B (seeding rate, thousand pcs./ha)				Average by factor A
	400	500	600	700	
No treatment	24 931	30 355	33 028	38 905	31 805
With treatment	24 669	30 128	30 141	31 506	29 111
Average by factor B	24 800	30 242	31 585	35 206	30 458

LSD₀₅ A = 527, LSD₀₅ B = 745, LSD₀₅ = 1053 (for quotient differences)

In the pod formation phase, a positive correlation was noted ($r = 0.38$, the relationship is moderate). The p -value is below the traditionally accepted significance threshold ($p = 0.0149$), which indicates a statistically significant positive correlation. Therefore, an increase in the nodule mass on a single plant is accompanied by an increase in the yield. As $R^2 = 0.1466$, therefore, only 14.66% of the variation in soybean yield is due to the variation in the nodule mass; the remaining 85.34% of the yield variability depends on other factors.

In the seed filling phase, the dependence is weak ($r = 0.125$), the p -value is above the standard significance threshold ($p = 0.2478$), which confirms the hypothesis of no significant correlation. The positive slope of the line (+0.5925) implies some increase in yield with the growth of tuber mass; however, the coefficient of determination is low ($R^2 = 0.0158$), which indicates a weak dependence between the tuber mass and the yield.

An indicator that characterizes the magnitude and activity of the symbiotic apparatus of legume crops, including soybeans, is the overall symbiotic potential (OSP). On average, in the experiment, it was significantly higher in the no-till variant (by 2694 kg×days/ha, LSD₀₅ = 527) than in the variant with traditional cultivation technology (see Table 4). It should be noted separately that the higher the seeding rate, the more pronounced the advantage of direct sowing. The greatest increase is observed when moving from the rate of 600 thousand to the rate of 700 thousand units/ha.

CONCLUSION

According to field trial results, under the conditions of the Amur region on meadow chernozem-like soil, the overall symbiotic potential of soybeans was higher with direct sowing at a seeding rate of 700 thousand units/ha. At the same time, the best development and accumulation of fresh and dry nodule mass on a single plant were recorded at a seeding rate of 500 thousand units/ha. The greatest significance in the relationship between nodule mass on a single plant and yield occurs at the pod formation stage, while the seed filling and maturing stages show a less pronounced effect.

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Оценка первичных ответных реакций лиственницы сибирской на использование биопрепаратов в лесных питомниках Свердловской области

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Восстановление лесных участков с помощью посадки лиственницы сибирской на Урале затруднено из-за сложности получения семян и их низких посевных качеств. Одним из способов повышения эффективности выращивания качественного посадочного материала является использование биопрепаратов с ростостимулирующим действием. В связи с этим было проведено исследование по определению влияния препаратов из экстракта древесной зелени ели и его компонентов (нейтральных и кислых) на рост 1-летних сеянцев лиственницы сибирской в двух питомниках, расположенных на территории Свердловской области. Установлено, что в Оброшинском питомнике сохранность 1-летних сеянцев в опытных вариантах была ниже на 16–28% по сравнению с контролем, а в Березовском питомнике она превышала контрольные значения на 11–30%. Также были изучены особенности развития корневой системы (длина главного и бокового корней, плотность размещения боковых корней и др.). Показано, что у сеянцев из Оброшинского питомника длина главного корня меньше и более выражен рост боковых корней в латеральном направлении, чем у растений из Березовского питомника. Изучены морфологические параметры надземной части сеянцев, выявлены различия как между вариантами в пределах одного питомника, так и между разными питомниками. Оценена степень влияния почвенных условий на рост сеянцев. Установлено, что степень проявления стимулирующего эффекта зависела от вида препарата, его дозировки и условий роста растений. Сделано заключение о положительном влиянии биопрепаратов на сохранность и биометрические характеристики сеянцев лиственницы сибирской в первый год роста в условиях открытого грунта.

Ключевые слова: лиственница сибирская, эмульсионный экстракт, кислые компоненты, нейтральные компоненты, питомники

Estimation of the early responses of Siberian larch to the use of biopreparations in forest nurseries of the Sverdlovsk region

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Reforestation by planting Siberian larch in the Urals is complicated due the difficulty of obtaining seeds and their low sowing qualities. One of the ways to increase the efficiency of growing high-quality planting material is to use biopreparations with growth-stimulating action. In this regard, a study was conducted to determine the effect of preparations from the extract of spruce wood greenery and its components (neutral and acidic) on the growth of 1-year-old seedlings of Siberian larch in two nurseries located in the Sverdlovsk region. It was found that in the Obroshinsky nursery, the survival rate of 1-year-old seedlings in the experimental variants was 16–28% lower than in the control, while in the Berezovsky nursery it exceeded the control values by 11–30%. The developmental features of

the root system (length of the main and lateral roots, density of lateral roots, etc.) were also studied. It was shown that the seedlings from the Obroshinsky nursery had a shorter main root and more pronounced lateral root growth in the lateral direction than the plants from the Berezovsky nursery. The morphological parameters of the above-ground part of the seedlings were studied, and differences were identified both between the variants within the same nursery and between different nurseries. The influence of soil conditions on seedling growth was assessed. It was found that the degree of the stimulating effect depended on the type of preparation, its dosage, and plant growth conditions. A conclusion was made about the positive effect of biopreparations on the safety and biometric characteristics of Siberian larch seedlings in the first year of growth in open ground conditions.

Keywords: Siberian larch, emulsion extract, acidic components, neutral components, nurseries

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Conflict of interest

The authors declare no conflict of interest.

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INTRODUCTION

Siberian larch (*Larix sibirica* Ledeb.) and Sukachev's larch (*L. sukaczewii* Dylis) are the most promising coniferous species for artificial reforestation and forestry in the Urals. The main limiting factors for their widespread introduction into cultivation are the difficulties in providing seeds for forestry production, as well as the low sowing quality of the seeds, whose germination significantly decreases in subsequent years of storage¹ [1]. Despite this, larch planting material is widely used both in urban landscaping and in artificial reforestation when creating pure and mixed stands. Larch can be planted with large seedlings as well as 2-year-old propagula. Characterized by rapid growth in its early years, larch can form highly productive pure stands in plantations.

When growing larch planting material in a nursery, one of the possible ways to increase

growth efficiency (achieving standard morphometric indicators by most 2-year-old seedlings) is the use of various agricultural techniques and additional measures to increase seed germination – flotation, snow treatment, and treatment with growth stimulants² [2]. Currently relevant are the development, testing, and implementation in practice of growth-stimulating preparations obtained by environmentally safe methods from plant raw materials. These preparations can not only positively affect seed germination, seedling survival, and growth, but also increase the stress resistance of plants [3–5]. For the implementation of drugs in forestry practice, it is necessary to study the regional characteristics of their use.

Previously, a method for isolating extractive substances from plant materials (in particular, from logging waste) was developed. Based on the obtained emulsion extracts of conifer-

¹Chernov N.N. Features of the creation of larch culture in the Urals// Forests of the Urals and agriculture in them, 2005, Iss. 26, pp. 111–115.

²Gribov S.E., Karbasnikov A.A., Karbasnikova E.B., Korchagov S.A. Prospective Assessment of Siberian Larch (*Larix sibirica*) in the Landscaping of the City of Vologda. *Forestry journal*, 2017, no. 2, pp. 95–106.

ous greenery (fir, spruce), preparations with growth-regulating properties have been created [6]. These preparations have been successfully tested in growing Scots pine and Siberian spruce seedlings in forest nurseries in the Sverdlovsk region [7, 8]. However, we have not found any information in the domestic scientific literature on the use of such preparations in growing larch seedlings.

The purpose of this work is to study the effect of a preparation made from the extract of fir tree greenery and its components on the growth of 1-year-old Siberian larch seedlings at the initial stage of development in the nursery conditions of the Sverdlovsk region.

MATERIAL AND METHODS

The cultivation of Siberian larch seedlings was carried out on the territory of production nurseries located in the vicinity of Yekaterinburg: Berezovsky (SPI SR "Berezovsky Forestry") and Obroshinsky (MSAI "Yekaterinburg Forestry").

The analysis of soil parameters was carried out in the Ecoanalytical Laboratory of the Institute of Biology of the Komi Scientific Center of the Ural Branch of the Russian Academy of Sciences using standard methods³. According to the obtained results, in the soils on the territory of the Berezovsky nursery the content of P_2O_5 was 1.1 mg/100 g, K_2O – 8.4 mg/100 g, N_{total} – 1.05 mg/100 g, humus content – 5.15%, pH_{salt} = 3.90, on the territory of the Obroshinsky nursery – respectively 0.8; 11.1 and 3.6 mg/100 g; 4.50%; pH_{salt} = 4.59. From the data provided it follows that the amount of organic matter in the arable layer meets the requirements of well-cultivated soil, while for other elements there is an insufficient supply to maintain the necessary soil nutrition^{4, 5}.

According to the granulometric composition, the soil in both nurseries is a medium sandy

loam. At the same time, the ratio of sand to clay fractions in the Obroshinsky nursery was 68.6% and 31.4%, and in the Berezovsky nursery – 60.5% and 39.5%, i.e., in the second case, the soil is characterized by a heavier granulometric composition.

For the study, an emulsion extract of spruce wood greenery was used – a spruce preparation (SP), as well as fractions of its acidic and neutral components. The acidic components (AC) are dominated by phenolic acids (paracoumaric, vanillic, caffeic, ferulic). The main component – *para*-hydroxyacetophenone – is known for its bactericidal and fungicidal activity. Neutral components (NC) contain essential oils, poly-prenols, carotenoids, and other biologically active substances [9].

In the field experiment, seeds of Siberian larch of the 1st quality class were used. Before sowing, the seeds were soaked for 6 hours in a solution of fir preparation (0.01; 0.05; 0.10; 0.25 ml/kg of seeds), neutral (0.0012; 0.012; 0.12 g/kg) and acidic components (0.05; 0.5; 5.0 g/kg). In the control, the seeds were soaked in distilled water. Six-row seed sowing was carried out on experimental plots measuring 1.5 × 1.0 m. The sowing rate was 3.0 g/linear meter. Agrotechnical care of the crops (soil loosening, weed removal, watering if necessary) was carried out timely in full amount. At the end of the first growing season, the larch seedlings were dug up to study the main biometric parameters (height and stem diameter, length of the main and lateral roots). For the seedlings, the number of lateral absorbing and conducting roots was taken into account, and their density per unit length of root (pcs./10 cm) was determined.

The weather conditions during the experiment are presented according to the data from the website "Weather and Climate"⁶ (see Table 1).

³Agrochemistry Workshop: A Textbook for Universities / Edited by V.G. Mineev. Moscow: Moscow State University Publishing House, 1989, 304 p.

⁴Soil Science: Textbook for Universities / edited by V.A. Kovda, B.G. Rozanov. Moscow: Higher School, 1988. Part 1: Soil and Soil Formation, 400 p.

⁵Instructions for growing planting material of trees and shrubs in forest nurseries of the Ural region. Moscow, 1998, 172 p.

⁶<http://www.pogodaiklimat.ru/climate/28440.htm>

The statistical processing of the obtained materials was carried out using the Statistica 10.0 program. The figures and tables present the mean values of the indicators and the standard error. The significance of differences in mean values was determined using Student's *t*-test.

RESULTS AND DISCUSSION

At the end of the growing season at the Obroshinsky nursery, the highest survival rate of seedlings was recorded in the control group (about 240 pcs./linear meter). Its superiority over the experimental variants was as follows: with seed treatment using the AC preparation – 20%, NC – 16%, SP – 28% (see Fig. 1).

In the Berezovsky nursery, the situation turned out to be different. The highest seedling survival was observed in the variant with SP treatment (220 pcs/m; plus 30% compared to the control). In the AC variant, survival was 11% higher than the control, and in the NC variant – 14% higher.

Data on the height and stem diameter of seedlings are shown in Figures 2 and 3. Figure 2 presents the absolute values of the studied parameters, while in Figure 3, the X-axis (zero value of the Y-axis) is taken as the control, and the value of each studied indicator is presented as a deviation from the control, expressed as a percentage.

Табл. 1. Температура воздуха и количество осадков

Table 1. Air temperature and amount of precipitation

Indicator	Month				
	V	VI	VII	VIII	IX
Air temperature, °C: in the year of the experiment average long-term value	10,9	15,7	20,9	20,6	10,9
	12,2	16,9	18,9	16,2	10,4
Amount of precipitation, mm: in the year of the experiment average long-term value	73	85	11	23	54
	47	73	93	75	45

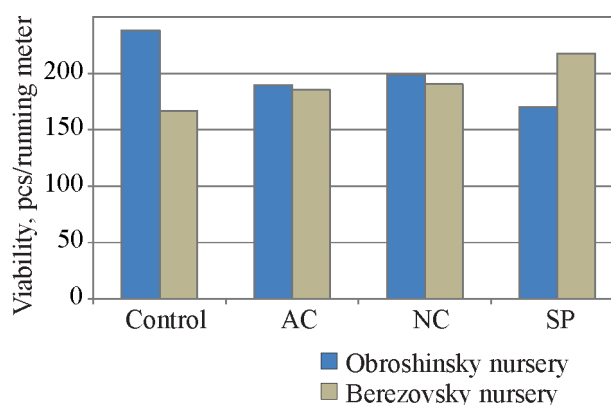


Рис. 1. Сохранность 1-летних сеянцев в разных вариантах эксперимента

Fig. 1. Survival of 1-year-old seedlings in different experimental variants

In the Obroshinsky nursery, the height of 1-year-old seedlings exceeded the control in the variants treated with AC (doses of 0.05 and 5.0g/ kg) and NC (dose of 0.12 g/kg, significantly at $p < 0,05$). The stem diameter in these variants was predominantly smaller than the control value. In the variants with SP seed treatment, the indicators exceeded the control both in height (by 3.5–10.0%, except for the dose of 0.1 ml/kg) and in stem diameter (by 4.5–12.5%).

In the Berezovsky nursery, in the version with acidic components at a dose of 0.05 g/kg, the height and diameter of the seedlings' stems were significantly higher than the control values. In the other experimental variants with components, the differences from the control were weakly expressed or absent. When using the spruce preparation at the doses of 0.05 and 0.25 ml/kg, the height of the seedlings was significantly higher than the control.

When comparing 1-year-old larch seedlings grown with the same doses of treatments in the Berezovsky and Obroshinsky nurseries, it was found that the seedlings from the first nursery were larger. In addition, in the Berezovsky nursery, there was a tendency for a positive correlation between changes in height and stem diameter, whereas in the Obroshinsky nursery no clear pattern was observed.

The root system plays an important role in the development of seedlings and their adapta-

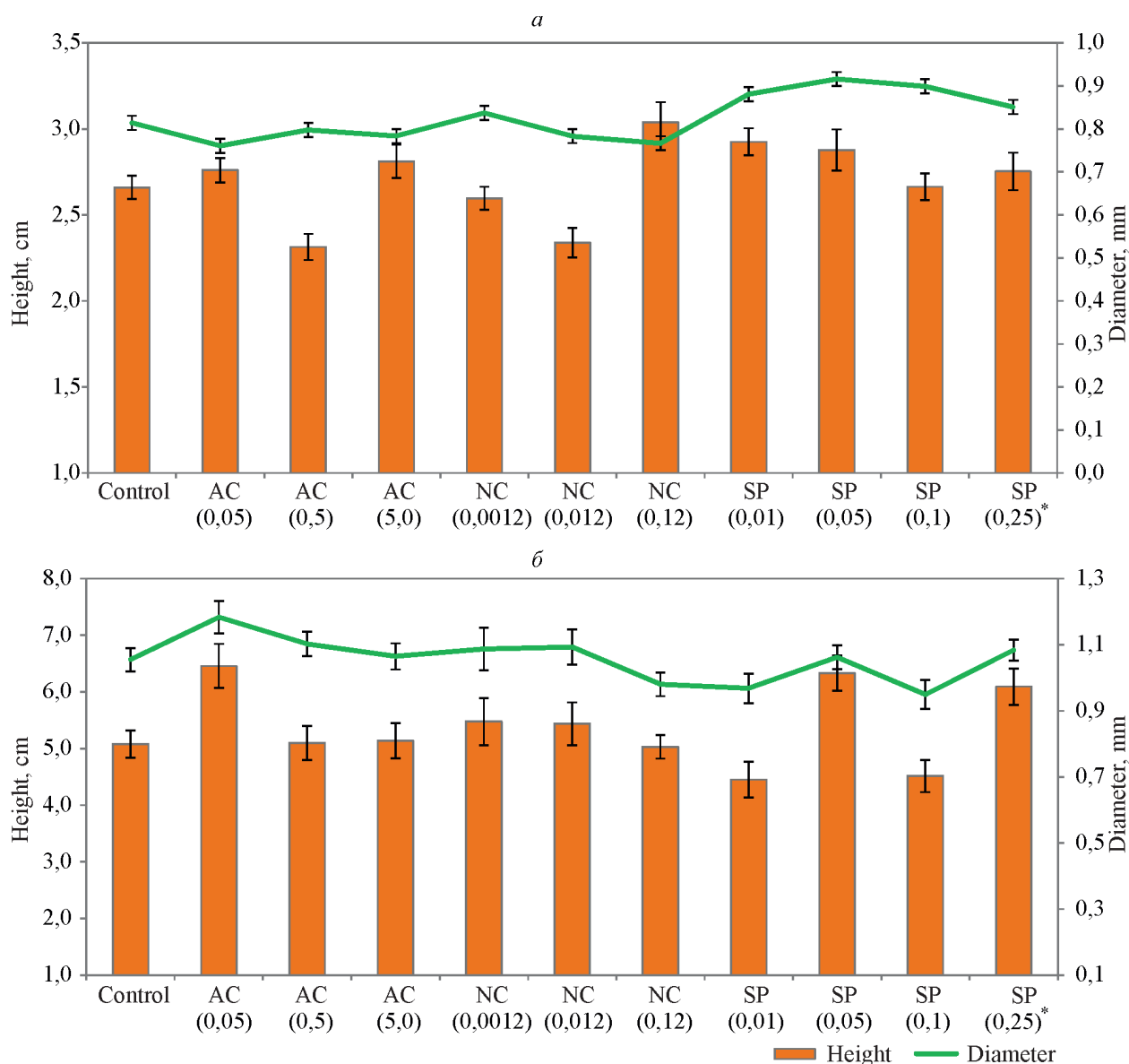


Рис. 2. Высота и диаметр 1-летних сеянцев лиственницы в Оброшинском (а) и Березовском питомниках (б)

*Доза препарата

Fig. 2. Height and diameter of 1-year-old larch seedlings in the Obroshinsky (a) and Berezovsky nurseries (б)

*Drug dosage

tion during planting⁷. Analysis of the main indicators of root system formation in 1-year-old larch seedlings, presented in Table 2, indicates that their root system consists of a taproot and lateral roots (first-order roots) developing on it. The length of the taproot in the control variant in both nurseries was similar. In the Obroshinsky nursery, the length of the taproot in the control seedlings was greater than in the experimental ones, and in most cases the differences were sig-

nificant. In the Berezovsky nursery, the opposite pattern was observed – in the experimental variants, the seedlings had a longer taproot than the plants in the control.

In seedlings from the Obroshinsky nursery, the density of lateral roots varies. Compared to the control, it is lower in the NC variants, but higher when using AC, and changes ambiguously when seeds are treated with SP. In seedlings from the Berezovsky nursery, the density

⁷Grossnickle S.C. Importance of root growth in overcoming planting stress // New Forest, 2005, vol. 30, pp. 273–294.

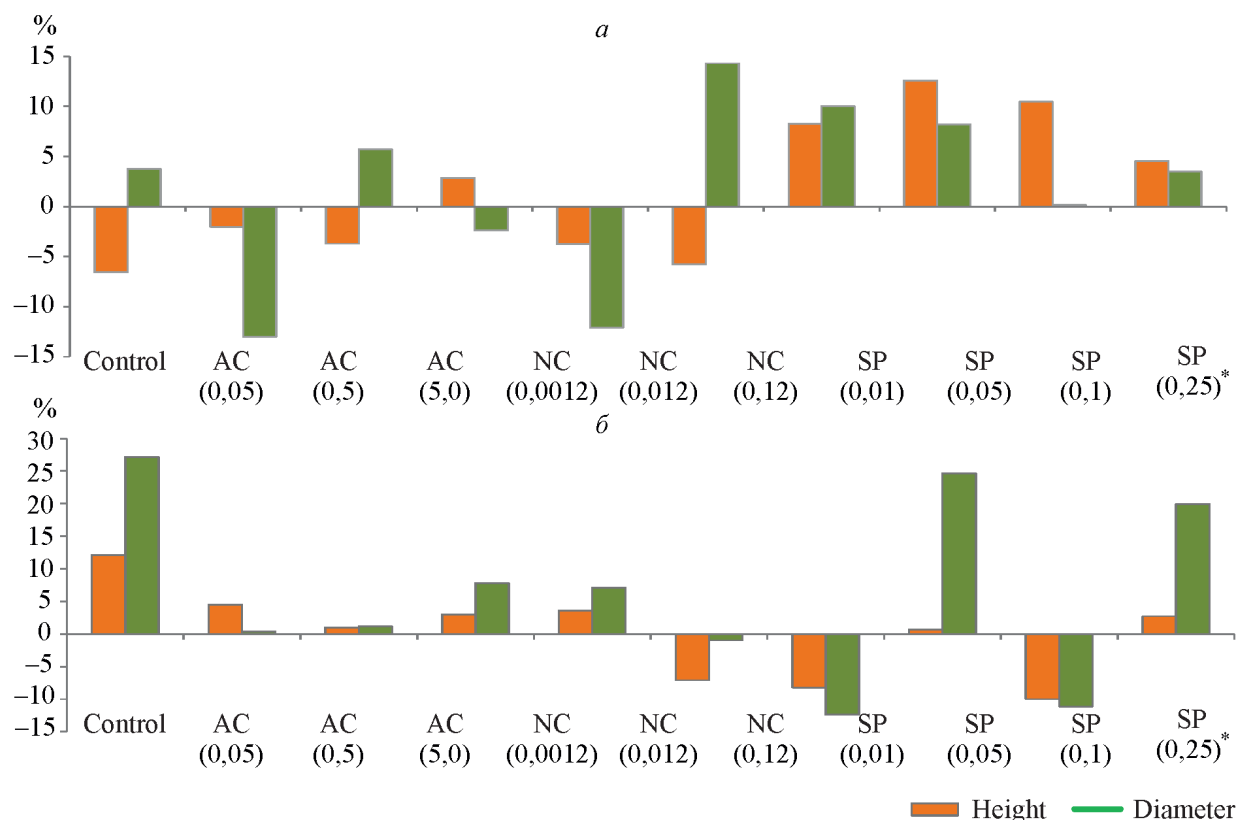


Рис. 3. Относительные значения высоты и диаметра 1-летних сеянцев лиственницы в опытных вариантах в Оброшинском (а) и Березовском питомниках (б)

*Доза препарата

Fig. 3. Relative values of height and diameter of 1-year-old larch seedlings in experimental variants in the Obroshinsky (a) and Berezovsky nurseries (b)

*Drug dosage

Табл. 2. Характеристики корневой системы 1-летних сеянцев лиственницы

Table 2. Characteristics of the root system of 1-year-old larch seedlings

Dose of the preparation	Obroshinsky nursery			Berezovsky nursery		
	Length of the main root, cm	Density of lateral root placement, pcs./10 cm	Ratio of the length of the lateral and main root	Length of the main root, cm	Density of lateral root placement, pcs./10 cm	Ratio of the length of the lateral and main root
Control (0,0)	12,9 ± 0,56	15,7 ± 0,66	0,37 ± 0,03	12,9 ± 0,60	14,7 ± 0,74	0,27 ± 0,05
<i>Neutral components, g/kg of seeds</i>						
0,0012	10,0 ± 0,42*	14,0 ± 0,67	0,36 ± 0,03	13,6 ± 0,82	16,9 ± 0,94	0,32 ± 0,04
0,012	12,3 ± 0,66	13,8 ± 0,99	0,39 ± 0,03	17,2 ± 0,56*	17,9 ± 0,57*	0,34 ± 0,03
0,12	10,0 ± 0,71*	15,7 ± 1,07	0,47 ± 0,06	16,7 ± 0,54*	16,9 ± 0,77	0,25 ± 0,03
<i>Acidic components, g/kg of seeds</i>						
0,05	11,7 ± 0,50	16,1 ± 0,67	0,36 ± 0,05	14,8 ± 0,87	14,5 ± 0,58	0,23 ± 0,03
0,5	12,6 ± 0,63	16,5 ± 0,71	0,32 ± 0,03	15,8 ± 0,50*	15,2 ± 0,84	0,24 ± 0,02
5,0	9,9 ± 0,44*	16,2 ± 0,67	0,46 ± 0,03*	15,9 ± 0,48*	14,7 ± 0,67	0,25 ± 0,03
<i>Spruce preparation, ml/kg of seeds</i>						
0,01	10,8 ± 0,54*	17,6 ± 0,76	0,39 ± 0,03	15,9 ± 0,54*	15,6 ± 0,77	0,23 ± 0,02
0,05	11,4 ± 0,57	15,5 ± 0,74	0,55 ± 0,05*	15,1 ± 0,54*	16,8 ± 0,73	0,23 ± 0,02
0,10	11,0 ± 0,45*	16,9 ± 0,75	0,36 ± 0,04	15,3 ± 0,59*	13,3 ± 0,59	0,38 ± 0,05
0,25	10,7 ± 0,49*	15,9 ± 0,86	0,39 ± 0,04	14,6 ± 0,53*	17,0 ± 0,62*	0,24 ± 0,03

* The differences are significant at $p < 0,05$.

of lateral roots was generally higher in the experimental variants, with significant differences observed only in the NC (dose 0.012 g/kg) and SP (dose 0.25 ml/kg) variants.

The formation of the root system in different nurseries when using biopreparations had a varied character (see Fig. 4). In the Obroshinsky nursery, the number of lateral roots and the share of conductive roots were higher in the control variant compared to the experimental ones, while in the Berezovsky nursery, these indicators in the control group of seedlings were significantly lower than in the experimental variants. In addition, the absolute number of conductive roots was significantly higher in the seedlings of the experimental variants of the Berezovsky nursery.

Comparing seedlings grown in different nurseries, it can be noted that plants from the Obroshinsky nursery have a shorter main root, while the ratio of lateral root length to main root length is higher. This indicates that in the Obroshinsky nursery, with a shorter main root, lateral root growth in the lateral direction is more pronounced, and the root system of the seedlings as a whole is more compact compared to the root

system of plants from the Berezovsky nursery.

The growth and development of larch seedlings occurred under extremely heterogeneous weather conditions. During the experiment, in the period of sowing, seed germination, and seedling emergence, favorable microclimatic conditions were noted, when the average air temperature was slightly below the long-term average with a sufficient amount of precipitation (see Table 1). The subsequent summer months were extreme: at the temperatures above the long-term averages, a very significant moisture deficit was observed. But, as a rule, it is precisely during this period that there is intensive consumption of mineral nutrition elements from the soil to ensure the linear accelerated growth of seedlings and the beginning of their accumulation of dry organic matter. Therefore, during this period, soil moisture for larch seedlings, obtained not only from natural precipitation but also through artificial watering, is extremely necessary^{8, 9} [10]. Manual watering, carried out in hot and dry weather conditions, primarily contributed to the preservation of the crops, but could not have a significant impact on the growth of the plants' root system.

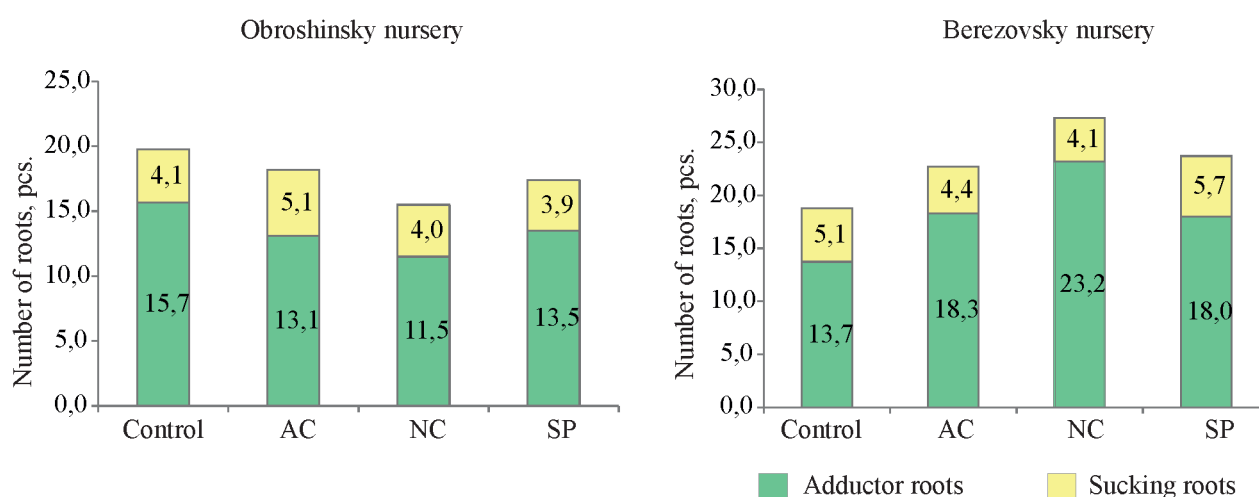


Рис. 4. Количество и соотношение корней 1-го порядка у 1-летних сеянцев лиственницы на опытных участках

Fig. 4. The number and ratio of the 1st order roots in 1-year-old larch seedlings in experimental plots

⁸Pak L.N., Bobrinev V.P. Peculiarities of larch tree seedling growth in the Baikal basin arboreta// Bulletin KrasSAU, 2013, N 12, pp. 157–161.

⁹Churagulova Z.S., Ishbulatov M.G., Murzabulatov B.S. The role of water-physical properties of soils in growing seedlings for forest reclamation of disturbed lands // Vestnik of the Bashkir State Agrarian University, 2016, N 4 (40), pp. 130–135.

The data obtained on the survival and growth of larch seedlings showed that soil conditions in the nurseries influenced the effectiveness of the treatments. Considering that the nurseries are located not very far from each other (about 40 km apart) and that the seedlings were grown at the same time, it can be concluded that weather conditions are not the main reason for the observed differences, although their indirect influence cannot be ruled out. It is known that soil conditions have a significant impact on seedling growth. The granulometric composition of the soil affects its water-physical and agrochemical properties, as well as its thermal regime. It has been established that soils rich in silt particles are better supplied with nutrients (see footnote 3).

It has also been shown that as the granulometric composition becomes heavier, the amount of adsorbed moisture and the water-retaining capacity of the soil increase¹⁰. According to the analysis results, the soil in the Berezovsky nursery has a heavier granulometric composition than in the Obroshinsky nursery and retains moisture better, which has a beneficial effect on plants under drought conditions. There is literature indicating that when moisture is present in the lower part of the root system (bottom watering), a larger root mass is formed, which ensures better survival of seedlings when planted in a forest plantation area [1]. Based on the above, it can be assumed that in this nursery these circumstances had a significant impact on the parameters of 1-year-old seedlings (in particular, on seedling height and seedling tree diameter).

It should also be noted that the Obroshinsky nursery had not been in operation for more than 20 years and was only restored in 2021. Some factors that could have a background effect on the growth of larch (pesticides, soil microbiological status) may be absent in the soil here.

CONCLUSION

Growing Siberian larch seedlings using preparations obtained from spruce conifer green extracts in two nurseries of the Sverdlovsk re-

gion showed the following: the survival rate of 1-year-old seedlings in the Obroshinsky nursery in the control was 16–28% higher than in the experimental variants; in the Berezovsky nursery, different results were noted – in the experimental variants, the survival rate of seedlings exceeded the control values by 11–30%. In addition, it was found that in certain experimental variants, the height and diameter of the seedling trees of 1-year-old seedlings grown in both nurseries exceeded the control. Thus, for plants from the Obroshinsky nursery, the seedling tree height was higher than the control value in the experimental variants using the spruce preparation (except for the dose of 0.1 ml/kg of seeds), acidic (doses of 0.05 and 5.0 mg/kg) and neutral components (dose of 0.12 mg/kg), and the diameter was greater by 4.5–10.4%. For seedlings from the Berezovsky nursery, the seedling tree height was approximately equal to the control values or exceeded them in almost all variants (the exceptions were variants with SP treatment at the doses of 0.05 and 0.25 ml/kg).

Complex weather conditions during the experiment, various soil conditions, and the history of nursery management can affect the manifestation of the stimulating effect of biopreparations on larch, which needs to be clarified in further studies.

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Изучение коллекции гороха в условиях Предуралья Республики Башкортостан

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В селекции новых высокопродуктивных сортов важная роль отводится правильному выбору исходного материала. В связи с этим целью настоящего исследования стало изучение коллекционного материала гороха посевного различного эколого-географического происхождения по важнейшим морфобиологическим и хозяйственно ценным признакам в условиях Предуральской лесостепной зоны Республики Башкортостан. Полевые опыты были заложены в 2022–2024 гг. Объектом исследования послужили 150 сортообразцов гороха. Контрастные погодные условия в годы изучения (ГТК от 0,51 до 1,30) дали возможность всесторонне оценить коллекционный материал по степени экологической адаптации к условиям региона. В результате проведенного исследования выделены сортообразцы – источники скороспелости: Памяти Хангильдина, Чишминский 80, 95, 75, Уладовский 303, Шихан, Л-26665, Л-31969, Л-31970, К-8720 (Франция), К-6363 (Германия), К-8717 (Англия) с продолжительностью вегетационного периода от $58,0 \pm 4,2$ до $64,3 \pm 6,2$ сут. Комплексом хозяйственно ценных признаков отличались сортообразцы Чишминский 75, 95, 229, Памяти Попова, Л-31969, Кормовой 23, Томас, Аксайский усатый 55 с большим количеством бобов на растении (от $4,50 \pm 0,14$ до $5,17 \pm 0,15$ шт.), семян с растения (от $18,4 \pm 0,6$ до $22,2 \pm 0,7$ шт.), высокой озерненностью боба (от $4,19 \pm 0,08$ до $4,51 \pm 0,09$ шт.) и семенной продуктивностью (масса семян с растения – от $4,13 \pm 0,24$ до $4,91 \pm 0,30$ г). В качестве источников высокого содержания белка в зерне (от $23,5 \pm 0,4$ до $26,1 \pm 0,5\%$) выявлены следующие сортообразцы: Памяти Хангильдина, Чишминский 229, Штамбовый Мальцева, Аванс, Эффектный, К-9457 (Тюменская область, Россия), К-9425 (Франция), Орел-326, -332, Северянин, Аксайский усатый 55, К-6109 (Нидерланды). Выделенные сортообразцы рекомендуются использовать в селекции гороха при создании новых высокопродуктивных технологичных сортов, адаптивных к условиям Предуралья.

Ключевые слова: *Pisum sativum* L., исходный материал, скороспелость, урожайность, адаптивность

Studying a pea collection in the Cis-Ural region of the Republic of Bashkortostan

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In breeding of new high-yielding cultivars, an important role is given to the source material. In this regard, the purpose of the work was to study the pea collection material of different ecological and geographical origin according to the most important morphobiological and economically valuable traits in the conditions of the Cis-Ural forest-steppe zone of the Republic of Bashkortostan. Field experiments were conducted in 2022–2024. The object of the study came to be 150 pea cultivars. Contrasting weather conditions during the years of the study (HTC from 0.51 to 1.3) made it possible to comprehensively evaluate the collection material according to the degree of ecological adaptation to the conditions of the region. As a result of the study, the sources of early maturation were identified: Pamyati Khangildina, Chishminsky 80, 95, 75, Uladovsky 303, Shikhan, L 26665, L-31969, L-31970, K-8720 (France), K-6363 (Germany), K-8717 (England) with a growing season duration from 58.0 ± 4.2 to 64.3 ± 6.2 days. The following varieties were distinguished by a complex of economically valuable traits: Chishminsky 75, 95, 229, Pamyati Popova, L-31969, Kormovoy 23, Thomas, Aksaysky Usaty 55 with a large number of beans per plant (from 4.50 ± 0.14 to 5.17 ± 0.15 pcs.), seeds per plant (from 18.4 ± 0.6 to 22.2 ± 0.7 pcs.), high grain content per bean (from 4.19 ± 0.08 to 4.51 ± 0.09 pcs.) and seed productivity (seed weight per plant – from 4.13 ± 0.24 to 4.91 ± 0.30 g). The following varieties were identified as sources of high protein content in grain (from 23.5 ± 0.4 to $26.1 \pm 0.5\%$): Pamyati Khangildina, Chishminsky 229, Shtambovy Maltseva, Avans, Effektny, K-9457 (Tyumen region, Russia), K-9425 (France), Orel-326, -332, Severyanin, Aksaysky Usaty 55, K-6109 (Netherlands). The selected variety samples are recommended for use in pea breeding to create new highly productive technological varieties adaptable to the conditions of the Cis-Urals.

Keywords: *Pisum sativum* L., source material, early maturation, yield, adaptability

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Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Pea (*Pisum sativum* L.) is a valuable legume crop cultivated for grain, green fodder, hay, and silage [1]. Pea seeds contain 20–35% protein, 0.7–1.5% fat, 20–48% starch, 5.2–7.7% fiber [2]. Peas provide highly nutritious green fodder, hay, and straw. Pea straw contains 6–8% protein and up to 34% nitrogen-free substances [3]. As a legume crop, peas are a good forecrop for winter and spring cereals, row crops, and other crop rotation plants [4]. The growing deficit of digestible protein in feed requires a significant expansion of pea sowing and an increase in its yield.

In order to increase the gross grain harvest and improve product quality, it is necessary, along with the improvement of cultivation technology and the complex of sowing and harvesting machines, to create and introduce into agricultural production more high-yielding and adaptive pea varieties that meet the requirements of modern intensive agriculture [5]. The successful breeding of new varieties is facilitated by the scientifically based selection of initial material [1]. In this regard, the study and identification among the collection pea samples of lines and varieties possessing a certain set of economically valuable traits, for the purpose of creating new

high-yielding and technologically valuable varieties based on them, remain relevant.

The purpose of the study is to evaluate the collected material with the subsequent identification of valuable sources for the breeding of highly productive, technologically advanced, and most valuable in quality pea varieties under the conditions of the Cis-Urals of the Republic of Bashkortostan.

The following tasks were formulated in order to achieve the set goal:

- 1) to study the duration of the phases of pea plant development;
- 2) to evaluate pea varieties by the yield structure elements;
- 3) to determine the protein content in the seeds of varietal samples;
- 4) to identify the promising sources from a breeding perspective, possessing a set of economically valuable traits and properties.

MATERIAL AND METHODS

The study was conducted in 2022–2024 at the experimental field of the Laboratory of Breeding and Primary Seed Production of Grain Legumes and Cereals of the Bashkir Research Institute of Agriculture – Subdivision of the Ufa Federal Research Centre of the Russian Academy of Sciences (BashNIISKHh UFRC RAS). The objects of the study were 150 pea varieties and lines of various ecological and geographical origins from the collection of world genetic resources of the Vavilov All-Russian Institute of Plant Genetic Resources (VIR), BashNIISKHh UFRC RAS, and other research institutions.

The soils of the experimental plot are medium-thickness calcareous chernozems. The humus content in the top layer is 8.1%, phosphorus oxide – 23.5 mg, available potassium – 42.1 mg per 100 g of soil. The sum of absorbed bases is 48.5 mg-eq per 100 g of soil, soil solution pH 6.8–7.0.

Weather conditions in the years of field experiments were contrasting: from dry-hot in 2023 ($HTC = 0.51$) to relatively favorable in terms of the hydrothermal regime in 2022 and 2024 ($HTC = 1.30$ and 0.71 , respectively). This made it possible to comprehensively assess the studied collection material in terms of its ecological adaptability to the conditions of the region.

Sowing was carried out using the SKS-6-10 breeding seed drill. The plot area was 2 m². Replication was threefold. The early-ripening variety Pamyati Khangildina was used as a standard. Winter rye was used as the forecrop. Harvesting was done manually at full maturity. The sheaves were threshed using the MZB-1 breeding thresher. Sowing and crop maintenance followed the generally accepted practices for the growing zone.

For structural analysis, 30 plants were selected from the test plot allocated in each section. The plants were analyzed for the following traits: stem length, number of pods and seeds per plant, weight of 1000 seeds, number of seeds per pod, seed weight per plant (yield). The evaluation of the pea collection material was carried out in accordance with the Methodology of the State Variety Testing of Agricultural Crops¹. To determine the protein content in seeds, the M.M. Bradford method was used². The statistical processing of experimental data was carried out according to B.A. Dospekhov³, as well as in the MS Excel program.

RESULTS AND DISCUSSION

The duration of the growing season of agricultural crops is an important characteristic, largely determining their suitability for cultivation in particular soil and climatic conditions [6, 7]. This characteristic depends on the combination of the amount of heat and moisture, as well as on the individual response of the variety to these factors, determined by the features of the

¹Methodology of state variety testing of agricultural crops / edited by M.A. Fedin. Moscow: Kolos, 1985, 269 p.

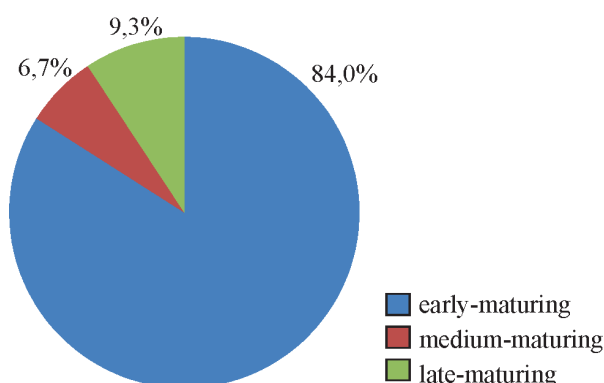
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³Dospekhov B.A. Methodology of field experiment (with the basics of statistical processing of research results). Moscow: Agropromizdat, 1985, 351 p.

genotype [8, 9]. In our study, the average duration of the growing season of the best pea varieties selected from the collection ranged from 60.0 ± 4.6 to 80.7 ± 5.5 days (see Table 1).

Depending on the length of the growing season, the 150 studied cultivar samples were divided into three groups: early-, medium- and late-maturing (see the figure).

As can be seen from the diagram, the main part of the collection material (84.0%) consists of medium-maturing cultivar samples. The share of early- maturing cultivar samples was 9.3%, and late- maturing ones accounted for 6.7% of the total number of studied varieties and lines. The variability of the vegetative period duration



Распределение сортообразцов гороха по группам с учетом продолжительности вегетационного периода

Distribution of the pea cultivar samples into groups depending on the duration of the growing season

Табл. 1. Продолжительность вегетационного периода сортообразцов гороха (в среднем за 2022–2024 гг.)

Table 1. Duration of the growing season of the pea cultivar samples (average for 2022–2024)

Variety specimen	Origin	Duration of the growing period, days	Deviation from standard, days
<i>Early-maturing</i>			
Pamyati Khangildina (standard)	Bashkortostan, Russia	$60,0 \pm 4,6$	–
Chishminsky 75	»	$60,3 \pm 4,7$	+0,3
Chishminsky 80	»	$58,3 \pm 4,1$	–1,7
Shikhan	»	$58,7 \pm 4,1$	–1,3
Chishminsky 95	»	$59,0 \pm 4,4$	–1,0
L-26665	»	$58,0 \pm 4,2$	–2,0
Uladovsky 303	Ukraine	$60,3 \pm 4,7$	+0,3
K-6363	Germany	$64,0 \pm 6,0$	+4,0
K-8717	England	$64,3 \pm 6,2$	+4,3
K-8720	France	$61,3 \pm 4,7$	+1,3
L-31969	Bashkortostan, Russia	$62,3 \pm 4,4$	+2,3
L-31970	»	$61,7 \pm 4,6$	+1,7
<i>Medium-maturing</i>			
Chishminsky 229	Bashkortostan, Russia	$66,0 \pm 4,6$	+6,0
Pamyati Popova	»	$66,3 \pm 4,7$	+6,3
Tomas	Tyumen region, Russia	$67,0 \pm 5,0$	+7,0
Velvet	Czech Republic	$68,3 \pm 4,6$	+8,3
Flagman 9	Samara region, Russia	$66,3 \pm 4,0$	+6,3
Omsky 9	Omsk region, Russia	$68,3 \pm 6,0$	+8,3
Omsky 18	»	$68,7 \pm 5,9$	+8,7
Kormovoy 23	Bashkortostan, Russia	$67,7 \pm 4,5$	+7,7
K-6753	Czech Republic	$69,0 \pm 5,2$	+9,0
K-8750	Portugal	$68,7 \pm 4,9$	+8,7
<i>Late maturing</i>			
Aksaisky usaty 55	Rostov region, Russia	$79,0 \pm 5,6$	+19,0
Shrek	Tyumen region, Russia	$80,7 \pm 5,5$	+20,7

was low: the coefficient of variation of this trait in the group of early- maturing cultivar samples ranged from 2.7 to 7.2%, in the medium- maturing ones – from 6.0 to 8.8%, and in the late- maturing ones – from 6.6 to 14.8%.

Stem length is an important morphological trait closely associated with plant resistance to lodging and their productivity. According to the classifier⁴, the studied pea varieties were divided into the following groups: dwarf (stem length less than 30 cm), semi-dwarf (stem length 31–60 cm) and medium-sized (stem length 61–100 cm). The majority of the collection material (60.5%) is represented by semi-dwarf forms, 33.5% are medium-sized forms, and 6.0% are dwarf. For breeding purposes, semi-dwarf cultivars such as Pamyati Khangildina, K-6363, K-8720 (early-maturing), Omsky 9 and 18, Thomas, Velvet, Flagman 9, K-6753, K-8750 (medium-maturing) with stem lengths ranging from 52.9 ± 1.7 to 59.6 ± 1.9 cm are of particular value (see Table 2).

One of the most significant traits in the structure of pea yield is the number of pods per plant [10]. In our experiments, on average for 2022–2024, depending on varietal characteristics and growing conditions, the number of pods per plant in the selected cultivar samples ranged from 4.09 ± 0.15 to 5.17 ± 0.15 pcs. (see Table 2). Based on this characteristic, promising breeding varieties have been selected with the maximum number of pods per plant (from 4.50 ± 0.14 to 5.17 ± 0.15 units): Chishminsky 75, 95, 80, Pamyati Khangildina, K-6363, L 26665, L-31969 (early-maturing), Pamyati Popova, Feed 23, Thomas, Velvet, Omsky 9 and 18, Chishminsky 229, K-6753 (medium -maturing), Shrek, Aksaysky Usaty 55 (late-maturing).

The number of seeds per plant is an integral value determined by the number of pods on the plant and the seeds in a pod, as well as an important component of yield⁵. In the pea varietal samples we selected, over three years, the number of seeds per plant ranged on average from $16.2 \pm$

0.5 to 22.2 ± 0.7 pcs. (see Table 2). The varietal samples Chishminsky 75, 95, 80, Pamyati Khangildina, L-31969, K-6363 (early-maturing), Chishminsky 229, Kormovoy 23, Thomas, Pamyati Popova, Omsky 18 (medium-maturing), Aksaysky Usaty 55, Shrek (late-maturing) with the highest values of this trait (from 18.2 ± 0.6 to 22.2 ± 0.7 pcs.) are recommended for use in breeding as sources of high plant yield.

The trait “number of seeds per pod” in peas depends on the genetic characteristics of the variety and environmental factors [11]. In our experiments, on average for 2022–2024, in terms of pod fullness, the standard variety Pamyati Khangildina significantly ($p \leq 0.05$) exceeded the varieties Chishminsky 75 and 95 (early-maturing), Chishminsky 229, Pamyati Popova, Thomas, Kormovoy 23 (medium-maturing), Shrek (late-maturing) (see Table 2).

The weight of 1000 seeds (seed size) plays an important role in the formation of pea yield [12]. In our study, averaged over three years, the early-maturing varieties Shikhan, Chishminsky 95, and the lines L-26665, L-31969, as well as the medium-maturing specimens K-6753, K-8750, significantly exceeded the standard variety at the 5% significance level in this trait (see Table 2). These specimens are recommended for use in breeding work as sources of seed size.

The mass of seeds per plant (productivity) consists of individual elements of the yield structure: the number of pods per plant, seeds per pod, and the mass of 1000 seeds [13]. According to the results of the study, the following varieties and lines showed the highest average productivity in 2022–2024 under the conditions of the Republic of Bashkortostan: Chishminsky 75, 80, 95, Pamyati Khangildina, L-31969 (early-maturing), Chishminsky 229, Pamyati Popova, Kormovoy 23, Thomas, K-6753, K-8750 (medium-maturing), Aksaysky Usaty 55 (late-maturing). For the listed breeding lines, the seed mass per plant ranged from 4.10 ± 0.25 to 4.91 ± 0.30 g (see Table 2). The highest yield

⁴International classifier of the CMEA genus *Pisum* L. L.: VIR Publishing House, 1986, 54 p.

⁵Ermolova O.V., Korotkova O.V. Study of genetic diversity of collection material of pea (*Pisum sativum* L.) in the conditions of the Rostov region // Grain Economy of Russia, 2015, N 6, pp. 124–134.

Табл. 2. Показатели морфобиологических и хозяйственно ценных признаков сортообразцов гороха (в среднем за 2022–2024 гг.)

Table 2. Indicators of morphobiological and economically valuable traits of the pea cultivar samples (average for 2022–2024)

Variety specimen	Stem length, cm	Quantity, pcs.			Weight, g	
		beans on a plant	seeds in a bean	seeds per plant	seeds per plant	1000 seeds
Early-maturing						
Pamyati Khangildina (standard)	59,6 ± 1,9	4,72 ± 0,14	4,11 ± 0,08	19,1 ± 0,5	4,10 ± 0,25	215,5 ± 5,3
Chishminsky 75	62,0 ± 1,8	4,70 ± 0,14	4,30 ± 0,10*	20,1 ± 0,6	4,32 ± 0,27	215,9 ± 5,6
Chishminsky 80	65,5 ± 2,0	4,55 ± 0,12	4,08 ± 0,08	18,2 ± 0,5	4,10 ± 0,26	225,0 ± 7,1
Shikhan	65,3 ± 1,9	4,33 ± 0,13	4,05 ± 0,09	17,0 ± 0,5	4,08 ± 0,26	240,8 ± 7,5*
Chishminsky 95	70,1 ± 2,0	4,71 ± 0,15	4,33 ± 0,09*	20,0 ± 0,6	4,67 ± 0,29*	234,1 ± 6,3*
L-26665	72,7 ± 2,0	4,58 ± 0,14	3,74 ± 0,07	16,7 ± 0,5	3,84 ± 0,24	232,6 ± 6,2*
Uladovsky 303	71,2 ± 1,9	4,27 ± 0,13	3,92 ± 0,08	16,2 ± 0,5	3,40 ± 0,22	210,4 ± 5,4
K-6363	59,8 ± 1,8	4,66 ± 0,13	4,07 ± 0,09	18,2 ± 0,6	3,28 ± 0,23	180,7 ± 4,9
K-8717	61,4 ± 1,7	4,09 ± 0,15	4,16 ± 0,10	16,2 ± 0,5	3,08 ± 0,22	190,2 ± 4,8
K-8720	58,0 ± 1,7	4,34 ± 0,13	3,90 ± 0,09	16,9 ± 0,6	3,13 ± 0,23	185,5 ± 4,5
L-31969	65,6 ± 1,9	4,50 ± 0,14	4,19 ± 0,08	18,4 ± 0,6	4,23 ± 0,26	230,3 ± 6,3*
K-31970	65,1 ± 1,8	4,41 ± 0,14	3,84 ± 0,07	16,8 ± 0,5	3,70 ± 0,24	220,8 ± 5,8
Medium-maturing						
Chishminsky 229	80,0 ± 2,2	5,16 ± 0,16*	4,46 ± 0,08*	22,2 ± 0,7*	4,91 ± 0,30*	220,5 ± 5,5
Pamyati Popova	68,5 ± 1,9	4,52 ± 0,13	4,51 ± 0,09*	20,1 ± 0,6	4,12 ± 0,24	205,4 ± 5,2
Tomas	57,3 ± 1,7	4,75 ± 0,14	4,30 ± 0,09*	20,4 ± 0,6*	4,18 ± 0,25	205,2 ± 4,8
Velvet	55,7 ± 1,8	4,67 ± 0,13	3,82 ± 0,07	16,9 ± 0,5	3,21 ± 0,24	190,6 ± 4,9
Flagman 9	55,1 ± 1,7	4,43 ± 0,12	3,74 ± 0,08	16,4 ± 0,5	3,61 ± 0,25	220,0 ± 6,0
Omsky 9	56,2 ± 1,7	4,71 ± 0,14	3,79 ± 0,07	17,5 ± 0,6	3,68 ± 0,25	210,3 ± 5,3
Omsky 18	59,0 ± 1,8	4,68 ± 0,15	4,10 ± 0,10	18,8 ± 0,6	3,76 ± 0,24	200,8 ± 4,6
Kormovoy 23	65,6 ± 1,9	5,04 ± 0,15*	4,33 ± 0,10*	21,3 ± 0,7*	4,37 ± 0,26	205,1 ± 4,7
K-6753	52,9 ± 1,7	4,52 ± 0,14	4,06 ± 0,10	17,8 ± 0,6	4,18 ± 0,26	235,7 ± 6,5*
K-8750	56,4 ± 1,8	4,29 ± 0,13	4,00 ± 0,08	17,0 ± 0,5	4,15 ± 0,27	244,3 ± 7,3*
Late maturing						
Aksaisky usaty 55	78,2 ± 2,0	5,17 ± 0,15*	4,25 ± 0,09	21,7 ± 0,7*	4,34 ± 0,28	200,9 ± 4,9
Shrek	85,0 ± 2,2	4,93 ± 0,14	4,31 ± 0,10*	20,4 ± 0,6*	3,94 ± 0,26	190,5 ± 4,5

* Statistically significantly exceeds the standard ($p \leq 0,05$).

was characteristic of breeding lines from the medium-maturing group: their seed yield per 1 m² was 222–230 g, while for breeding lines from the early- and late- maturing groups it was 180–210 and 190–224 g, respectively.

One of the main directions of breeding work with peas is the creation of high-protein varieties [14]. In peas grown in most regions of the Russian Federation, the seeds contain on average 22–26% protein. For example, in pea seeds cultivated in the Ural economic region, the content of storage proteins reaches 20.9–24.2% [15]. Analysis of the protein content in the seeds

of the varieties we studied revealed significant diversity among them in this characteristic. Depending on the genetic features of the variety and weather conditions, the content of storage proteins in the seeds varied from 18.0 ± 0.3 to $26.1 \pm 0.5\%$. The fluctuation of this trait over the years within the variety ranged from 0.3 to 5.3%. The characteristics of high-protein variety samples, which significantly ($p < 0.05$) exceeded the other varieties and lines we studied in seed protein content, are presented in Table 3. These variety samples are recommended for use in pea breeding as a source of high protein content.

Табл. 3. Содержание протеина в семенах высокобелковых сортообразцов гороха
(в среднем за 2022–2024 гг.)

Table 3. Protein content in the seeds of high-protein pea cultivar samples (average for 2022–2024)

Variety specimen	Origin	Content of storage proteins, %
Pamyati Khangildina	Bashkortostan, Russia	23,5 ± 0,4
Chishminsky 229	»	23,5 ± 0,4
Standard Maltsev	Voronezh region, Russia	23,7 ± 0,3
Avans	Altai Territory, Russia	23,7 ± 0,4
Effektny	Ukraine	26,1 ± 0,5
K-9457	Tyumen region, Russia	24,1 ± 0,4
K-9425	France	25,0 ± 0,3
Orel-326	Oryol region, Russia	23,7 ± 0,4
Orel-332	»	23,7 ± 0,3
Severyanin	Kirov region, Russia	23,8 ± 0,4
Aksaisky usaty 55	Rostov region, Russia	23,5 ± 0,3
K-6109	Netherlands	25,5 ± 0,5

CONCLUSION

As a result of studying 150 collection samples of pea by economic and biological characteristics and properties under the conditions of the Cis-Urals of the Republic of Bashkortostan, the following varieties and lines were identified:

1) earliness: Pamyati Khangildina, Chishminsky 75, 80, 95, Shikhan, Uladovsky 303, L-26665, K-6363 (Germany), K-8717 (England), K-8720 (France), L-31969, L-31970;

2) the highest number of beans per plant: from the early- maturing group – Chishminsky 75, 95, 80, Pamyati Khangildina, K-6363 (Germany), L-26665, L-31969; from the medium- maturing group – Chishminsky 229, Kormovoy 23, Thomas, Omsky 9 and 18, Velvet, K-6753 (Czech Republic);

3) the largest number of seeds per plant: from the early- maturing group – Chishminsky 75, 80, 95, Pamyati Khangildina, K-6363 (Germany), L-31969; from the medium- maturing group – Thomas, Chishminsky 229, Kormovoy 23, Omsky 18, Pamyati Popova;

4) large-seededness: from the early- maturing group – Shikhan, Chishminsky 95, L-26665, L-31969, from the medium- maturing group – K-8750 (Portugal), K-6753 (Czech Republic);

5) high seed productivity: from the early- maturing group – Chishminsky 75, 80, 95, Pamyati

Khangildina, L-31969, from the medium- maturing group – Chishminsky 229, Thomas, Pamyati Popova, Kormovoy 23, K-6753 (Czech Republic), K-8750 (Portugal);

6) high protein content in seeds: from the early- maturing group – Pamyati Khangildina, from the medium- maturing group – Chishminsky 229.

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Полевая оценка гибридов кукурузы на устойчивость к основным грибным патогенам

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Приведены данные исследований гибридов кукурузы на устойчивость к грибным патогенам в условиях юга Дальнего Востока. Широко распространенными заболеваниями, которые наносят существенный вред культуре, являются северный гельминтоспориоз (*Helminthosporium turcicum* Pass) и фузариоз початков (*Fusarium moniliforme* Sheldon). Часто при благоприятных условиях степень развития грибных заболеваний может достигать свыше 50%. Наличие информации по степени поражения кукурузы патогенами даст возможность выявить источники устойчивости для селекции. Цель работы – выделить устойчивые гибриды кукурузы к основным грибным заболеваниям. Материалом для полевых опытов служили 182 гибрида контрольного питомника, которые относятся к четырем группам спелости: раннеспелой – 10 образцов, среднеранней – 79, среднеспелой – 70 и среднепоздней – 23. Оценка генотипов на степень поражения возбудителями северного гельминтоспориоза и фузариоза початков проводили на естественном фоне в условиях муссонного климата Приморского края. Выявлено, что в среднем за 2 года показатели степени поражения северным гельминтоспориозом в зависимости от генотипа колебались от 7 до 35%, фузариозом – от 2 до 23%. Высокой полевой устойчивостью (степень поражения – до 10%) к *H. turcicum* обладают 9,9% генотипов (18 образцов), к *F. moniliforme* – 69,8% (127). По комплексу устойчивости к данным заболеваниям характеризуются образцы Приморский 547, 580, 583, 587, 588, 589, 597, 612, 660, 665, 666, 677, 679, 683, 685, 686. Симптомы пузырчатой головни обнаружены у шести генотипов. Частота встречаемости данного заболевания соответствовала 1,8 (Приморский 587) – 4,5% (Приморский 524).

Ключевые слова: кукуруза, генотип, грибные заболевания, *Helminthosporium turcicum* Pass, *Fusarium moniliforme* Sheldon, степень развития

Field evaluation of corn hybrids for resistance to major fungal pathogens

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The data of the research of corn hybrids for resistance to fungal pathogens in the conditions of the southern Far East are presented. *Helminthosporium turcicum* Pass (Northern corn leaf blight) and

Fusarium moniliforme Sheldon (Fusarium ear rot) are the widespread corn pathogens causing significant damage to the crop. Often, under favorable conditions, the degree of development of fungal diseases can reach over 50%. Presence of information on the extent of corn infestation by pathogens will help identify the sources of resistance for breeding. The purpose of this study is to identify the corn hybrids resistant to major fungal diseases. The material for the field experiments consisted of 182 hybrids from the control nursery, which belong to four maturity groups: early-maturing – 10 samples, middle-early – 79, medium-maturing – 70 and middle-late – 23. The evaluation of the genotypes for the degree of damage by the pathogens of the Northern corn leaf blight and Fusarium ear rot was carried out against a natural background in the monsoon climate of the Primorsky Territory. It was found that, on average, over 2 years, the incidence rates of the Northern corn leaf blight, depending on the genotype, ranged from 7 to 35%, and Fusarium ear rot – from 2 to 23%. 9.9% of the genotypes (18 samples) have high field resistance (damage level – up to 10%) to *H. turcicum*, and 69.8% (127) to *F. moniliforme*. The following samples are characterized by a complex of resistance to these diseases: Primorsky 547, 580, 583, 587, 588, 589, 597, 612, 660, 665, 666, 677, 679, 683, 685, 686. Symptoms of corn smut virus were detected in six genotypes. The incidence rate of this disease was 1.8 (Primorsky 587) – 4.5% (Primorsky 524).

Keywords: corn, genotypes, fungal diseases, *Helminthosporium turcicum* Pass, *Fusarium moniliforme* Sheldon, degree of development

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Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Corn (*Zea mays*) is an ancient crop native to South and Central America. It is one of the most productive agricultural crops in the world¹ [1–5]. Recently, thanks to selective breeding, the corn cultivation zone has significantly expanded into the northern regions of the Russian Federation [6]. Corn grain, which is used to prepare feed and food products, is rich in starch, fat, and other nutrients [7, 8]. Corn has also become widely used as a cereal component in the creation of mixed crops [9]. In addition, it is a universal forecrop for other agricultural crops, since it does not have common pathogens and pests with them. [10].

In the Primorsky Territory, corn is one of the leading crops, with a cultivated area of approx-

imately 80,000 hectares. However, the region's climatic conditions favor the development of fungal diseases², which negatively affect the sowing quality of seeds and the overall yield of corn.

Every year, this crop is significantly affected by pathogens such as Northern corn leaf blight and Fusarium ear rot (caused by an imperfect fungus *Helminthosporium turcicum* Pass and *Fusarium moniliforme* Sheldon) [11–14]. Often, under favorable conditions, the degree of development of fungal diseases can reach over 50% [15, 16].

The purpose of the study is to identify the sources of resistance to the most common corn diseases for further use in the breeding process.

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MATERIAL AND METHODS

The field experiments were carried out using 182 hybrids from the control nursery, which belong to four maturity groups: early-maturing – 10 samples, middle-early – 79, medium-maturing – 70 and middle-late – 23. The genotypes were assessed for the degree of damage by the pathogens of Northern corn leaf blight and Fusarium ear rot against a natural background in the monsoon climate of the Primorsky Territory.

Growing season weather conditions for 2023 and 2024 were as follows: the sum of active temperatures above 10°C from May to Sep-

tember was 2788–2926°C, precipitation for the same period was 529.5–833.5 mm, which is 69.5–373.5 mm more than the long-term average. A significant amount of precipitation fell in August 2023 (HTC = 6.6), and the minimum – in September 2023 (HTC = 0.1) (see Fig. 1).

The soil of the experimental plot is meadow-brown bleached soil of heavy mechanical composition. The thickness of the arable horizon is 22–25 cm. The humus content in the soil is 3.47–3.55 ± 0.51%, the pH of the salt extract is 5.0–5.4 ± 0.1, the available phosphorus is 60–64 ± 12 mg/kg of soil, the exchangeable potassi-

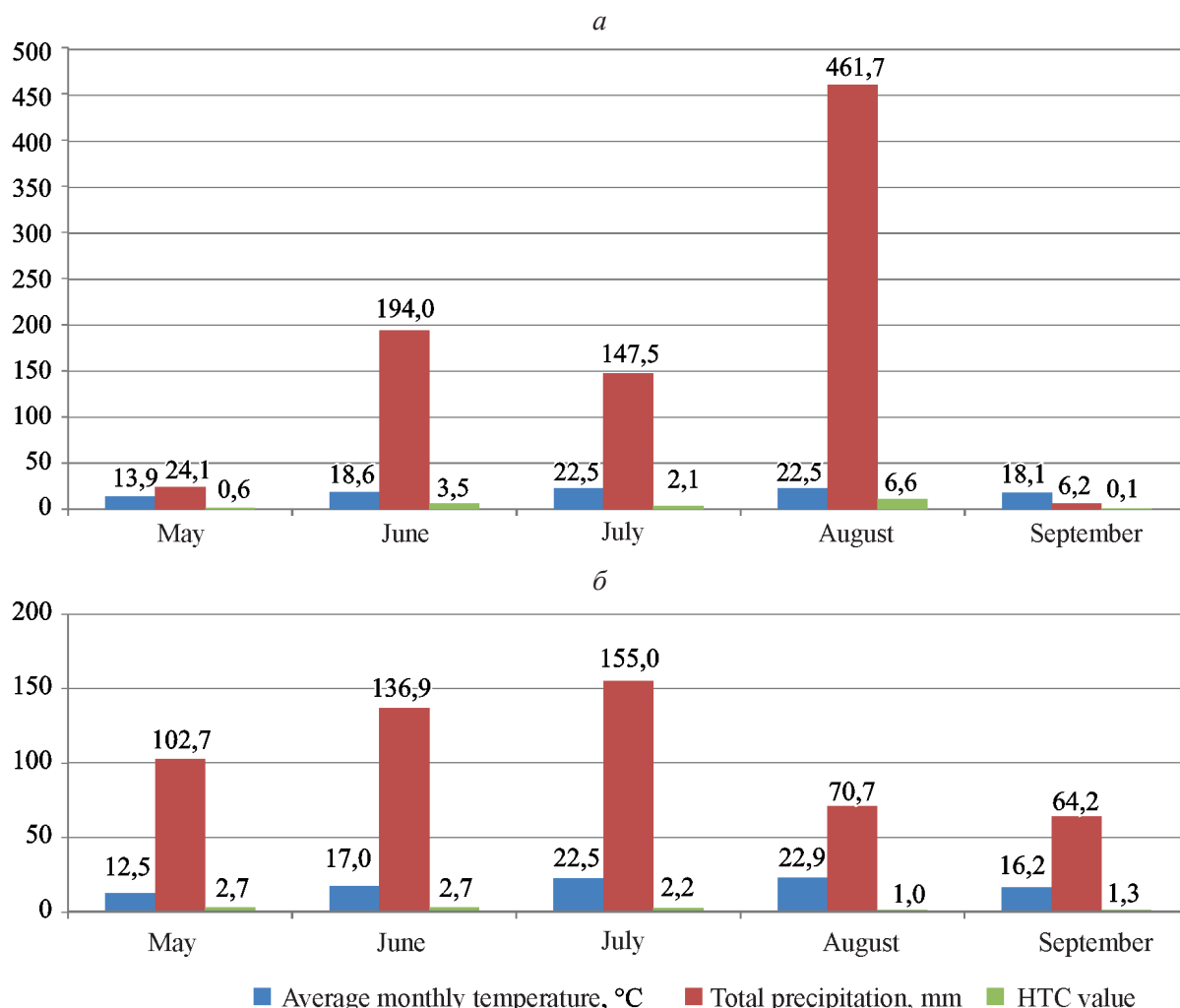


Рис. 1. Метеорологические условия за 2023 г. (а) и 2024 г. (б)

Fig. 1. Meteorological conditions in 2023 (a) and 2024 (b)

³Grisenko G.V., Dudka E.L. Methodology of phytopathological research on corn // VASKhNIL, All-Russian Research Institute of Corn, Dnepropetrovsk, 1980, 62 p.

⁴Vilkova N.A., Ivashchenko V.G., Frolova A.N. Methodological recommendations for assessing corn for complex resistance to pests and diseases. Moscow: VASKhNIL, 1988, 43 p.

um is $63-68 \pm 11$, and the nitrogen is $60-65 \pm 5$ mg/kg of soil.

The degree of development of the pathogens was assessed visually according to the methodology of phytopathological research on corn³ and methodological recommendations for assessing corn for comprehensive resistance to pests and diseases⁴.

The assessment of infection with Northern corn leaf blight was carried out using a five-point scale (see footnotes 3, 4):

0 – absence of lesion;

1 – a few spots scattered on the lower leaves (weak);

2 – moderate lesion of the lower leaves (slight);

3 – multiple spots on the lower leaves, spreading to the leaves of the middle tier (medium);

4 – numerous spots spreading from the lower and middle leaves to the upper ones (severe);

5 – multiple lesions on all leaves, possible premature death of plants (very severe).

The degree of damage to ears by Fusarium ear rot was calculated using a five-point scale (see footnotes 3, 4):

1 – up to 2.0% (up to 5 grains) are affected;

2 – from 2.1 to 5.0% (6–15 grains) are affected;

3 – from 5.1 to 10.0% (16–30 grains) are affected;

4 – over 10.1% of the surface is affected (more than 30 grains of local type of manifestation);

5 – over 10.1% of the surface is affected (more than 30 grains scattered across the cob).

The prevalence of the disease (incidence) was determined according to the formula

$$P = (n \cdot 100) / N, \%, \quad (1)$$

where P – prevalence of the disease; n – number of affected corn plants; N – total number of the plants studied.

The degree of development (degree of damage) of the disease was calculated using the formula

$$R = (\Sigma (a \cdot b) \cdot 100) / (N \cdot K), \%, \quad (2)$$

where R – development of the disease; $\Sigma (a \cdot b)$ – the sum of the products of the number of diseased plants (a) by the corresponding damage score (b); N – total number of the plants studied, K – the highest score on the record scale.



Рис. 2. Растения кукурузы, пораженные *H. turcicum*
Fig. 2. Corn plants infected by *H. turcicum*

RESULTS AND DISCUSSION

Like all grain crops, corn is susceptible to fungal diseases, the most common of which is Northern corn leaf blight (see Fig. 2). Initially, the leaves become covered with small brownish-gray spots, which then enlarge as the disease progresses.

Figure 3 presents data on the extent of Northern corn leaf blight in a control corn nursery. In 2023 and 2024, the extent of *H. turcicum* infestation on corn ranged from 0 to 58%, depending on the genotype. In 2023, excessive rainfall (461.7 mm) in August contributed to a significant spread (70–100%) of this disease. In 2023, 0 samples had the lowest degree of *H. turcicum* development (0–10%), 30 samples had 11–20%, 70 samples had 21–30%, 60 samples had 31–40%, 19 samples had 41–50%, and 3 hybrids (Primorsky 638, Primorsky 647, Primorsky 655) had over 50%. The prevalence of the disease in the standard Slavyanka sample was 94%, and the degree of development was 25%.

Meteorological conditions in 2024 were most favorable for corn growth and development. As a result, the incidence of Northern corn leaf blight was low. 96.7% of the studied genotypes had a disease prevalence of 0–10% (see Fig. 3). Of these, 46 accessions demonstrated immunity (incidence and prevalence of 0%) to *H. turcicum* in 2024: Primorsky 505, 506, 507, 509, 510,

512, 516, 521, 527, 538, 539, 541, 552, 564, 565, 566, 573, 574, 575, 580, 583, 587, 588, 594, 597, 612, 637, 649, 671, 673, 675, 677, 679, 683, 685, 686, 696, 719, 721, 722, 729, 738, 745, 757, 764, 786. The prevalence of this pathogen in the standard was 20%, the degree of development was 6% (see Fig. 4).

The dominant type of smut disease of corn in the southern Far East is Fusarium wilt *F. moniliforme* (see Fig. 5).

Research in 2023 identified 129 corn genotypes characterized by low (0–10%) susceptibility to fusarium ear rot, accounting for 70.9% of the total number of samples studied in the nursery (see Fig. 6). Among these, two hybrids (Primorsky 576 and Primorsky 730) exhibited immunity to this disease (see Fig. 4).

According to 2024 data, 72.4% of the genotypes (131 samples) have a minimum degree of development of *F. moniliforme*, of which 6.9% are characterized by immunity (Primorsky 527, 533, 562, 565, 566, 567, 571, 608, 633). Hybrids Primorsky 527, Primorsky 565, and Primorsky 566 are characterized by complex resistance to Northern corn leaf blight and Fusarium ear rot. In the standard variety-population Slavyanka, the prevalence of *F. moniliforme* in 2023 and 2024 was at the level of 34–36%, the development index was 8%.

In total, over 2 years of research, 18 hybrids were slightly affected (up to 10%) by Northern

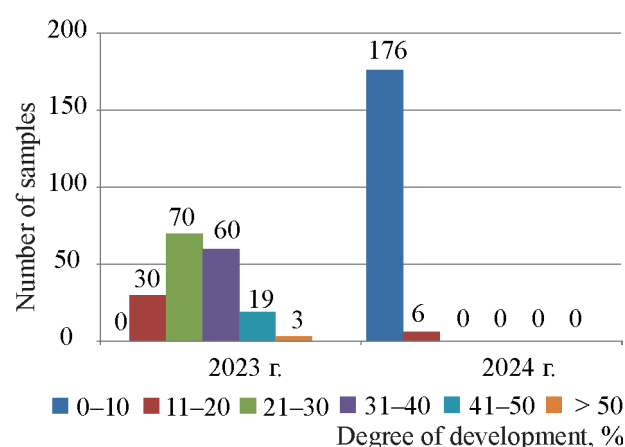


Рис. 3. Результаты оценки образцов кукурузы на степень развития *H. turcicum*

Fig. 3. Results of the evaluation of corn specimens for the progression of *H. turcicum*

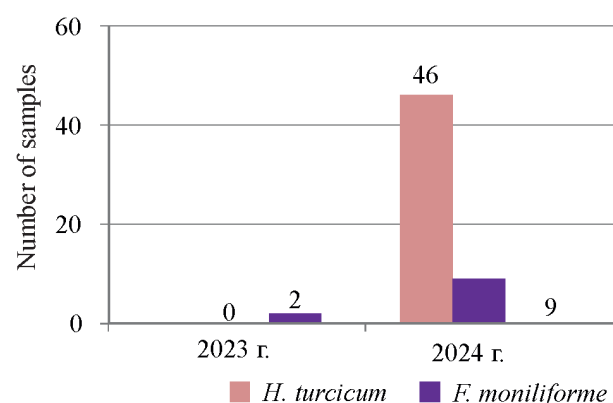


Рис. 4. Показатели иммунитета генотипов кукурузы к грибным патогенам

Рис. 4. Parameters of the immunity of corn genotypes to fungal pathogens



Рис. 5. Початок кукурузы, пораженный *F. moniliforme* (оригинал)

Fig. 5. Corn ear infected by *F. moniliforme* (original)

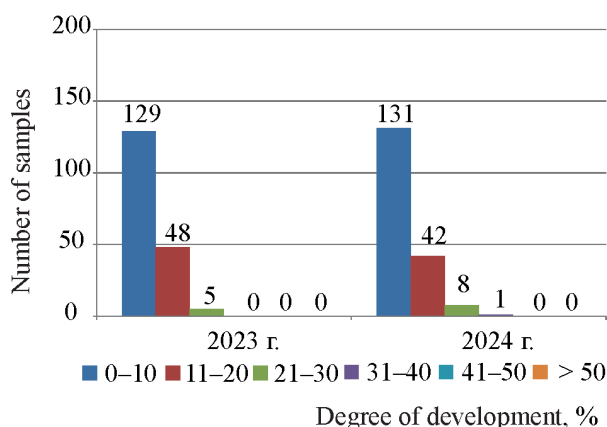


Рис. 6. Результаты оценки образцов кукурузы на степень развития *F. moniliforme*

Fig. 6. Results of the evaluation of corn specimens for the degree of development of *F. moniliforme*

corn leaf blight, and 127 by Fusarium ear rot. Primorsky 547 and Primorsky 660 samples, which belong to the middle-early maturity group, are characterized by a complex of resistance to these diseases; Primorsky 580, 583, 588, 589, 597, 612 – middle-late group; Primorsky 587, 665, 666, 677, 679, 683, 685 and 686 – medium-maturing group (see Fig. 7). The maximum

(30–35%) degree of development of *H. turcicum* was noted in the hybrids Primorsky 638, 643, 647, 655 and 656, *F. moniliforme* (20–27%) in the hybrids Primorsky 502, 649, 742, 767 and 786. In the standard sample, the degree of development of *H. turcicum* corresponds to 15%, *F. moniliforme* – 8%.

The grain yield of the selected hybrids varied from 4.2 (Primorsky 683) to 11.4 t/ha (Primorsky 589) (see Fig. 7). The genotypes Primorsky 583, Primorsky 588, and Primorsky 589 are characterized by the highest yield, exceeding the standard (6.5 t/ha) by 3.7–4.9 t/ha ($LSD_{05} = 1,15$ t/ha).

Another of the most damaging diseases of cobs is smut (*Ustilago zeae* Unger). This disease manifests itself on all above-ground parts of the plant as blister-like swellings of varying shapes and sizes (see Fig. 8). Infection with this pathogen can occur throughout the entire corn growing season. Symptoms of smut were detected in 2023 in the Primorsky 520, 524, and 551 hybrids, and in 2024 in the Primorsky 524, 587, 589, and 795 hybrids. The incidence rates were 1.8% (Primorsky 587) to 4.5% (Primorsky 524).

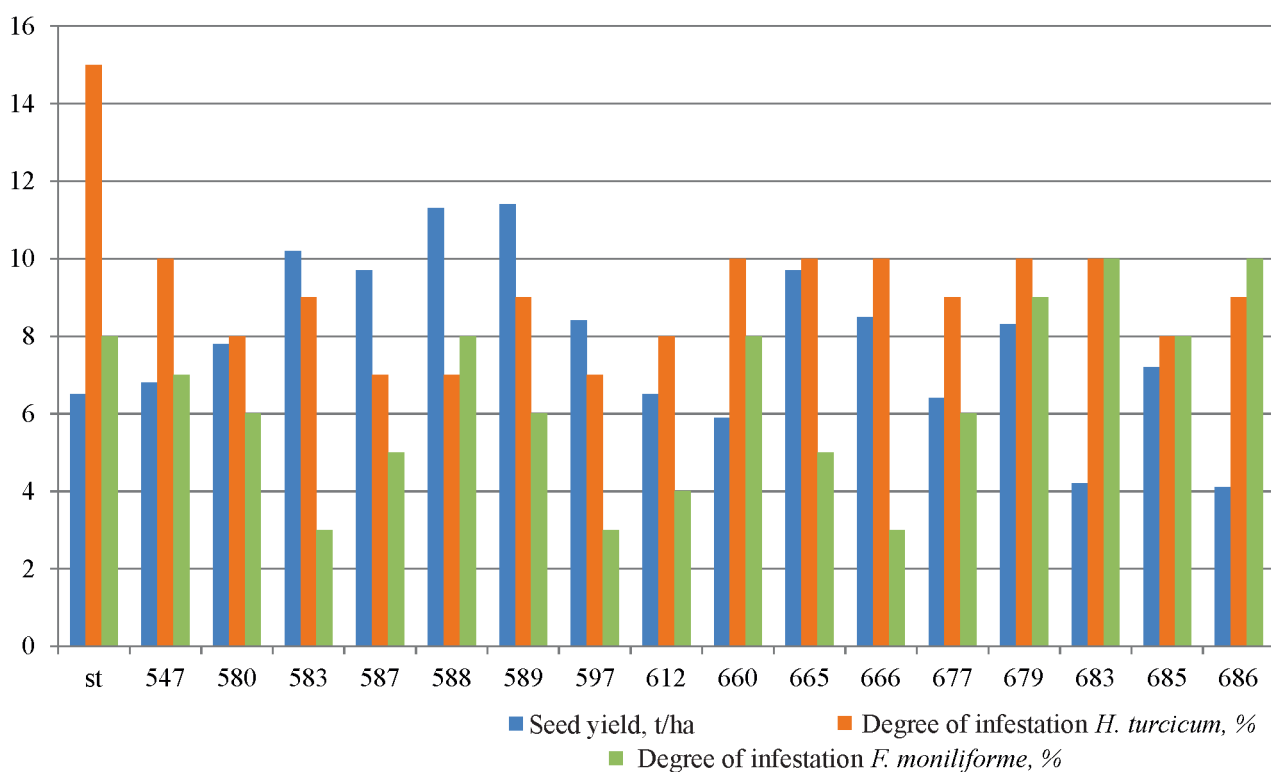


Рис. 7. Показатели урожайности и степени поражения грибными патогенами гибридов кукурузы

Fig. 7. Parameters of the yield of corn hybrids and the degree of the damage caused by fungal pathogens



Рис. 8. Стебель (а) и початок кукурузы (б), пораженные *U. zeae* (оригинал)

Fig. 8. Corn stalk (a) and ear (b) infected by *U. zeae* (original)

CONCLUSIONS

1. The conducted studies to assess the degree of damage of corn hybrids by fungal pathogens made it possible to isolate samples for further use in breeding for resistance to *Helminthosporium turcicum* Pass and *Fusarium moniliforme* Sheldon.

2. According to our data, on average over 2 years, the incidence rates of Northern corn leaf blight, depending on the genotype, ranged from 7 to 35%, and fusarium ear rot – from 2 to 23%. High field resistance (development level – up to 10%) to *H. turcicum* is characteristic of 18 genotypes (9.9% of the total number of studied samples), and to *F. moniliforme* – 127 (69.8%). The Primorsky samples 547, 580, 583, 587, 588, 589, 597, 612, 660, 665, 666, 677, 679, 683, 685 and 686 stood out for their resistance to these diseases.

3. Symptoms of corn smut were detected in six genotypes. The frequency of *U. zae* occurrence varied from 1.8% (Primorsky 587) to 4.5% (Primorsky 524).

4. Selective material of corn distinguished by its resistance to fungal diseases is promising for the creation of new genotypes.

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Микробный белок в кормлении тиляпии: распределение минеральных веществ в органах и тканях и их влияние на метаболизм

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В условиях современного развития аквакультуры особое внимание уделяется вопросам повышения эффективности кормления и улучшения здоровья рыб. Применение специализированных кормовых добавок, обогащенных белками и микроэлементами, является одним из перспективных направлений. В данной работе рассматривается влияние белково-минеральной кормовой добавки DREAMFEED® (ООО «ГИПРОБИОСИНТЕЗ») на рост и физиологическое состояние нильской тиляпии (*Oreochromis niloticus*), а также особенности накопления и резорбции важных микроэлементов в тканях и органах рыб. В ходе исследования сеголетки нильской тиляпии были разделены на две группы. Представители опытной группы получали корм, включавший 94% кормовой добавки DREAMFEED®, 5% рыбьего жира и 1% премикса. В контрольной группе использовался комбикорм производства ООО «БИФФ» (рыбная мука – 35%, пшеничная мука – 22, мясная мука – 20, кукурузный глютен – 10, рыбий жир – 7, кровяная мука – 5, премикс – 1%). Опытный корм характеризовался более высоким содержанием белка (64,3%) и сниженным уровнем жира (8,9%) по сравнению с контрольным кормом. Рыбоводно-биологический анализ продемонстрировал более высокий прогнозируемый рост у экспериментальной группы, что подтверждалось коэффициентом аппроксимации (0,981 против 0,963 у контроля). Концентрация гемоглобина в опытной группе на всех этапах превышала показатели контрольной группы на 10,1–14,2 г/л. В экспериментальной группе наблюдалось снижение скорости оседания эритроцитов до оптимальных уровней (не более 2,5 мм/ч). В течение всего периода исследования концентрация общего белка в сыворотке крови у представителей опытной группы сохранялась на уровне выше 29,2 г/л, в то время как у контрольных особей данный показатель оставался ниже 26,2 г/л. Анализ динамики накопления меди в тканях и органах рыб обеих групп показал сходные тенденции, однако были выявлены отдельные различия, обусловленные составом комбикормов. Проведенное исследование подтверждает эффективность использования кормовой добавки DREAMFEED® для улучшения продуктивных и физиологических показателей нильской тиляпии.

Ключевые слова: белок, кормовая добавка, микроорганизмы, медь, прирост, физиология, кормление

Microbial protein in tilapia feeding: distribution of minerals in organs and tissues and their impact on metabolism

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In the context of the modern development of aquaculture, special attention is paid to improving the efficiency of feeding and improving the health of fish. The use of specialized feed additives enriched with proteins and trace elements is one of the promising directions. This paper examines the effect of the protein-mineral feed additive DREAMFEED® OOO "GIPROBIOSINTEZ" on the growth and physiological condition of the Nile tilapia (*Oreochromis niloticus*), as well as the features of accumulation and resorption of important trace elements in the tissues and organs of fish. During the study, Nile tilapia fingerlings were divided into two groups. The experimental group received feed containing 94% DREAMFEED® feed additive, 5% fish oil and 1% premix. In the control group, compound feed produced by the OOO "BIFF" was used (fish meal – 35%, wheat flour – 22, meat meal – 20, corn gluten – 10, fish oil – 7, blood meal – 5, premix – 1%). The experimental feed was characterized by a higher protein content (64.3%) and a reduced fat level (8.9%) compared to the control feed. Fish-farming and biological analysis demonstrated higher predicted growth in the experimental group, which was confirmed by the approximation coefficient (0.981 versus 0.963 in the control). The hemoglobin concentration in the experimental group at all stages exceeded the control group by 10.1–14.2 g/l. In the experimental group, a decrease in the erythrocyte sedimentation rate to optimal levels (no more than 2.5 mm/h) was observed. Throughout the study period, the concentration of total protein in the blood serum of the experimental group remained above 29.2 g/l, while in the control individuals this figure remained below 26.2 g/l. Analysis of copper accumulation dynamics in the tissues and organs of fish from both groups revealed similar trends, but some differences were identified due to the feed composition. This study confirms the effectiveness of the DREAMFEED® feed additive in improving the performance and physiological parameters of the Nile tilapia.

Keywords: protein, feed additive, microorganisms, copper, gain, physiology, feeding

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Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

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INTRODUCTION

In modern aquaculture, special attention is paid to the use of biologically active substances in the feeding of fish and other cultivated organisms in order to optimize growth indicators, strengthen immunity, and increase resistance to diseases [1–5]. Domestic scientists are actively developing new approaches to feed production, focused on the use of biologically active substances and adapted to the conditions of the Russian market, which is confirmed by a number of scientific studies [6–10].

In recent decades, the development of aquaculture has required the search for new, effective, and environmentally safe sources of protein for feeding fish. One of the promising areas in this field is the production of microbial protein based on natural gas. Microbial protein can serve as a complete and high-quality component of feed [11, 12]. Its use allows not only to increase the nutritional value of feed, but also to reduce dependence on traditional sources of protein (for example, fish meal), which is relevant in conditions of limited natural resources [13, 14].

In the Russian Federation, the previously existing capacities of the microbiological industry, focused on the production of microbial protein from hydrocarbon raw materials, were lost. Nevertheless, the scientific and technological groundwork in this area has been preserved, which allowed research and development to be resumed.

One of the most successful projects in restoring the industrial technology for producing microbial protein from natural gas is the work of specialists at the OOO "GIPROBIOSINTEZ". As a result of directed auto-selection of obligate methane-oxidizing bacteria (*Methylococcus capsulatus*) under continuous cultivation conditions, the GBS-15 strain, suitable for industrial application, was obtained. This strain has been deposited in the All-Russian Collection of Industrial Microorganisms, is not pathogenic, does not contain genetically modified elements, and does not include genes from other organisms. Based on it, the feed additive DREAMFEED® was created at the OOO "GIPROBIOSINTEZ",

representing a concentrate of microbial protein from the inactivated culture of *Methylococcus capsulatus* cells.

The objectives of the study are to assess the impact of the feed additive DREAMFEED® as a protein-mineral component on the productivity and physiological condition of Nile tilapia (*Oreochromis niloticus*), as well as to study the processes of accumulation and resorption of copper, potassium, and other trace elements in the organs and tissues of fish.

The following tasks were formulated to achieve the stated objectives:

- 1) production of an experimental batch of compound feed with 94% replacement of fish meal by the feed additive DREAMFEED® and conducting experimental trials on tilapia fingerlings;
- 2) assessment of productive indicators and survival of fish during cultivation using experimental feed;
- 3) analysis of the dynamics of copper content in tilapia during the cultivation process.

MATERIAL AND METHODS

The study examined the effect of various feeding regimes on juvenile Nile tilapia under controlled conditions. The experiment was conducted in the aquarium complex and laboratory of the Scientific Research Laboratory "Sturgeon Breeding and Advanced Aquaculture Objects" at the Astrakhan State Technical University. The test subjects were 100 Nile tilapia fingerlings per aquarium in the control and experimental groups (with two repetitions). The duration of the experiment was 120 days.

Glass aquariums with a volume of 400 liters, equipped with aeration, filtration, and thermostatic systems, were used to create controlled conditions. Daily monitoring of environmental parameters included measuring temperature and oxygen (manual thermo-oximeter OxyGuard Handy Polaris), as well as the concentration of nitrogen-containing compounds (nitrate tests by Aquarium Pharmaceuticals).

The experimental feed was produced in laboratory conditions using pressing, drying, and

sieving methods. The content of the feed additive DREAMFEED® in the experimental feed was 94%. The recipe also included 1% premix and 5% fish oil. As a control, a compound feed produced by the ООО “BIFF” was used: fish meal – 35%, wheat flour – 22%, meat meal – 20%, corn gluten – 10%, fish oil – 7%, blood meal – 5%, premix – 1%. Fish feeding was carried out in accordance with daily standards and feed tables, taking into account body weight and water temperature (25–26 °C).

For the purpose of comparative assessment of feed efficiency, a set of physiological and biochemical blood parameters was determined. Blood samples for analysis were collected *in vivo* from the tail vein into the Eppendorf tubes before the start and at the end of the experiment. Heparin was used as an anticoagulant for hematological studies. Hemoglobin concentration was determined photometrically using “Agat-Med” reagent kits (Russia), and the erythrocyte sedimentation rate (ESR) was measured using the Panchenkov method. For biochemical analysis, blood serum was obtained by coagulating blood samples in test tubes without heparin. Serum protein content was determined by the biuret method using the “Agat-Med” reagent kits. Quantitative determination of copper ions in the tissues of the liver, muscles, bones, and head was carried out by atomic absorption spectrometry using a “Квант-2А” spectrometer.

To assess growth characteristics, the average daily growth rate (using the compound interest formula), average daily gain, and mass accumulation coefficient were calculated. The assessment of growth intensity was carried out in duplicate.

The obtained data were subjected to statistical processing using the Excel software package, including the calculation of the mean, the standard error of the mean, and the assessment of the significance level of differences using the Student's *t*-test.

RESULTS AND DISCUSSION

DREAMFEED® is produced using a mineral medium containing salts of various trace el-

ements, including copper, the concentration of which in the finished product can reach 200–300 mg/kg. Considering the lower concentration of copper in traditional feed components and its ability to accumulate in tissues, it was necessary to assess the effect of this supplement on the bodies of fish.

The composition and nutritional value of the feed used are shown in the table, and the macroelement content is shown in Figure 1. According to the data, the experimental feed has higher protein content (64.3%), copper (299 mg/kg), and potassium (7290 mg/kg), as well as lower fat content (8.9%) compared to the control feed.

The dynamics of changes in the body weight of fish in the experimental and control groups are shown in Fig. 2.

Data analysis showed that in the experimental group, which received feed with a 94% replacement of fish meal with the DREAMFEED® protein feed additive, there was a more even growth trajectory without sharp fluctuations. This is confirmed by a higher coefficient of determina-

Состав опытного и контрольного комбикормов, %
The composition of experimental and control feed, %

Compound feed	Moisture	Ash	Crude protein (according to Kjeldahl)	Protein (according to Barnstein)	Crude fat (lipids)
Control	4,63	9,82	44,7	39,10	13,1
Experiment	4,41	5,84	68,9	64,30	8,9

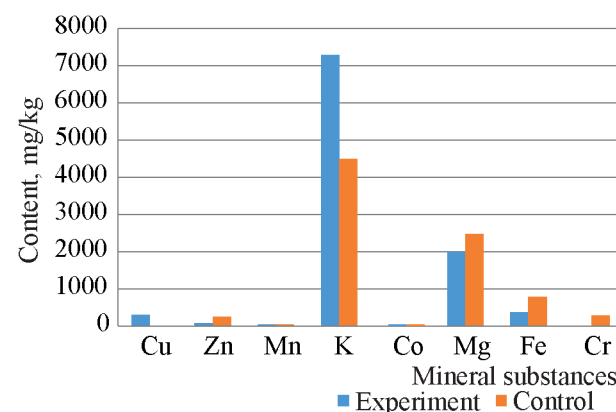


Рис. 1. Содержание микроэлементов в комбикормах
Fig. 1. The content of trace elements in animal feed

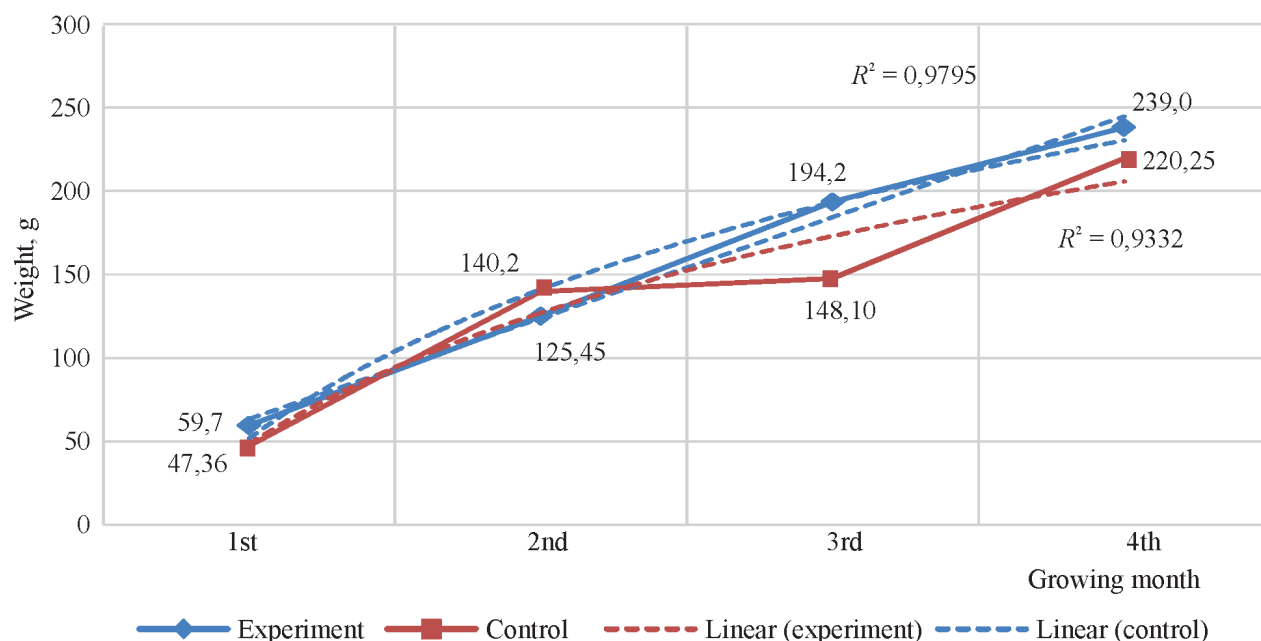


Рис. 2. Динамика изменения массы тела тилляпии

Fig. 2. Dynamics of changes in the body weight of tilapia

tion ($R^2 = 0,981$) compared to the control ($R^2 = 0,963$), which indicates a greater predictive value of the growth model and suggests that higher growth rates may be maintained with continued use of the experimental feed.

Even though the differences in absolute and relative growth, average daily growth rate, and mass accumulation coefficient between the experimental and control groups were not statistically significant, there is a positive trend in favor of the experimental group (see Fig. 3). According to the analysis results, the absolute biomass

increase in the experimental group exceeded the control value by 6.41 g, and the relative increase by 0.05%. At the same time, the average daily growth rate in the control group was slightly higher than the corresponding value in the experimental group (by 0.1 g/day).

It's worth noting that fish survival in both groups remained at 100% throughout the entire experimental period when optimal cultivation conditions were maintained. The condition of tilapia in the studied cultivation conditions was assessed based on physiological and biochemi-

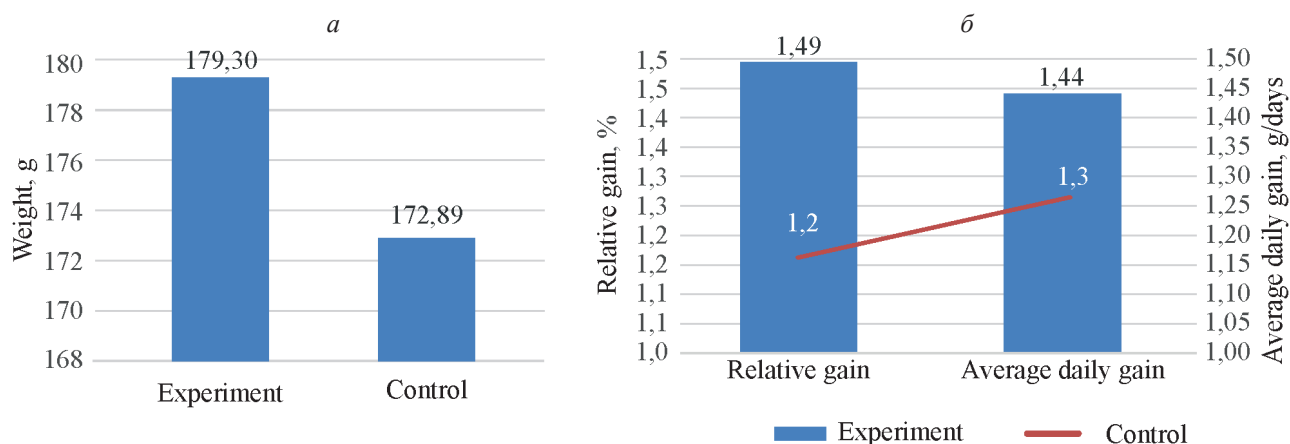


Рис. 3. Показатели прироста опытной и контрольной групп:

a – абсолютный прирост; *б* – относительный и среднесуточный прирост

Fig. 3. Growth rates of the experimental and control groups:

a – absolute gain; *б* – relative and average daily gain

cal blood indicators, which are sensitive markers of physiological and pathological changes.

The study results showed that in the control group, which received the feed produced by the ООО “BIFF,” hemoglobin levels were 10.1–14.2 g/l lower than in the experimental group throughout the experiment. In the experimental group, hemoglobin concentration ranged from 68.0 to 72.3 g/l, staying within the borderline values typical for tilapia (75–80 g/l).

An increased ESR indicates the presence of a pathological process in the body (for example, with inflammation or anemia), while a sharp decrease in this indicator is observed in processes that lead to blood thickening (fluid loss). At the first stage, the ESR was higher than the normal values for fish (2.0–2.5 mm/h). As tilapia fed with DREAMFEED® protein feed supplement grew, their ESR dropped to normal levels and did not exceed 2.5 mm/h. In the control group, this indicator remained high, peaking in the 3rd month of growth at 4 mm/h.

The total protein content in blood serum is an important indicator that reflects the overall metabolic processes happening in the body. During the experiment, it was found that the concentration of total protein in the blood serum of fish in the experimental group was statistically significantly higher than in the control group, reaching a maximum difference of 13.5 g/l in the 3rd month of cultivation. There was a trend of decreasing total protein concentration in both groups by the end of the experiment. In the control group, the decrease was 22.14% (from 26.2 to 20.4 g/l), while in the experimental group it was 4.24% (from 33.0 to 31.6 g/l). It is assumed that the decrease in total protein levels may be related to the lower water temperature during the winter growing period.

Analysis of copper content in individual organs and tissues of the fish was also conducted (see Fig. 4). At the initial stage of cultivation, the copper concentration in the liver of tilapia in the experimental group exceeded that in the control group by 1274 mg/kg. During further observation, the copper level in the liver ranged between 631–780 mg/kg. By the end of the experiment,

the copper concentration in the liver of the experimental group was 1275 mg/kg, which is 272 mg/kg (21.41%) higher than in the control.

The copper concentration in muscle tissue decreased in both groups: in the experimental group – from 2.62 to 1.62 mg/kg, and in the control group – from 2.53 to 1.84 mg/kg. The values obtained correspond to the permissible level of copper in food products (< 10 mg/kg) [11]. The copper content in the head tissues increased slightly: in the experimental group by 0.22 mg/kg, and in the control group by 0.18 mg/kg. In the fish bone tissue, the copper concentration decreased during the cultivation period: in the experimental group, from 3.91 to 1.58 mg/kg (59.59%), and in the control group, from 2.43 to 1.50 mg/kg (38.27%).

Thus, the level of copper in the muscle tissue of fish in both groups is within acceptable limits for food. Despite the relatively high copper content in the liver (the main storage of this element), no negative effects on tilapia growth or physiological condition were observed. The fish survival rate was 100%, and hematological indicators remained within the normal range.

CONCLUSIONS

1. The experimental feed containing the DREAMFEED® additive had a higher protein content (64.3% vs 35.0%) and a lower fat content (8.9% vs 13.1%) compared to the control feed (produced by the ООО “BIFF”). A comparative analysis of the trace element composition showed that the experimental and control feeds differed significantly in the content of certain elements. The experimental feed had higher levels of copper (299 mg/kg) and potassium (7290 mg/kg), while the control feed was richer in zinc, magnesium, iron, and chromium.

2. Modeling fish growth dynamics revealed a potentially higher and more stable growth rate in the experimental group, which is supported by a higher coefficient of determination ($R^2 = 0,981$) compared to the control group ($R^2 = 0,963$).

3. The growth dynamics analysis showed that the experimental group displayed a more stable growth pattern, marked by uniformity and

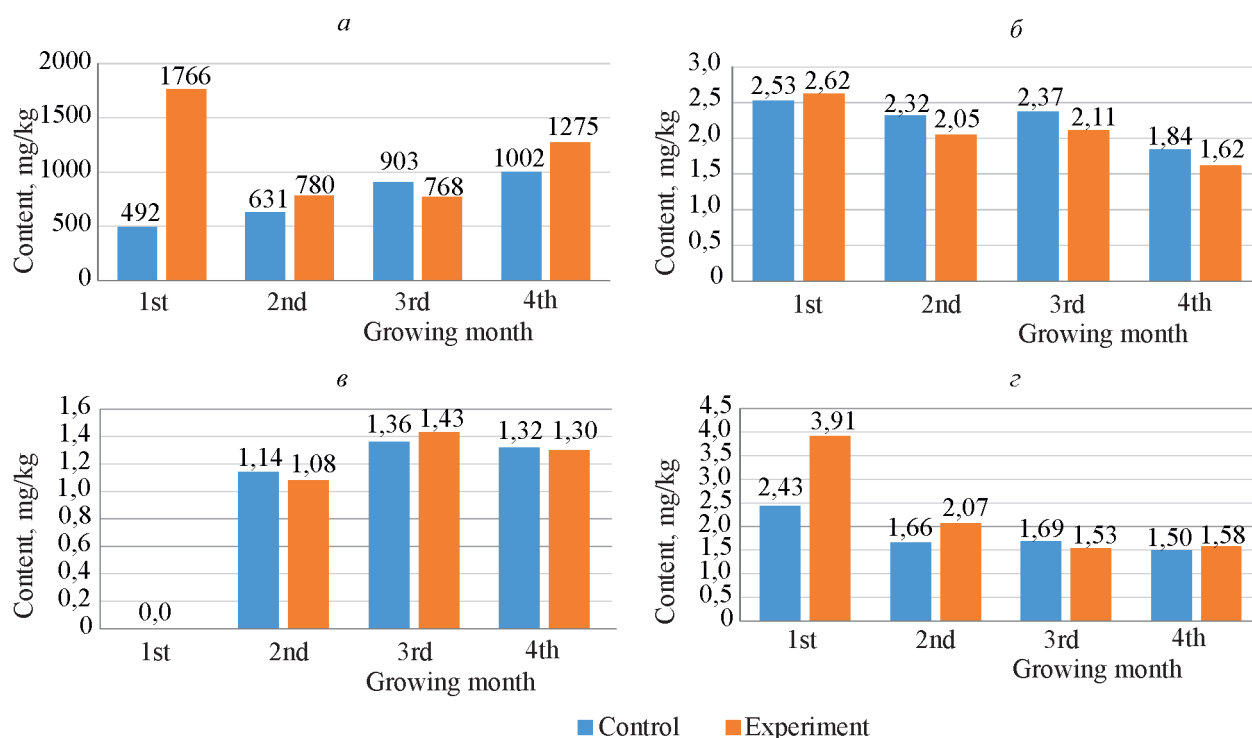


Рис. 4. Динамика изменения содержания меди в тканях и органах рыб:

a – печень; *б* – мышечная ткань; *в* – голова; *г* – костная ткань

Fig. 4. Dynamics of changes in copper content in fish tissues and organs:

a – liver; *б* – muscle tissue; *в* – head; *г* – bone tissue

no sharp fluctuations. At the same time, despite similar growth rates in both groups, the experimental group had a higher determination coefficient compared to the control group. This indicates better predictability of the growth model for the experimental group and suggests the potential for maintaining stable, or even increased, growth rates with prolonged use of feed supplemented with DREAMFEED®.

4. A study of the physiological and biochemical indicators of blood showed that adding DREAMFEED® to the feed has a positive effect on the fish's physiological condition. In the experimental group compared to the control group, the following changes were noted: an increased hemoglobin concentration (10.1–14.2 g/l higher than the control values); a decrease in the erythrocyte sedimentation rate to optimal values, not exceeding 2.5 mm/h; an increase in the total serum protein concentration (values exceeded 29.2 g/l).

5. Analysis of copper content in the tissues and organs of tilapia revealed a general pattern

of changes in both the experimental and control groups. The copper concentration in muscle tissue did not exceed the allowable limits for food products (10 mg/kg). Despite the increased copper content in the liver, which is the main store of this trace element, no negative effects on growth rates or the overall condition of the fish were observed.

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Анализ влияния генотипа на молочную продуктивность коров голштинской породы в условиях ООО «СПК «Межениновский»»

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Статья посвящена актуальной теме – изучению влияния генетических факторов на продуктивные качества крупного рогатого скота молочного направления. В ходе научно-исследовательской работы в ООО «СПК «Межениновский»» Томской области проведена оценка коров голштинской породы линий Вис Бэк Айдиал и Рефлекшн Соверинг с целью определения влияния происхождения животных на их молочную продуктивность, также рассчитаны основные селекционно-генетические параметры: коэффициенты вариации, корреляции и регрессии изучаемых признаков. Установлено, что коровы линии Рефлекшн Соверинг характеризуются более высоким уровнем молочной продуктивности и в среднем по стаду превосходят сверстниц: по удою за всю лактацию – на 1519,1 кг, содержанию молочного жира – на 151,9 кг, содержанию молочного белка – на 127,6 кг. При анализе коэффициента наследуемости отмечено наибольшее влияние на живую массу потомства – 32%. Доля влияния на количество молочного белка составляет 28%, на удой – 14%, на содержание молочного жира – 8%. Установлено, что большее влияние на продуктивные качества первотелок оказывают генотип отцов-производителей и условия содержания. Рассчитанный эффект селекции показал, что при дальнейшем использовании коров линий Вис Бэк Айдиал и Рефлекшн Соверинг можно добиться увеличения следующих показателей (по отношению к группе коров общего стада): удой за 305 дней за первое поколение – на 223,9 кг, за один год – на 49,7 кг, содержание молочного жира – на 4,5 и 1,1 кг, молочного белка – на 17,4 и 3,7 кг соответственно. Поэтому для получения качественной продукции и увеличения ее объемов в условия хозяйства экономически целесообразно использовать коров линий Вис Бэк Айдиал и Рефлекшн Соверинг. Рентабельность получения товарного молока от данных животных превышает показатели по всему стаду на 39,5%.

Ключевые слова: фенотип, генотип, молочная продуктивность, коэффициенты корреляции, вариации, регрессии и наследуемости, селекционный дифференциал, эффект селекции

Analysis of the influence of the genotype on the dairy productivity of Holstein cows in the conditions of the OOO APC "Mezheninovsky"

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The article focuses on a topical issue – the study of the influence of genetic factors on the productive qualities of dairy cattle. During the research work at the "Mezheninovsky" Agricultural Produc-

tion Cooperative, Tomsk Region, an evaluation of Holstein cows of the Vis Back Ideal and Reflection Sovereign lines was conducted to determine the influence of the animals' origin on their milk productivity. The main selection and genetic parameters were also calculated: the coefficients of variation, correlation, and regression of the studied traits. It has been found that cows of the Reflection Sovereign line are characterized by a higher level of milk productivity and, on average, surpass their peers in the herd: in milk yield for the entire lactation – by 1519.1 kg, milk fat content – by 151.9 kg, milk protein content – by 127.6 kg. When analyzing the heritability coefficient, the greatest influence on the live weight of the offspring was noted being at the level of 32%. The influence on the amount of milk protein is 28%, on milk yield – 14%, on milk fat content – 8%. It has been established that the genotype of the fathers and the conditions of keeping have a greater influence on the productive qualities of first-calf heifers. The calculated selection effect showed that with further use of cows of the Vis Back Ideal and Reflection Sovereign lines, it is possible to achieve an increase in the following indicators (in relation to the group of cows of the general herd): milk yield in 305 days for the first generation – by 223.9 kg, in one year – by 49.7 kg, milk fat content – by 4.5 and 1.1 kg, milk protein – by 17.4 and 3.7 kg, respectively. Therefore, to produce high-quality milk and increase its production under farm conditions, it is economically feasible to use cows of the Vis Back Ideal and Reflection Sovereign lines. The profitability of commercial milk production from these animals exceeds the herd average by 39.5%.

Keywords: phenotype, genotype, milk production, correlation coefficients, variations, regressions and heritability, breeding differential, breeding effect

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Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

The main problem in dairy farming remains increasing the productivity of animals by breeding the most valuable breeds, genotypes, and lines of cattle. The most effective method for improving livestock breeds is line breeding¹ [1].

Currently, in the structure of livestock products, the issue of increasing milk production is quite pressing, and solving it is linked to im-

proving the genetic resources of domestic cattle breeds and increasing their productive longevity² [2]. Because of this, domestic dairy breeds need to be improved to increase their milk productivity. Using the world's genetic resources for this purpose, which involves importing animals with different genetic selection, comes with certain adaptation problems, including adjusting to new natural and climatic conditions^{3, 4} [3].

¹Krestyaninova E.I., Solovieva O.I. Variability of milk productivity in cows of the Vis Back Ideal line during three lactations // Proceedings of the International Scientific Conference of Young Scientists and Specialists dedicated to the 160th anniversary of V.A. Mikhelson, Moscow, 2020, vol. 1, pp. 137–140.

²Kostomakhin N.M., Voronkova O.A., Gabedava M.A. Productivity and terms of economic use of Holsteinized cows of different lines // Scientific support for the safety and quality of livestock products: collection of articles based on the materials of the All-Russian (national) scientific and practical conference / edited by S.F. Sukhanova, Kurgan, 2018, pp. 86–89.

³Fedorenko V.F., Mishurov N.P., Marinchenko T.E., Tikhomirov A.I. Analysis of the state and prospects for improving the genetic potential of dairy cattle: a scientific and analytical review: textbook. Manual, Moscow, 2019, 108 p.

⁴Kostomakhin N.M., Safronov S.L. Reserves for increasing milk production in agricultural enterprises // Current problems of the agro-industrial complex and innovative ways to solve them: collection of articles based on the materials of the International scientific and practical conference. Kurgan, 2021, pp. 201–204.

At this stage, the goal of breeding work is to fix positive traits in the offspring. Breeding under proper feeding, control, and regulation of cows' reproductive function, along with creating suitable living conditions, helps develop cattle with high milk productivity, strong constitution, and good reproductive ability for long-term productive use [4–6].

Taking the above into account, a scientific and practical experiment was conducted at the OOO APC "Mezheninovsky" in the Tomsk region, for the first time to assess the impact of genotype on the productive qualities of cattle.

It should be noted that using higher-potential animals helps increase milk production profitability and speeds up the breeding process in the population.

The purpose of the study was to examine the impact of genetic potential on the milk productivity of Holstein Black-and-White cows of the Vis Back Ideal and Reflection Sovereign lines used at the OOO APC "Mezheninovsky".

The research objectives were:

- 1) to conduct a comparative analysis of milk productivity in the first lactation of cows of the specified lines;
- 2) to identify the level of influence of mothers' genotype on the offspring productivity;
- 3) to predict the economic efficiency of milk production using Vis Back Ideal and Reflection Sovereign lines.

MATERIAL AND METHODS

The research was conducted in 2023.

In the studied farm, they used semen from purebred Holstein bulls of the Vis Back Ideal and Reflection Sovereign lines to inseminate cows and heifers. Nowadays, most of the dairy herd on the farm comes from the offspring of these lines.

For the study, they selected Holstein Black-and-White cows with high milk production in their first lactation.

The experiment was carried out according to the scheme shown below (see the figure).

Analysis of the studied indicators was carried out based on primary and final livestock records for the period from 2021 to 2023. The breeding-genetic productivity parameters were determined according to the results of biometric processing using the N.A. Plokhinsky's method. The level of statistical significance was $p \geq 0.95$.

RESULTS AND DISCUSSION

Milk production is one of the most important economically useful traits of cattle, so when evaluating dairy cattle as a whole, it's crucial to first consider their ability to produce milk, which is especially important when comparing the productive qualities of animals from different groups [7].

The main indicators characterizing milk productivity are the amount of milk per lactation,

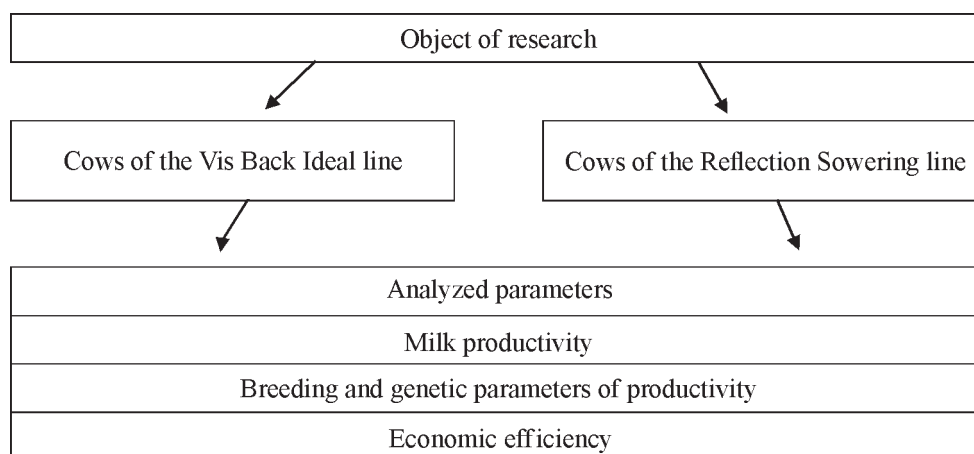


Схема наблюдений
Observation scheme

and the fat and protein content in the milk [8]. The milk productivity of the experimental cow groups is shown in Table 1.

As you can see from the data, cows of the Reflection Sovereign line have higher milk productivity and on average exceed their peers across the herd: by 1,519.1 kg in total milk yield per lactation, by 151.9 kg in milk fat, and by 127.6 kg in milk protein.

Evaluating animals based on breeding and genetic traits is an important part of breeding work, as it helps determine the potential for increasing livestock production. The most important breeding traits for dairy cattle are milk yield, the fat and protein content in the milk, and body weight [9, 10]. The listed breeding and genetic parameters for the herd under study are presented in Table 2.

The correlation between economically useful traits in breeding work with dairy cattle is extremely important. The correlation coefficient shows the degree of connection between traits. Equally important is the regression coefficient, which shows how the value of economically useful traits changes as the level of relatedness increases⁵ [9, 10].

When looking at the main breeding-genetic parameters of productivity, it was found that all

groups of cows are uniform, as the coefficient of variation is less than 15% (for milk yield over 305 days, milk fat and protein content). For live weight, the selected groups show an average level of variability.

The correlation coefficient for all the studied parameters in the groups is low, so there is a low connection between mothers and daughters in terms of productive traits.

During the analysis of the regression coefficient, it was found that when the milk yield in the mothers' group increases by 1 kg, the milk yield in the daughters' group of both lines increases by 0.09 kg, milk fat content by 0.04 kg, milk protein by 0.13 kg, and body weight by 0.15 kg.

When analyzing the heritability coefficient, the biggest impact on the offspring's live weight is observed at 32%. The share of influence on the amount of milk protein is 28%, on milk yield – 14%, and on milk fat content – 8%. So, the genotype of the sire bulls and the living conditions have a greater influence on the productive traits of first-calf heifers.

The selection effect shows that if cows from the Vis Back Ideal and Reflection Sovereign lines continue to be used, the following indicators will increase compared to the general herd: milk yield over 305 days for the first generation

Табл. 1. Характеристика коров по молочной продуктивности (первая лактация)
Table 1. Cow characteristics by milk production (first lactation)

Indicator	Line		On average across the lines	On average across the rest of the herd
	Vis Back Ideal	Reflection Sovereign		
Live weight, kg	415,5 ± 20,8	401,1 ± 20,1	408,3 ± 20,4	418,2 ± 20,9
Milk yield for 305 days, kg	9056,1 ± 452,8	8949,9 ± 447,5	9003,0 ± 450,2	7701,5 ± 385,1
Duration of lactation, days	315	322	320	314
Milk yield for the entire lactation, kg	9352,9 ± 467,6	9447,8 ± 472,4	9445,8 ± 472,3	7928,7 ± 396,4
Milk fat content:				
%	3,8 ± 0,19	3,8 ± 0,19	3,8 ± 0,19	3,8 ± 0,19
кг	291,5 ± 14,6	310,6 ± 15,5	297,8 ± 14,9	158,7 ± 7,9
Milk protein content:				
%	3,2 ± 0,16	3,2 ± 0,16	3,2 ± 0,16	3,2 ± 0,16
кг	245,6 ± 12,3	261,0 ± 11,9	250,5 ± 12,5	133,6 ± 6,7

⁵Zavertyaev B.P. Prospects for the development of marker and genomic selection in dairy cattle breeding: teaching aid. St. Petersburg, 2020, 240 p.

Табл. 2. Основные селекционно-генетические параметры

Table 2. Main breeding and genetic parameters

Coefficient	Line		On average across the lines	On average across the rest of the herd
	Vis Back Ideal	Reflection Sovereign		
Milk yield for 305 days, kg				
Variation	1,10	1,10	1,50	1,10
Correlation	0,08	0,12	0,07	0,01
Regression	0,09	0,10	0,09	0,01
Heritability	0,16	0,24	0,14	0,02
Milk fat content, kg				
Variation	6,10	5,90	8,50	6,20
Correlation	0,08	0,12	0,04	0,01
Regression	0,07	0,09	0,04	0,01
Heritability	0,16	0,24	0,08	0,02
Milk protein content, kg				
Variation	6,60	6,50	9,40	6,80
Correlation	0,08	0,12	0,14	0,01
Regression	0,07	0,09	0,13	0,01
Heritability	0,16	0,24	0,28	0,02
Live weight, kg				
Variation	17,00	17,40	23,80	16,40
Correlation	0,08	0,11	0,16	0,01
Regression	0,08	0,08	0,15	0,01
Heritability	0,16	0,22	0,32	0,02

by 223.9 kg, for one year by 49.7 kg, milk fat content by 4.5 and 1.1 kg respectively, and milk protein by 17.4 and 3.7 kg (see Table 3).

Based on the data received, we can conclude that to increase production volumes, it makes sense to use cows from the Vis Back Ideal and Reflection Sovereign lines.

An important factor for successful dairy farming is the economic efficiency of milk production. To determine the practical significance of using Black-and-White Holstein cows of the Vis Back Ideal and Reflection Sovereign lines, the economic efficiency of milk production was calculated (see Table 4).

The economic efficiency analysis of Holsteinized cows of the specified lines was carried out based on milk productivity.

Since the amount of milk produced per lactation, adjusted to a standard fat content of 3.40%, from cows of the Vis Back Ideal and Reflection Sovereign lines is 1,695.6 kg higher compared to the average for the whole herd, the revenue from selling milk from these lines will be 417.7 thousand rubles, which is 67.1 thousand rubles more than the average herd revenue. Therefore, the profit and profitability level from using cows of these lines are higher by 67.1 thousand rubles and 39.5%, respectively.

Thus, in order to get high-quality products and increase production volumes at the OOO APC "Mezheninovsky", it is economically reasonable to use cows from the Vis Back Ideal and Reflection Sovereign lines.

CONCLUSIONS

1. The group of first-calf heifers of the Reflection Sovereign line is characterized by the highest milk productivity, with indicators that are higher than those of their peers in milk yield over the entire lactation by 1519.1 kg, milk fat content by 151.9 kg, and milk protein content by 127.6 kg.

2. When analyzing the main breeding-genetic parameters of productivity, it was found that: first-calf heifers are uniform in the studied parameters; the most significant influence on cows' productive qualities comes from the genotype of the sire and the conditions of keeping; using cows from the Vis Back Ideal and Reflection Sovereign lines made it possible to increase the following indicators (compared to cows of the general herd): milk yield over 305 days of lactation – by 223.9 kg, milk fat content – by 4.5 kg, milk protein content – by 17.4 kg.

3. To get high-quality products and increase their volume at the OOO APC "Mezheninovsky", it makes economic sense to use cows from the Vis Back Ideal and Reflection Sovereign lines. The profitability of producing marketable milk from these animals is 39.5% higher than the average for the whole herd.

Табл. 3. Эффект селекции

Table 3. Breeding effect

Indicator	Line		On average across the lines	On average across the rest of the herd
	Vis Back Ideal	Reflection Sovereign		
Milk yield for 305 days, kg				
Selection differential of mothers	1532,1	1874,4	1641,0	1636,4
Selection differential of fathers	2003,0	1562,5	2225,5	2854,6
General selection differential	1767,5	1718,5	1919,8	2245,5
Selection effect for the first generation	282,8	412,4	268,8	44,9
Selection effect in one year	62,8	91,6	59,7	10,0
Milk fat content, kg				
Selection differential of mothers	57,7	56,8	57,3	67,3
Selection differential of fathers	93,9	35,6	100,1	116,4
General selection differential	75,8	46,2	78,7	91,9
Selection effect for the first generation	12,1	11,1	6,3	1,8
Selection effect in one year	2,7	2,5	1,4	0,4
Milk protein content, kg				
Selection differential of mothers	53,3	50,7	52,9	60,4
Selection differential of fathers	67,0	26,2	76,3	93,4
General selection differential	60,2	38,5	64,6	76,9
Selection effect for the first generation	9,6	9,2	18,9	1,5
Selection effect in one year	2,1	2,0	4,0	0,3

Табл. 4. Экономическая эффективность производства молока в расчете на 1 гол.

Table 4. Economic efficiency of milk production per 1 head

Indicator	Line		On average across the lines	On average across the rest of the herd
	Vis Back Ideal	Reflection Sovereign		
Milk yield for the entire lactation, kg	9352,9	9447,8	9445,8	7928,7
Milk fat content, %	3,8	3,8	3,8	3,8
Milk yield in terms of basic fat content (3,40%), kg	10453,2	10559,3	10557,1	8861,5
Total costs for feeding and maintenance, thous. rubles	169,9	169,9	169,9	169,9
Production cost of 1 kg of milk, rubles	16,3	16,1	16,1	19,2
Selling price of 1 kg of milk, rubles	39,57	39,57	39,57	39,57
Revenue, thous. rubles	413,6	417,8	417,7	350,6
Profit, thous. rubles	243,7	247,9	247,8	180,7
Production profitability level, %	143,5	145,9	145,9	106,4

4. To prevent inbreeding, dairy farms are recommended to introduce new animal lines into the herd (Siling Trijun Rockit and Roseif Citation, Pabst Governor).

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Бруцеллез крупного рогатого скота на территории Республики Тыва за 1975–2024 гг.

✉ Лопсан Ч.О.

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Представлены динамика и факторы влияния на эпизоотическую ситуацию по бруцеллезу крупного рогатого скота на территории Республики Тыва за 1975–2024 гг. Эпизоотическая ситуация в регионе стационарно неблагоприятная. Бруцеллез крупного рогатого скота за последние 50 лет зарегистрирован в 17 районах и прилегающей территории к г. Кызылу у 54 101 гол. крупного рогатого скота в 532 неблагоприятных пунктах. Данные пункты в основном сконцентрированы на равнинных территориях с более мягким климатом и относительно хорошим травостоем, благоприятными для развития мясного и молочного скотоводства. Бруцеллез крупного рогатого скота не зарегистрирован только на территории Тере-Хольского района. До 1995 г. отмечено увеличение больных бруцеллезом животных. После ликвидации на территории региона совхозов, перехода скота в многочисленные личные подсобные хозяйства с традиционным отгонно-пастбищным ведением животноводства на подножном корме с частыми сменами мест стоянок и разобщенному содержанию животных заболеваемость крупного рогатого скота значительно снизилась. В целом за исследуемый период по Республике Тыва индекс неблагоприятия составил 7,2%, индекс очаговости – 102 больных животных на один неблагоприятный пункт, индекс эпизоотичности – 1064%. Наиболее напряженная эпизоотическая ситуация по бруцеллезу отмечена в первые два десятилетия анализируемого периода (1975–1994 гг.) при общественном ведении животноводства с компактным и скученным содержанием большого количества поголовья в одних стадах и помещениях. В последние три десятилетия (1995–2024 гг.) с началом ликвидации совхозов, молочно-товарных комплексов и реструктуризации собственности с созданием многочисленных частных хозяйств с отгонно-пастбищным (кочевым) ведением животноводства на подножном корме с частыми сменами мест стоянок и пастбищ, приведшему к некоторому разрыву контактов между стадами, сократилось массовое заражение животных и значительно улучшилась эпизоотическая ситуация, которая оставалась стабильно неблагоприятной.

Ключевые слова: бруцеллез, неблагоприятный пункт, индекс неблагоприятия, очаговость, эпизоотичность

Brucellosis of cattle on the territory of the Republic of Tuva for the period of 1975–2024

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The dynamics and factors influencing the epizootic situation of bovine brucellosis in the Republic Tuva for the period of 1975-2024 are presented. The epizootic situation in the region is permanently unfavorable. Over the past 50 years, bovine brucellosis has been registered in 17 districts and the surrounding area of Kyzyl in 54,101 heads of cattle in 532 affected areas. These areas are mainly located in flat areas with a milder climate and relatively good herbage, favorable for the development of meat and dairy cattle breeding. Brucellosis of cattle has not been registered only in the territory of the Tere-Kholsky district. Until 1995, there was an increase in the number of animals identified as sick with brucellosis. After the liquidation of state farms in the region, the transfer of livestock to numerous personal subsidiary farms with traditional distant-pasture keeping of farm animals put to grass with

frequent changes of cattle camps and separated animal husbandry, the incidence of cattle diseases has decreased significantly. In general, during the study period in the Republic Tuva, the index of unfavorability amounted to 7,2 %, the focality index showed 102 heads of sick animals per one contamination zone, the epizooticity index was at the level of 1064%. The most intense epizootic situation for brucellosis was observed in the first two decades of the analyzed period (1975-1994) under public livestock management, with compact and crowded keeping of a large number of livestock in the same herds and premises. In the next three decades (1995-2024), with the beginning of the liquidation of state farms, dairy and commodity complexes and the restructuring of ownership with the creation of numerous private farms with distant-pasture keeping of farm animals (nomadic) livestock farming put to grass with frequent changes of cattle camps and pastures, which led to a certain break in contacts between herds, the mass infection of animals decreased and significantly improved the epizootic situation, which, however, remained consistently dysfunctional.

Keywords: brucellosis, contamination zone, index of unfavorability, focality, epizooticity

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Conflict of interest

The author declares no conflict of interest.

Brucellosis is a chronic infectious disease common to animals and humans. Clinically, brucellosis is characterized by polymorphism, a long latent course, and joint damage, abortions, retained placenta, orchitis, bursitis, endometritis, and mastitis [1, 2]. Brucellosis is caused by small, polymorphic, non-motile, Gram-negative rods, *Brucella abortus*, measuring 0.3–0.5 µm. They are highly invasive and are considered intracellular parasites, but can also be found outside the cell. *Brucella* bacteria survive in food products for a long time—milk for up to 10 days, meat for up to 100 days, and butter, cheese, and feta cheese for up to 80 days. However, they are very sensitive to high temperatures and are instantly killed by boiling in milk. The source of the causative agent is animals infected with brucellosis. Infection occurs through food, sexual contact, and airborne transmission [3].

Brucellosis in cattle was first recorded in Russia in 1900–1901, its emergence being linked to the import of breeding cattle from abroad. The epizootic situation for brucellosis in cattle in the Russian Federation remains tense, including in the Siberian Federal District. In the Republic of Tuva, the average long-term incidence rate ex-

ceeds the national average by 11.19 times [4]. Brucellosis causes economic losses in livestock production, negatively impacting the country's food security [5–7].

Until 1952, vaccination was not used to prevent brucellosis in the Soviet Union. Brucellosis was controlled through research and culling of infected animals from herds. In the Tuva Autonomous Region, the brucellosis vaccine was introduced in 1956.

The purpose of the study is to examine the epizootic situation of bovine brucellosis in the Republic of Tuva for the period 1975–2024.

For a retrospective analysis, they used materials from the State Archive, Tuvastat, the Ministry of Agriculture and Food, the Veterinary Service of the Republic of Tuva, district branches of the Veterinary Center, republican and inter-district laboratories, as well as results from their own research and observations. The epizootic analysis of the brucellosis situation was conducted according to the commonly accepted methodological recommendations in epizootiology.

The dynamics of the number of unfavorable locations was considered as an indicator of the decline or expansion of brucellosis areas. For

this purpose, the epizootic indicator of the index of unfavorability (IU) was calculated using the formula

$$IU = \frac{\text{Number of unfavorable locations}}{\text{Number of settlements}} \times 100^1.$$

In this study, the number of troubled years over ten-year observation periods characterizes the intensity of the epizootic situation over time and is expressed as the epizooticity index (EI) according to the formula

$$EI = \frac{\text{Number of years the disease has been recorded}}{\text{Number of years of observation}} \times 100^2.$$

The average number of infected animals found at one unfavorable location is one of the indicators of the intensity of the epizootic process and is calculated as the focality index (FI) using the formula

$$FI = \frac{\text{Number of sick animals}}{\text{Number of unfavorable locations}} \times 100^3.$$

The work was carried out at the Tuvan Research Institute of Agriculture, which is a branch of the Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences. Overall, over 50 years (from 1975 to 2024), bovine brucellosis was recorded in 17 districts, including the territory of the capital Kyzyl, in 532 affected settlements. The index of unfavorability for the Republic of Tuva was 7.2%, the focality index was 102 sick animals per registered problematic spot, and the epizooticity index was 1064%, indicating a high prevalence, intensity, and persistent problems with brucellosis in the region throughout the period under review.

Most of the animals that tested positive for brucellosis during the study period were found in the central, western, and southern regions, where, due to natural and geographical condi-

tions (flat areas with a milder climate) and the availability of feed resources (relatively rich grasslands, developed crop production), industrial dairy farms are concentrated and meat and dairy cattle farming is well developed (see Table 1).

From 1975 to 1984, out of 1,470 settlements, a total of 116 unfavorable locations (districts) and the highest number of sick animals (30,832 heads) were recorded over 10 years, indicating a very high level of epizootic tension. The index of unfavorability is 7.9% – the highest of all periods, as well as the focality index being the highest with 266 sick animals per one unfavorable location, also the epizooticity index is very high – 1160% (see Table 2).

Brucellosis in cattle was detected every year for all 10 years in 14 districts. The highest number of sick animals was found in the Tandinsky (6,386 heads), Kaa-Khemskey (5,025), Ulug-Khemskey (4,665), and Dzun-Khemchiksky (3,720 heads) districts. The smallest number of sick animals was recorded in remote areas: in the Mongun-Tayginsky district, 96 animals were detected over 5 years, and in the Todzhinsky district, 19 animals were detected over 3 years. In the newly established Sut-Kholsky district in 1983, based on the problematic state farm “Sut-Khol” of the Dzun-Khemchiksky district, 196 animals were detected in 1984.

In the years 1985–1994, there was an increase in the number of troubled districts for cattle brucellosis up to 17, and unfavorable sites up to 140 (which is 24 more than in the previous period, or 20.7%). However, the detection of sick animals decreased to 18,771 heads (down by 12,061 heads, or 39.1%), indicating a reduction in the intensity of the epizootic situation. As the epizootic boundaries expanded, the index of unfavorability increased from 1.6% to 9.5%. The focality index, conversely, decreased to 134, with one unfavorable site fewer sick animals detected than in the previous period, almost half that of

¹Dzhupina S.I., Kolosov A.A. Methods of epizootological research: method. recommendations. Novosibirsk, 1991, 56 p.

²Sidorchuk A.A., Voronin E.S., Glushkov A.A. General epizootology. Moscow: Kolos, 2005, 176 p.

³Dzhupina S.I. Methods of epizootological research and theory of the epizootic process. Novosibirsk: Nauka, 1991, 142 p.

Табл. 1. Количество неблагоприятных лет и выявленных больных бруцеллезом животных за 1975–2024 гг.

Table 1. Number of unfavorable years and animals identified as sick with brucellosis for the period of 1975–2024

District	Unfavorable years	Sick animals identified, heads	District	Unfavorable years	Sick animals identified, heads
Kyzylsky	45	4763	Kaa- Khemsky	33	8340
Bay-Tayginsky	44	2720	Ovyursky	30	1563
Barun-Khemchiksky	43	2049	Sut-Kholsky	24	1336
Dzun-Khemchiksky	43	5413	Mongun-Taiginsky	19	1114
Tes-Khemsky	42	2428	The city of Kyzyl	18	70
Erzinsky	42	2456	Chedi-Kholsky	16	201
Tandinsky	39	8538	Chaa-Kholsky	15	233
Ulug-Khemsky	35	6804	Todzhinsky	9	79
Piy- Khemsky	35	5994	Tere-Kholsky	0	0

the previous period. However, in terms of enzooticity, due to the expansion of the number of unfavorable areas, the epizooticity index was the highest ever observed—1400%.

From 1985 to 1994, brucellosis was detected every year in the same problem areas as in the previous period. The highest number of sick animals was recorded in Kaa- Khemsky (3,241 heads), Piy- Khemsky (2,562), Kyzylsky (2,309), and Ulug- Khemsky (2,063 heads). There was a sharp increase in the number of detected sick animals: in the Mongun-Taiginsky district by 10.4 times – up to 995 heads, in Sut-Kholsky by 5.2 times – up to 1,014 heads, in Todzhinsky by 3.1 times – up to 59 heads, as well as in Kyzyl by 44.2% and Bay-Taiga by 22.4%. In other regions, a decrease in the number of sick animals was noted, especially in Dzun-Khemchiksky (by 3.54 times) and Tandinsky (by 3.27 times). While brucellosis hadn't been recorded in the area near the city of Kyzyl in the previous period, between 1985 and 1994 it was observed in 5 years in 9 animals among livestock owned by residents who had moved from affected areas. Because of this, the territory of Kyzyl also gained an unfavorable status. In the newly formed Chedi-Kholsky District, created from the subdivisions of Tandinsky and Ulug-Khemsky districts in 1983, 11 animals were found with brucellosis in 1993 and 1994. Also,

in the Chaa-Kholsky district, established in 1993 based on the unfavorable “Druzhba” state farm of the Ulug-Khemsky district, 7 animals with brucellosis were identified in 1994.

From 1995 to 2004, the epizootic situation at the district level remained the same. Sick animals were recorded in 17 administrative units, but the number of unfavorable sites decreased by 5 (down to 135). There were 11.4 times fewer sick animals detected (1,651 head), the index of unfavorability dropped to 9.2%, and the focality index sharply fell—almost 11 times—to 12.2, showing positive trends in the epizootic situation of bovine brucellosis in the republic. The epizooticity index decreased slightly since there were still many unfavorable locations (135), standing at 1,350%: brucellosis epizooticity remained high.

Brucellosis was detected every year for 10 years in two districts: Barun-Khemchiksky (190 heads) and Dzun-Khemchiksky (325 heads). One of the highest rates was also in the Sut-Kholsky district – over 9 years, 293 cases of brucellosis in cattle were reported there. In other districts, brucellosis was recorded over different numbers of years – from 9 to just 1 year, but there was a general trend of a sharp decrease in the number of sick animals. An increase in the number of detected cases was only noted in Chede-Kholsky, Chaa-Kholsky districts, and Kyzyl, by 11.5, 8.4,

Табл. 2. Индексы неблагополучия, очаговости и эпизоотичности бруцеллеза крупного рогатого скота в Республике Тува
Table 2. Indices of unfavorability, focality and epizooticity of bovine brucellosis in the Republic of Tuva

District	Index																	
	of unfavorability						of focality						of epizooticity					
	1975– 1984	1985– 1994	1995– 2004	2005– 2014	2015– 2024	1975– 2024	1975– 1984	1985– 1994	1995– 2004	2005– 2014	2015– 2024	1975– 2024	1975– 1984	1985– 1994	1995– 2004	2005– 2014	2015– 2024	1975– 2024
Bay-Tayginsky	12,5	12,5	10	12,5	7,5	11,0	101	124,0	8,8	35,0	9,0	61,8	100	100	80	100	60	88
Mongun-Taiginsky	16,7	30	16,66	0	0	12,6	19,2	111,0	4,6	0	0	58,6	50	90	50	0	0	38
Barun-Khemchiksky	11,1	11,1	11,1	11,1	3,3	9,6	92,9	55,5	19,0	33,3	14,0	47,7	100	100	100	100	30	86
Sut-Kholsky	1,4	14,2	12,9	5,7	0	6,9	196	101,0	11	6,8	0	55,7	10	100	90	40	0	48
Dzun-Khemchiksky	7,7	7,7	7,7	6,9	3,1	6,6	372	105,0	32,5	24,3	24,5	125,9	100	100	100	90	40	86
Ulug-Khemsy	10,0	10,0	9,0	4,0	2,0	7,0	467	206,0	5,2	3,8	7	194,4	100	100	90	40	20	70
Tandinsky	7,7	7,7	6,2	5,4	3,1	6,0	639	195,0	5,6	4,7	30,5	218,9	100	100	80	70	40	78
Piy- Khemsy	7,1	7,1	6,4	2,9	1,4	5,0	337	256,0	5,1	2,3	5,5	171,3	100	100	90	40	20	70
Kaa- Khemsy	5,9	5,9	4,7	2,9	0	3,9	503	324,0	6,4	4,6	0	252,7	100	100	80	50	0	66
Chaa-Kholsky	0	2,5	17,5	10,0	7,5	7,5	0	7,0	8,4	38,0	5	15,5	0	10	70	40	30	30
Kyzylsky	6,7	8,3	7,5	8,3	6,7	7,5	200	231,0	9,7	38,9	47,1	105,8	80	100	90	100	80	90
Chedi-Kholsky	0	3,3	15,0	6,7	1,7	5,3	0	5,5	14,1	5,5	41,0	12,6	0	20	90	40	10	32
The city of Kyzyl	0	50,0	90,0	30,0	10,0	36,0	0	1,8	4,7	3,0	10,0	3,9	0	50	90	30	10	36
Tes-Khemsy	14,2	12,9	12,9	12,9	7,1	12,0	129	87,4	12,2	26,0	2,0	57,8	100	90	90	90	50	84
Erzinsky	15	16,7	15,0	16,7	6,7	14,0	158	54,3	32,6	8,1	29,5	58,5	90	100	900	100	40	84
Ovyursky	16,7	15,0	10,0	0	8,3	10,0	111	41,9	6,0	0	7,8	52,1	100	90	60	0	50	60
Todzhinsky	4,3	7,1	1,4	0	0	2,6	6,4	11,8	1,0	0	0	8,8	30	50	10	0	0	90
Tere-Kholsky	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Republic of Tuva	7,9	9,5	9,2	6,3	32,7	7,2	266	134,0	12,2	20,4	19,8	102,0	1160	1400	1350	930	480	1064

and 4.9 times, respectively. Thus, unlike previous years, when hundreds of animals with brucellosis were detected annually, during this period brucellosis started to be detected from single cases to a few dozen. Despite this, problem areas still remained numerous.

From 2005 to 2014, the trend in brucellosis continued in a positive direction, with only 14 unfavorable districts and 93 unfavorable sites identified (less than in the previous period by 1.5 times – 42 points). However, the number of infected animals found increased by 245 – up to 1,896, raising the epizootic pressure in the unfavorable sites. The index of unfavorability dropped to 6.3%, but despite this, the focality index rose to 20.4 (compared to 12.2 for one problem district in the previous period). The epizooticity index went down to 930% from 1350% in the previous period, or 1.5 times, which shows positive progress and a reduction in brucellosis cases in the region. By the end of the decade in 2014, there were only seven unfavorable districts left, with 110 brucellosis-infected animals identified.

An increase in the number of detected sick animals over the study period was noted in five districts of the republic. In three of them, brucellosis was registered throughout all 10 years, and the largest number of sick animals was found: in Kyzylsky district – 389 animals, an increase of 4.5 times; in Bay-Tayginsky – 350 animals, an increase of 5.0 times; in Barun-Khemchiksky – 333 animals, an increase of 1.8 times. The number of sick livestock also increased in the Tes-Khemsky district by 2.1 times (up to 234 heads) and in the Chaa-Kholsky district by 2.6 times (up to 152 heads), where brucellosis had been recorded for 9 and 4 years, respectively. In the other districts of the republic, the number of sick animals continued to decrease. In the Mongun-Tayginsky, Ovyursky, and Todzhinsky districts, where the disease had appeared in previous periods, no cases of cattle illness were detected.

From 2015 to 2024, the positive trend of decreasing brucellosis continued, with 13 districts identified, and the number of problem areas (48)

and sick animals (951) was halved. The index of unfavorability was 32.7%, the focality index remained almost at the level of the previous decade (19.8), and the epizooticity index dropped by half (to 480%), indicating a continuing positive trend toward improving the region's health regarding cattle brucellosis.

During this period, no cases of brucellosis were found in cattle in the Sut-Kholsky and Kaa-Khemsky districts, where it had appeared before. The Mongun-Tayginsky and Todzhinsky districts also remained unaffected. The number of sick animals increased compared to the previous period in the Tandinsky, Piy-Khemsky, Chedi-Kholsky, and Erzinsky districts, as well as in the city of Kyzyl. There have been new cases of brucellosis in livestock reported in the Ovyursky district. However, it's worth noting that the number of years during the study period when sick animals were found has significantly decreased: for 8 years brucellosis was reported only in the Kyzylsky district, while in other districts it was recorded from one year up to six years.

The appearance of private small-scale farms with a small number of livestock, separate housing of animals, no contact with animals from other farms, and the shift of livestock farming to the traditional seasonal grazing system with frequent changes of pastures all played a positive role in reducing the incidence of brucellosis in cattle at the time, which helped improve the epizootic situation.

The most effective method for preventing and combating brucellosis is specific immunization of animals using vaccines [8–10]. Different vaccines have been used at various times for this purpose. For the first time, in 1956, as part of special anti-brucellosis measures for preventing brucellosis in cattle in the Tuva Autonomous Region, a vaccine from the *Br. abortus* 19 strain was used, along with the slaughter of all compromised livestock and the implementation of a set of anti-brucellosis measures. This led to an improvement in the epizootic situation; however, due to the vaccine's reactogenicity and the persistence of post-vaccination reactions, there were some difficulties in differential diagno-

sis and assessing the epizootic situation, which caused some confusion. With the introduction of the live low-agglutinating vaccine from the *Br. abortus* 82 AB strain for immunization in 1974, which does not cause post-vaccination seropositivity, it became possible to use serological studies to identify animals sick with brucellosis that were being sent to slaughter, along with carrying out veterinary-sanitary and organizational-management measures. However, due to its abortogenic properties, from 2003 to 2006 they partially switched, and later completely, to the live low-agglutinating vaccine from the *Br. abortus* 75/79 AB strain, which is still used today for the specific prevention of brucellosis in cattle. Only the breeding stock of cattle (heifers, young cows, cows) is vaccinated.

The vaccination rate for the entire period analyzed, 1975–2024, is 0.1% of the total livestock, and 26.1% of the breeding stock (see Table 3).

The highest vaccination rates (21% of the total livestock and 56.2% of breeding stock) were recorded between 1985 and 1994. In industrial livestock farming, each division of state farms had dairy-production farms. The livestock was separated by sex and age and kept isolated from each other in separate herds. Once the animals reached a certain age, sexual maturity, insemination, and gave birth, they were moved to milking herds. From 1995 to 2004, vaccination rates dropped by almost half. In the past two decades (2005–2024), vaccination levels have been extremely low, especially in 2015–2024 (2% of the

total livestock and 4.6% of the breeding stock), only in problem farms, even with the switch to immunizing breeding stock with *Br. abortus* 82 AB, *Br. abortus* 75/79 AB vaccines, which do not cause post-vaccination seropositivity.

Along with vaccinating animals only in problem farms in the region, sick animals are identified through serological testing of the breeding herd to fight brucellosis. The level of testing of cattle from 1975 to 2024 was 37.5% of the total herd and 90% of the breeding herd; from 1975 to 1984, it was 36.1% and 95.6%, respectively. During 1985–1994, while dairy farms in state farms were still operating, there was a slight increase in the level of inspections (38% of the total livestock and 101.6% of the breeding stock), linked to a 1.4-fold increase in the cattle population. In 1995–2004, the overall livestock inspection rate dropped 1.6 times, and the breeding stock rate fell by nearly half. The level of research from 2005 to 2014 increased 1.7 times for both total and breeding stock. Sick animals were detected 11.3 times less, which confirms a positive trend toward improving the epizootic situation in the republic regarding brucellosis. In 2015–2024, the level of research on breeding stock increased to 105%.

Despite this, measures to combat brucellosis by vaccinating the breeding herd only in problematic farms, along with the increasing level of research showing positive trends and a decrease in detected sick animals, do not improve the persistently unfavorable epizootic situation of

Табл. 3. Уровень вакцинации и исследований маточного поголовья крупного рогатого скота на бруцеллез за 1975–2024 гг.

Table 3. Level of vaccination and testing of the breeding stock of cattle for brucellosis for the period of 1975–2024

Years	Breeding stock	Vaccinated, heads			The proportion of vaccines, %	Researched, heads	The proportion of those studied, %
		strain 19	strain 82	strain 75/79			
1975–1984	640 995	30 840	136 731	167 571	26,1	612 859	95,6
1985–1994	713 967	10 921	390 345	401 266	56,2	725 126	101,6
1995–2004	599 485	–	157 119	161 107	26,9	316 152	52,7
2005–2014	580 145	–	5563	100 684	18,3	507 815	87,5
2015–2024	789 492г	271	–	36 577	4,6	829 761	105
1975–2024	3 324 084	42 032	6 89 758	867 205	26,1	2 991 713	90

brucellosis in cattle across the Republic of Tuva, since relapses and acute outbreaks due to the introduction of the pathogen from outside cannot be ruled out [11].

CONCLUSION

Under the current socio-economic conditions in the Republic of Tuva, one of the factors contributing to the region's problems with cattle brucellosis is keeping different species and age-sex groups of animals together, having breeding bulls in the same herd, as well as uncontrolled natural mating, which spreads out calving over a long period, making it difficult to carry out timely preventive immunization, blood sampling for testing, and other veterinary-sanitary and anti-brucellosis measures according to the official established procedures.

An important factor (feature) of the region's long-term problems was the unauthorized movement of animals with an unfavorable brucellosis status of their products, as well as exchanges between producers for breeding and improving offspring in different administrative districts and settlements, and violations by livestock owners of veterinary and sanitary rules for keeping and moving animals, which led to the spread of brucellosis to various areas, which became a characteristic feature of this infection in the Republic of Tuva.

In the current epizootic situation regarding brucellosis in cattle in the territory of the Republic of Tuva, for effective management and control of the epizootic situation in unfavorable and threatened areas, it is necessary:

- to provide the entire breeding population of cattle with long-lasting, sufficiently strong immunity against brucellosis using live, weakly agglutinating vaccines (*Br. abortus* 75/79 AB) [12];

- conduct timely and comprehensive systematic planned studies to identify sick animals and brucellosis carriers in accordance with the Veterinary Rules approved by the Order of the Ministry of Agriculture and Food of the Russian Federation No. 703 of November 22, 2024, as well as the Guidelines for the Use of the *Br. abortus*

75/79 AB vaccine and the Interstate Standard GOST 34105–2023, with full implementation of the entire set of veterinary-sanitary, organizational, and anti-epizootic measures;

- ensure labeling and recording of all types of farm animals according to the Horriot Program (Federal Law of 28.06.2023), which came into effect in the Russian Federation on March 1, 2024, which will make it possible to keep track of all livestock in farms, monitor the movement and exit of animals, quickly identify the source of infection, improve the biological safety of animal husbandry, and also trace the movement of animal products to prevent the spread of infectious diseases, including bovine brucellosis.

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Добавка на основе соевого сырья как обогащающий компонент кормовой смеси

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Причиной низкой продуктивности сельскохозяйственных животных является недостаток протеина в рационе кормления. Устранить эту проблему можно за счет увеличения объемов потребления животными высокобелковых кормов. Цель исследования – разработать обогащающую кормовую добавку на основе соевого сырья. Представлена технология получения обогащающей добавки и результаты исследования ее химического состава. Добавка получена на основе сои сорта Сентабринка. Ее химический состав и микробиологические показатели определены стандартными общепринятыми методами исследования. Установлено, что добавка содержит в значительном количестве (на 100 г) белки (41,67 г), жиры (19,87), углеводы (19,60), пищевые волокна (7,8 г), минеральные вещества (5,66 мг), а также витамин С – 2,11 мг, витамин Е – 20,85 и β-каротин – 3,58 мг. Проведен анализ возможности использования добавки для обогащения рациона кур-несушек и улучшения химического состава комбикорма. Химический состав кормовой смеси, приготовленной по разработанной рецептуре, улучшился практически по всем наиболее важным нормируемым показателям, оставшись в рекомендуемых пределах. Содержание сырого жира увеличилось на 58,6%, сырого протеина – на 5,8, сырой клетчатки – 5,1%. Удалось исключить дополнительное внесение аминокислот (лизин, метионин), которыми богата соевая добавка. До максимально допустимого предела путем обогащения увеличилось содержание витамина Е – до 2,45 вместо 1,01 мг/100 г. Исследованные образцы по микробиологическим показателям в течение одного года хранения находились в пределах нормы. Динамика изменения перекисного числа в процессе хранения добавки свидетельствует о ферментативном процессе окисления ее липидной фракции, превышающем допустимую норму при сроке хранения 12 мес (10,8 ммоль активного кислорода/кг жира). Срок годности кормовой добавки принят 11 мес. Разработанная добавка может быть использована для обогащения ежедневного рациона корма сельскохозяйственных животных и птицы.

Ключевые слова: добавка, зерно сои, корм, обогащение, химический состав, микробиологические показатели, срок годности

Soybean-based additive as an enriching component of feed mixtures

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The reason for the low productivity of farm animals is the lack of protein in the diet. This problem can be solved by increasing the consumption of high-protein animal feed. The purpose of the study was to develop an enriching feed additive based on soybean raw materials. The technology for producing an enriching additive and the results of its chemical composition are presented. The additive is obtained on the basis of the Sentyabrinka soybean variety. Its chemical composition and microbiological characteristics are determined by standard conventional methods of investigation. The additive is found to contain a significant amount (per 100 g) of proteins (41.67 g), fats (19.87 g), carbohydrates (19.60 g), dietary fibers (7.8 g), minerals (5.66 mg), as well as vitamin C – 2.11 mg, vitamin E – 20.85 mg and β-carotene – 3.58 mg. Analysis of the possibility of using additives to enrich the diet of laying hens and improve the chemical composition of the combined feed was carried out. The chemical composition of the feed mixture, prepared according to our formulation, has improved in almost all the most important standardized indicators remaining within the recommended limits. The content of crude fat increased by 58.6%, raw protein – by 5.8% and crude fiber – by 5.1%. It became possible

to eliminate the additional application of amino acids (lysine, methionine), which the soy additive is rich in. Vitamin E content was increased to the maximum permissible limit of 2.45 instead of 1.01 mg/100 g through enrichment. The samples tested for microbiological indicators were within normal limits during one storage year. The evolution of the peroxide number during storage indicates an enzymatic oxidation process of its lipid fraction, exceeding the acceptable standard for 12-month storage (10.8 mmol active oxygen/kg fat). The shelf life of the feed supplement is 11 months. The developed additive can be used to enrich the daily ration of feed for farm animals and poultry.

Keywords: additive, soybean, feed, enrichment, chemical composition, microbiological indicators, shelf life

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Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

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INTRODUCTION

Soybeans are a highly effective feed product. They are rich in protein, essential amino acids, and energy, which help ensure high productivity in farm animals and poultry. You can use whole soybeans as well as meal, cake, pressed meal, and other processed products. Soy is used as feed on its own or mixed with corn, sorghum, oats, peas, and other raw materials. Its green mass has high nutritional value for 20–30 days after flowering begins [2, 3].

According to scientists, a common reason for low productivity in farm animals is a protein deficiency in their diet. You can fix this problem by increasing the amount of high-protein feed they eat by at least 1.5 times. The best approach here is to use soy as one of the main components of the animals' diet [4].

Soybeans are rich in vitamins A, D, C, and E. They contain three times more vitamin B1 than dry cow's milk and six times more vitamin B2 than wheat. Soy also has 19–22% oil and up to 30% carbohydrates. The carbohydrates in soybeans are mainly sugars. They also contain a large amount of macro- and microelements, as

well as mineral salts [6]. Soy is used in making balanced feed for all types of farm animals. Many animal feed producers create nutrient mixes based on soybeans that are balanced in vitamins and minerals. This product is in high demand among farmers who want to give their animals everything they need for growth and development, improving productivity, and boosting health [7, 8]. When feeding animals natural soy or untreated soybean meal, it's important to remember that they contain a number of toxic substances that reduce the nutritional value of the feed and suppress animal growth (trypsin inhibitor, saponins, urease, hemagglutinin, lipoxidase, etc.). The enzyme urease, for example, converts urea into ammonia, and if there's too much of this enzyme in the feed, it can cause ammonia poisoning in the body. Because of this, you can only feed soy grain and soybean meal to monogastric animals and poultry after it has been heat-treated [4, 9].

Full-fat soy is a processed soy product (usually through extrusion) made without removing the oil. It's an important and valuable component of animal diets and feed mixes. After extrusion,

full-fat soybean meal becomes a highly nutritious, safe, and cost-effective feed product. Its use helps increase productivity, improve animal health, and reduce production costs. However, it's important to monitor the quality of heat treatment to preserve the nutritional properties and avoid secondary spoilage of the product [2, 9].

Soybean oil meal is a product obtained from processing soybean seeds during the chemical production of soybean oil. Soybean meal is produced in large amounts on an industrial scale: up to 80% of the world's and Russia's total soybean production is processed. It contains a lot of minerals, amino acids, and proteins, and is used as a base for various animal feeds, being one of the highest quality plant-based products for feeding farm animals [4]. Soybean oil meal is easily digestible and, in terms of its biological value, is close to animal proteins. You can add soybean meal to the main diet (the recommended inclusion rate is up to 35%) for any farm animals and poultry [10–12].

Soybean oil cake is an eco-friendly product obtained after mechanically pressing oil from soybean seeds during extrusion-press processing. It comes in full-fat and semi-defatted varieties. Full-fat cake is made without removing the oil (full-fat soybeans), while semi-defatted cake (residual oil content 6–14%) is produced by pressing the full-fat cake on a mechanical press. It is used in compound feeds and feed mixes as a high-quality protein ingredient for fattening farm animals and poultry [13]. Protein has high biological value and digestibility, making it indispensable in livestock farming. In addition to protein, it contains trace elements – calcium, iron, phosphorus, manganese, and zinc. The presence of fats increases the caloric content of the diet [14–16].

Recent studies have shown that soybean hulls are used as an additional roughage during the dry season when pasture availability and nutrient quality are lower in milk production. Soybean hulls improve feed intake, milk production, and nitrogen utilization in dairy cows, which supports their use as an alternative to silage in various feeding systems [17].

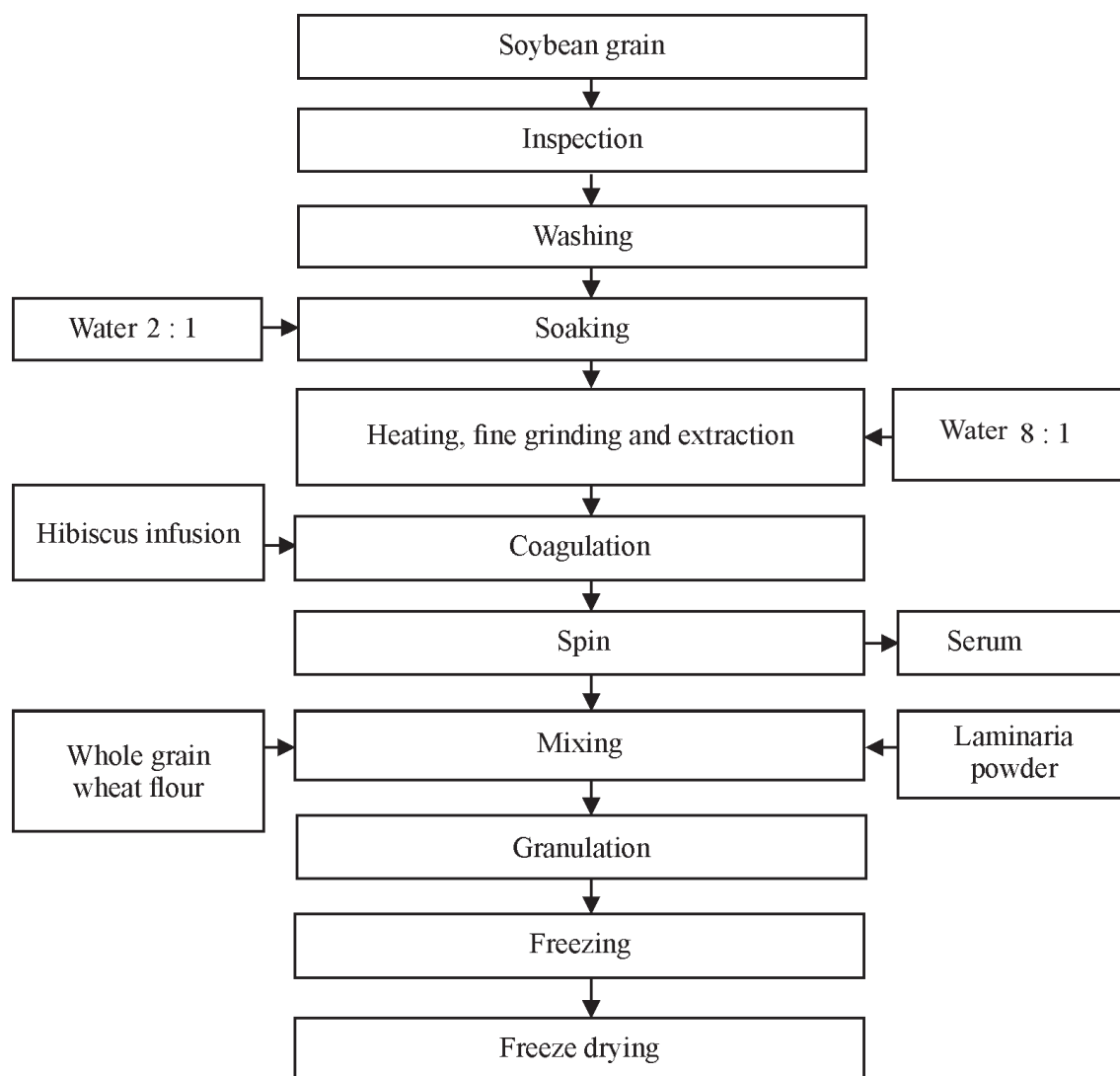
A review of the literature reveals the existing range of soybean processing products for feed purposes. However, one of the current priority areas for processing agricultural raw materials is the development of new resource-saving technologies to improve the efficiency of biotech feed production. Works on the development of technologies that ensure the comprehensive processing of plant raw materials, reduction in the consumption of raw materials and thermal energy resources, improvement in the quality and competitiveness of products, and reduction of the man-made impact on the environment are highly relevant.

The purpose of the study is to develop an effective fortifying feed additive based on soybean raw materials.

MATERIAL AND METHODS

The content of moisture, proteins, essential amino acids, fats, fatty acids, dietary fibers, ash, and macroelements (potassium, calcium, magnesium, phosphorus) was determined using near-infrared spectroscopy with a “FOSS NIRSystem 5000” infrared scanner. To determine the content of raffinose, stachyose, and sucrose, a Capillary Electrophoresis system “Kapel” was used. The content of phospholipids was determined by inorganic phosphorus, vitamin E by a color reaction with Fe^{3+} ions and dipyrindyl, vitamin C according to GOST 24556–89, and the content of β -carotene by spectrophotometric method. Microbiological analysis of feed was carried out in accordance with the “Rules for Bacteriological Examination of Feed” (1975), GOST 25311–82 and TR 201/00/CU. The peroxide value in the supplement was determined according to GOST 34118–2017. The chemical composition of the feed for 21-week-old laying hens when adding a soy enrichment supplement was calculated according to GOST 18221–2018.

We have developed a technology for producing a nutritious feed supplement, which is based on thermo-acid coagulation (see the figure). The supplement is made from the Sentyabrinka va-



Технологическая схема получения обогащающей добавки
Process scheme for the production of enriching additives

riety of soybeans, bred by the Federal Scientific Center "All-Russian Research Institute of Soybeans" (FSC VNIISoy) (GOST 17109–88), grown in the breeding nurseries of the All-Russian Research Institute of Soybeans (Sadovoe village, Tambov district, Amur region).

When obtaining the enriching additive, the soybeans were soaked and ground in water after inspection and washing, then heated to 98–100 °C and extracted with thorough mixing. Next, the aqueous suspension was coagulated with a pre-prepared hibiscus infusion at a temperature of at least 90 °C. The resulting mass was then filtered and pressed [18]. To improve the chemical composition and quality characteristics of the

finished pellets, whole wheat flour was added to the mixture at 5.5% of the total mass. To better achieve a uniform mixture, prevent crumbliness of the finished pellets, and also to enrich them with vitamins, minerals, and improve the structural properties of the final supplement, 0.5% of kelp powder was added to the wet mixture. After stirring the mass to a uniform consistency, it was granulated, frozen at a temperature of –70 °C, and freeze-dried until reaching 5.4% moisture.

Laminaria powder was obtained by crushing dried leaves in a laboratory mill. Hibiscus infusion was used as a coagulant for the soy suspension, which was prepared by steeping dried petals in hot water for 1 hour.

RESULTS AND DISCUSSION

The chemical composition of the developed feed additive has been studied, including the content of amino acids and fatty acids (see tables 1–3).

The data from the tables show that the supplement is rich in proteins (41.67 g), fats (19.87), carbs (19.60), sugars, and dietary fiber (7.8 g). The enriching supplement also contains a significant amount of essential amino acids, fatty acids, and minerals at 5.66 mg/100 g, including potassium, calcium, magnesium, and phosphorus. The supplement contains 2.11 mg of vitamin C, 20.85 mg of vitamin E, and 3.58 mg of beta-carotene. Thanks to this composition, it can be included in the feed formulas for all types of farm animals and poultry to enrich them with valuable nutrients and boost their nutritional value.

The daily feed ration for replacement pullets aged 21 weeks was studied. The control was a SK PK-1 compound feed, the formulation of which is shown in Table 4. In this feed formula, the total amount of soybean meal, soybean oil, methionine, and lysine monohydrochloride was replaced with an equal amount of soybean-enriching additive.

The chemical composition of the feed with the soy-enriching additive was studied in comparison with the control according to the main indicators regulated by GOST 18221–2018 (see Table 5).

Table 5 shows that the chemical composition of the feed mixture prepared according to our developed recipe has improved in almost all the most important regulated indicators, while remaining within the recommended limits. For example, the crude fat content increased by 58.6%, crude protein by 5.8%, and crude fiber by 5.1%. In addition, it was possible to remove synthetic amino acids (lysine, methionine) from the recipe, which are abundant in the added soy supplement. The vitamin E content increased to the maximum allowable limit – up to 2.45 instead of 1.01 mg/100 g through enrichment.

Табл. 1. Химический состав и энергетическая ценность добавки (в 100 г)

Table 1. Chemical composition and energy value of the additive (in 100 g)

Indicator	Content ($M \pm m$)
Proteins, g	41,67 ± 0,45
Carbohydrates, g:	19,60 ± 0,6
sucrose	0,95 ± 0,01
raffinose	0,10 ± 0,001
stachyose	0,47 ± 0,01
Fats, g	19,87 ± 0,6
Phosphatides, g	1,05 ± 0,02
Dietary fibers, g	7,8 ± 0,05
Mineral substances, g	5,66 ± 0,1
Potassium, mg	2536 ± 46,57
Calcium, mg	574 ± 4,62
Magnesium, mg	479 ± 2,69
Phosphorus, mg	650 ± 11,93
Vitamin C, mg	2,11 ± 0,02
β-carotene, mg	3,58 ± 0,02
Vitamin E, mg	20,85 ± 0,23
Energy value, kcal	423,91

Табл. 2. Содержание незаменимых аминокислот в соевой обогащающей добавке, %

Table 2. Essential amino acid content in a soybean enrichment additive, %

Amino acid	Content ($M \pm m$)
Lysine	6,99 ± 0,1
Phenylalanine	5,13 ± 0,1
Leucine	10,25 ± 0,2
Isoleucine	3,19 ± 0,05
Valine	7,17 ± 0,1
Threonine	3,91 ± 0,06
Methionine + cystine	3,65 ± 0,05

Табл. 3. Содержание жирных кислот в соевой обогащающей добавке, %

Table 3. Fatty acid content in a soybean enrichment additive, %

Fatty acid	Content ($M \pm m$)
Palmitinic	11,68 ± 0,1
Stearic	3,97 ± 0,1
Linoleic	55,34 ± 0,5
linolenic	0,51 ± 0,01
Oleinic	21,07 ± 0,2

The shelf life of the developed enriching additive was determined using microbiological indicators. For this, the additive under study was produced and stored for the necessary period of time (every month) at a temperature not

exceeding 20°C and an air relative humidity of 75%. According to GOST 3898–56 and earlier studies, dried soy-based products are stored for an average of 9–12 months. Because of this, it was decided to study the samples that have been stored for this period of time.

All foods that contain lipids are prone to oxidative changes (rancidity) when stored for a long time. This process negatively affects the product's consumer qualities. Lipid oxidation products also have carcinogenic effects and pose health risks (like cancer and others), so the peroxide value is an important factor when determining shelf life.

Microbiological indicators and peroxide value were studied in the samples stored for 9–12 months. The research results are shown in Table 6.

The samples tested for microbiological indicators stayed within normal limits throughout the entire storage period. The change in peroxide value during storage of the additive shows an enzymatic oxidation process of its lipid fraction, exceeding the allowable limit after 12 months of storage (10.8 mmol of active oxygen/kg of fat). At the same time, the additive turns a darker color and develops a slight bitter taste. Based on this, we consider the maximum shelf life to be 11 months.

Табл. 4. Рецепт комбикорма ПК-1 для кур-несушек (контроль) и опытная рецептура, %

Table. 4. Formula for the compound feed PK-1 for laying hens (control) and the experimental formula, %

Component	Content	
	control	experiment
Wheat	45	45
Corn	17	17
Soy enriching additive	–	22,35
Soybean meal (SP 44)	19	–
Lime meal	6	6
Soy oil	3	–
Defluorinated phosphate	1,5	1,5
Methionine 98,5%	0,23	–
L-lysine monohydrochloride 98%	0,12	–
Table salt	0,15	0,15
Gravel	7	7
Premix	1	1
Total	100	100

Табл. 5. Химический состав комбикорма ПК-1 для кур-несушек возрастом 21 нед (контроль) и разработанного комбикорма (в 100 г)

Table 5. Chemical composition of the compound feed PK-1 for laying hens aged 21 weeks (control) and the developed compound feed (in 100 g)

Component	Content, %		
	GOST standard 18221–2018	Control	Experience
ME, kcal	–	275	–
Crude fat, %	3,50–5,00	2,80	4,44
Crude protein, %	16,50–18,00	17,30	18,30
Crude fiber, %	2,50–5,50	4,70	4,94
Lysine, %	0,70–0,86 and more*	0,70	1,72
Methionine + cystine, %	0,60–0,73 and more *	0,60	1,20
Calcium, %	3,00–3,60	3,34	3,37
Phosphorus, %	0,60–0,70	0,81	0,84
Sodium, %	1,16–0,20	0,32	0,28
Vitamin E, mg	1,00–2,50	1,01	2,45

* When producing compound feed for chickens without the use of synthetic amino acids, it is permissible to increase the mass fractions of lysine, methionine and cystine above the specified limits..

Табл. 6. Микробиологический профиль и показатель перекисного числа свежей и хранящейся в течение 9–12 мес соевой обогащающей добавки

Table 6. Microbiological profile and peroxide number of the fresh and stored for 9–12 months soybean enriching additive

Determined indicator	Permissible levels, mg/kg, no more than	Shelf life of the additive, months				
		Fresh	9	10	11	12
<i>S. aureus</i>	Not acceptable in 0,1 g	Not detected				
QMAFAnM, CFU/g	Not more than 5·10 ⁴	Less than 1·10 ¹				
Yeast, CFU/g	Not more than 100	Less than 10				
Molds, CFU/g	Not more than 10	Less than 10				
Sulfite-reducing clostridia	Not acceptable in 0,1 g	Not detected				
Peroxide value, mol/kg	Not more than 10,0	2,3 ± 0,04	6,2 ± 0,10	7,0 ± 0,11	8,6 ± 0,12	10,8 ± 0,20

CONCLUSION

A nutritional supplement based on high-quality soybean raw materials has been developed, which can increase the feed's nutritional value. The chemical composition of the feed mixture made with the developed supplement has improved in almost all the most important regulated indicators, while still staying within the recommended limits. The content of crude fat increased by 58.6%, crude protein by 5.8%, and crude fiber by 5.1%. It was possible to eliminate the need for additional amino acids (lysine, methionine) in the formula, which are abundant in the soybean supplement. By enriching it to the maximum allowable level, the vitamin E content increased (2.45 instead of 1.01 mg/100 g). The shelf life of the feed additive is 11 months. It can be used to enrich the daily diet of livestock and poultry feed.

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Применение алгоритмов компьютерного зрения и глубокого обучения для инвентаризации деревьев в садах интенсивного типа

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Представлен метод мониторинга выпадов (погибшие деревья с признаками усыхания кроны и ствола) в интенсивных садах на основе аэрофотосъемки деревьев с беспилотного летательного аппарата DJI Mavic 3 Multispectral в междурядьях (высота съемки 1,5–2,0 м) и алгоритмов компьютерного зрения и глубокого обучения. Собран оригинальный датасет из 5366 изображений яблоневых садов, размеченный по трем классам: погибшие деревья (класс «Dead»), кандидаты на выпад (класс «Candidate») и молодые посадки (класс «Newly»). Аугментация данных (синтетическая генерация новых изображений на основе существующих) включала моделирование изменений освещенности ($\pm 15\%$), цветового тона (-20° по hue), гауссовского шума (0,5%) и размытия ($\sigma = 0,5$ пикселя), что повысило устойчивость модели к работе в условиях садовых насаждений. Проведено сравнение пяти версий архитектуры YOLOv12; оптимальной признана модель YOLOv12l ($mAP@50(B) = 0,810$; Precision = 0,820; Recall = 0,831), обеспечивающая баланс точности и производительности (9,58 мс/кадр). Разработано специализированное ПО с графическим интерфейсом, реализующее постобработку видеопотока, трекинг (отслеживание) объектов и визуализацию результатов. Использование алгоритма ByteTrack (с компенсацией движения камеры) позволило снизить число переключений ID распознанных классов деревьев до 2,3 на 1000 кадров и повысить точность распознавания до 92,4%, что на 41% превышает результаты распознавания без трекинга. Программа поддерживает настройку зоны анализа кадра в зависимости от параметров сада (ширина междурядий, угол съемки) и совместима с геоинформационными платформами, что позволяет формировать цифровые карты выпадов с привязкой к координатам GNSS-RTK. Практическая значимость полученных результатов заключается в уменьшении трудозатрат на инвентаризацию, повышении точности и скорости мониторинга состояния насаждений.

Ключевые слова: интенсивное садоводство, мониторинг, инвентаризация насаждений, компьютерное зрение, машинное обучение

Application of computer vision and deep learning algorithms for tree inventory in intensive orchards

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A method for monitoring plant extinction (dead trees with signs of crown and trunk drying) in intensive orchards is presented based on aerial photography of trees from a DJI Mavic 3 Multispectral unmanned aerial vehicle in row spacing (shooting height 1.5–2.0 m) and computer vision and deep learning algorithms. An original dataset of 5,366 images of apple orchards was compiled, labeled into three classes: dead trees (class "Dead"), candidates for plant extinction (class "Candidate"), and

young plantings (class "Newly"). Data augmentation (synthetic generation of new images based on the existing ones) included modeling of the changes in illumination ($\pm 15\%$), color tone (-20° in hue), Gaussian noise (0.5%), and blur ($\sigma = 0.5$ pixels), which increased the model's robustness to work in garden planting conditions. Five versions of the YOLOv12 architecture were compared; the YOLOv12l model was recognized as optimal ($mAP@50(B) = 0.810$; Precision = 0.820; Recall = 0.831), providing a balance between accuracy and performance (9.58 ms/frame). Specialized software with a graphical interface was developed that implements video stream post-processing, object tracking, and visualization of results. The use of the ByteTrack algorithm (with camera motion compensation) allowed reducing the number of ID switches of the recognized tree classes to 2.3 per 1000 frames and increasing the recognition accuracy to 92.4%, which is 41.0% higher than the recognition results without tracking. The program supports customization of the frame analysis zone depending on garden parameters (row spacing, shooting angle) and is compatible with geoinformation platforms, allowing the creation of digital maps of crop losses referenced to GNSS-RTK coordinates. The practical significance of the obtained results lies in the reduction of labor costs for inventory, and the increase in the accuracy and speed of monitoring the condition of the plantings.

Keywords: intensive horticulture, monitoring, plantation inventory, computer vision, machine learning

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Автор заявляет об отсутствии конфликта интересов.

Conflict of interest

The author declare no conflict of interest.

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INTRODUCTION

One of the main factors for productivity and efficiency in intensive orchards with a planting density of up to 2–3 thousand trees per hectare is keeping the rows full. Dyewood of plants (dead trees showing signs of crown and trunk drying) disrupt the even distribution of plants, the structure of the rows, reduce the efficiency of mechanized operations, increase operating costs, and can lead to a 15–20% crop loss [1, 2]. At the same time, traditional methods of inventorying plantations, which are based on agronomists inspecting them, are highly subjective, require a lot of work, and don't scale well to large areas [3].

Modern unmanned aerial vehicles (UAV) filming technologies combined with computer vision methods make it possible to automate monitoring and reduce the time needed for crop surveys. In most studies, RGB cameras are used for monitoring crops, which, unlike LiDAR or multispectral systems, provide enough useful information while being much simpler to process [4]. The study [5] proposed a system using images captured by UAVs and methods for recognizing and analyzing the condition of trees. Similar approaches are described in works [6, 7], where the use of UAVs with RGB cameras and deep learning algorithms made it possible to count and classify trees, as well as accurately detect gaps in the rows.

Despite the existing developments, key scientific problems remain unsolved, which makes this research relevant:

- the lack of specialized methods for accurately recording dyewood of trees using UAVs. Most of them use remote sensing data (at a survey altitude of 20–100 m) [5, 6], where the resolution is insufficient to recognize visual signs of tree shrinkage. These methods are also aimed at counting gaps in rows of garden plants. The proposed method is based on photographing trees in the rows (camera height 1.5–2.0 m), which makes it possible to diagnose individual plants;
- the lack of effective methods for tracking trees in video data obtained from UAVs. Filming between rows from a low height for tree recognition involves using a video stream. At the same time, current methods of processing images from UAVs are focused on single (static) shots, high-resolution orthophotos [8], and don't address the problem that comes up when analyzing consecutive frames: the same tree in different frames is recognized as different objects, which leads to significant errors in the final quantitative assessment of the dyewood of trees;
- insufficient adaptability to changing conditions when shooting garden plants. Existing computer vision algorithms show a drop in accuracy with variations in natural lighting and overlapping tree canopies in dense plantings. This limits their practical use in real-world settings, where the visual characteristics of fruit trees can vary significantly [9]. In the proposed method, this problem is solved through a set of measures to increase robustness, including data augmentation and the use of a modern neural network architecture optimized to work with variable visual features.

The goal of the study is to develop a method for monitoring the dyewood of fruit trees in rows of intensive orchards.

The proposed method combines high-precision tree recognition based on the modern convolutional neural network model YOLOv12, robust tracking to minimize recognition errors, and specialized software (SW) adapted for garden plant inventory tasks.

MATERIAL AND METHODS

Modern convolutional neural network models trained on diverse datasets show high accuracy and performance in recognizing biological objects [10, 11]. Some of the most common architectures include Faster R-CNN, RetinaNet, EfficientDet, and the YOLO (You Only Look Once) family of models. Analysis shows that YOLOv12 eliminates the key shortcomings of well-known architectures by using the Area Attention module and the optimized R-ELAN (Residual Efficient Layer Aggregation Network) feature aggregation network; the model adjusts the lighting, improving object recognition accuracy. Using 7×7 convolutions and multi-scale features makes it possible to significantly improve the accuracy of recognizing objects of different sizes and shapes [12, 13]. For the experiments, various YOLOv12 model configurations were chosen, from nano (n) to extra (x), differing in computational complexity and the number of trainable parameters. To optimize the training process, the transfer learning method was used [12]. The initial setup of the weight coefficients was done using YOLOv12 models trained on the COCO dataset (over 330k labeled images, 80 categories).

When taking aerial photos of the rows of garden plants, they used the RGB camera of the DJI Mavic 3 Multispectral drone, flying along the rows at a height of 1.5–2.0 meters under various natural lighting conditions (see Fig. 1).

For training the model, a collected representative dataset was used, including 5,366 labeled images, created in industrial intensive apple orchards (OOO “Zorinsky Sad”, Kursk region, Oboyansky district, Zorino village) (see Fig. 2).

The original images for labeling had a resolution of 4032×3024 pixels, which provided a high level of detail for accurately recognizing the characteristic signs of crown and trunk drying.

Image labeling (highlighting trees with bounding boxes) was done using the RoboFlow platform. Three object classes are labeled in the images:



Рис. 1. Проведение аэрофотосъемки в междурядьях сада с использованием БПЛА DJI Mavic 3 Multispectral

Fig. 1. Conducting aerial photography in the orchard rows using the DJI Mavic 3 Multispectral UAV

- “Dead”, dead trees with signs of crown and trunk drying out (5547 annotations);
- “Candidate”, trees with borderline signs of life, requiring additional monitoring (1720 annotations);
- “Newly”, newly planted young trees, distinguished by their morphological features and sizes (711 annotations).

Labeling multiple classes made it possible to move from binary classification 'tree/background' to a multifactor analysis of the plantings' conditions.

To improve the model's adaptability to different operating conditions and expand the training dataset, data augmentation was done (synthetic generation of new images based on existing ones) (see Fig. 3).

It included adjusting brightness ($\pm 15\%$), color hue (-20°), adding Gaussian noise (0.5%), and blurring ($\sigma = 0.5$ pixels). These transformations mimicked different lighting conditions, seasonal changes, and hardware inaccuracies, which allowed the original dataset to grow from 5,366 to 11,865 images and improved the model's generalization ability. The resulting dataset was split into training (70%), validation (15%), and test (15%) sets while maintaining class balance.

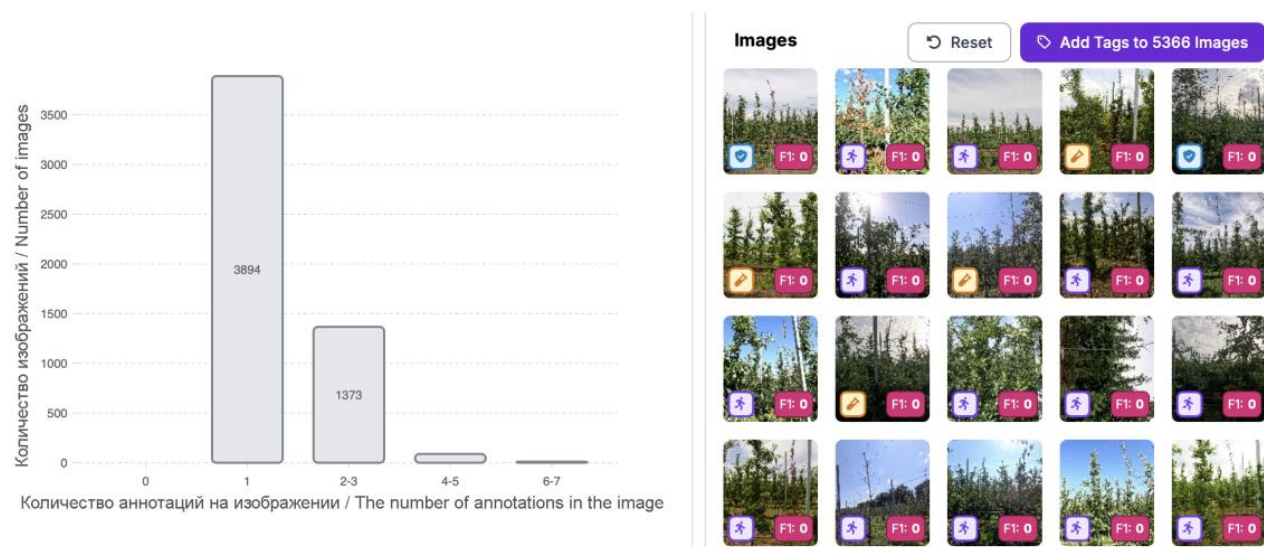


Рис. 2. Распределение изображений по количеству аннотаций и примеры кадров из датасета, сформированного в условиях промышленных яблоневых садов интенсивного типа

Fig. 2. Distribution of the images according to annotation count and frame examples from a dataset captured in industrial-scale intensive type apple orchards

To evaluate the performance of the models, commonly used metrics like mean Average Precision for bounding box detection (mAP@50(B)) were used, along with Recall and Precision. Additionally, the F1 score (the harmonic mean value of Precision and Recall), IoU (Intersection over Union) to assess the overlap between predicted and true boxes, and FPS (Frames Per Second) – the processing speed of frames – were calculated. To analyze training convergence, the values of the loss function (prediction and classification errors for object presence) were tracked over the training epochs [14].

The experiments were carried out on a computing system with two NVIDIA GeForce RTX 2080 Ti graphics cards. We used the PyTorch framework and the Ultralytics library to implement deep learning algorithms, and for data processing and visualization, we used the OpenCV, NumPy, and Matplotlib libraries.

RESULTS AND DISCUSSION

As a result of the experiments, YOLOv12 models were trained in five versions: YOLOv12n (nano), YOLOv12s (small), YOLOv12m (medium), YOLOv12l (large), and YOLOv12x (extra-large). The change in the mAP@50(B) met-

ric during the training process of the models is shown in Fig. 4.

A comparison was made of five versions of YOLOv12 (n, s, m, l, x). The highest accuracy (mAP@50 = 0.811) was shown by YOLOv12x, but its resource demands (199.0 GFLOPs) limit practical use. The YOLOv12n and YOLOv12s models offered high inference speed (3.34–3.85 ms/frame), but with lower accuracy. At the same time, the lowest error value (Box Loss = 1.51) was shown by the YOLOv12n model, which can be explained by its less complex architecture. The YOLOv12l model showed the optimal balance between accuracy (mAP@50 = 0.810, Precision = 0.820, Recall = 0.831) and performance (9.58 ms/frame). The loss function analysis showed that the lowest error values were reached by the 45th epoch, after which overfitting started. Additional calculated metrics (mAP@50-95, F1-score, IoU, and FPS) confirmed the identified trends, so the YOLOv12l model was chosen as the most reasonable for post-processing video material.

As a result of the research, Python software with a graphical interface was developed, implementing the full cycle of video data post-processing using the YOLOv12l model: from load-

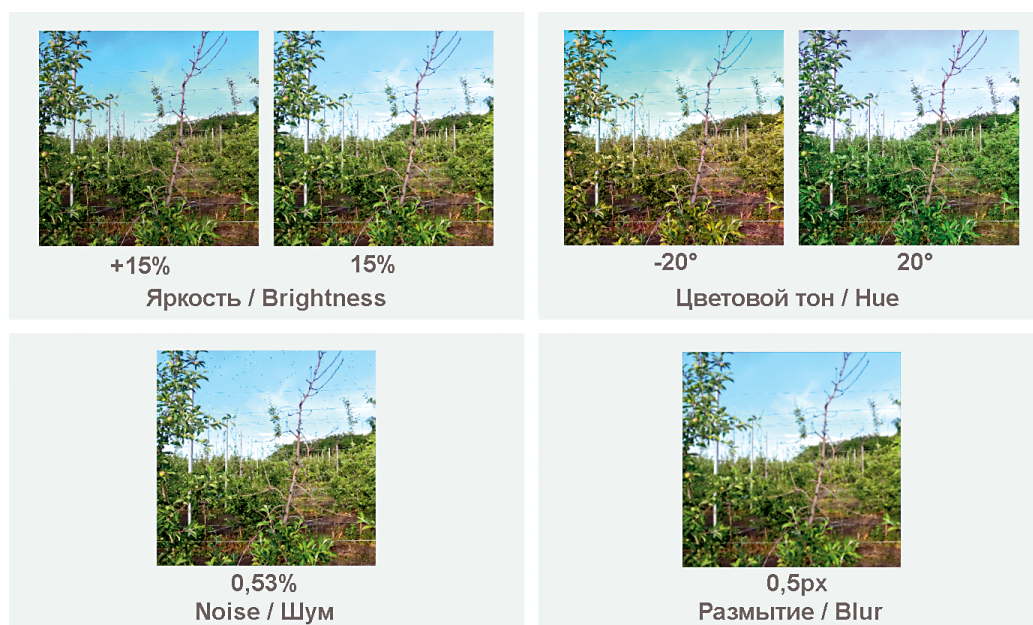


Рис. 3. Используемые методы аугментации набора данных

Fig. 3. Methods used for dataset augmentation

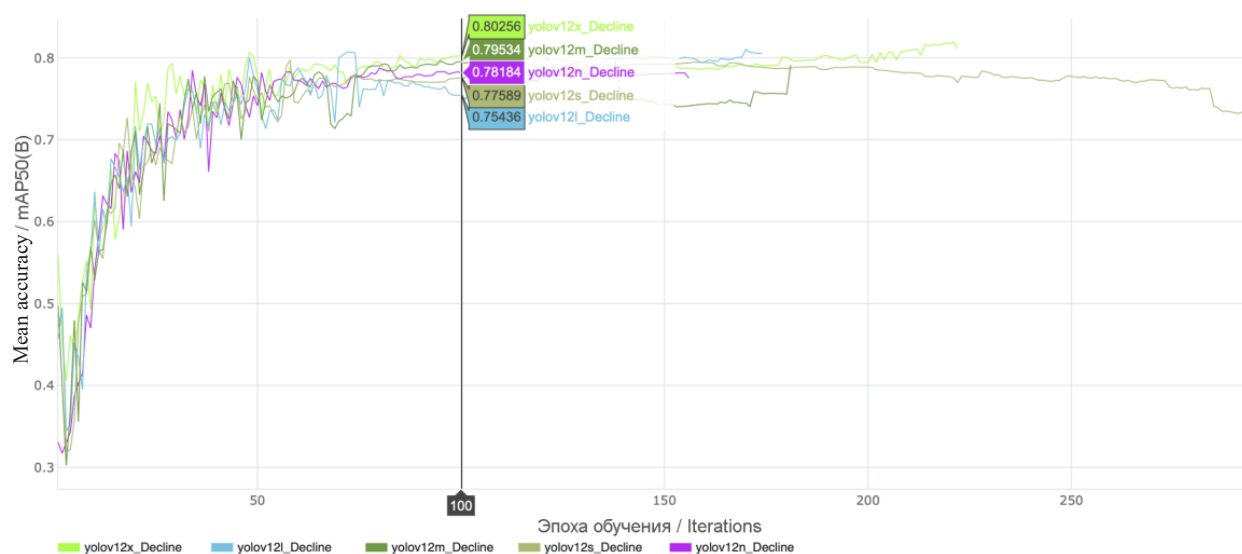


Рис. 4. График зависимости средней точности моделей (метрика mAP@50(B)) от эпохи обучения

Fig. 4. Graph of the dependence of the average precision of models (mAP@50(B) metric) on the training epoch

ing the original video files obtained with the RGB camera of the DJI Mavic 3 Multispectral drone to analysis, visualization, and exporting results (see Fig. 5).

The developed software supports the full video data processing cycle, including object recognition with tracking, filtering results by confidence threshold, suppressing duplicate detections (Non-Maximum Suppression), and adjusting the frame analysis zone (row spacing, shooting angle, etc.). It also features automatic selection of computing resources (CPU/GPU), saving results to a database (SQLite), and exporting to various formats (.txt and .xlsx) with logging of all parameters.

Stable tracking of objects between frames is provided by tracking algorithms (ByteTrack, BoT-SORT, OC-SORT) that use objects' kinematic and visual features (see Fig. 6).

The program's interface lets you adjust tracking settings: confidence threshold for initializing a new ID (new_track_thresh), how long to keep an ID when the object temporarily disappears from the frame (track_buffer), matching thresholds for overlap and object proximity (match_thresh, proximity_thresh), and the camera motion compensation method (gmc_method) for stabilizing tracking. Setting these parameters

minimizes the frequency of ID switching and ensures stable tracking of the trees in the video frames along the row. Based on the video processing results, the program automatically saves images with detected losses and generates a report.

An experimental evaluation of object tracking algorithms was carried out on video recordings at 1920×1080 resolution and 60 fps, captured from a UAV in the rows under different lighting conditions. For each tracking algorithm, we adjusted the parameters, and then recorded the stability metrics for following objects in the frames: the number of ID switches per 1000 frames, the share of correctly maintained IDs over the sequence, as well as the share of correctly recognized dyewoods of trees (accuracy and completeness metrics per frame), and the average processing speed (frames/sec).

Figure 7 shows an example of the program at work: in a row of 224 trees (row length 216 m), 27 dyewoods of trees were identified, in the classes “Dead” and “Candidate”.

During the experimental evaluation of the tracking algorithms, it was found that the ByteTrack algorithm shows the best results for key inventory-related parameters, ensures the minimum number of ID switches (on average 2.3 per

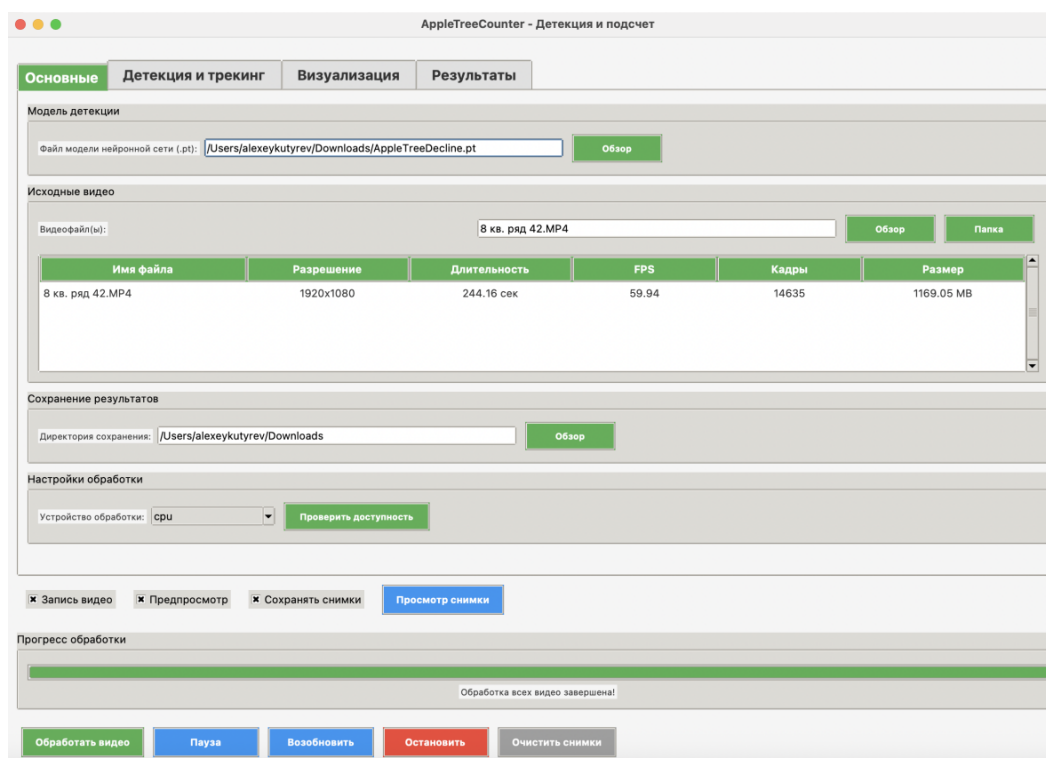


Рис. 5. Интерфейс программы для постобработки видеоданных и мониторинга выпадов в рядах интенсивных садов

Fig. 5. Interface of the program for video data post-processing and monitoring of plant extinction in the rows of intensive orchards

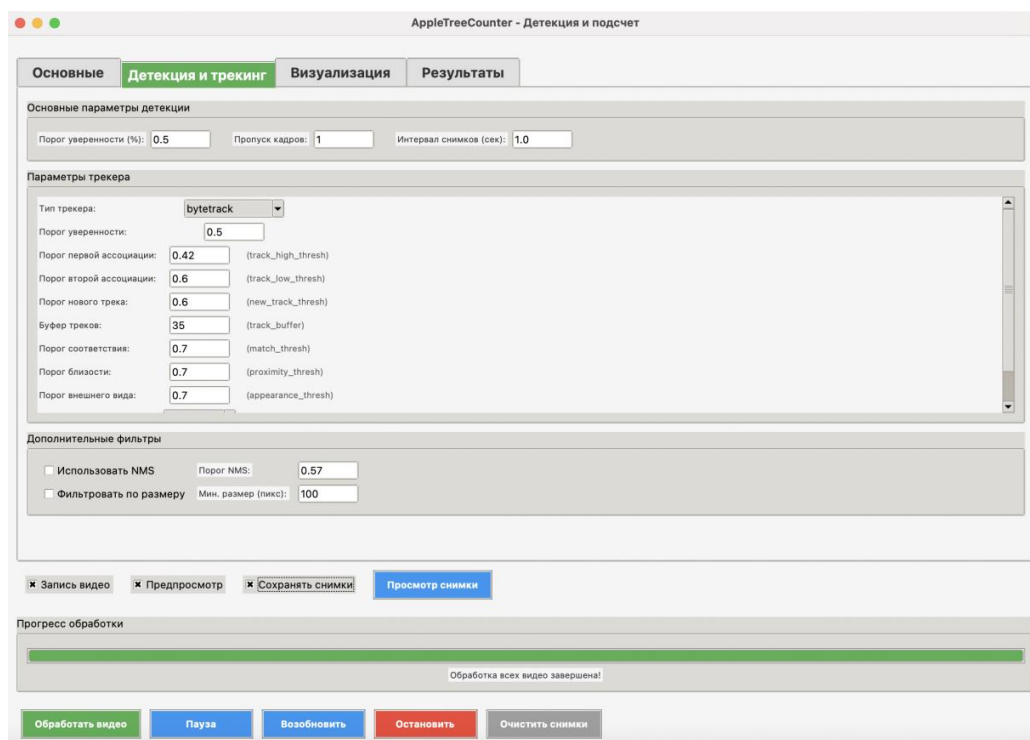


Рис. 6. Вкладка «Детекция и трекинг» в интерфейсе программы, настройка алгоритмов трекинга

Fig. 6. "Detection and Tracking" tab in the program interface, configuration of the tracking algorithms

1000 frames), and has the highest tracking stability (95.7% of IDs maintained) (see the table).

It turns out that the main classification mistakes (~15% of cases) are due to the similarity in visual features between dead trees (the "Dead" class) and trees with borderline signs of life (the "Candidate" class).

For a comprehensive assessment of performance, a calculation of an integrated metric was carried out, combining recognition accuracy and the stability of tree tracking in the frame using a formula

$$A_{track} = \left(\frac{TP}{TP + FR}\right)\left(1 - \frac{N_{sw}}{N_{obj}}\right),$$

where A_{track} – overall recognition accuracy taking tracking into account, TP – number of true positive detections (correctly recognized trees);

FR – number of false positive detections (trees incorrectly identified); N_{sw} – number of ID switches for the analyzed video segment, N_{obj} – the total number of unique objects (trees) involved in tracking.

Using this metric made it possible to more reliably assess the impact of tracking on the final inventory accuracy. Applying the ByteTrack algorithm with global motion compensation (GMC) allowed achieving a recognition accuracy of 92.4%. This result is 41% higher than the recognition accuracy without using tracking algorithms. This confirms its significant role in improving the reliability of the developed method.

The method we developed based on YOLOv12l and ByteTrack has shown high efficiency for monitoring fruit drop in intensive orchards. A key advantage was its integration with



Рис. 7. Пример работы программы: результаты распознавания выпадов в рядах садовых насаждений
Fig. 7. Example of program operation: results of recognition of plant extinction in the rows of orchard plantings

Результаты проведения экспериментальной оценки различных алгоритмов трекинга
Results of conducting an experimental evaluation of various tracking algorithms

Algorithm	Average number of ID switches per 1000 frames	Saved IDs (persistence of object tracking in video frames), %	Accuracy of recognizing outliers by the Precision metric, %	Fullness of detecting attacks by the Recall metric, %	Frame processing speed, FPS, frames/sec
ByteTrack	2,3	95,7	92,4	89,1	102
BoT-SORT	3,1	93,2	90,8	87,5	96
OC-SORT	5,8	88,4	85,6	84,9	110

geoinformation systems [15]: using the Mavic 3 Multispectral drone with a GNSS receiver allows for precise geotagging of detected fruit drop and creating digital maps for import into QGIS or ArcGIS.

CONCLUSIONS

1. As a result of the study, a method was developed to monitor dyewood of trees in intensive orchards using low-altitude RGB aerial photography (1.5–2.0 m) and deep learning algorithms. A comparison of five versions of the YOLOv12 architecture showed that the YOLOv12l model offers the best balance of computational efficiency and recognition accuracy (mAP@50(B) = 0.81; Precision = 0.82; Recall = 0.83) and can be recommended for post-processing video data obtained from drones between rows, allowing the condition of individual plants to be diagnosed.

2. The developed software with a graphical interface provides a full data analysis cycle – from video upload to visualization and exporting results. Using the YOLOv12l model combined with the ByteTrack tracking algorithm ensured stable tracking of trees between frames, which helped increase the accuracy of detecting losses to 92.4% and minimize errors related to ID switching.

Using data augmentation during the model training phase made it possible to create a system that is highly adaptable to different lighting conditions and planting densities, which proves its usefulness for monitoring crops in real-world conditions.

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Управление агроценозами: методология принятия решений в технологиях

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В настоящее время задача обеспечения продовольствием Российской Федерации особенно актуальна, поскольку уровень зависимости нашей страны от импорта пищевых продуктов превысил порог национальной безопасности. Главным фактором имеющегося потенциала страны является биологизация и экологизация интенсификационных процессов с высокой техногенной оснащенностью. Все разработки в сельском хозяйстве должны быть направлены на максимальное освоение природно-климатического потенциала страны. Уровень душевого потребления зерна как один из основных критериев мировой и национальной продовольственной безопасности составляет 1,0–1,2 т/чел. Для производства 1 кг мяса требуется 3 кг зерна. Сохраняющаяся относительно высокая доля импортной мясной и особенно молочной продукции сужает ресурсы рынка фуражного зерна для развития отечественного животноводства и в первую очередь скотоводства. Отмечен дефицит белков растительного и животного происхождения. Однако общие условия ведения земледелия, растениеводства и животноводства закономерно сопровождаются ростом удельных затрат и энергозатрат на получение дополнительной единицы продукции. Земледелие Сибири не соответствует своему потенциалу. Преобладают экстенсивные агротехнологии. Имеется возможность двух- или трехкратного увеличения производства зерна в стране. Для конкретных условий потребуется обоснование величины урожайности как интегрального показателя земледелия для выбора агротехнологий возделывания зерновых культур. В связи с этим кардинальные достижения в АПК возможны только на основе создания и внедрения инновационных технологий, которые возникают в сложных процессах, обеспечивающих стабильность их выходных показателей, требующих междисциплинарных исследований. Это вызывает необходимость для инновационных процессов создания новой методологической базы. Нужны систематизированные теоретические знания из различных технологий, способные генерировать неординарные решения технологических и технических задач. Возникает необходимость смены парадигмы исследований.

Ключевые слова: земледелие, животноводство, агротехнология, зерновые культуры, урожайность, энергоемкость, затраты

Agrocenoses management: methodology of decision-making in technologies

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The task of providing Russia with food is currently especially relevant, since the level of our country's dependence on food imports has exceeded the thresholds of national security. And the main factor in the existing potential of the country is the biologization and ecologization of intensification processes with high technogenic equipment. All developments in agriculture should be aimed at maxi-

imum reclamation of the natural and climatic potential of the country. The level of per capita grain consumption as one of the main criteria of world and national food security is 1.0 – 1.2 tons / person. 3 kg of grain are required to produce 1 kg of meat. The remaining relatively high share of imported meat and especially dairy products narrows the resources of the feed grain market for the development of domestic animal husbandry and, first of all, cattle breeding. A deficiency of plant and animal proteins has been noted. However, the general conditions of farming, crop production and livestock farming are naturally accompanied by an increase in specific costs and energy costs to obtain an additional unit of output. Siberian agriculture does not meet its potential. Extensive agricultural technologies prevail. There is an opportunity to increase grain production in the country by 2 or 3 times. For specific conditions, it will be necessary to justify the yield value as an integral indicator of agriculture for the selection of agricultural technologies for cultivating grain crops. Therefore, fundamental achievements in the agro-industrial complex are possible only on the basis of the creation and implementation of innovative technologies that arise in complex processes ensuring the stability of their output indicators which requiring multidisciplinary research. And this causes the need for the creation of a new methodological base for innovative processes. Systematized theoretical knowledge from various technologies is needed, capable of generating extraordinary solutions to technological and technical problems. There is a need to change the research paradigm.

Keywords: agriculture, animal husbandry, agricultural technology, grain crops, yield, energy intensity, costs

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Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of intrerst.

INTRODUCTION

Wheat production is the backbone of the country's grain-product complex, and its development determines the country's food security. The per capita grain consumption level is one of the main criteria for global and national food security.

Currently, the Russian Federation's agro-industrial complex faces the following main problems: technical and technological lag in food production compared to developed countries due to the low-income levels of producers, stagnation in machinery production for agriculture and the food industry, decreased competitiveness of food and raw materials in domestic and international markets, and low natural fertility of arable soils.

A feature of grain production in Siberia is the almost complete exhaustion of extensive farming techniques and the stabilization of their productivity over the last 20–25 years at around 1.2 tons per hectare in the steppe zone and 1.5 tons per hectare in the southern forest-steppe. Grain production remains not only largely extensive and energy-intensive, but also environmentally unbalanced. Shortcomings in the development of livestock and crop production create a problem with animal and plant-based protein. This situation doesn't match the potential resources of the region's agricultural landscapes [1]. Analysis shows that agriculture, both in Siberia and in Russia as a whole, is not reaching its potential. However, there is a chance to double or even triple yields in both the Siberian Federal District and Russia [2–4]. To make major progress in the

agribusiness sector, innovative development is needed – it's one of the key drivers for boosting the national economy.

Special attention should be paid to the main soil treatment – an important method for regulating the water, air, and temperature conditions of the soil to boost plant biological activity and ensure environmental safety. The effects of soil treatment are long-lasting [5]. At the same time, management is seen as the process of shaping purposeful behavior of a system. Management refers to the processes of technological and technical influence on the subsystems and elements of a system using the system's target functions. The results of these interconnections are implemented in resource-saving technologies that ensure the efficiency of growing agroecosystems. If technology doesn't change, production and the economy are at a standstill. Any technology includes a sequence of technological operations, and the problem of managing the choice of the optimal number, size, and timing of operations isn't solved even in modern precision farming systems [6].

A key aspect of technological and technical updates in production is justifying the productivity levels of crop products for which new equipment needs to be developed [7]. It is precisely with the rational selection and combination of mechanization tools that the efficiency of agricultural production technologies is increased. However, farmers are interested in the price of the equipment they buy. There is a clear link between the average price of a tractor and its traction class as well as the fuel and lubricants it consumes during use [8]. To get the necessary output parameters, it's important to optimize processes in terms of material, energy, and labor resources. However, up to now there is no single methodological approach to developing technologies for cultivating agroecosystems. The issue of developing scientific principles, methodological approaches to technology development, and choosing energy resources for different conditions is still relevant [9, 10].

There's a contradiction between the desired economic efficiency and the environmental sustainability of agro-landscapes. This problem arises from the conflict between the need to increase the efficiency of cultivating agroecosystems through management techniques and technical means, and the insufficiency of available resources to achieve this. When choosing options from the system, a criterion is applied that shows how well the goal is being met. The criteria chosen for each level of the hierarchy are basically mathematical models of preference.

The goal of the study is to establish the relationship between the main indicators of management impacts on technological and technical processes and soil parameters as a dynamic system, based on the development of a research methodology. This system takes into account the existing diversity of soil conditions, allowing the creation of the desired properties as a whole, which achieves the necessary conditions for the growth and development of agroecosystems.

The research objectives are:

- to establish the main directions of innovative development of energy-intensive technologies for cultivating agroecosystems (using grain crops as an example);
- to develop a methodology for managing energy-intensive technologies to ensure the increased efficiency of cultivated agroecosystems.

The subject of the study is a system of methods for controlling the effects of technologies and technical tools on soil as a dynamic system by creating the required properties in it, ensuring the efficiency of cultivating agroecosystems in specific conditions.

MATERIAL AND METHODS

The research methodology is based on the methods from efficiency theory, hierarchy analysis, analysis and synthesis, probability theory and mathematical statistics, optimization, experimental studies, and methods of mathematically approximating experimental data.

RESULTS AND DISCUSSION

The level of development of agricultural production is determined by the efficiency of using mechanized processes, which reduce the competitiveness of the produced goods. High energy intensity of the technologies used is due to the presence of irregularities that create heterogeneity of the structure of the soil cover (HSSC), leading to oscillatory processes. To quantitatively assess the soil cover heterogeneity, they use a contrast coefficient, which has a correlation with crop yields¹. HSSC registering can boost crop yields by up to 56% [11]. According to², for natural systems, it's not the magnitude that matters, but the proper shape of the spatial distribution of energy impact.

Because of this, the new approach to management is focused on the system's own laws of evolution and self-organization. The methodology is part of economic research, including both theoretical and empirical levels of understanding. It helps to develop a logical framework and the sequence of research to get specific results. So, choosing technological priorities requires uniting technical, social, environmental, organizational, technological, and other requirements. Increasing grain production is possible either by extensive or intensive use of the resources applied [12]. The primary requirement for assessing the minimum necessary grain production is its break-even point (revenue from sales equals total costs) [13]. The possibilities and needs for technological changes are determined by the structure of the allocated capital and technologies. The priority in economic development choices comes from the principle of minimizing the cost of attracting a unit of production resource. The current level of economic development is determined by technological innova-

tions and management flexibility [14]. Using flexible technological systems leads to a twofold or greater increase in productivity. To boost the efficiency of agricultural production, it's necessary to create a value-added chain: profitability – yield – processes – properties.

The optimal properties of soils are a function of a number of independent variables and a combination of soil properties. The dependence of one indicator on others most often follows an exponential relationship. The way soils are used is determined by the set level of profitability of the cultivated crop, and profitability is determined by the level of yield, which defines the optimal soil properties. It is the soil properties that drive the processes [15]. However, domestically produced equipment doesn't take into account the statistical specifics of the conditions in which it's used. It's outdated not just physically, but morally too: the principles for evaluating technical equipment parameters are outdated. What's needed isn't averaging, but functional connections, because that requires more investment. Reducing the energy intensity of agricultural production is the key factor that ensures the competitiveness of its products³.

Any technology for growing crops, considering the requirements for it, should be seen as a system [16, 17]. The integrity of technology as a system is a necessary property for its stable existence and the creation of an effect [18]. With a systems approach, data and information are defined by a set of models for decision-making. Because of this, the systems approach is always comprehensive.

The technical base helps increase crop yields in less time, while smart machinery reduces the need for resources and costs [19]. Because of this, to improve the efficiency of machine tech-

¹*Dobrotvorskaya N.I.* The structure of the soil cover in the system of agroecological land assessment in the forest-steppe of Western Siberia: extended abstract of Doctor's thesis in Agriculture, Barnaul, 2009, 40 c.

²*Knyazeva E.N., Kurdyumov S.P.* Laws of evolution and self-organization of complex systems. Moscow: Science, 1994, 236 p.

³*Fedorenko V.F.* Information support for resource conservation issues in the engineering and technical sphere of the agro-industrial complex // Machine-technological support for increasing labor productivity in crop production and animal husbandry: collection of scientific documents. XIII International scientific and practical conf. "New technologies and equipment for resource conservation and increasing labor productivity in agricultural production". Moscow, 2005, vol. 1, pp. 272–283.

nologies, it's necessary to change the principles behind how machines are designed. Changing the operating principle means a new technical system emerges. From a systems approach, evaluating a technical tool should be done by looking at the growth in crop yields for the grain complex, as well as the reduction in losses and resource intensity. The output of the system is the function of the system's impact on the environment with lower costs, and eliminating losses is an economic task. The usefulness of a product is assessed taking into account negative consequences [20]. All developments and innovations should ensure the maximum use of the country's natural and climatic potential, so knowledge of their characteristics is needed (see Table 1).

For a competitive grain-product complex (3.0 t/ha – average global yield), intensive technologies are needed, which corresponds to the accepted classification [2]. Yield forecasts in the EU and Russia are presented in [21] (see the figure).

The development of the economy in the Russian Federation is in stagnation [22]. Intensive-type technology is used by 10–15% of farms [23, 24]. Forecasts of cereal crop yields in the Russian Federation and resource costs for the period up to 2020 are shown in Table 2, the methodology algorithm is based on the hierarchy method⁴ – in Table 3.

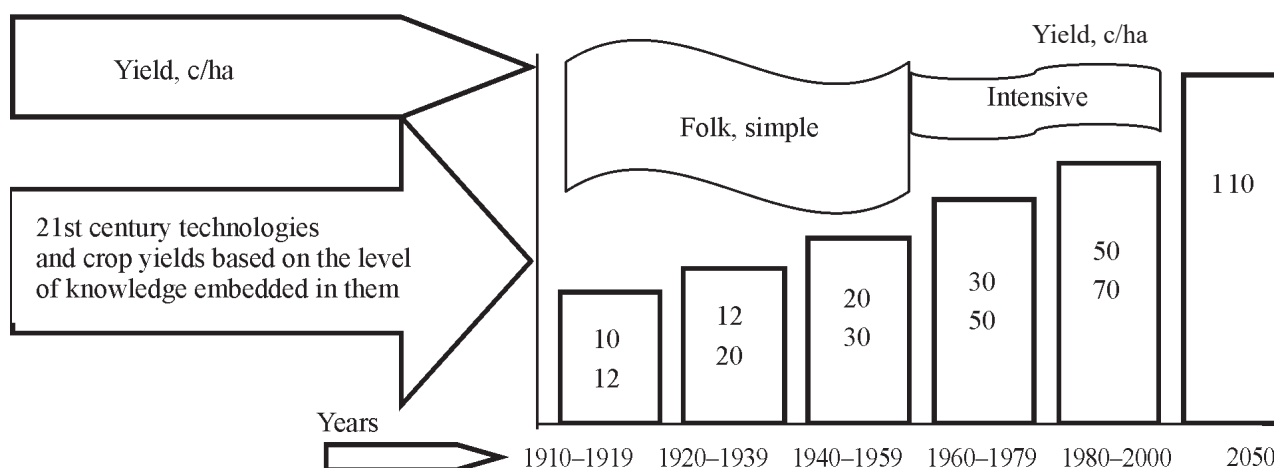
Data analysis [2] allows us to conclude: in the European Union, grain production yields are

Табл. 1. Производство и потребление зерновых культур на душу населения в Сибирском федеральном округе и Сибири

Table 1. Production and consumption of grain per capita in the Siberian Federal District and Siberia

The Siberian region	Production of grains and legumes, thousand tons		Grain production per capita, kg			Per capita consumption of cereals and legumes, kg
	2020–2024 (on average)	2024	2020–2024 (on average)	2024	2024, % to the average	
Republic of Altai	10,0	9,3	47	44	93,6	192
Republic of Tuva	14,9	5,6	44	17	38,6	150
Republic of Khakassia	152,7	123,6	287	234	81,5	245
Altai Territory	5048,5	5565,7	2357	2631	111,6	1053
Krasnoyarsk Territory	2511,7	1930,2	881	678	77,0	527
Irkutsk Region	830,8	632,5	354	271	76,6	481
Kemerovo Region	1389,9	1130	540	444	82,2	468
Novosibirsk Region	2789,9	2412,7	998	865	86,7	686
Omsk Region	3043,8	3819,9	1655	2101	127,0	957
Siberian Federal District	16169,6	15912,3	969	960	99,0	646
Republic of Buryatia	115,6	108,8	118	112	95,0	356
Transbaikal Territory	143,0	96,6	144	98	68,0	428
Siberia	16428,1	16117,7	881	870	98,8	619

⁴Saati T. Decision making. The analytic hierarchy process. Moscow: Radio and Communications, 1993, 320 p.



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Табл. 2. Прогноз распространения и затраты материально-технических ресурсов для производства зерновых и зернобобовых культур Российской Федерации на 2020 г.

Table 2. Forecast of distribution and costs of material and technical resources for the production of grain and leguminous crops in the Russian Federation for 2020

Indicator	Application volume, mln ha, %	Productivity (by main zones), c/ha	Resource costs per 1 ha of crops		
			motor fuel, kg	fertilizers, kg a. i.	pesticides, kg
Grain crops	64	27			
Normal technologies:	32/50	23			
mouldboard	7	25	120	До 80	До 1
non-mouldboard	4	24	105	До 85	До 1,1
minimal	12	21	90	До 90	До 1,5
null	9	20	75	До 100	До 3
Intensive technologies:					
mouldboard	10	34	130	>140	До 2,5
non-mouldboard	5	32	115	>140	До 3
minimal	10	29	105	>160	До 3,5
null	7	27	95	>180	До 4,5

guided by long-term forecasts, while in the Russian Federation they rely on medium- or short-term forecasts; in the European Union, grain production yields will reach 110 c/ha by 2050; in

the Russian Federation, they will be 27 c/ha until 2020 (see Table 2); S-shaped curves are used to describe innovative developments as well as the yields of agrocenoses (GC)⁶. In the work [32],

⁵Kushnarev A.S., Ignatiev E.I., Utenkov G.L., Utenkova T.I. Environmental problems of MTA application // Actual problems of agriculture in mountain territories: Proc. of the VI International scientific-practical conf. Gorno-Altai, 2017, pp. 352–357.

⁶Foster R. Innovation: the attacker's advantage; trans. from English / general. ed. by V.I. Danilov-Danilyan. Moscow: Progress, 1987, 272 p.

Табл. 3. Алгоритм иерархии принятия решений при управлении технологиями возделывания агроценозов

Table 3. Algorithm of the decision-making hierarchy in managing agrocnoses cultivation technologies

Item No.	Hierarchy level	Goal tree	Decision tree		Source
			Methods	Functions	
I	2	3	4	5	
<i>Global goal (mission)</i>					
I	Upper	Providing the district's population with high-quality domestic food, and industry with raw materials Ensuring food security in the region	Systems analysis Calculation and analytical; principles: min, max	Strategy for the socio-economic development of the agro-industrial complex of the Siberian Federal District until 2035 Double growth of labor productivity Resource saving	[25, 26] [27]
<i>Strategic goals</i>					
II	Social	Ensuring stable production of crop and livestock products	Theory of Markov processes	Probability of degeneration: $g(x, y) = (10/21)^x \times (14/25)^y$	[27]
<i>Tactical targets</i>					
III	Economic. Ensuring the growth of crop yields in agrocnoses (GC)	III. 1. Production of competitive agrocnoses (grain crops, GC) III. 2. Break-even feasibility conditions III. 3. Optimal yield (for profit) III. 4. Productivity for expanded reproduction of agrocnoses III. 5. Productivity as a random variable III. 6. 1. Yields based on the quality of technological processes III. 6.2. Reducing energy consumption and improving the quality of primary soil cultivation	Calculation and analytical Calculation and analytical The max principle The max principle Probabilistic-statistical Calculation and statistical Particle method; theoretical mechanics	Break even point, $\delta Y = 2,0 \text{ t/ha}$; $\delta Y = 0,44Y$ $Y_{np} = (B / (\Pi - A_0)) + (1/\alpha)$ $Re \geq 30\%$; $Y_p = (B(1 + Re)) / (\Pi - A_0(1 + Re))$; B – distribution: $M = \Gamma(p + q) / ((\Gamma(p)\Gamma(q))$ $Y = 11,09 + 4,66h - 0,46h^2(v + 1)$ For spherical aggregates saturated with Ca, the soil hardness decreases by 10–15 times For $Y \geq 3,0 \text{ t/ha}$ $\Xi Y T = 31\%$; $H Y T = 49\%$; $\Pi Y T = 20\%$ Exponential functions are the inorganic world, living systems are power functions: $f(x) = ax^m$ Reducing soil degradation from MTA	[28, 29] [30] [30]
IV	Technological	Ensuring the required level of technology intensity	Parametric synthesis; the max principle		
V	Ecological	VI. 1. Reducing soil cover degradation VI. 2. Environmental problems of the MTA	Nature-like technologies Analysis of the application of MTA		[30] [17] [31]

Окончание табл. 3

1	2	3	4	5
VI	Technical	Selection of the criterion for the efficiency of applied energy and MTA Justification of the rational structure of primary soil cultivation Efficiency of sequential execution of technological processes Justification of an automated technological complex for soil cultivation Justification of the parameters and operating modes of the working bodies of combined MTA	Energy analysis and MTA Principles of decomposition, optimization Theories of machines and mechanisms Spectral and correlation analysis The min principle, Ashby principle Energy intensity analysis of MTA, TMO, modeling and optimization methods, TMO Systems analysis of the research object	Efficiency factor $W = 18-23\%$ – non-mouldboard; $W \geq 23\%$ – tillage; $W \leq 18\%$ – minimal Efficiency factor: $\eta = A_p/A_3 = \eta_1$ $\eta_2 \eta_3 \dots \eta_n$ For non-stationary processes: $\zeta(t) = A(t)X(t)$ $E_N = N_{EH}\xi_N/B_p v_p$ min Superpositions; Ashby; block modularity; Bellman; controllability, optimality, min, max See footnote 5 [32] [33] [34] [32] [30]
VII	Methodological	Justification of an innovative solution for energy-intensive technologies for cultivating agrocenoses (GC)		
VIII	Soil	Physical, mechanical and strength properties of soil	Experimental method, approximation method	$\tau = (1 + 0.145th^{73}(0,101W) / (0,145th^{73}(0,101W) - 0,3$ [30]
IX	AO	AO resource potential	AO Analysis	Property, personnel, technological, etc. [31]

Ca – ионы кальция; x, y – параметры отрасли растениеводства и животноводства; δY – урожайность (Y), соответствующая точке безубыточности, т/га; Y_{np} – оптимальная урожайность, т/га; Y_p – урожайность расширенного воспроизводства, т/га; Π – цена реализации, р/т; B – постоянные затраты, р/га; A_0 – условно удельные переменные затраты, р/т; Re – рентабельность, %; ТМО – теория массового обслуживания; α – коэффициент снижения урожайности; $\Gamma(p), \Gamma(q)$ – стандартные гамма функции; h – глубина заделки семян, м; $\approx_h$ – коэффициент вариации заделки семян в почву; ЭУТ, НУТ, ИУТ – соответственно экстенсивный, нормальный и интенсивный уровни технологического возделывания ЗК; W – влажность почвы, %; a – коэффициент пропорциональности; m – показатель степени, $m \approx 2,0$; η – коэффициент полезного действия механизма; A_{np}, A_3 – полезная и затраченная работа, Дж; $\zeta(t)$ – нестационарный случайный процесс; $A(t)$ – временная функция; $X(t)$ – нормальный стационарный случайный процесс; E_N – энергетический критерий оценки МТА; N_{EH} – номинальная мощность двигателя трактора, кВт; ξ_N – коэффициент загрузки двигателя; B_p – рабочая ширина захвата МТА, м; v_p – рабочая скорость движения МТА, м/с; R_a – тяговое сопротивление МТА, кН; F_k – сила перекачивания агрегата, кН; a – глубина обработки, м; B – ширина захвата почвообрабатывающего агрегата, м; m – эмпирический коэффициент; T_{cp} – средняя твердость почвы по глубине обработки, мПа; N_{ep}, N_{ex} – эффективная мощность двигателя при рабочем и холостом ходе МТА, кВт; β – коэффициент пропорциональности; τ – касательные напряжения при сдвиге почвы, н/м²

Ca – calcium ions; x, y – parameters of the crop and livestock industry; δY – yield (Y), corresponding to the break-even point, t/ha; Y_{np} – optimal yield, t/ha; Y_p – selling price, rubles/t; B – fixed costs, rubles/ha; A_0 – conditionally specific variable costs, rubles/t; Re – profitability, %; ТМО – queueing theory; α – yield reduction coefficient; $\Gamma(p), \Gamma(q)$ – standard gamma functions; h – seeding depth, m; $\approx_h$ – proportionality coefficient; m – exponent, $m \approx 2,0$; η – efficiency of the mechanism; A_{np}, A_3 – useful and expended work, J; $\zeta(t)$ – non-stationary random process; $A(t)$ – time function; $X(t)$ – normal stationary random process; E_N – energy criterion for MTA assessing; N_{EH} – rated power of the tractor engine, kW; ξ_N – engine load factor; B_p – MTA working width, m; v_p – MTA operating speed, m/s; R_a – MTA traction resistance, kN; F_k – rolling force of the unit, kN; a – processing depth, m; B – working width of the tillage unit, m; m – empirical coefficient; T_{cp} – average soil hardness at the depth of cultivation, mPa; N_{ep} – effective engine power during MTA working and idle runs, kW; β – proportionality coefficient; τ – shear stresses of soil, N/m²

five laws of progress are formulated. The meaning of progress lies in the possibility of saving both living and materialized labor, reducing the cost of produced goods, increasing human life expectancy, and moving toward social progress. It's necessary to meet the conditions for sustainable and balanced development, so the functional relationships obtained reveal the existing reserves of agroecosystem efficiency and serve as a basis for digitalization.

CONCLUSION

The conducted literature analysis makes it possible to identify existing reserves, outline the problem, and synthesis helps to solve it. The methodology determines the directions of growth and development of agrocenoses through a system of management impacts of technologies and their technical support on the soil, taking into account multidisciplinary, and allows identifying the main reasons for the increase in energy intensity of crop production technologies, caused by HSSC; justify the rational structure of crop and livestock industries; justify the yield size of the grain product complex as an integral indicator of agriculture and determine the necessary level of technologies and their technical support; argue for a rational structure of technology intensification levels and the structure of primary soil cultivation; develop a flexible automated soil cultivation technological complex for complex systems; for diagnosing soil properties, use its hardness, and use the obtained functional relationships for digitalization. At the same time, yield should be described by the B-distribution, and S-shaped Foster curves should be used to describe innovative developments (see footnote 6).

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Transliteration of the authors. English title of the article.

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Photos, screenshots must be uploaded separately as files of the following format*.jpeg files (*.doc and *.docx if the image has additional marks). The resolution of the image should be >300 dpi. The image files should be given a name corresponding to the figure number in the text. In the description of the file a caption should be given separately, which should correspond to the name of the picture placed in the text.

Graphs, charts, histograms, etc. should be attached as a separate file in Microsoft Excel program.

Attention should be paid to the spelling of formulas in the article. All formulas must be editable, i.e. it must be possible to make changes to them. To avoid confusion, it is necessary to write Greek (α , β , π , etc.), Russian (A, a, B, b, etc.) letters and numbers in straight font, Latin letters in italics (*W*, *Z*, *m*, *n*, etc.). Mathematical signs and symbols should also be written in straight font. It is necessary to clearly indicate upper and lower superscript characters (W_1 , F_1 , etc.).

INTERACTION BETWEEN THE JOURNAL AND THE AUTHOR

The Editorial Board asks the authors to be guided by the above stated rules when preparing the article.

All the articles submitted to “Siberian Herald of Agricultural Science” go through preliminary check for compliance with formal requirements. At this stage the Editorial Board reserves the right to:

- accept the article for review;
- return the article to the author (authors) for revision with a request to correct the mistakes or add the missing data;
- return the article which is designed not according to the journal’s requirements to the author (authors) without consideration;
- reject the article due to its inconsistency to the journal’s goals, lack of originality and little scientific significance.

Correspondence with the authors of the manuscript is maintained through a key contact mentioned in the manuscript.

All scientific articles submitted to the editorial board of the journal “Siberian Herald of Agricultural Science” undergo obligatory double-blind reviewing (author and reviewer do not know about each other). Manuscripts are sent in accordance with their research profile for reviewing to the members of the Editorial Board.

In controversial cases, the editor may involve several specialists in the review process, as well as the Editor-in-Chief. If the reviewer’s opinion is positive, the article is submitted to the editor for preparation for publication.

In case a decision is made to have the manuscript revised, reviewer’s comments and remarks are passed to the author. The latter is given two months to make amendments. If, within this period, the author has not notified the editors about the actions planned, the article is removed from the publication waiting list.

In case there is a decision to reject the article, the notification with the editorial decision is sent to the author.

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

REVERSAL OF EDITOR/ REVIEWER’S DECISION

In case the author does not agree with the conclusions of the reviewer and/or editor, they can dispute the decision made. In order to do this, the author should:

- amend the manuscript in compliance with the comments substantiated by reviewers and editors;
- clearly outline their stance on the issue under question.

The editors facilitate the second submission of manuscripts that could potentially be accepted but were rejected due to the need of significant amendments or collection of the additional data, and are ready to clearly explain what must be rectified in the manuscript for it to be accepted for publication.

ACTIONS OF THE EDITORIAL BOARD IN CASE OF PLAGIARISM AND DATA FALSIFICATION DETECTION

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

ERRORS RECTIFICATION AND ARTICLE WITHDRAWAL

In case of error detection that affect understanding of an article but do not distort the results of research, they can be rectified by replacing the pdf-file of an article. In case of error detection that distort the results of research or in case of plagiarism or misconduct of the author (authors) connected with data falsification, the article can be withdrawn. The withdrawal can be initiated by the editors, the author, organization or private individual. Such article is marked with the note “Article withdrawn”, the page of the article gives the reason for withdrawal. Information about the article withdrawal is sent to data bases where the journal is indexed.