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СИБИРСКИЙ ВЕСТНИК СЕЛЬСКОХОЗЯЙСТВЕННОЙ НАУКИ

SIBIRSKII VESTNIK SEL'SKOKHOZYAISTVENNOI NAUKI

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

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MECHANISATION, AUTOMATION, MODELLING AND DATAWARE

ПРОБЛЕМЫ. СУЖДЕНИЯ

PROBLEMS. SOLUTIONS

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КОРНЕВАЯ ГНИЛЬ ЯРОВОЙ ПШЕНИЦЫ В ПОЛЕВЫХ СЕВООБОРОТАХ ЛЕСОСТЕПИ ИРКУТСКОЙ ОБЛАСТИ

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Приведены результаты исследований по оценке распространенности корневых гнилей и урожайности яровой пшеницы в лесостепной зоне Иркутской области в полевых севооборотах на разных фонах удобренности и приемах обработки почвы. Схема опыта: предшественники – пар в севообороте (пар – пшеница – овес), горохоовсяная смесь и кукуруза в севообороте (горохоовсяная смесь – пшеница – кукуруза – пшеница); приемы обработки почвы – вспашка плугом ПЛН-5-35 на глубину 20–22 см, дискование БДТ-3 на глубину 12–14 см; удобрение – без удобрений, полное минеральное удобрение $N_{45}P_{45}K_{45}$. Распространенность корневой гнили в среднем за 3 года снижалась в севообороте с 33%-м насыщением пшеницей и посеве ее по паровому предшественнику по сравнению с 50%-м насыщением по горохо-овсу на 6,1%, по кукурузе на 0,9%; по дискаторной обработке почвы по сравнению со вспашкой в паровом предшественнике на 11,8%, по горохо-овсу на 4,7%, по кукурузе на 9,2%; по удобренному фону в трехпольном севообороте по пару на 4%, по горохо-овсу на 1,9%, по кукурузе на 4,8%. Статистически достоверная наибольшая урожайность яровой пшеницы отмечена в трехпольном севообороте с 33%-м насыщением пшеницей по пару при вспашке почвы, что выше по аналогичной обработке почвы в севообороте с 50%-м насыщением пшеницей при посеве по горохоовсяной смеси на 31,3%, по кукурузе на 23,8%. Внесение минеральных удобрений $N_{45}P_{45}K_{45}$ повышало урожайность, а обработка почвы дискованием и предшественники горохоовсяная смесь и кукуруза снижали. За ротацию снизилась распространенность корневой гнили от исходного показателя с одновременным ростом урожайности – с 33%-м насыщением севооборотов пшеницей на 9,0 и 35,0%, с 50%-м – на 6,6 и 45,7%.

Ключевые слова: яровая пшеница, корневая гниль, севооборот, вспашка, дискование, минеральные удобрения, урожайность

ROOT ROT OF SPRING WHEAT IN FIELD CROP ROTATIONS IN THE FOREST-STEPPE OF THE IRKUTSK REGION

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The paper presents the results of the studies to assess the prevalence of root rots and yields of spring wheat in the forest-steppe zone of the Irkutsk region in field crop rotations on different backgrounds of fertilization and tillage practices. The experiment scheme: forecrops – fallow in crop rotation (fallow – wheat – oats), pea-oat mixture and corn in crop rotation (pea-oat mixture – wheat – corn – wheat); tillage methods – plowing with PLN-5-35 plow to a depth of 20-22 cm, BDT-3 disking to a depth of 12-14 cm; fertilization - no fertilizer, complete mineral fertilizer $N_{45}P_{45}K_{45}$. The prevalence of root rot decreased on average for 3 years in the crop rotation with 33% saturation of wheat and its sowing on a fallow forecrop in comparison with 50% saturation in pea-oats by 6.1%, in corn by 0.9%; disc tillage compared to plowing in fallow forecrop by 11.8%, in pea oats by 4.7%, in corn by 9.2%; on fertilized background in three-field crop rotation in fallow by 4%, in pea oats by 1.9%, in corn by 4.8%. Statistically reliable highest yield of spring wheat was observed in three-field crop rotation with 33% saturation of wheat on fallow at soil plowing, which is higher than similar soil treatment in crop rotation with 50% saturation of wheat at sowing on pea and oat mixture by 31.3%, on corn by 23.8%. Application of mineral fertilizers $N_{45}P_{45}K_{45}$ increased the yield, while tillage with discing and the forecrops such as pea and oat mixture and corn decreased the yield. Over the rotation, root rot incidence decreased from baseline with a concomitant increase in yield – with 33% wheat saturated in the rotations by 9.0% and 35.0%, and with 50% wheat saturated in the rotations by 6.6% and 45.7%.

Keywords: spring wheat, root rot, crop rotation, plowing, disking, mineral fertilizers, yield

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INTRODUCTION

The widespread minimization of soil treatments has ambiguous effects on the phytosanitary situation in the wheat agro-ecosystem, specifically on the prevalence of root rots. Research conducted both in Russia and abroad has indicated a trend of negative impacts of shallow and no-till treatments on the phytosanitary condition of various soil types. Significant accumulation of root rot pathogens has been observed in the plow layer of soil during minimal stubble mulch, shallow, and nonmouldboard cultivation and in the absence of primary soil treatments [1-3].

With the application of superficial soil treatments, the taxonomic composition of root rot pathogens also changes. According to epy Ural scientists, the region previously witnessed the prevalence of wheat infections by *Bipolaris sorokiniana*; however, there is currently a gradual change in the microbiota structure with a dominance of *Fusarium* fungi [4]. It has been established that in mouldboard soil treatments, *Helminthosporium* root rot predominates, while in no-till, *Fusarium* rot dominates. In the conditions of Western Siberia, a significant increase in plant infestation with common root rot under the No-Till technology was not detected [5]. A trend was identified showing an increase in the number of epy pathogens in the initial years after switching to no-till technology and their reduction thereafter [6]. The development of spring wheat root rots was determined by its forecrop, whose influence increased throughout the vegetation [7]. The role of autumn fallow as a method to conserve soil moisture, accumulate nutrients, clear soil from weeds, disease pathogens, and pests has been established [8].

The influence of fertilizers under different soil treatment systems on the prevalence of root rot is ambiguous. There are reports of increased root rot prevalence both in the background of no fertilizer application during mouldboard and differentiated treatments, and with the introduction of organic and mineral fertilizers against the backdrop of disc harrowing to a depth of 10-12 cm [9, 10]. Wheat's resistance to pathogenic organisms under intensive cultivation technologies significantly decreases as nitrogen nutrition levels increase [11]. Against the backdrop of nitrogen fertilizers, the soil's infestation with pathogenic microorganisms tends to decrease, especially in no-till options. This correlation is even more pronounced against the background of complex fertilizers [12].

According to literary sources, surface and no-till treatments provide the greatest resource conservation, reduce production costs, and optimization of plant nutrition and the phytosanitary situation in crops due to the use of fertilizers and plant protection products prevents a decrease in crop productivity [13-15].

The issue is also important for the Irkutsk region, where the comprehensive influence of soil treatment methods, crop rotations, and fertilizers on the prevalence of spring wheat root rots has not been studied.

The purpose of the research is to assess the prevalence of root rots and the yield of spring wheat when cultivated under different crop rotations and intensification levels in the forest-steppe zone of the Irkutsk region.

MATERIAL AND METHODS

Research was conducted between 2017 and 2020 in the forest-steppe zone of the Irkutsk region at the experimental field of the Irkutsk Research Institute of Agriculture. The soil of the site is heavy loamy gray forest with a humus content in the 0–30 cm layer of about 5% (GOST 26213–91), total nitrogen – 0.22% (GOST R 58596–2019), pH_{salt} – 5.5 (GOST R 58594–2019), total absorbed bases – 21–25 mg-equi./100g (GOST 27821–88), hydrolytic acidity – 7.3–8.0 mg-equiv./100g (GOST 26212–91), degree of base saturation – 73–83%; availability of P_2O_5 – 100–120 kg/ha, K_2O – 80–100 kg/ha (GOST R 54650–2011).

The three-factor field experiment had the following variations: forecrop (factor *A*) - fallow in a three-field crop rotation with 33% saturation with wheat (fallow - wheat - oats); a mix of peas and oats and corn in a four-field crop rotation with 50% saturation with wheat (peas and oats mix - wheat - corn - wheat); soil treatment methods (factor *B*) – plowing with a PLN-5-35 plow to a depth of 20–22 cm, disk harrowing with a BDT-3 to a depth of 12–14 cm; fertilization (factor *C*) – no fertilizers, full mineral fertilizer $N_{45}P_{45}K_{45}$.

The experimental plot area was 70.0 m^2. The experiment was replicated three times. The spring wheat variety used was Buryat awned wheat. Seeds were not treated, and fungicides were not used. Ammonium nitrate with a nitrogen content of 34.4% and diammonium phosphate with an NPK (%) ratio of 10:26:26 were applied. The fertilizer dose was determined based on the nutrient content in the soil, depending on the predecessor, targeting a yield of spring wheat of 3.5 tons/ha for pure fallow, 2.6 tons/ha for corn, and 2.2 tons/ha for annual grasses. Sowing was done on May 20th with a seeding depth of 5–6 cm and a sowing rate of 7 million germinating seeds/ha.

The prevalence of root rots (P, %) was determined according to the recommendations of the All-Russian Plant Protection Institute[1]. Wheat yield was measured using a "Terrion" combine. Statistical processing of experimental data was carried out using the variance analysis method and the Snedecor V5[2] software package.

RESULTS AND DISCUSSION

Out of the 4 years of research, 2017 and 2020 were favorable for plant growth and develop-

[1] *Tanskii V.I., Levitin M.M., Ishkova T.I. et al.* Methods of pest accounting. Recommendations of VIZR // Plant protection and quarantine. 2002, no. 3, pp. 51-52.

[2] *Sorokin O.D.* Applied statistics on the computer. 2nd ed. Novosibirsk: SUE PBCA SB RASKhN, 2012, 282 p.

ment at the start of vegetation. In May, there was twice as much precipitation and 15.2 mm more than the norm, and the average daily air temperature was 1.4 and 2.8 °C higher than the multi-year average.

The beginning of the vegetation period in 2018 and 2019 was droughty. In May and June 2018, precipitation was below the norm by 1.9 and 2.3 times, respectively, and in May 2019, it was 1.7 times below the norm. The first and second ten days of June were also dry. The temperature conditions varied these years – in 2018, average daily temperatures in May and June were respectively 1.5 and 5.1 ºC higher than the multi-year average, while May 2019 was cold with an average air temperature 1.7 ºC below the norm.

The crop rotation was laid out in 2017 on a plot where various agricultural crops, including cereals, were grown the previous year. Here, in the sprouting phase of spring wheat, the prevalence of root rot was 52.7% and was taken as the initial average value, which was 3.5 times higher than the economic threshold of harmfulness set at the beginning of vegetation (15%).

The seeds used in the experiment (see Table 1) were infected on average over four years by a complex of pathogens: to a greater extent by fungi of the genera *Fusarium* sp. (72.1%), *Alternaria* sp. (34.6%), and to a lesser extent – *Bipolaris* sp. (7.8%), *Penicillium* sp. (3.3%), the total wheat seed infection rate was 88.7%. In 2019 and 2020, the infection rate of *Alternaria* sp. significantly increased (93.7 and 38.5%, respectively).

In 2018, the prevalence of root rots, as proven by a variance analysis of experimental data, was influenced by the level of fertilization and the type of preceding crop (see Table 2). This indicator decreased when using mineral fertilizers $N_{45}P_{45}K_{45}$ and increased in crop rotation with 50% wheat saturation when sown after pea and oat mixtures and corn, and was not dependent on different types of soil treatment. However, there was a trend of reduced disease prevalence against the background of disc-tillage.

In 2019, fertilization did not have a significant effect on the prevalence of root rot. A statistically significant reduction in root rot prevalence by 19.6% was noted in the variants where soil discing was performed. The most reliably low disease prevalence rates were ensured by sowing wheat after corn, while the pea and oat mixture slightly increased this value within the experiment's error margin (see Table 2).

In 2020, when sowing on fallow without using fertilizers, a decrease in root rot prevalence was noted, significant compared to the forecrop corn (by 19.7%) and insignificant compared to the pea and oat mixture (by 7.8%). Complete mineral fertilization increased, and soil discing decreased the disease prevalence within the limits of experimental error.

Fertilizers contributed to a slight decrease in the prevalence of root rot of spring wheat in three-field crop rotation: by 4% for fallow, 1.9% for pea and oat, and 4.8% for corn.

The yield of spring wheat in the experiment during the research years statistically significantly depended on the studied factors (see Table 3).

Табл. 1. Результаты фитопатологического анализа семян яровой пшеницы, %
Table 1. Results of phytopathological analysis of spring wheat seeds, %

Study year	Healthy seedlings	Agent				Total infestation
		Alternaria sp.	*Bipolaris* sp.	*Fusarium* sp.	*Penicillium* sp.	
2017	0,0	0,0	6,0	98,0	1,0	100,0
2018	42,0	6,0	15,0	29,0	8,0	58,0
2019	2,0	93,7	8,7	91,7	1,0	98,0
2020	1,0	38,5	1,5	69,5	0	99,0
Average	11,3	34,6	7,8	72,1	3,3	88,7

Табл. 2. Распространенность корневых гнилей яровой пшеницы в опыте, 2018–2020 гг., т/га
Table 2. Prevalence of root rots of spring wheat in the trial, 2018–2020, t/ha

Forecrop (factor *A*)	Tillage (factor *B*)	2018			2019			2020			Average for 3 years
		No fertilizers	$N_{45}P_{45}K_{45}$ (factor *C*)	Average	No fertilizers	$N_{45}P_{45}K_{45}$ (factor *C*)	Average	No fertilizers	$N_{45}P_{45}K_{45}$ (factor *C*)	Average	
Fallow	Plowing (control)	42,5	42,1	42,3	73,0	66,2	69,6	40,3	50,0	52,6	54,8
	Disking	37,2	43,4	40,3	42,1	40,8	41,5	39,9	54,3	47,1	42,9
	Average	39,9	42,8	41,3	57,6	53,5	55,6	40,1	52,2	46,2	47,7
Pea and oat mixture	Plowing	53,2	39,9	46,6	73,5	72,5	73,0	55,2	42,1	48,7	56,1
	Disking	64,8	63,9	64,4	40,8	48,5	44,7	40,5	49,8	45,2	51,4
	Average	59,0	51,9	55,5	57,2	60,5	58,9	47,9	45,9	46,9	53,8
Corn	Plowing	65,7	61,9	63,8	34,9	30,8	32,9	62,6	63,3	63,0	53,2
	Disking	54,3	37,0	45,7	31,5	28,9	30,2	56,9	55,0	56,0	43,9
	Average	60,0	49,5	54,8	33,2	29,9	31,6	59,8	59,2	59,5	48,6
Average	Plowing	53,8	47,9	50,9	60,5	56,5	58,5	52,7	51,8	52,3	53,9
	Disking	52,1	48,1	50,1	38,1	39,4	38,9	45,8	53,0	49,4	46,1
	Average	53,0	48,0	50,5	49,3	48,0	48,7	49,3	52,4	50,9	50,0
LSD_{05} for the factors		*C* = 4,58; *B* = 4,58; *BC* = 6,48; *A* = 5,61; *AC* = 7,93; *AB* = 7,93; *ABC* = 11,22			*C* = 2,61; *B* = 2,61; *BC* = 3,69; *A* = 3,20; *AC* = 4,52; *AB* = 2,52; *ABC* = 6,39			*A* = 16,9; *B* = 13,8; *C* = 13,8; *BC* = 19,5; *AC* = 23,9; *AB* = 2,52; *BC* = 19,5			
Factor influence share, %		*C* = 1,8; *B* = 0; *A* = 21,4; *AB* = 57,2; *AC* = 0,5; *BC* = 0			*A* = 41,1; *B* = 36,0; *C* = 0,1; *AB* = 20,0; *AC* = 1,3; *BC* = 1,1			*A* = 60,0; *B* = 0; *C* = 0; *AB* = 2,2; *AC* = 0; *BC* = 6,5			

The introduction of mineral fertilizers $N_{45}P_{45}K_{45}$ increased the yields, while soil discing and the preceding crops pea and oat mixture and corn reduced them.

The highest yield of spring wheat during the research years and on average over 3 years was noted in a three-field rotation with 33% wheat saturation following fallow during soil plowing, which was higher than the similar soil treatment in rotation with 50% wheat saturation when sown after a pea and oat mixture by 31.3%, and after corn by 23.8%. With disc-tillage, the yields were lower than plowing when sown after all the forecrops: fallow by 18.0%, pea and oat mixture by 8.4%, and corn by 13.4%. The full mineral fertilizer $N_{45}P_{45}K_{45}$ in the experiment contributed to an increase in the yield compared to the unfertilized variants on average over 3 years by 0.3 tons/ha.

CONCLUSION

On average over 3 years in a three-field rotation with 33% wheat saturation and its sowing following fallow (fallow – wheat – oats), the prevalence of root rot was lower than in the rotation with 50% saturation of this crop: for pea and oat by 6.1%, and for corn by 0.9%. Disc-tillage over an average of 3 years of observation more effectively limited the prevalence of root rot compared to plowing in a fallow forecrop by

Табл. 3. Урожайность яровой пшеницы в опыте, 2018–2020 гг., т/га

Table. 3. Yield of spring wheat in the trial, 2018–2020, t/ha

Forecrop (factor *A*)	Tillage (factor *B*)	2018			2019			2020		
		No fertilizers	$N_{45}P_{45}K_{45}$ (factor *C*)	Average	No fertilizers	$N_{45}P_{45}K_{45}$ (factor *C*)	Average	No fertilizers	$N_{45}P_{45}K_{45}$ (factor *C*)	Average
Fallow	Plowing (control)	1,95	2,21	2,08	3,28	3,31	3,30	3,16	3,71	3,44
	Disking	1,95	1,88	1,92	2,27	2,32	2,30	2,74	3,27	3,01
	Average	1,95	2,05	2,00	2,78	3,32	2,80	2,95	3,49	3,22
Pea and oat mixture	Plowing	1,40	1,65	1,53	1,87	2,27	2,07	2,15	2,74	2,45
	Disking	1,38	1,50	1,44	1,68	2,05	1,87	1,94	2,52	2,23
	Average	1,39	1,58	1,49	1,78	2,16	1,97	2,05	2,63	2,34
Corn	Plowing	1,25	1,88	1,57	2,47	2,61	2,54	2,34	2,89	2,62
	Disking	0,91	1,06	0,99	2,43	2,66	2,55	2,01	2,57	2,29
	Average	1,08	1,47	1,28	2,45	2,64	2,55	2,18	2,73	2,46
Average	Plowing	1,53	1,91	1,73	2,54	2,73	2,64	2,55	3,11	2,83
	Disking	1,41	1,48	1,45	2,13	2,34	2,24	2,23	2,79	2,51
	Average	1,47	1,70	1,59	2,34	2,54	2,44	2,39	2,95	2,67
LSD_{05} for the factors		*C* = 0,1; *B* = 0,1; *BC* = 0,13; *A* = 0,12; *AC* = 0,16; *AB* = 0,16; *ABC* = 0,23			*C* = 0,10; *B* = 0,10; *BC* = 0,15; *A* = 0,13; *AC* = 0,18; *AB* = 0,18; *ABC* = 0,25			*A* = 0,08; *B* = 0,07; *C* = 0,07; *BC* = 0,09; *AC* = 0,11; *AB* = 0,11; *ABC* = 0,16		

11.8%, for pea and oat by 4.7%, and for corn by 9.2%.

The saturation reduction of the rotation with spring wheat from 50 to 33% positively affected its yield, which increased by 37% when sowing wheat after the pea and oat mixture and by 30.9% after the corn forecrop.

When applying full mineral fertilizer $N_{45}P_{45}K_{45}$ for wheat, the yield on average increased by 12.5%.

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ГЕНОТИПИЧЕСКАЯ РЕАКЦИЯ ЯЧМЕНЯ НА ПОВЫШЕННОЕ СОДЕРЖАНИЕ КАДМИЯ В ПОЧВЕ

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Представлены результаты сравнительной оценки на контрольном и провокационном почвенном фоне по кадмию сортов ярового ячменя (*Hordeum vulgare* L.), полученных различными методами. Всего изучено 10 сортов: Родник Прикамья, Новичок, Дина, Зазерский 85, Triumph, Tallon (гибридизация и отбор); Форвард, Бионик, Витрум (клеточная селекция); Памяти Дудина (мутагенез). Исследования проводили в 2021 г. в климатических условиях Кировской области. Семена растений каждого сорта высевали в вегетационные емкости, наполненные дерново-подзолистой почвой. Провокационный почвенный фон по кадмию (6,4 ± 0,5 мг/кг) создавали путем внесения в почву ацетата кадмия. Среднее значение урожайности сортов ячменя в контроле (почвенный фон без кадмия) составило 279 г/м^2, на провокационном фоне – 216 г/м^2. В условиях кадмиевого стресса урожайность гибридов снижалась по сравнению с контролем на 12,2%, регенерантов – на 29,6, мутанта – на 42,4%. Среди исследованных сортов стабильно высокую урожайность как на контрольном (334 г/м^2), так и на кадмиевом фоне (263 г/м^2) показал сорт Бионик, имеющий регенерантное происхождение. Продуктивная кустистость гибридных сортов ячменя на контрольном фоне варьировала от 2,8 до 4,1 шт., у регенерантов – от 3,4 до 4,8, сорта-мутанта – 4,3 шт. В условиях кадмиевого стресса продуктивная кустистость снижалась в среднем на 2,7 шт. – у гибридов, на 3,4 – у регенерантов, на 2,6 шт. – у мутанта. Бионик независимо от почвенного фона по сравнению с другими сортами имел наибольшую продуктивную кустистость. Значимых различий в содержании полифенолов в зерне исследуемых сортов на контрольном и провокационном почвенном фоне по кадмию не выявлено. В условиях кадмиевого стресса отмечено снижение содержания флавоноидов в зерне, а также накопление кадмия (0,29–0,92 мг/кг). Сорта гибридного происхождения в большей степени проявляли способность к накоплению кадмия в зерне.

Ключевые слова: ячмень, кадмий, урожайность, продуктивная кустистость, полифенолы, флавоноиды

GENOTYPICAL RESPONSE OF BARLEY TO INCREASED CADMIUM CONTENT IN SOIL

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The results of a comparative evaluation of spring barley (*Hordeum vulgare* L.) varieties obtained by different methods on control and provocative soil background for cadmium are presented. A total of 10 varieties were studied: Rodnik Prikamya, Novichok, Dina, Zazersky 85, Triumph, Tallon (hybridization and selection); Forward, Bionic, Vitrum (cell selection); In memory of Dudin (mutagenesis). The studies were carried out in 2021 under the climatic conditions of the Kirov region. Seeds of the plants of each variety were sown in vegetation containers filled with soddy-podzolic soil. Cadmium provocative background (6.4 ± 0.5 mg/kg) was created by adding cadmium acetate to the soil. The average yield of barley varieties in the control (soil background without cadmium) was 279 g/m^2; against a provocative background – 216 g/m^2. Under the conditions of cadmium stress, the yield of hybrids decreased compared to the control by 12.2%, regenerants – by 29.6%, mutant – by 42.4%.

Among the studied varieties, the Bionic variety, which has a regenerated origin, showed a consistently high yield both on the control (334 g/m^2) and cadmium background (263 g/m^2). Productive bushiness of hybrid barley varieties against the control background varied from 2.8 to 4.1; in regenerants – from 3.4 to 4.8; mutant varieties – 4.3 pieces. Under the conditions of cadmium stress, productive bushiness decreased by an average of 2.7 – in hybrids; for 3.4 – for regenerants, for 2.6 pieces – a mutant. Bionic, regardless of the soil background, compared with other varieties, had the highest productive bushiness. Significant differences in the content of polyphenols in the grain of the studied varieties on the control and provocation soil background for cadmium were not revealed. Under the conditions of cadmium stress, a decrease in the content of flavonoids in grain was noted, as well as the accumulation of cadmium (0.29–0.92 mg/kg). Varieties of hybrid origin showed the ability to accumulate cadmium in grain to a greater extent.

Key words: barley, cadmium, yield, productive bushiness, polyphenols, flavonoids

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INTRODUCTION

Among the first-class pollutants, cadmium raises the greatest concern due to its ability to bioaccumulate in the food chain [1]. Currently, various methods are being developed to prevent cadmium from entering food raw materials and food products. One of them is monitoring the content of cadmium in arable soils, as well as in mineral fertilizers produced based on phosphate rock. According to regulatory documentation, depending on the type of fertilizer and its phosphate content (no more than 5% and equal to or more than 5%), the concentration of cadmium should not exceed 3 and 20 mg/kg respectively[1]. However, even with a low cadmium content in fertilizers, over time, this element accumulates in the soil when fertilizers are applied [2, 3]. The approximate permissible concentration of cadmium in the soils of agricultural lands has been established only for its gross forms. Depending on the granulometric composition and acidity of the soil, it varies from 0.5 to 2.0 mg/kg[2].

The danger of elevated cadmium content in the soil for plants lies in inducing stress in them [4]. Depending on its nature and severity, as well as the type of plant, stress can lead to a series of pathological changes in plant tissues of various levels [5]. One of them is the production of polyphenols, the protective role of which is associated with antioxidant activity [6]. It should be noted that phenolic compounds are increasingly being considered as biochemical markers of stress in cereals [7].

Interest in polyphenols is not limited to plant stress resistance. It also focuses on non-extractable polyphenols, which play an important role

[1]GOST P 58658-2019. Products and food with improved characteristics. Mineral fertilizers. General technical conditions. Moscow, 2020, 19 p.

[2]SanPiN (Sanitary Regulations and Standards) 1.2.3685-21. Hygienic norms and requirements to ensure safety and (or) harmlessness for humans of habitat factors. https://docs.cntd.ru/document (accessed on: 01.03.2023).

in the nutritional value of products, as well as their inhibitory activity regarding α-glucosidase [8, 9].

An important task to maintain the yield and quality of crop products in conditions of soil pollution with cadmium is to develop stress-tolerant varieties using various methods [10].

The prospects of these varieties can be assessed using a variety of indicators (morphometric, physio-biochemical), as well as by the productivity of plants [11]. Along with this, when selecting varieties with increased resistance to cadmium, it is important to determine the level of accumulation of the toxic metal in the structural parts of the plants, especially in the grain.

The aim of the study is to investigate the genotypic reactions of barley in soil conditions with an excess of cadmium ions.

MATERIAL AND METHODS

The studies were conducted in 2021 at the Federal Agricultural Research Center of the North-East named after N.V. Rudnitsky (Kirov Region) under vegetative trial conditions. The research subjects were 10 varieties of spring barley of various origins, created using breeding and biotechnological methods (see Table 1).

The experiment was conducted under close to field conditions. 35 seeds of each variety were sown in vegetative containers 150 cm long, 130 cm wide, and 30 cm high, filled with sody-podzolic soil (organic matter content – 2.5 ± 0.3%, nitrogen in terms of nitrate form – 1.7 ± 0.5 mg/kg, mobile phosphorus – 50 ± 10 mg/kg).

The feeding area for the plants was 4 × 15 cm. To create a provocative soil background for cadmium, a solution of cadmium acetate was introduced into the soil a month before epy sowing. According to atomic absorption spectroscopy, the content of mobile cadmium compounds in the soil as a result of model pollution was 6.4 ± 0.5 mg/kg. The control background was soil without cadmium. During the experiment, plants were watered as the soil dried out. The criteria for evaluating resistance were productive (yield calculated per 1 m^2, bushiness) and biochemical (content of polyphenols, flavonoids, cadmium in grain) plant characteristics.

The content of polyphenols and flavonoids in the grain was determined by the spectrophotometric method on a PE 5300 VI spectrophotometer (Russia) (glass cuvettes with an optical layer thickness of 1 cm)[3]. Gallic acid was used as an internal standard when determining the content of polyphenolic compounds, and rutin when determining flavonoids. The total content of polyphenols was determined in alkaline extracts from grain, free polyphenols and flavonoids – in

Табл. 1. Сорта ячменя, полученные различными методами
Table 1. Description of barley varieties obtained by various methods

Variety	Origin	Selection criterion
Hybridization and selection		
Rodnik Prikamya	Russia	Standard
Novichok	»	Aluminum and acid tolerance
Dina	»	Rapid maturity, acid tolerance
Zazersky 85	Belarus	
Triumph	Denmark	High yield
Tallon	Australia	
Cell selection		
Forward	Russia	Aluminum and acid tolerance
Bionik		Drought tolerance, aluminum and acid tolerance
Vitrum		Aluminum and acid tolerance
Mutagenesis		
Memory of Dudin	Russia	High yield

[3]Shupletsova O.N., Tovstik E.V. The content of polyphenols in the grain of barley varieties of regenerant origin, grown on different soil backgrounds // Methods and technologies in plant breeding and crop production: Proceedings of the VIII International Scientific and Practical Conference (Kirov, April 6, 2022). Kirov, 2022, pp. 120-125.

aqueous-alcoholic. The content of bound polyphenols in the grain was determined by the difference between the total content of polyphenols in alkaline extracts and the content of free polyphenols in ethanol extracts.

The cadmium content in the grain was determined by atomic absorption spectroscopy using the "Spectr 5-4" instrument (Russia). Grain samples were prepared for analysis by the dry ashing method[4].

The mathematical processing of the experimental data was carried out using statistical analysis[5]. Microsoft Excel software was used to interpret the obtained data.

RESULTS AND DISCUSSION

The assessment of the resilience of varieties is primarily based on analyzing visible changes in plant morphology under stress conditions. In this context, a comparison of the productive features of plants on both the control and the cadmium-provocative soil backgrounds was conducted. Depending on the experimental variant, the yield of the varieties varied widely (see Fig. 1, *a*).

The yield of most barley varieties averaged 279 g/m^2 in the control and 216 g/m^2 in the provocative background. Under stress conditions, this parameter's values decreased compared to the control: in hybrid-origin varieties by 12.2%, regenerants by 29.6%, and mutants by 42.4% (see Fig. 1, *a*). However, for the Novichok and the Tallon varieties, the yield increased in the presence of cadmium in the soil compared to the control conditions.

One of the varieties with consistently high yields on both control and cadmium backgrounds was the regenerant-origin Bionic variety (334 and 263 g/m^2). This variety also showed the highest productive bushiness (see Fig. 1, *б*).

According to literature data, the shoot formation intensity in cereals is one of their adaptation mechanisms to the excess of toxic metal ions in the soil. This allows plants not only to grow successfully under ion toxicity conditions but

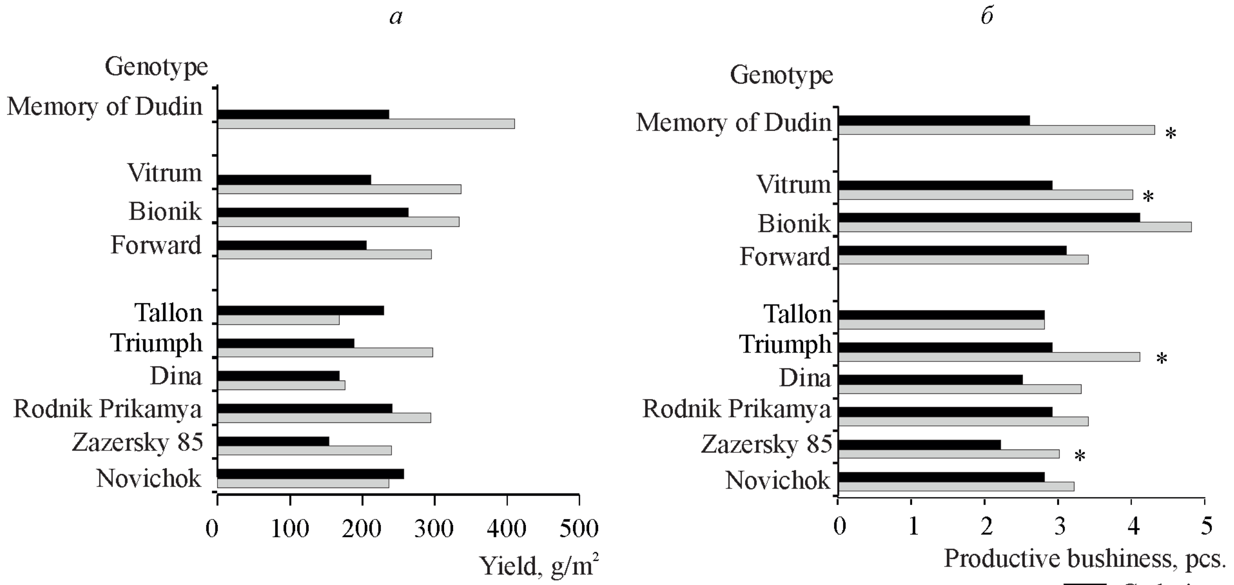

Рис. 1. Средняя урожайность (*а*) и продуктивная кустистость (*б*) генотипов на контрольном и кадмиевом фоне
Fig. 1. Average yield (*a*) and productive bushiness (*б*) of the genotypes on the control and cadmium background

[4]GOST 26929-94. Sample preparation. Mineralization for determination of toxic elements content. URL: https:// docs.cntd.ru/document (accessed on: 01.03.2023).

[5]GOST R 8.736-2011. State system for ensuring the uniformity of measurements. Direct multiple measurements. Methods of measurement results processing. Basic provisions. https://docs.cntd.ru/document (accessed on: 01.03.2023)

[6]*Titov A.F., Kaznina N.M., Talanova V.V.* Plant resistance to cadmium (on the example of cereal family): textbook; Institute of Biology of the Karelian Scientific Center RAS. Petrozavodsk: Karelian Scientific Center RAS, 2012, 55 p.

also to maintain a high reproductive potential. Although productive bushiness is an inherited characteristic of a variety, it also depends on the growth conditions of the plants[6]. According to analysis report, the productive bushiness of the hybrid barley varieties in the control background ranged from 2.8 to 4.1 pieces, for regenerants – from 3.4 to 4.8, and for the mutant variety it was 4.3 pieces. In the cadmium background, the productive bushiness of the varieties predictably decreased compared to the control background (on average: 2.7 pieces – hybrids, 3.4 – regenerants, 2 pieces – mutant). The exception was the Tallon variety, for which no significant differences in the level of productive bushiness were found between the control and provocative backgrounds (see Fig. 1, *б*). The Zazerskiy 85 and the Memory of Dudin varieties showed the highest sensitivity to cadmium: a decrease in the indicator compared to the control by 26.7% and 39.5%, respectively.

In addition to the productive characteristics of plants, biochemical indicators of the grain were evaluated. The assessment of polyphenol content in the grain of the studied varieties was of practical interest. It is known that one of the most important functions of polyphenolic compounds is their participation in protecting plants from oxidative stress [6]. The profile of polyphenolic compounds in the above-ground mass of plants can depend not only on growth conditions but also on varietal characteristics [12]. The recorded values of polyphenol content in the grain under both control and cadmium-provocative backgrounds varied within a narrow range (from 7.78 to 9.56 mg/g), indicating the absence of significant differences between the varieties (see Table 2).

Varieties with both a high level of polyphenol content in the grain (Rodnik Prikamya, Vitrum, Dina, Memory of Dudin) and a low level (Zazersky 85) were identified. Regardless of the variety, the content of free polyphenols in the grain was lower than that of bound ones. The presence of a soil stressor reduced the content of free polyphenols in the barley grain of all studied genotypes. While under control conditions their proportion in the total count reached 21.5-50.5% depending on the genotype, under stress conditions, it ranged from 20.9-26.3%.

In recent years, the non-extractable fraction of polyphenols has been increasingly viewed as key due to its stability during processing and its ability to reach the large intestine, providing a positive effect on human health [13, 14]. Based on the results of the conducted studies, the content of bound polyphenols in the grain of various varieties on the control background varied widely (49.5-78.5%), partly due to the lower recorded values for Forward and Bionics. Under a cadmium-provocative background, there was a noted increase in the content of bound polyphenols relative to the control in the varieties. However, varietal differences were less pronounced than on the control background (73.7-79.1% of the total polyphenol content) (see Table 2). The increase in bound and decrease in free polyphenols in the grain under the influence of cadmium indicates the presence of stress in all studied genotypes, regardless of their origin.

A practical interest was the assessment of the flavonoid content in grain as markers of stress resistance, which are part of the free fraction of polyphenols [15]. It was assumed that varieties with different stress resistance might have varying levels of antioxidant protection and, accordingly, experience different effects of oxidative stress caused by growing conditions.

Depending on the growing conditions of the plants and varietal characteristics, the level of flavonoids varied widely (see Table 2). On a control background, the content for hybrid origin varieties varied from 0.013 to 0.115 mg/g, regenerants ranged from 0.047 to 0.063, and mutant variety was 0.056 mg/g. The highest amount of flavonoids was noted in the "Dina" variety, and the lowest in the "Tallon". A decrease in flavonoid content was observed on a provocative background in all the studied varieties (except for Tallon), but to a greater extent in hybrid origin varieties: Triumph (61.2% relative to control) and Dina (62.6%), as well as among regenerants in the Vitrum variety (76.3%).

[6] *Titov A.F., Kaznina N.M., Talanova V.V.* Plant resistance to cadmium (on the example of cereal family): textbook; Institute of Biology of the Karelian Scientific Center RAS. Petrozavodsk: Karelian Scientific Center RAS, 2012, 55 p.

Табл. 2. Содержание полифенолов и флавоноидов в зерне генотипов ячменя, полученных различными методами

Table 2. The content of polyphenols and flavonoids in the grain of barley genotypes obtained by various methods

Genotype	Control background: Polyphenols free/bound, mg/kg / %	Control background: Polyphenols Total, mg/kg	Control background: Флавоноиды, мг/г	Cadmium background: Polyphenols free/bound, mg/kg / %	Cadmium background: Polyphenols Total, mg/kg	Cadmium background: Flavonoids, mg/g
Hybridization and selection						
Novichok	2,32 ± 0,07 / 42,6	8,48 ± 0,34	0,046	2,09 ± 0,11* / 77,5	9,29 ± 0,04	0,039
Zazersky 85	2,01 ± 0,03 / 73,8	7,78 ± 0,01	0,057	2,01 ± 0,15 / 76,1	8,42 ± 0,56	0,039
Rodnik Prikamya	2,64 ± 0,07 / 70,8	9,05 ± 0,11	0,076	2,09 ± 0,10* / 77,1	9,12 ± 0,39	0,050
Dina	2,00 ± 0,28 / 78,5	9,31 ± 0,22	0,115	1,98 ± 0,01 / 78,9	9,37 ± 0,14	0,043
Triumph	2,41 ± 0,01 / 72,6	8,81 ± 0,74	0,049	2,01 ± 0,11* / 77,4	8,89 ± 0,39	0,019
Tallon	2,27 ± 0,11 / 72,5	8,26 ± 0,75	0,013	1,90 ± 0,01 / 79,1	9,08 ± 0,16	0,027
Cell engineering						
Forward	4,42 ± 0,61 / 50,1	8,85 ± 0,13	0,063	2,09 ± 0,10* / 76,9	9,07 ± 0,32	0,047
Bionik	4,49 ± 0,45 / 72,5	8,89 ± 0,39	0,047	2,39 ± 0,16* / 73,7	9,09 ± 0,33	0,021
Vitrum	2,74 ± 0,03 / 69,8	9,06 ± 0,14	0,059	2,39 ± 0,08* / 73,8	9,10 ± 0,07	0,014
Mutagenesis						
Memory of Dudin	2,49 ± 0,02 / 73,4	9,36 ± 0,12	0,056	2,09 ± 0,01* / 78,2	9,59 ± 0,12	0,033

*$p \leq 0,05$.

The next stage of the research was the assessment of cadmium accumulation in the grain of the studied genotypes on a cadmium background (see Fig. 2).

The value of this indicator, according to atomic absorption spectroscopy, was 0.29-0.92 mg/kg, exceeding the maximum allowable concentration (MAC) in grain (0.1 mg/kg) for all the studied varieties. On a provocative background, regenerant genotypes, induced as a result of cell selection under stress conditions, accumulated cadmium in regenerative organs 1.75 times less (on average 0.32 mg/kg dry weight) compared to varieties (on average 0.56 mg/kg dry weight) that did not undergo *in vitro* selection.

CONCLUSIONS

1. The reaction of barley varieties to an excessive amount of cadmium in the soil was studied. Significant genotypic differences in stress sensitivity among varieties obtained by different methods were noted. The presence of a soil stressor reduced the content of free polyphenols in the grain of all genotypes, complicating their bioavailability. Regenerant varieties such as Forward, Bionic, Vitrum, created as a result of *in vitro* selection, had a higher level of free polyphenols under stressful conditions (on average 2.29 mg/g) but with a relatively low proportion of flavonoids (on average 0.027 mg/g) compared to hybrids like Rodnik Prikamya, Novichok,

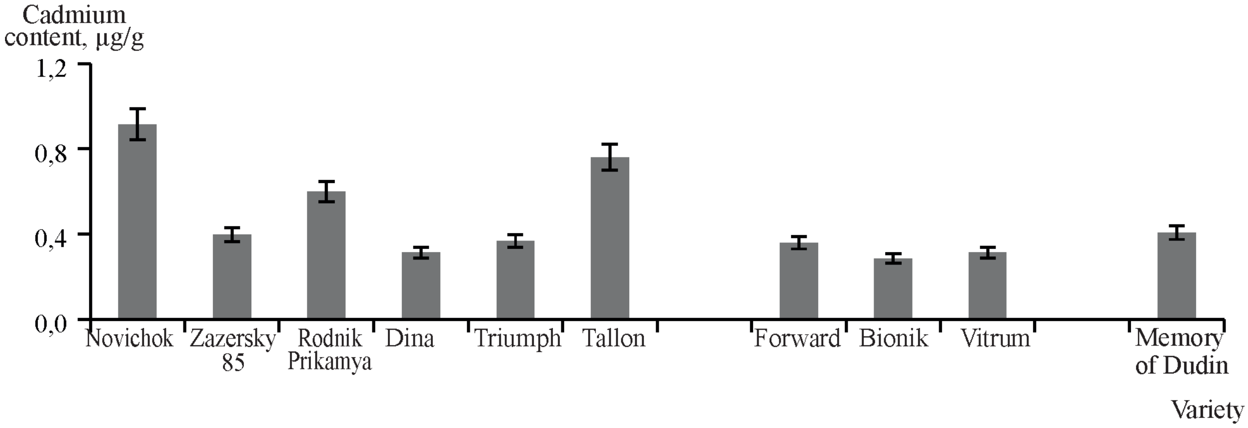

Рис. 2. Содержание кадмия в зерне ячменя
Fig. 2. Cadmium content in barley grain

Dina, Zazerskiy 85, Triumph, Tallon (2.01 and 0.036 mg/g respectively) and the mutant Memory of Dudin (2.09 and 0.036 mg/g respectively). The results indicate the weakest manifestation of oxidative stress of regenerants on a provocative background among the studied genotypes.

2. A varying nature of cadmium ion accumulation in the grain was shown, which significantly depends on the genetic specifics of the plants. Regenerant varieties, induced as a result of callus cell selection on selective media, accumulated cadmium to a lesser extent (on average 0.31 µg/g) compared to the mutant (on average 0.41 µg/g) and hybrid-origin varieties (on average 0.56 µg/g).

3. The activity of barrier functions, which reduce the negative impact of cadmium on plants, along with the manifestation of oxidative stress, influenced the formation of yield (productive bushiness). Genotypes with high yields on a soil background with cadmium were identified: Bionic (263 g/m^2), Novichok (260), and Memory of Dudin (250 g/m^2).

4. The use of biotechnological methods alongside traditional breeding allows expanding the genotypic diversity of adaptive forms/stress-tolerant varieties, which enhances the potential to maintain yields in conditions of soil contamination with cadmium.

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ИЗУЧЕНИЕ СЕЛЕКЦИОННЫХ ФОРМ ПОЛБЫ (*TRITICUM DICOCCUM* (SCHRANK) SCHUEBL.)

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Представлены результаты изучения хозяйственно полезных признаков растений селекционных линий полбы (*Triticum dicoccum* (Schrank) Schuebl.) полуголозерной с фиолетовой окраской перикарпа зерна. Изучали семь селекционных линий F_9, созданных двухступенчатой гибридизацией фиолетовозерной твердой пшеницы с голозерной и безостой полбами, и пять селекционных образцов полуголозерной полбы. В полевых опытах отбирали растения по селекционно ценным признакам. С 2020 по 2022 г. проводили фенологические наблюдения, структурный анализ и оценивали количественные признаки растений селекционных форм полбы с фиолетовой окраской зерна. Двухфакторный дисперсионный анализ показал существенные факторы – селекционные линии и годы изучения. В процессе изучения выявлено, что для дальнейшей селекционной работы ценность представляют линии полбы, несущие сочетание хозяйственно важных признаков. Короткостебельная фиолетовозерная форма 27-1 устойчива к полеганию, вымолачиваемость зерна – 80%, масса 1000 зерен – 34–37 г. Линия 27-12 обладает зерном с фиолетовой окраской, высоким показателем натуры зерна около 800 г/л и хорошей для двухзернянки продуктивностью зерна, достигающей 400 г/м^2. Фиолетовозерная линия полбы 31-16 обладает хорошей кустистостостью (3–4 шт.), коротким стеблем (71–74 см), высокими показателями устойчивости к полеганию (4–5 баллов) и вымолачиваемости зерна (80%). С 2021 по 2022 г. такие же исследования проводили с полуголозерной полбой из коллекции Всероссийского института генетических ресурсов растений им. Н.И. Вавилова (ВИР). Выделена селекционная линия полбы 41/14 по высокому показателю вымолоченных зерен (85%). Основными недостатками созданных форм пшеницы двузернянки с фиолетовоокрашенными зернами пока остаются относительно невысокий урожай зерна, недостаточно прочный колосовой стержень, неполная вымолачиваемость зерновки из цветковых и колосковых чешуй. Однако дальнейшей селекционной работой можно добиться улучшения этих признаков, а также повышение урожайности зерна, массы 1000 зерен и более полное освобождение зерновки из чешуй при молотьбе.

Ключевые слова: полба, гибрид, селекционная линия, признак

STUDY OF THE BREEDING FORMS OF EMMER WHEAT (*TRITICUM DICOCCUM* (SCHRANK) SCHUEBL.)

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The results of the study of economically useful features of the plants of the semi-naked emmer wheat breeding lines (*Triticum dicoccum* (Schrank) Schuebl.) with purple pericarp coloring of grain are presented. Seven breeding lines F_9, created by two-step hybridization of the purple-grain durum wheat with naked and awnless emmer, and five breeding samples of semi-naked emmer wheat were studied. In the field experiments, plants were selected for selection valuable traits. Phenological observations, structural analysis, and evaluation of the quantitative traits of the plants of emmer wheat breeding forms with purple grain coloration were carried out from 2020 to 2022. Two-way analysis of variance showed significant factors - the breeding lines and the years of study. In the course of the study, it was found that for further breeding work, emmer wheat lines carrying a combination of economically important traits are of value. Short-stalked purple-grain form 27-1 is resistant to lodging, the yield of the grain - 80%, the weight of 1000 grains – 34–37 g. Line 27–12 has grains with purple color, high grain-unit value of about 800 g/l and good grain productivity for emmer wheat reaching 400 g/m^2. Purple emmer line 31–16 has a good bushiness (3–4 pieces), short stalk (71–74 cm), high lodging resistance (4–5 points) and grain threshing capacity (80%). From 2021 to 2022, the same studies were conducted with emmer wheat from the collection of the N.I. Vavilov All-Russian Institute of Plant Genetic Resources (VIR). The selection line of emmer wheat 41/14 was distinguished by the high indicator of threshed grains (85%). The main disadvantages of the established forms of emmer wheat with purple-colored grains still remain relatively low grain yield, insufficiently strong ear shank, not complete grinding of the grain from the flowering glumes and husks. However, further breeding work can improve these traits, as well as increase the grain yield, the weight of 1000 grains and a more complete release of the grain from the chaff during threshing.

Keywords: emmer wheat, hybrid, breeding line, trait

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INTRODUCTION

European breeders place significant emphasis on the programs aimed at developing cereal varieties for whole grain functional nutrition. Among these cereals is emmer wheat (*Triticum dicoccum* (Schrank) Schuebl.), also known as amelcorn. Emmer grain is primarily used for porridge preparation. This crop boasts valuable nutritional components such as dietary fibers and antioxidant substances. Its grain contains more antioxidants beneficial for human health than soft wheat grain[1].

The amelcorn grain is challenging to separate from its husk, a factor that hampers its practical use. Presently, breeders are developing varieties where the grain easily detaches from the glume and lemma. In this direction, Russia has produced a naked grain variety of emmer called Gremme[2].

In light of this, it is proposed to classify such naked grain forms of amelcorn under a new sub-

[1]*Lachman J., Orsak M., Pivec V., Jiru K.* Antioxidant activity of grain of einkorn (*Triticum monococcum* L.), emmer (*Triticum dicoccum Schuebl* [Schrank]) and spring wheat (*Triticum aestivum* L.) varieties // Plant soil environment, 2012, vol. 58. no 1. pp. 15–21.

[2]*Temirbekova S., Ionov E., Ionova N., Afanasyeva Y.* Winter and spring dinkel wheat // Agrarian review. 2014, no. 6 (46), pp. 40-42.

species – *Triticum dicoccon* (Schrank) Schuebl. subsp. *Nudicoccon* Kobyl. et Smekal. [1].

The main goal for breeders is to create varieties that are well-adapted to local environmental conditions and possess maximum nutritional value [2]. Secondary metabolites, associated with the coloring of cereal grains, play a significant role in enhancing a crop's nutritional value. Some cereals have colored grains containing a substantial amount of anthocyanins in their outer layers. They exhibit high antioxidant activity in rice grain with colored pericarp [3]. Using ingredients from the whole grain of such cereals is a strategy for producing functional food products [4]. The coloring of cereal grains is determined by anthocyanins – natural antioxidants belonging to the class of flavonoid compounds (flavonoids)[3].

They are water-soluble phenolic pigments of plants [5]. A vast body of knowledge on the genetics of their biosynthesis in barley has been accumulated [6]. Depending on the localization of these compounds in the grain and their chemical formula, the grain color can be red, blue, or purple. The purple coloring of the grain is due to anthocyanin compounds localized in the pericarp[4].

In wheat with dark-colored grains, anthocyanins play a protective regulatory role against biotic and abiotic stresses [7].

Flavonoids are vital for human health. They play a positive role in the treatment and prevention of diseases such as cardiovascular diseases, arthritis, various types of cancer, Alzheimer's disease, type II diabetes, and obesity[5].

They regulate cholesterol metabolism [8] and inhibit the obesity process [9].

Given this, cereals with colored grains are of interest in terms of functional nutrition. However, wheat varieties with a high antioxidant content in their grain are rare, and they are not cultivated in Russia. This property is especially crucial to impart to amelcorn, the grain of which is mainly used for cooking porridge. Additionally, producing forms of emmer with grain that easily detaches from the husk is also essential for practical use.

The purpose of the research is to evaluate new breeding lines of emmer with purple grain coloring and semi-naked forms with regular grain coloring based on economically beneficial traits.

MATERIAL AND METHODS

The study utilized five half-naked breeding lines of emmer wheat (*Triticum dicoccum* (Schrank) Schuebl.) developed by V.D. Kobylansky at the N.I. Vavilov All-Russian Institute of Plant Genetic Resources (VIR), and seven purple-grained lines derived from F_9 hybrid populations from complex crossings conducted by E.I. Gordeeva using marker-assisted selection [10] at the Institute of Cytology and Genetics of the Siberian Branch of the Russian Academy of Sciences. The origins of the purple-grained lines involved naked emmer wheat Gremme, awnless emmer wheat k-25516 (from the global VIR collection), and wheat Tri15744 (donor of purple pericarp grain coloration). The half-naked emmer wheat lines of hybrid origin (35 in total) were developed by the VIR researcher V.D. Kobylansky in 2017. Most of them were discarded during subsequent breeding work due to a lengthy vegetative period and fragile spikes. After further evaluation until 2021, five stable lines were selected and included in the experiment. One of the main criteria for their selection was a naked grain yield of no less than 40% during threshing. Lines with a prolonged vegetative period were also excluded. Planting in all study years was done manually in the first decade of May on fallow field plots, each measuring 0.25 m^2 with four replicates, using a sowing rate of 75 germinating seeds per linear meter. The Gremme variety and the collection sample k-25516 were used as standards. In 2020, plantings at the end of May were partially damaged

[3] *Prochazkova D., Bousova I., Wilhelmova N.* Antioxidant and prooxidant properties of flavonoids // Fitoterapia. 2011, vol. 82, pp. 513–523.

[4] *Knievel D.C., Abdel-Aal E.M., Rabalski I., Nakamura T., Hucl P.* Grain color development and the inheritance of high anthocyanin blue aleurone and purple pericarp in spring wheat (*Triticum aestivum* L.) // Journal of Cereal Science. 2009, vol. 50, pp. 113–120.

[5] *Pojer E., Mattivi F., Johnson D., Stockley C.S.* The Case for Anthocyanin Consumption to Promote Human Health // A Review of Comparative Reviews in Food Sciences. 2013, no. 12, pp. 483–508.

by insect pests. By the end of the plant's vegetation in 2020, there were occasional heavy rains, affecting plant lodging. In 2021 and 2022, the conditions for plant growth and development were more favorable.

During the structural analysis of emmer wheat plants, a previously published method for determining grain nature was used [11]. The threshing of spikes was done using the MK1 spike thresher. Statistical analysis of results separately for purple-grained forms and half-naked forms from the VIR was conducted according to the methodology using two-factor ANOVA and Student's t-test[6].

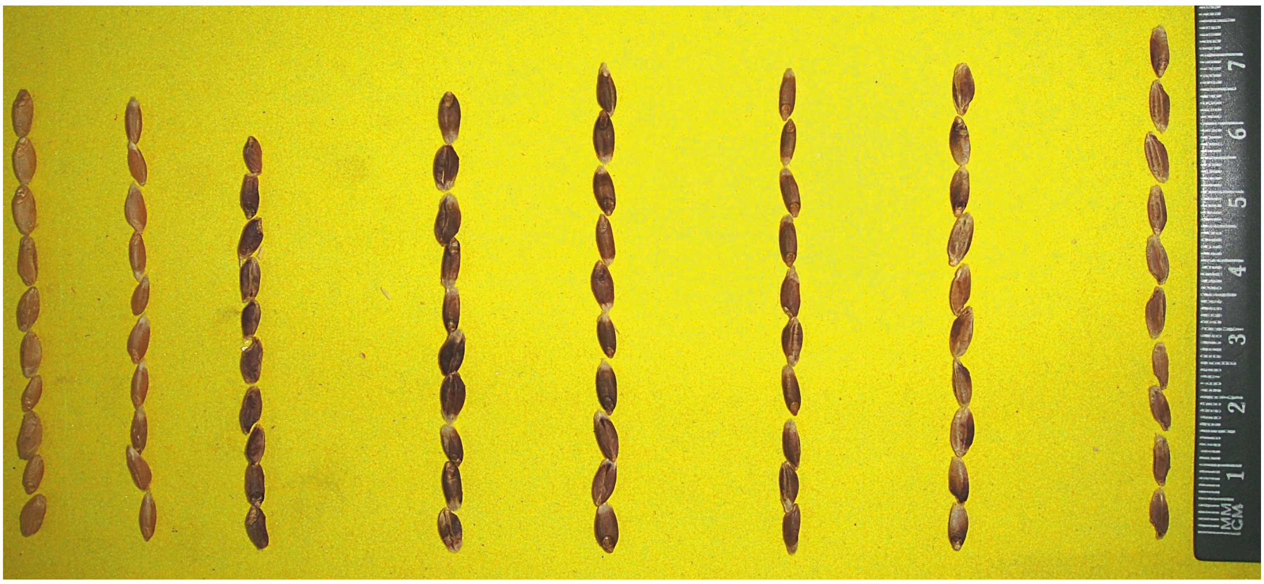
RESULTS AND DISCUSSION

In the populations of the nine purple-grained forms of the crop, no emergence of plants without this grain trait was observed. Within each purple-colored line in the older generations (from the seventh to the ninth), homogeneity for this trait was noted. This fact suggests that the studied forms have a high degree of homozygosity for these genes. However, the lines themselves varied in the intensity of grain coloration (see the figure).

All purple-grained breeding forms showed high resistance to diseases over the years of study. The half-naked breeding forms obtained from the VIR were slightly affected (0-2 points on a 5-point scale) by powdery mildew and brown rust. All emmer wheat plants were slightly affected by Septoria.

Almost all of the studied emmer wheat forms, except for the Gremme variety, have a rather brittle and fragile spike axis, which in field conditions leads to grain yield loss during plant lodging in the maturity phase and during harvesting. Therefore, the plants were harvested immediately after reaching full grain ripeness.

Two-factor ANOVA of the purple-grained forms, conducted for five quantitative traits, re-



а *б* *в* *г* *д* *е* *ж* *з*

Семена родительских форм фиолетовозерной полбы:

а – голозерная полба Греммэ; *б* – безостая полба к-25516; *в* – фиолетовозерная пшеница Tri15744. Семена фиолетовозерных линий гибридов: *г* – среднестебельная 27-3; *д* – низкостебельная 31-16; *е* – длинностебельная 27-12; *ж* – низкостебельная 27-1; *з* – низкостебельная 31-20

Seeds of the parent forms of the purple colored grain emmer wheat:

а – naked emmer wheat Gremme; *б* – awnless emmer k-25516; *в* – purple-colored grain wheat Tri15744. Seeds of the purple-colored emmer lines: *г* – mid-stemmed 27-3; *д* – low-stemmed 31-16; *е* – long-stemmed 27-12; *ж* – low-stemmed 27-1; *з* – low-stemmed 31-20

[6] *Dospekhov B.A.* Methodology of field experiment with the basics of statistical processing of research results. Moscow, 1985.

vealed significant factors. The manifestation of traits such as straw length and grain yield was significantly influenced by the following factors: “breeding lines”, “study years” – and (borderline significant) the “interaction” of these two factors. The “breeding lines” factor was found significant for all five traits. The “study years” factor was not significant for the manifestation of grain nature, the proportion of threshed plants, and the weight of 1000 grains. Their least significant difference (LSD) did not exceed the table value (see Table 1).

In a similar manner, a two-factor ANOVA was conducted on the same traits of the half-naked emmer wheat forms developed at the VIR. Only one factor – “breeding lines” – was significant. The “study years” factor was not significant, and the LSD did not exceed the table value.

The results obtained from the ANOVA allow us to identify significant differences in the studied traits based on the least significant difference and through pairwise comparisons, using standard errors. Table 2 presents data for seven traits of seven purple-grained and five half-naked breeding forms of emmer wheat.

The proportion of threshed caryopses, although not reaching the level of the naked emmer wheat Gremme variety, but exceeding 80%, was noted for 2 study years in the half-naked breeding sample 41/14. Once in 3 years, the 80% mark was exceeded by the purple-grained breeding forms 31-16, 31-19, and 27-1.

In terms of the weight of 1000 grains, none of the studied forms significantly exceeded the best standard for this trait – the naked Gremme variety. Over 3 study years, the best indicators for this trait were from the purple-grained 27-1, 27-3, and 27-12. The breeding sample 27-1 had the highest trait value in 2020 (37.9 ± 2.6 g) and in 2021 (34.4 ± 3.1 g). In 2022, the highest weight of 1000 grains was in form 27-3, equal to 35.4 ±

Табл. 1. Результаты двухфакторного дисперсионного анализа пяти количественных признаков семи фиолетовозерных (2020–2022 гг.) и пяти полуголозерных селекционных форм полбы (2021, 2022 гг.), Новосибирск

Table 1. The results of the two factor variance analysis of five quantitative traits of seven violet grain (2020–2022 years) and five semi-naked grain breeding emmer forms (2021, 2022 years), Novosibirsk

Title	Culm length, cm	Share of threshed grains, %	Grain unit, g/l	Thousand kernel weight, g	Yield, g/m^2
Purple-grained					
F_{act} years (F_{05} = 3,09)	9,85	1,14	0,09	2,34	13,9
Range of mean values of all lines in each year	81,2 ... –85,3	68,7 ... –72,5	746,0 ... –747,6	30,2 ... –31,1	315,6 ... –365,0
LSD_{05} years	2,01	5,8	7,15	0,93	20,6
F_{act} lines (F_{05} = 2,19)	115,8	6,74	41,2	19,3	14,3
Range of mean values of every line for all years	72,8 ... –102,2	64,0 ... –79,7	722,5 ... –793,4	27,8 ... –33,1	286,6 ... –384,0
LSD_{05} lines	3,08	8,9	10,9	1,42	31,5
Half-naked					
F_{act} years (F_{05} = 3,94)	1,45	1,96	0,19	0,26	1,42
Range of mean values of all lines in each year	102,1 ... –104,2	60,6 ... –65,1	744,6 ... –747,0	26,2 ... –27,6	296,5 ... –308,0
LSD05 years	3,39	6,4	11,08	1,29	19,3
F_{act} lines (F_{05} = 2,46)	10,11	16,6	2,54	6,06	15,23
Range of mean values of every line for all years	95,9 ... –109,9	46,3 ... –83,5	739,3 ... –763,1	24,6 ... –28,0	257,1 ... –345,9
LSD05 lines	5,36	10,1	17,5	2,04	30,5

Табл. 2. Показатели признаков семи фиолетовозерных (2020–2022 гг.) и пяти полуголозерных селекционных форм полбы (2021, 2022 гг), Новосибирск

Table 2. Indexes of characteristics of seven violet grain (2020–2022 years) and five semi-naked grain breeding emmer forms (2021, 2022 years), Novosibirsk

Emmer wheat name	Study year	Number of productive stems, pcs.	Culm length, cm	Share of threshed grains, %	Grain unit, g/l	Thousand kernel weight, g	Yield, g/m^2	Resistance to lodging, point
Gremme, standard	2020	2,1 ± 0,2	106,6 ± 2,6	94,6 ± 3,7	766 ± 9	42,3 ± 2,2	492 ± 71	2
	2021	2,2 ± 0,3	104,3 ± 3,9	97,5 ± 1,4	757 ± 11	38,4 ± 4,6	455 ± 25	2
	2022	2,3 ± 0,3	105,9 ± 3,5	98,9 ± 0,1	762 ± 15	40,7 ± 2,8	497 ± 31	3
к-25516, standard	2020	2,5 ± 0,3	104,7 ± 3,3	14,7 ± 1,9	768 ± 7	35,4 ± 1,1	368 ± 38	2
	2021	2,3 ± 0,4	105,3 ± 3,1	13,6 ± 3,4	753 ± 14	33,6 ± 0,8	370 ± 36	2,5
	2022	2,6 ± 0,5	107,8 ± 4,1	11,7 ± 3,3	776 ± 10	33,8 ± 0,9	438 ± 22	3
Purple-grained								
31-16	2020	3,1 ± 0,7	71,0 ± 2,6**	74,4 ± 14,3	715 ± 15*	28,9 ± 3,5	332 ± 34	4
	2021	3,9 ± 0,8	73,3 ± 3,9**	82,4 ± 7,9	778 ± 15	32,4 ± 1,1	359 ± 44	4,5
	2022	4,1 ± 0,7	74,6 ± 5,3**	73,8 ± 8,6	758 ± 14	32,5 ± 1,0	375 ± 20	5
31-19	2020	1,7 ± 0,3	71,3 ± 2,1**	86,9 ± 7,3	716 ± 16*	27,4 ± 3,4	275 ± 41*	3
	2021	1,8 ± 0,3	72,1 ± 2,3**	75,1 ± 17,2	720 ± 15	28,3 ± 3,1	291 ± 56*	3,5
	2022	1,6 ± 0,4	75,0 ± 3,6**	72,6 ± 11	734 ± 15	29,6 ± 1,4	316 ± 18*	3,5
31-20	2020	1,8 ± 0,3	70,8 ± 2,1**	73,8 ± 11,0	719 ± 15*	27,0 ± 2,3*	267 ± 30*	3
	2021	1,9 ± 0,3	71,4 ± 2,1**	69,1 ± 11,5	723 ± 17	28,6 ± 2,2	298 ± 36*	4
	2022	1,8 ± 0,4	78,3 ± 3,6**	62,7 ± 7,0	726 ± 13*	27,6 ± 0,9	309 ± 25*	3,5
27-1	2020	2,1 ± 0,5	75,6 ± 2,9**	53,3 ± 11,0	791 ± 17	37,9 ± 2,6	389 ± 25	3
	2021	2,1 ± 0,4	76,1 ± 2,9**	80,5 ± 7,9	719 ± 19	33,6 ± 1,8	330 ± 19*	4
	2022	1,9 ± 0,4	79,9 ± 3,9*	76,4 ± 8,0	740 ± 17	34,4 ± 3,1	323 ± 21*	3,5
27-3	2020	2,5 ± 0,4	85,4 ± 3,1**	46,5 ± 10,0	724 ± 12	29,6 ± 3,9	304 ± 28	2
	2021	2,7 ± 0,5	86,6 ± 2,9*	74,8 ± 8,5	768 ± 17	32,4 ± 2,1	370 ± 63	3,5
	2022	3,1 ± 0,5	88,4 ± 2,0*	75,3 ± 10,0	754 ± 14	35,4 ± 0,9	455 ± 25	3,5
27-12	2020	2,2 ± 0,3	95,5 ± 4,4	58,2 ± 6,5	802 ± 13	31,2 ± 2,2	364 ± 50	2
	2021	2,4 ± 0,3	103,3 ± 4,8	61,6 ± 5,6	796 ± 10*	32,2 ± 2,0	338 ± 33	3
	2022	2,1 ± 0,5	107,9 ± 5,6	58,0 ± 11	782 ± 12	34,5 ± 1,5	449 ± 26	3
28-12	2020	2,3 ± 0,5	98,7 ± 5,4	52,7 ± 8,3	722 ± 29	29,0 ± 2,3	272 ± 38*	2
	2021	2,5 ± 0,6	89,0 ± 6,2	52,7 ± 8,3	743 ± 15	29,7 ± 3,6	260 ± 55*	2,5
	2022	2,3 ± 0,5	92,9 ± 6,0	62,1 ± 11	729 ± 13*	28,6 ± 2,0	327 ± 51	3,5
Half-naked								
53/15	2021	1,7 ± 0,3	94,5 ± 4,7	41,5 ± 13,4	767 ± 16	26,2 ± 1,4*	258 ± 26*	3
	2022	1,5 ± 0,4	97,3 ± 5,9	51,2 ± 5,6	735 ± 20	25,4 ± 2,5*	264 ± 28*	4
41/14	2021	2,0 ± 0,4	101,7 ± 4,0	85,3 ± 4,4	745 ± 11	28,9 ± 2,7	300 ± 13*	3
	2022	2,3 ± 0,5	104,5 ± 5,7	81,7 ± 6,5	742 ± 17	28,2 ± 1,6	313 ± 33	3
50/15	2021	2,5 ± 0,4	108,5 ± 5,5	50,0 ± 8,9	751 ± 16	25,2 ± 1,5*	347 ± 30	2,5
	2022	2,7 ± 0,7	111,3 ± 5,9	56,8 ± 11,2	736 ± 25	23,9 ± 1,2*	345 ± 46	3
57/14	2021	2,3 ± 0,3	99,7 ± 5,1	57,9 ± 10,5	753 ± 20	24,8 ± 2,9*	260 ± 29*	3
	2022	2,6 ± 0,7	97,5 ± 5,7	63,4 ± 8,5	773 ± 9	25,2 ± 1,3*	254 ± 21	4
38/15	2021	2,6 ± 0,6	106,3 ± 5,9	68,5 ± 10,0	742 ± 22	27,6 ± 2,2*	317 ± 44	2
	2022	2,3 ± 0,7	110,3 ± 7,3	72,7 ± 14,8	737 ± 17	28,4 ± 1,7	363 ± 51	3

Note. Significant differences from the best standard in the year of study:
*$p < 0.05$;
**$p < 0.01$.

0.9 g. High grain unit values over the 3 study years were noted for the purple-grained hybrid line 27-12. In 2021, its grain unit value (796 ± 10 g/l) significantly exceeded the best standard's trait value. The highest grain unit value (802 ± 13 g/l) was reached in 2020. The highest grain productivity indicators among all the studied breeding samples were achieved in 2022 by the purple-grained forms 27-12 (449 ± 26 g/m2) and 27-3 (455 ± 25 g/m^2). For the Gremme standard, this trait's value that year was 497 ± 31 g/m^2. In the previous 2 study years, the yield of this variety was above 450 g/m^2. The studied forms had varying degrees of lodging. The highest lodging resistance score (4–5 points) on a 5-point scale over 3 years was held by the short-stalked line 31-16. It also exhibited increased tillering (3-4 shoots) compared to other forms. Lines developed from the VIR did not have significant breeding value. Overall, the purple-grained lines proved to be more promising for further breeding work.

Among the forms studied, the sample from the VIR global collection k-25516, hybrid lines 27-1, 27-12, 31-16, and VIR breeding forms 53/15 and 50/15 can be attributed, in terms of phenotype, to the species *Triticum dicoccum* (Schrank) Schuebl., i.e., to amelcorn, whose spikelets contain 2 grains each. In other forms, including the Gremme variety, the spikelets often set 3, and sometimes even 4 grains, which is typical for *Triticum durum* L. Nevertheless, Gremme is recognized as a naked emmer wheat variety, proposed to be classified under a new subspecies of emmer – *Triticum dicoccon* (Schrank) Schuebl. subsp. *Nudicoccon* Kobyl. et Smekal. [1]. Currently, the important feature of the Gremme variety – naked grain – has not been passed on to our breeding forms, as the main emphasis in the initial phase of creating breeding material was on obtaining plants with purple grain color.

Breeders from all countries strive to produce the varieties that possess high nutritional value and good adaptability to local environmental conditions [2]. The emmer wheat forms being created align with these breeding directions and are recommended for use in functional nutrition.

CONCLUSION

In the course of the study, it was found that for further breeding work, the value lies in emmer wheat lines carrying a combination of economically important traits. The short-stalked purple-grained form 27-1 is resistant to lodging, with a grain threshability reaching 80%, and a 1000 grain weight of 34-37g. Line 27-12 has grain with a purple hue, a high grain unit value (around 800 g/l), and good grain productivity for emmer (400 g/m^2). The purple-grained emmer wheat line 31-16 has good tillering (3-4 shoots), a short stem (71-74 cm), high resistance to lodging (4-5 points), and a grain threshability reaching 80%. The breeding line 41/14 has been singled out from the half-naked emmer forms derived from VIR due to its high threshed grain indicator (85%). The main drawbacks of the created breeding emmer wheat forms remain the relatively low grain yield, not sufficiently strong spike axis, and incomplete threshing of the grain from the glume and lemma. However, further breeding can achieve improvements in these traits.

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ВЛИЯНИЕ ПОГОДНЫХ УСЛОВИЙ НА ВАРИАБЕЛЬНОСТЬ ФИЗИОЛОГИЧЕСКИХ ПАРАМЕТРОВ ЛИСТА У СОРТОВ ГРУШИ

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Представлены результаты изучения адаптационного потенциала многолетних плодовых культур в зависимости от климатических изменений. Произведена оценка физиологического состояния некоторых сортов груши в течение летних периодов в 2021, 2022 гг. на территории плодовых насаждений Краснодарского края. Исследованы два российских сорта (Фламенко, Люберская) и два европейских (Конференция, Вильямс). Для усиления негативного воздействия летних стрессовых факторов проведен эксперимент по искусственному высушиванию свежесобранных листьев груши при постоянной комнатной температуре. До и после стресса определяли относительное содержание воды в листьях и выход электролитов по общепринятым методикам. Установлено, что относительная влажность воздуха является важным фактором для нормального развития листа, и изменение ее показателей в летние месяцы скоррелировано с вариабельностью значений стрессового параметра листьев груши – с выходом электролитов. Выявлено, что широко распространенный европейский сорт Конференция оказался наиболее восприимчивым к воздействию искусственного стресса. После кратковременного высушивания для данного сорта было характерно резкое увеличение выхода электролитов до ~36% на фоне значительного снижения относительного содержание воды в листьях (71–73%), что обусловлено развитием окислительных процессов, приводящих к нарушению целостности клеточных мембран. Отечественные сорта Фламенко и Люберская, а также европейский сорт Вильямс, напротив, по исследованным физиологическим параметрам не имели сильных различий (изменение физиологических параметров составило от 1,1 до 1,3 раза), что позволило их определить, как более устойчивые сорта к данному типу стрессового воздействия.

Ключевые слова: селекция, сорта груши, адаптация, относительное содержание воды, выход электролитов

INFLUENCE OF WEATHER CONDITIONS ON THE VARIABILITY OF PHYSIOLOGICAL LEAF PARAMETERS IN PEAR CULTIVARS

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The results of the study of the adaptation potential of perennial fruit crops depending on climatic changes are presented. The physiological state of some pear varieties during summer periods in 2021, 2022 in the fruit plantations of the Krasnodar Territory were evaluated. Two Russian varieties (Flamenko, Luberskaya) and two European varieties (Conference, Williams) were studied. An experiment on artificially drying freshly harvested pear leaves at constant room temperature was conducted to amplify the negative effects of summer stressors. The relative water content of leaves and electrolyte leakage were determined before and after the stress according to generally accepted methods. It was found that relative humidity is an important factor for normal leaf development, and the change in its values in the summer months correlated with the variability of values of the stress parameter of pear leaves - electrolyte leakage. It was found that the widespread European variety Conference was the most susceptible to the effects of artificial stress. After a short drying period, this variety was characterized by a sharp increase in the electrolyte leakage to ~36% on the background of a significant decrease in the relative water content in the leaves (71–73%), due to the development of oxidative processes, leading to a violation of the integrity of cell membranes. Russian varieties Flamenko and Luberskaya, as well as the European variety Williams, on the contrary, by the studied physiological

parameters had no strong differences (the change of physiological parameters was from 1.1 to 1.3 times), which allowed them to be identified as more resistant varieties to this type of stress exposure.
Keywords: selection, pear cultivars, adaptation, relative water content, electrolyte leakage

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INTRODUCTION

The adaptive potential of plants is an important component in breeding selection, and it is especially informative for specific growth zones. The modern assortment of pear varieties in the southern region of the country is primarily represented by European varieties such as Williams, Conference, Abbat Fetel, and Beurré Clairgeau [1]. It should be noted that these varieties were developed in milder climatic conditions, which differ from the PriKubanskaya gardening zone of the Krasnodar Territory in terms of temperature regime and humidity levels.

During the summer period, high average and maximum air temperatures, a decrease in precipitation, and a reduction in relative air humidity can become particularly critical for plants, leading to a deficit in available water. Only drought-resistant varieties can maintain their physiological state under such conditions by activating mechanisms to mitigate stress [2, 3]. At the physiological level, this is achieved by regulating osmotic pressure in cells and activating the antioxidant defense system [4, 5]. In susceptible varieties, drought leads to disruptions in physiological stability due to the development of oxidative stress in plant cells [6-8].

Assessing the drought resistance of perennial woody plants is complicated by their large size, lengthy life cycle, and the challenge of creating artificial systems to simulate this stress factor. Individual leaves can serve as model objects for evaluating drought resistance in perennial woody plants when placed under water deficit conditions[1, 2]. Such studies simulate drought either through natural drying or by temperature-induced artificial dehydration of leaves.

Simulating drought allows for the assessment of the plant's physiological state in response to this specific type of stress. In field conditions, distinguishing the negative impact of drought is complicated by the presence of a whole range of stressors in the environment, both biotic and abiotic.

The purpose of the study is to assess the reaction of pear varieties to drought stress both in field conditions and in the laboratory.

The objectives of the research are to artificially impose drought on the leaves of pear varieties, determine physiological parameters before and after short-term stress exposure, and assess the drought resistance of the studied pear varieties.

[1] *Percival G.C., Sheriffs C.N.* Identification of drought-tolerant woody perennials using chlorophyll fluorescence // Journal of Arboriculture. 2002, vol. 28 (5), pp. 215−223.

[2] *Saprykina I.N.* Resistance of cherry and plum cultivars from secondary Cisurals micro source area to the environment abiotic factors // Bulletin of agrarian science. 2013, vol. 41 (2), pp. 54−57.

MATERIAL AND METHODS

The study was conducted in the Pri-Kubanskaya gardening zone of the Krasnodar Territory in 2021 and 2022, based on the garden plantation of the Collective Use Center "Research and Breeding Collection of Genetic Resources of Garden Crops" of the FSBSI "North Caucasian Federal Scientific Center of Horticulture, Viticulture, and Winemaking" (NCFSC HVW). The subjects of the research were two Russian pear varieties, Lyuberskaya and Flamenko, and two European varieties, Williams and Conference. The Flamenko and Williams varieties are summer ripening, while Lyuberskaya and Conference are late summer ripening. The zoned variety Williams was used as a control for the conditions of the southern region. The studied varieties have large-sized fruits, they are of high dessert and canning quality, with high yield and other commercial and consumer qualities.

The varieties were grafted onto the BA-29 rootstock. The orchard was established in 2007, with a planting scheme of 5 × 2 meters. Leaves were sampled from the middle part of one-year shoots from 3-6 trees of each variety at the beginning and middle of the summer period. Weather data were provided by the Krasnodar meteorological station (synoptic index 34929). To enhance the negative impact of the current weather conditions of the summer periods of 2021 and 2022, an experiment was conducted to artificially dry freshly harvested pear leaves in a closed transparent plastic container for 2 hours at room temperature.

The relative water content in the leaves was determined according to the commonly accepted weight method[3]. The calculation of electrolyte leakage was carried out using a conductometer according to the method of Dionisio-Sese et al.[4] The studies were conducted in 2-3 replicates. The data are presented as means and their errors. Statistically significant differences were obtained as a result of the conducted Duncan's comparative test with a significance level of 0.05. Correlation analysis was used to assess the relationship between the studied parameters.

RESULTS AND DISCUSSION

According to the weather indicators for the summer period of 2021, higher values of relative air humidity were characteristic compared to 2022 (see Fig. 1). In terms of temperature regime, the studied period did not differ between the years. The maximum values of relative water content (91.1%) during the summer period of 2021 were found in the leaves of the Flamenko variety. In 2022, the studied varieties did not significantly differ, and the values of this indicator ranged from 78.9 to 82.3% (see Fig. 2). After short-term drying of the leaves in 2021 and 2022, the most significant decrease in the parameter was observed in the Conference variety, which amounted to 17.2% and 9.7% respectively.

In terms of electrolyte leakage under control conditions, pear variety indicators varied in the range of 8.8 to 13.2%. Only in 2021, the Conference variety had a minimum value of 7.9% (see Fig. 3). Stress exposure for most of the studied varieties contributed to a slight increase in this parameter. Only the Conference variety showed an increase in electrolyte leakage by 1.7 times in 2021 and 3.7 times in 2022.

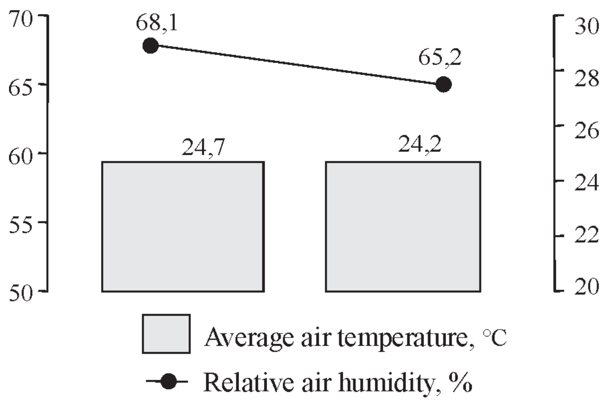

Рис. 1. Погодные показатели летнего периода 2021, 2022 гг.

Fig. 1. Weather indicators of the summer period 2021, 2022

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[3] *Jiang Y., Huang B.* Drought and heat stress injury to two cool-season turfgrasses in relation to antioxidant metabolism and lipid peroxidation // Crop Science. 2001, vol. 41, pp. 436–442. DOI: 10.2135/cropsci2001.412436x.

[4] *Dionisio-Sese M.L., Tobita S.* Antioxidant responses of rice seedlings to salinity stress // Plant Science. 1998, vol. 135, pp. 1–9.

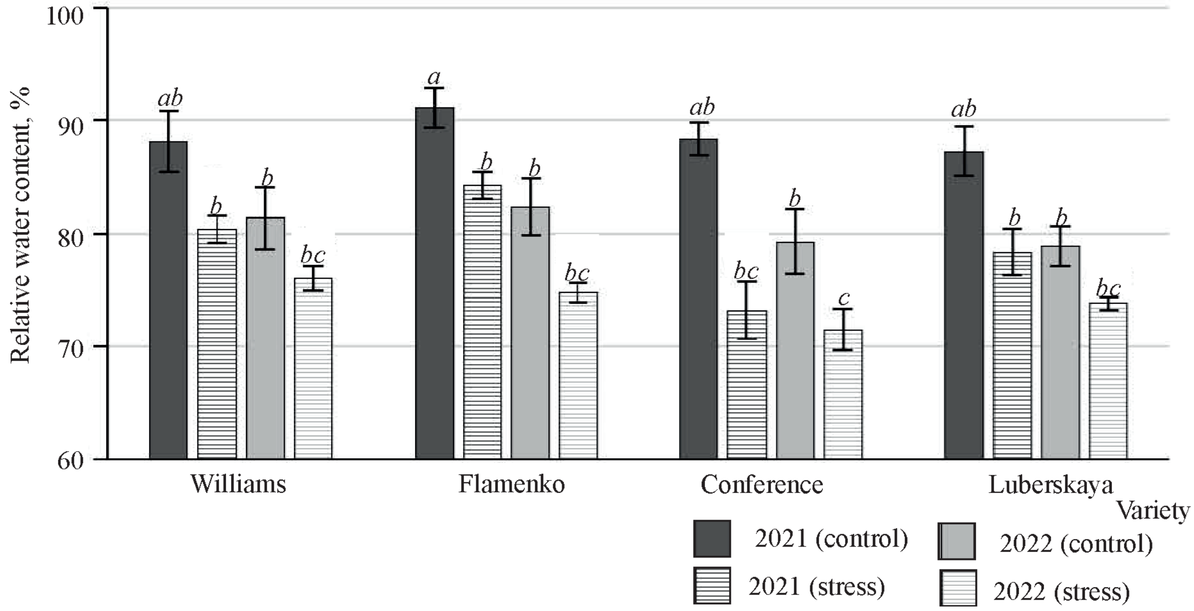

Рис. 2. Относительное содержание воды в листьях груши в летние периоды 2021, 2022 гг.
Здесь и в рис. 3: достоверные различия показателей отмечены латинскими буквами ($p < 0,05$)
Fig. 2. Relative water content in pear leaves in the summer periods of 2021, 2022
Significant differences are marked in Latin letters ($p < 0.05$).

The results of the correlation analysis assessing the relationship between the studied physiological parameters of pear variety leaves and the weather conditions of the summer periods of 2021 and 2022 showed that statistically significant direct relationships were identified between the average values of relative air humidity and electrolyte leakage in the Flamenko and Conference varieties (see table). For the Flamenko variety, such a correlation was characteristic during the more humid summer of 2021, while for the Conference variety it was during the summer months of 2022. For the control variety Williams, an inverse relationship was found between the average air temperature of 2021 and electrolyte leakage.

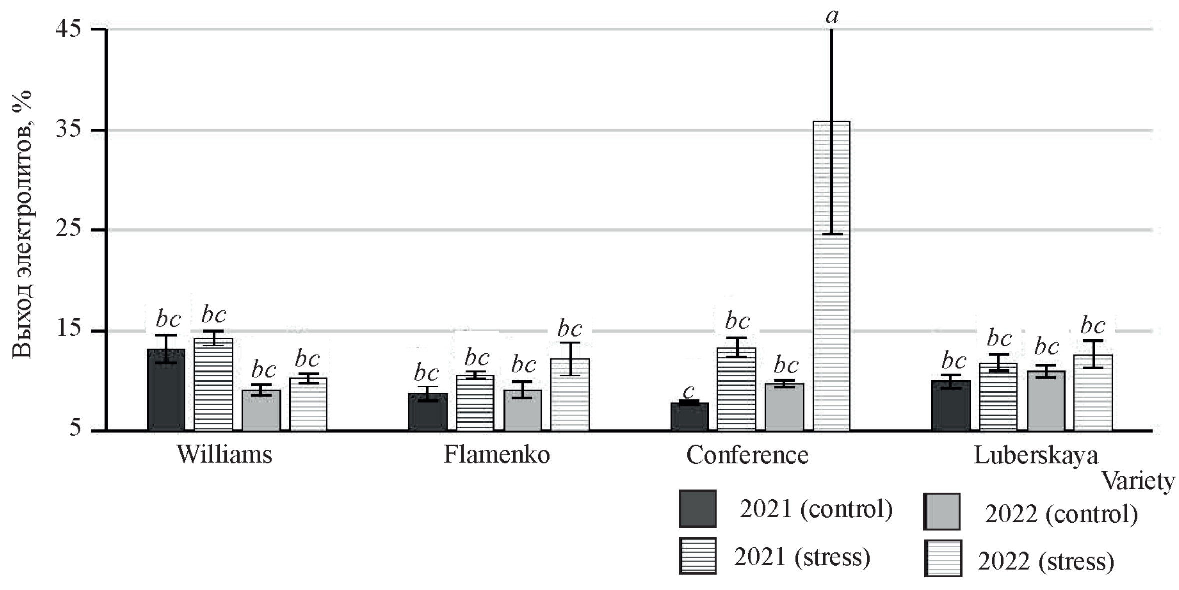

Рис. 3. Выход электролитов в листьях груши в летние периоды 2021, 2022 гг.
Fig. 3. Electrolyte leakage in pear leaves in the summer period of 2021, 2022

According to the obtained data, the physiological state of the pear varieties Williams, Conference, and Flamenko depended on fluctuations in air temperature and relative air humidity during the studied years of 2021 and 2022. Notably, in the Flamenko variety, during short-term leaf drying in experimental conditions in 2021, there was a statistically significant decrease in the relative water content in the leaves by 7.5%, which corresponded to the variety's reaction to fluctuations in relative air humidity under control conditions according to correlation analysis ($r = 0.92$ with $p < 0.05$). The Conference variety proved especially sensitive to fluctuations in summer air humidity and temperature and to artificial stress exposure. Under control conditions, a direct dependence of electrolyte leakage level from leaf tissues on relative air humidity was detected only in 2022 ($r = 0.86$ with $p < 0.05$). According to experimental data, a similar correlation for this variety was also evident in 2021: relative water content decreased by 1.2 times, while the level of electrolyte leakage increased by 1.7 times. Therefore, the Conference variety is the most sensitive among the studied pear varieties to moisture levels. Depending on the degree of drought during the summer period, its physiological state will change more intensively compared to other varieties. This variety's weak resilience was confirmed in our earlier studies on a range of physiological parameters [9]. Moreover, in a study evaluating pear drought resistance in the foothill zone of Kabardino-Balkaria, the authors also noted the Conference variety as the most sensitive according to water regime indicators, while the Williams variety was classified as a variety with a medium level of resilience [10].

At the same time, it's worth noting that the Conference variety accounts for the largest share of the entire pear assortment in European countries [11]. This variety originated back in the 19th century. Given the widespread climate changes currently happening, even for the milder conditions of Spain and Italy (leaders in pear production), its adaptation potential is limited by such negative impacts [12]. In this context, studying domestic pear varieties and searching for the most adapted ones with high production qualities is especially relevant. In the Krasnodar region, researchers expand and continuously update the pear variety assortment with genotypes suitable for cultivation in the southern region based on field and laboratory data [1, 13, 14].

CONCLUSION

During the studied summer periods, the weather conditions of 2021 proved to be more favorable for the examined pear varieties than those of 2022. Relative air humidity is an important factor that has a direct impact on the physiological parameters of pear leaves. Drying the leaves under experimental conditions allowed for an evaluation of the adaptive capabilities of different pear varieties. It was found that the widely cultivated European variety Conference was the most susceptible to this stress factor. In contrast, the Russian varieties Flamenko

Основные корреляции относительной влажности воздуха и средней температуры летнего периода с уровнем выхода электролитов в листьях груши
Main correlations of relative humidity and average summer temperature with electrolyte leakage in pear leaves

Weather index	Leaf physiological index	
	Electrolyte output in the summer period of 2021	Electrolyte output in the summer period of 2022
Relative air humidity in the summer period of 2021	0,92*	–
Relative air humidity in the summer period of 2022	–	0,86***
Average summer temperature 2021	–0,9**	–
Average summer temperature 2022	–	–

* Correlation coefficient of the Flamenco variety.
** Correlation coefficient of the Williams variety.
*** Correlation coefficient of the Conference variety.

and Lyuberskaya demonstrated resilience based on the studied physiological parameters after artificial drought. Further research will provide a more detailed characterization of the adaptive potentials of various pear varieties.

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ВАРИАБЕЛЬНОСТЬ ПРИЗНАКОВ ТЕХНОЛОГИЧЕСКОГО КАЧЕСТВА ЛЬНОТРЕСТЫ СОРТОВ ЛЬНА-ДОЛГУНЦА

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Представлен анализ результатов переработки льнотресты различного качества ряда сортов льна-долгунца отечественной и иностранной селекции с определением следующих признаков технологического качества: выход и номер длинного и короткого волокна, процентономер этих же признаков с оценкой вариабельности. Основные исследования проводили на площадках льносеющих и льноперерабатывающих предприятий Тверской, Смоленской, Псковской, Костромской, Вологодской областей в 2001–2022 гг. Установлено, что больше всего в разрезе сортов варьируют значения выхода длинного волокна из низкокачественной льнотресты (номер 0,75): коэффициент вариации в данном случае составил 40,8%. Наиболее однородные данные по выходу длинного волокна зафиксированы при переработке льнотресты номер 1,25 (коэффициент вариации 26,5%), что несколько меньше изменчивости этого признака у волокна из высококачественной льнотресты номер 1,75 (коэффициент вариации 29,9%). При сравнении фактических значений выхода и процентономеров длинного волокна с установленными нормами определены сорта, из льнотресты которых можно получить больший объем длинного волокна хорошего качества. Среди них такие новые сорта, как Александрит, Василек, Грант, Сурский, Цезарь, а также сорта, уже находящиеся в производстве: Ленок, Зарянка, Лидер, София, А 93, Тверской, Томский 17, Лира, Тост. Выявлены сорта льна-долгунца с максимальным соотношением комплексных показателей, определяющих эффективность работы льноперерабатывающих предприятий – процентономеров длинного и короткого волокна. Доля процентономеров длинного волокна в процентономерах всего произведенного волокна колеблется от 68,2 до 70,2% (льнотреста низкого качества) для лучших сортов Ленок, Зарянка, Василек, от 68,5 до 72,6% (льнотреста среднего качества) для сортов Тост, Томский 17, Александрит, от 72,1 до 73,9% (льнотреста высокого качества) для сортов Ленок, Лира, Пралеска.

Ключевые слова: сорт, льнотреста, вариабельность, выход и номер длинного и короткого волокна, процентономер, норма, признак технологического качества

VARIABILITY OF THE TRAITS OF TECHNOLOGICAL QUALITY OF FIBER FLAX VARIETIES FLAX STRAW

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The results of processing flax sraw of various quality varieties of flax of domestic and foreign selection with the determination of the following signs of its technological quality are presented: the output and numbers of the long and short fibers, and the percentage numbers of the same signs with an assessment of their variability. The main research was carried out at the sites of flax-growing and flax-processing enterprises of the Tver, Smolensk, Pskov, Kostroma, Vologda regions in 2001–2022. It was found that the values of the yield of long fiber from low-quality flax straw (number 0.75): the coefficient of variation in this case was 40.8%. The most homogeneous data on the yield of long fiber were observed from the flax straw number 1.25 (the coefficient of variation 26.5%), which is slightly less than the variability of this feature from the high-quality flax straw number 1.75 (the coefficient of variation 29.9%). By comparing the actual values of yields and percentages of long fiber with the established standards, the varieties from which, depending on its quality, it is possible to obtain a greater volume of good quality long fiber from flax straw were identified. Among them there are such new varieties as Alexandrit, Vasilek, Grant, Sursky, Caesar, as well as the following varieties in production: Lenok, Zaryanka, Leader, Sofia, A 93, Tverskaya, Tomsky 17, Lira, Toast. The varieties of fiber flax with the maximum ratio of complex indicators that determine the efficiency of flax processing enterprises – the percentage of long and short fiber are identified. The share of long fiber percentage numbers in the percentage numbers of total fiber produced varies from 68.2 to 70.2% (low quality flax) for the best varieties Lenok, Zaryanka, Vasilek, from 68.5 to 72.6% (medium quality flax) for the varieties Toast, Tomsky 17, Alexandrit, from 72.1 to 73.9% (high quality flax) for the varieties Lenok, Lira, Praleska.

Keywords: variety, flax straw, variability, long and short fibers yield and number, percentage number, norm, a sign of technological quality

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INTRODUCTION

In the context of today's market economy, factors related to the quality of products come to the forefront. Improving this quality becomes a crucial condition for their competitiveness in markets of various levels [1–5]. In flax cultivation, improving the quality of fibrous products is intrinsically linked to the development of new long-stalked flax varieties, which possess a high content of high-quality fiber [6–8].

In the primary industry of bast fiber processing, the technological quality of flax straw, determined by the yield and grade of long and short fiber, depends both on the grade of the flax straw and on the peculiarities of the varieties [9]. For flax straw of each grade, standards for yield and quality of long and short fiber are set when processed using traditional technology[1] [10, 11]. Among the set of properties determining the quality of any material, which ensures the processing level and the intended use of raw materials, the most important is the uniformity of the product [12]. The inconsistency in the physical properties of flax straw is one of the main reasons for its underutilization by flax processing enterprises.

Sorting flax straw by grade aims to mitigate the negative consequences, ensuring the selection of an optimal processing mode and labor organization at individual production cycle operations. However, given that in the Russian Federation between 30 and 50 varieties of long-stalked flax are cultivated and processed, each with its own characteristics, the technological quality traits of flax straw of the same grade can vary significantly [13]. This can result in both an actual exceedance of fiber yield and quality compared to the standards in place and a reduction in these indicators specifically related to varietal features. Therefore, it is necessary to determine the variability of technological quality traits of flax straw depending on its grade for the respective long-stalked flax varieties.

Since the efficiency of flax processing enterprises is determined by meeting the standards for fiber yield and quality, it is reasonable to

[1]Order of 28.11.2011. "Norms of yield and quality of fiber from retted flax straw", approved by FSBI "Len Agency". Moscow, 2011.

identify the varieties from which the maximum fiber yield, especially long fiber considered more quality and being the main product of primary processing, can be obtained. A criterion in this case can be the ratio of complex indicators – percentage grades of long and short fiber for specific varieties. It is known that currently, in the Russian Federation, the proportion of long fiber in the total production volume does not exceed one-third, whereas abroad it can reach 60–70% or more [14].

Research Objectives:

1. Determination of the variability of technological quality attributes of flax straw of various numbers within different varieties of long-stalked flax varieties.

2. Identification of long-stalked flax varieties with the best ratio of complex indicators determining the profitability of flax processing enterprises, specifically the percentage of long and short fiber.

The research results will allow optimization of the product batch formation process of a specific quality, driven by market demands during specific time intervals, taking into account the potential for diversifying its use.

MATERIAL AND METHODS

The research was conducted under the production conditions of flax-growing farms and flax processing enterprises in the Tver, Smolensk, Pskov, Kostroma, and Vologda regions from 2001 to 2022. Individual experiments were conducted at the Federal Research Center for Bast Fiber Crops.

In forming the rolls of flax straw, the readiness level for mechanical processing was determined, including the measurement of the fiber's separability from the wood. Additionally, the quality of the flax straw was evaluated according to GOST 24383-89 "Flax straw. Requirements during procurement." Control developments were carried out in accordance with a special methodological program, which entailed preparing flax straw for processing under production conditions at flax processing enterprises, noting moisture and impurity indicators in batches weighing at least 2 tons[2]. The optimal processing regime, depending on the quality of flax straw, was selected according to the technical operation rules of flax factories. The conveyor speed of the dryer, throughput capacity of the milling-beating unit, rotation frequency of the milling rolls, conveyor speed of the beating machine, rotation frequency of the beating drums in two sections of the main beating machine, and two sections of the machine for processing under-beaten material were determined.

The technological operations algorithm was as follows: feeding flax straw rolls to the unwinder and the SKP-10-LU dryer conveyor, drying the flax straw, mechanical processing on the MTA-1Л milling-beating unit to obtain long fiber followed by refining on the TL-4-2 beating machine, drying beating waste on the SKP-10-KU dryer, processing beating waste on the KPML-2 or AKLV preparing unit to produce short fiber.

The total fiber yield, long and short fiber yield, was calculated based on current regulatory documentation. The quality of long fiber was evaluated according to GOST 10330-76 "Retted Flax. Technical conditions" (Amendment No. 4), and the short one - according to GOST 9394-73 "Short Flax Fiber. Technical conditions."

Experimental data were processed using standard variation statistics methods[3, 4]. The arithmetic mean of the technological quality attributes of the flax straw, the range of data variation, the coefficient of variation, and the standardized deviation were calculated.

RESULTS AND DISCUSSION

During the research period, control developments of 5253 batches of flax straw of various quality from 35 varieties of long-stalked flax varieties of domestic and foreign breeding were conducted: Aleksim, Escalina, Lenok, A 93, A

[2]Order of the Ministry of Agriculture of the Russian Federation No. 23 p of 10.03.2016. "The procedure for determining the norms for conversion of flax and hemp straw into fiber" (in edition of the Resolution of the Government of the Russian Federation No. 450 dated 12.06.2008).

[3]*Nivorozhkina L.N., Arzhapovsky S.V., Rudyaga A.A.* Statistical methods of data analysis: textbook. Moscow: Rif. 2018, 320 p.

[4]*Ivchenko T.I., Medvedev Y.I.* Mathematical statistics: textbook. Moscow: Librocom. 2020, 352 p.

29, Mogilevsky 2, Dashkovsky, Zaryanka, Tver, Alpha, Tomsky 16, Tomsky 17, Lyra, Elektra, Tomsky 18, Toast, Leader, Impulse, Veralin, Suzanne, Sofia, Smolich, Vasilek, Agata, Diplomat, Universal, Praleska, Sursky, Caesar, Alexandrit, Nadezhda, Grant, Visit, Atlant, Fakel. Table 1 shows data on the output and quality of long and short fibers in terms of long-stalked flax varieties from low-quality flax straw (number 0.75), table 2 - data on medium-quality flax straw (number 1.25), and table 3 - on high-quality flax straw (number 1.75).

The data from tables 1-3 show that the values of characteristics for the same flax straw number for the studied varieties differ significantly. The minimum yield of long fiber from the flax straw number 0.75 is 1.4% (Caesar variety), the maximum is 11.3% (Lenok variety). From the flax

Табл. 1. Выход и качество длинного и короткого волокна из льнотресты номер 0,75 в разрезе сортов льна-долгунца

Table 1. Yield and quality of long and short fiber in the section of flax varieties from flax seed number 0.75

Variety	Long fibre			Short fibre			% № of total fibre	Total fibre yield, %
	Fibre yield, %	Number	% №	Fibre yield, %	Number	% №		
Aleksim	5,9	10,42	61,5	17,4	3,50	60,9	122,4	23,3
Escalina	5,9	10,00	59,0	23,8	3,00	71,4	130,4	29,7
Lenok	11,3	10,80	122,0	16,0	3,25	52,0	174,0	27,3
A 93	7,9	10,46	82,6	21,3	3,33	70,9	153,5	29,2
A 29	3,9	9,40	36,7	20,3	2,60	52,8	89,5	24,2
Mogilevsky 2	5,3	10,78	57,1	18,7	2,50	46,8	103,9	24,0
Dashkovsky	4,8	10,55	50,6	20,6	2,64	54,4	105,0	25,4
Zaryanka	10,4	11,00	114,4	16,2	3,00	48,6	163,0	26,6
Tverskoj	7,7	10,50	80,8	19,3	4,00	77,2	158,0	27,0
Tomsky 16	3,8	11,16	42,4	18,7	3,00	56,1	98,5	22,5
Tomsky 17	4,4	10,28	45,2	23,9	3,00	71,7	116,9	28,3
Lira	3,4	10,94	37,2	20,2	3,19	64,4	101,6	23,6
Elektra	2,6	10,59	27,5	24,2	3,00	72,6	100,1	26,8
Tomsky 18	3,3	10,17	33,6	25,1	3,00	75,3	108,6	28,4
Leader	9,2	9,61	88,4	19,4	4,00	77,6	166,0	28,6
Impulse	5,4	9,76	52,7	20,3	3,00	60,9	113,6	25,7
Veralin	6,7	10,75	72,0	22,4	3,50	78,4	150,4	29,1
Sofia	8,4	10,64	89,4	19,0	3,00	57,0	146,4	27,4
Smolich	5,9	10,17	60,0	19,4	3,00	58,2	118,2	25,3
Vasilek	8,9	11,00	97,9	15,2	3,00	45,6	143,5	24,1
Agata	6,7	10,21	68,4	13,8	3,00	41,4	109,8	20,5
Universal	6,2	10,00	62,0	21,2	2,33	49,4	111,4	27,4
Praleska	5,6	10,54	59,0	19,6	2,00	39,2	98,2	25,2
Sursky	2,3	9,00	20,7	25,9	2,00	51,8	72,5	28,2
Caesar	1,4	10,99	15,4	18,9	2,50	47,3	62,7	20,3
Alexandrit	6,9	9,75	67,3	18,1	2,00	36,2	103,5	25,0
Nadezhda	8,0	9,00	72,0	19,4	2,00	38,8	110,8	27,4
Grant	7,6	9,50	72,2	20,6	2,66	54,8	127,0	28,2
Vizit	6,9	9,00	62,1	21,2	2,00	42,4	104,5	28,1
Atlant	3,1	10,00	31,0	22,1	2,00	44,2	75,2	25,2
Fakel	3,6	9,00	32,4	22,3	2,00	44,6	77,0	25,9
Average	5,9	10,19	60,4	20,1	2,81	56,2	116,7	26,1

Note. Hereinafter in the tables: % No. - percent number.

straw number 1.25, the maximum yield of long fiber was 12.7% (Vasilek variety), the minimum was 2.0% (Elektra variety). From high-quality flax straw (number 1.75), the output ranged from 16.0% (Lyra variety) to 7.0% (Nadezhda variety).

Since the long fiber is the main product in the processing of flax straw, data on the long fiber was used to assess the variability of technological quality characteristics. Using the methods of variance statistics based on tables 1-3, the range of variation, dispersion, coefficient of variation, and standardized deviation were determined for the yield and quality (see Table 4).

Analysis of table 4 showed that the values of the long fiber yield from low-quality flax straw vary the most across varieties: the range of variation was 1.4-11.3%, and the coefficient of variation turned out to be quite high (V = 40.8%). The variability of this characteristic for long fiber from medium-quality flax straw is somewhat lower (V = 26.5%) than for fiber from high-quality flax straw (V = 29.9%). This means that for medium-quality flax straw of the long-stalked flax varieties, it is easier to select an optimal processing regime on production equipment.

The yield of long fiber from flax straw number 0.75 for the varieties Elektra (2.6%), Sursky (2.3%), and Caesar (1.4%) deviates from the average value by an amount exceeding the standardized deviation from the actual average feature value and has the lowest values. The minimum fiber yield from flax tow number 1.25 is observed in the varieties Elektra (2.0%), Tomsky

Табл. 2. Выход и качество длинного и короткого волокна из льнотресты номер 1,25 в разрезе сортов льна-долгунца

Table 2. Yield and quality of long and short fiber in the section of flax varieties from flax seed number 1.25

Variety	Long fibre			Short fibre			% № of total fibre	Total fibre yield, %
	Yield, %	Number	% №	Yield, %	Number	% №		
Aleksim	9,0	11,20	100,8	14,8	4,00	59,2	160,0	23,8
A 93	10,8	11,00	118,8	21,2	3,00	63,6	182,4	32,0
A 29	7,2	10,00	72,00	21,0	3,50	73,5	145,5	28,2
Mogilevsky 2	8,4	10,99	92,3	19,7	3,00	59,1	151,4	28,1
Dashkovsky	7,6	10,59	80,5	18,5	3,50	64,8	145,3	26,1
Zaryanka	9,3	11,33	105.4	19,6	3,00	58,8	164,2	28,9
Tverskoj	12,2	12,00	146,4	20,4	4,00	81,6	228,0	32,6
Tomsky 16	5,7	11,28	64,3	20,8	3,00	62,4	126,7	26,5
Tomsky 17	12,3	10,00	123,0	18,2	3,00	54,6	177,6	30,5
Elektra	2,0	10,37	20,7	30,6	3,00	91,8	112,5	32,6
Leader	9,3	11,29	105,0	19,7	4,00	78,8	183,8	29,0
Impulse	9,2	11,34	104,3	22,6	4,00	90,4	194,7	31,8
Susanna	10,2	10,92	111,4	13,0	4,00	52,0	163,4	23,2
Sofia	8,4	10,35	86,9	24,0	3,00	72,0	158,9	32,4
Smolich	7,4	10,60	78,4	21,4	3,17	67,8	146,2	28,8
Vasilek	12,7	11,00	139,7	18,4	3,75	69,0	208,7	31,1
Agata	10,1	11,96	120,8	21,6	3,56	76,9	197,7	31,7
Diplomat	8,6	11,00	94,6	31,1	4,00	124,4	219,0	39,7
Universal	8,0	10,29	82,3	21,4	2,50	53,5	135,8	29,4
Praleska	6,8	11,00	74,8	23,1	2,00	46,2	121,0	29,9
Cesar	7,0	10,82	75,7	19,9	2,75	54,7	130,4	26,9
Alexandrit	11,4	10,00	114,0	21,0	2,50	52,5	166,5	32,4
Nadezhda	7,9	10,00	79,0	21,0	2,00	42,0	121,0	28,9
Grant	11,6	10,00	116,0	16,9	3,24	54,7	170,7	28,5
Vizit	9,4	10,00	94,0	22,2	3,00	66,6	160,6	31,6
Atlant	7,2	10,00	72,0	22,4	2,00	44,8	116,8	29,6
Fakel	6,0	10,00	60,0	24,8	2,00	49,6	109,6	30,8
Average	8,8	10,73	94,6	20,7	3,16	27,9	159,1	29,5

Табл. 3. Выход и качество длинного и короткого волокна из льнотресты номер 1,75 в разрезе сортов льна-долгунца

Table 3. Yield and quality of long and short fiber in the section of flax varieties from flax seed number 1.75

Variety	Long fibre			Short fibre			% № of total fibre	Total fibre yield, %
	Yield, %	Number	% №	Yield, %	Number	% №		
Aleksim	9,9	11,22	111,1	14,1	3,67	51,7	162,8	24,0
Eskalina	9,3	11,34	105,5	19,6	3,33	65,3	170,8	28,9
Lenok	12,2	11,00	134,2	15,8	3,00	47,4	181,6	28,0
A 93	11,0	11,59	127,5	21,5	3,33	71,6	199,1	32,5
Mogilevsky 2	9,8	11,9	116,6	18,7	2,75	51,4	168,0	28,5
Dashkovsky	8,8	11,75	103,4	20,6	3,25	67,0	170,4	29,4
Zaryanka	11,4	12,00	136,8	19,2	3,00	57,6	194,4	30,6
Tverskoj	10,8	12,00	129,6	22,4	4,00	89,6	219,2	33,2
Tomsky 16	8,5	11,09	94,3	16,8	3,00	50,4	144,7	25,3
Tomsky 17	12,7	10,00	127,0	19,9	3,00	59,7	186,7	32,6
Lira	16,0	10,91	174,6	16,0	4,00	64,0	238,6	32,0
Elektra	8,2	11,18	91,7	20,5	3,58	73,4	165,1	28,7
Tomsky 18	11,4	10,00	114,0	18,5	6,00	111,0	225,0	29,9
Toast	12,6	10,70	134,8	19,3	3,50	67,6	202,4	31,9
Leader	13,4	12,00	160,8	19,0	4,00	76,0	236,8	32,4
Agata	9,0	11,43	102,9	20,3	3,58	72,7	175,6	29,3
Diplomat	8,4	11,00	92,4	32,6	4,00	130,4	222,8	41,0
Praleska	10,8	10,65	115,0	22,2	2,00	44,4	159,4	33,0
Sursky	14,8	11,00	162,8	18,2	3,67	66,8	229,6	33,0
Caesar	13,0	11,00	143,0	18,4	4,00	73,6	216,6	31,4
Alexandrit	13,0	9,75	126,8	19,0	2,68	50,9	177,7	32,0
Nadezhda	7,0	9,50	66,5	30,4	2,00	60,8	127,3	37,4
Grant	14,0	10,00	140,0	14,2	4,22	59,9	199,9	28,2
Average	11,1	11,00	122,2	19,9	3,46	68,0	190,2	31,0

Табл. 4. Вариабельность признаков технологического качества льнотресты по выходу и номеру длинного волокна

Table 4. Variability of the signs of technological quality of flax by yield and number of long fiber

Flax straw number	Characteristic	Average value	Range of variability (act.)	Range of variability (stand.)	Dispersion (S_x)	Coefficient of variation (*V*), %	Standardized deviate (*t*)
0,75	Yield, %	5,9	1,4–11,3	6,4–8,0	2,41	40,8	2,24
	Number	10,19	9,00–11,00	10,10–10,40	0,655	6,43	1,24
	% №	60,4	15,4–122,2	64,6–83,2	28,9	47,8	2,13
1,25	Yield, %	8,8	2,0–12,7	9,4–11,0	2,336	26,5	1,67
	Number	10,73	10,00–12,00	10,70–11,00	0,602	5,6	1,21
	% №	94,6	60,0–139,7	100,6–121,0	8,38	8,86	4,13
1,75	Yield, %	11,1	8,5–16,0	12,5–14,0	3,32	29,9	1,48
	Number	11,00	9,50–12,00	11,30–11,60	1,05	9,54	1,43
	% №	122,2	66,5–174,6	141,2–162,4	25,4	20,8	4,25

16 (5.7%), Praleska (6.8%), Caesar (7.0%), and Fakel (6.0%). The following varieties also had the lowest yield of long fiber (flax tow number – 1.75): Escalina (9.3%), Dashkovsky (8.8%), Tomsky 16 (8.5%), Elektra (8.2%), Agata (9.0%), Diplomat (8.4%), Nadezhda (7.0%).

Since a 1% decrease in the yield of long fiber results in a corresponding increase in the yield of short fiber, given that long fiber is approximately three times more expensive than short fiber, processing flax straw of the mentioned varieties using traditional technology might lead to a loss of 60–70% of the fiber's value. Thus, depending on its quality, it's more reasonable to process the flax straw of these varieties into uniform or short fiber. For obtaining both long and short fibers, it is most profitable to use the following varieties: Lenok, Zaryanka, Leader, Sofia, Vasilek (flax straw number – 0.75), A 93, Tver, Tomsky 17, Vasilek, Alexandrit, Grant (flax straw number – 1.25), Tomsky 17, Lyra, Toast, Leader, Sursky, Caesar, Alexandrit, Grant (flax straw number – 1.75). Moreover, although the actual average values for long fiber yield increase with increasing flax straw quality, they are much lower than the average values recorded in standards for fiber yield and quality (see Table 5).

Such complex indicators as percentages and their ratios are significantly below standardized values. However, according to tables 1-3, there are varieties where the ratio of percentages of long and short fibers, determining the efficiency of flax processing enterprises, matches the values set in foreign flax tow processing technologies. The varieties with the best complex indicator ratios are shown in figures 1-3.

Thus, based on the data on the variability of flax straw's technological quality characteristics depending on its number across long-stalked flax varieties, and also the list of varieties characterized by the best ratio of complex indicators, one can achieve improvements in the technical and economic performance of flax-producing and flax-processing enterprises.

CONCLUSIONS

1. It has been established that among the technological quality traits of flax straw, when viewed across long-stalked flax varieties, the yield of long fiber varies the most: the coefficient of variation for low-quality flax straw is 40.8%, medium-quality is 26.5%, and high-quality is 29.9%. Varieties have been identified from which, depending on the quality of the tow, the maximum yield of long fiber can be obtained: Lenok, Zaryanka, Leader, Sofia, Vasilek, A 93, Tver, Tomsky 17, Alexandrit, Grant, Lyra, Toast, Sursky, Caesar.

2. Varieties of long-stalked flax with the maximum ratio of complex indicators (percentages of long and short fiber) have been identified, which is the primary criterion for the efficiency of flax processing enterprises. These varieties include Lenok, Zaryanka, Vasilek (flax straw number – 0.75), Toast, Tomsky 17, Alexandrit (flax straw number – 1.25), Lenok, Lyra, Praleska (flax straw number – 1.75).

Табл. 5. Средние фактические и нормированные значения выхода и номера длинного волокна
Table 5. Average actual and normalized values of the output and the number of the long fiber

Flax straw number	Actual values				Standardized values			
	Yield, %	Number	% №	Ratio % No. of long and short fibers	Yield, %	Number	% №	Ratio % No. of long and short fibers
0,75	5,9	10,19	60,4	22,6:77,4	6,4	10,10	64,6	20,2:73,8
1,25	8,8	10,73	94,6	29,8:70,2	9,4	10,70	100,6	36,9:64,1
1,75	11,1	11,00	122,2	35,8:64,2	12,5	11,30	141,2	46,8:53,2

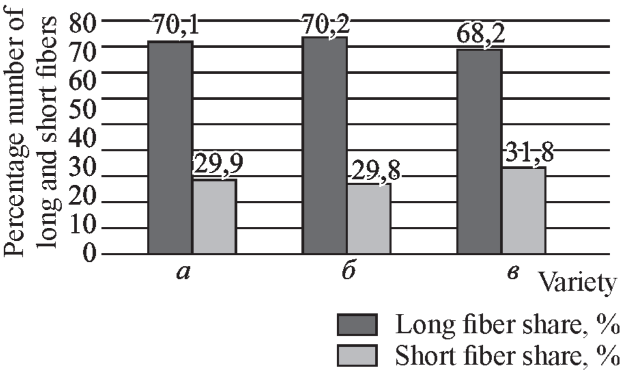

Рис. 1. Соотношение процентономеров длинного и короткого волокна из льнотресты номер 0,75 для сортов: *а* – Ленок; *б* – Зарянка; *в* – Василек

Fig. 1. The ratio of the percentage numbers of long and short fibers from flax fiber numbers 0.75 for the varieties: *а* – Lenok; *б* – Zaryanka; *в* – Vasilek

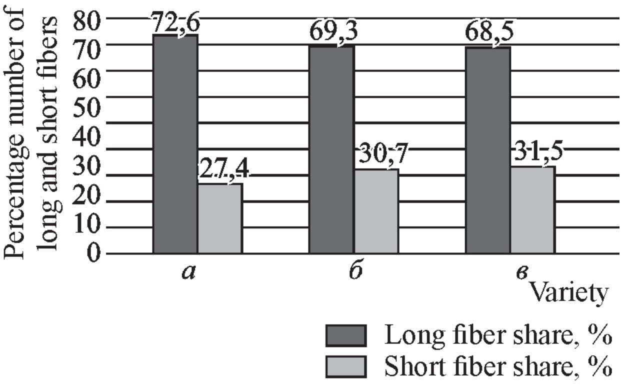

Рис. 2. Соотношение процентономеров длинного и короткого волокна из льнотресты номер 1,25 для сортов: *а* – Тост; *б* – Томский 17; *в* – Александрит

Fig. 2. The ratio of the percentage numbers of long and short fibers from flax fiber numbers 1.25 for the varieties: *а* – Toast; *б* – Tomsky 17; *в* – Alexandrit

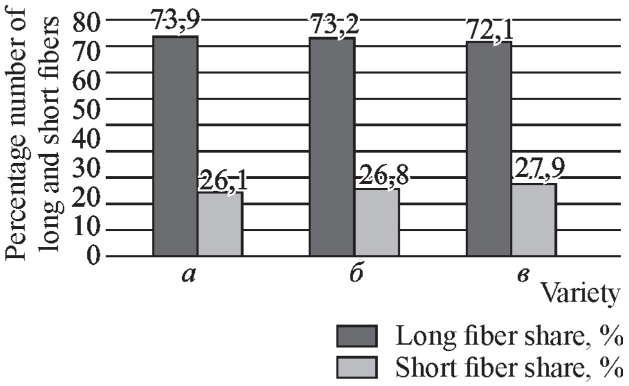

Рис. 3. Соотношение процентономеров длинного и короткого волокна из льнотресты номер 1,75 для сортов: *а* – Ленок; *б* – Лира; *в* – Пралеска

Fig. 3. The ratio of the percentage numbers of long and short fibers from flax fiber numbers 1.75 for the varieties: *а* – Lenok; *б* – Lira; *в* – Praleska

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ИММУНОЛОГИЧЕСКАЯ ОЦЕНКА ОЗИМЫХ СОРТОВ ЯЧМЕНЯ ПРОТИВ СЕТЧАТОЙ ПЯТНИСТОСТИ ЛИСТЬЕВ

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Проведена иммунологическая оценка высеваемых на юге России сортов ячменя озимого относительно поражения сетчатой пятнистостью листьев для дальнейшего использования в сельскохозяйственном производстве. Сетчатая пятнистость – доминат в патологическом комплексе заболеваний ячменя во всем мире. Патофизиологические процессы развития инфекции зависят от типа устойчивости сорта. На устойчивых сортах сетчатая пятнистость отмечена в виде небольших темных округлых пятен. Инфицирование часто происходит в результате механических повреждений листовой пластины. Симптомы заболевания сетчатой пятнистостью на восприимчивом сорте имеют характерный сетчатый рисунок с выраженными некрозами и обширными хлорозами. Одним из основных способов защиты посевов от болезни является возделывание устойчивых сортов. Исследование проведено в течение вегетационных сезонов 2020–2022 гг. на искусственном инфекционном фоне в фазу всходов вегетационного опыта и в фазу зрослых растений на естественном инфекционном фоне в полевых условиях. Изучено 10 сортов озимого ячменя отечественной и зарубежной селекции. Иммунологическая оценка в фазу всходов выявила два устойчивых к сетчатой пятнистости листьев сорта, балл: Виват (1,7) и Квант (1,6); сорта Артель (3,8), Фокс-1 (2,3) отечественной селекции и сорт Кариока (2,7) зарубежной селекции показали умеренную устойчивость. Полевая умеренная устойчивость выявлена у четырех сортов ячменя озимого, %: Виват (18,3), Квант (26,6), Маруся (19,9), Фокс-1 (24,9). Иммунологическая оценка рекомендуемых к посеву на юге России сортов ячменя – один из основных компонентов в стратегии повышения эффективности мероприятий по защите растений и улучшения экологической составляющей посевов сельскохозяйственных культур.

Ключевые слова: ячмень озимый, листовые заболевания, сетчатая пятнистость, иммунологическая оценка

IMMUNOLOGICAL ASSESSMENT OF WINTER BARLEY CULTIVARS AGAINST LEAF NET BLOTCH

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Immunological assessment of winter barley varieties sown in the south of Russia in relation to leaf net blotch infestation for further use in agricultural production has been carried out. Barley net blotch is dominant in the pathologic complex of barley diseases worldwide. The pathophysiological processes of infection development depend on the type of resistance of the variety. Net blotch on resistant varieties is noted as small dark rounded spots. Infection often occurs as a result of mechanical damage to the leaf plate. The symptoms of net blotch disease on a susceptible variety have a characteristic reticulate pattern with pronounced necrosis and extensive chlorosis. One of the main ways to protect crops from the disease is the cultivation of resistant varieties. The study was conducted during the growing seasons of 2020–2022 on artificial infectious background in the sprouting phase phase of the vegetation experiment and in the adult plant on the natural infectious background in field conditions. 10 varieties of winter barley of domestic and foreign selection were selected. Immunological assessment in the sprouting phase revealed two varieties resistant to leaf net blotch, score: Vivat (1.7) and Kvant (1.6); the varieties Artel (3.8), Fox-1 (2.3) of domestic selection and Carioca (2.7) of foreign selection showed moderate resistance. Field moderate resistance was detected in four winter barley varieties, %: Vivat (18.3), Kvant (26.6), Marusya (19.9), Fox-1 (24.9). Immunological assessment of barley varieties recommended for sowing in the south of Russia is one of the main components in the strategy of increasing the efficiency of plant protection measures and improving the ecological component of crops.

Keywords: winter barley, leaf diseases, net blotch, immunological assessment

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INTRODUCTION

Barley (*Hordeum vulgare* ssp. *vulgare* L.) is one of the first cereal species used by humans. Its cultivation began more than 10,000 years ago, almost simultaneously in different regions [1]. Currently, barley is grown in over 100 countries worldwide. It ranks fourth among cereal crops in terms of yield and planting area, following wheat, rice, and maize. Its high adaptability to adverse environmental conditions (cold, drought, soils deficient in micronutrients) provides a wide range of agroclimatic zones for cultivation, allowing barley to be a major product not only for fodder purposes but also for brewing and food consumption [2]. The Russian Federation is the global leader in barley production. In 2022, the sown area for this crop amounted to 659.6 thousand hectares, of which 176.4 thousand hectares (or 26.7% of the total area) was in the Krasnodar region. The gross harvest of winter barley in 2022 in Russia reached 3.41 thousand tons, with the Krasnodar region contributing 1.21 thousand tons (or 35.5%)[1]. The ratio of the area to yield indicators points to higher yields of winter barley in the conditions of intensive crop farming in southern Russia.

Net blotch of barley leaves (pathogen – *Pyrenophora teres* Drechs.) is predominant among diseases in the southern conditions of Russia. Its appearance is recorded in the fall on residues and winter forms, and with the resumption of vegetation in the spring, the onset of the disease on the leaf surface is noted from late March to early April[2]. The climatic peculiarities of the region contribute to the widespread distribution of this disease [3]. At the beginning of spring, the disease manifests as individual spots scattered across the foliage. Subsequent-

[1]Federal State Statistics Service. Bulletin “Gross yields and productivity of agricultural crops in the Russian Federation in 2022”. https://rosstat.gov.ru/compendium/document/13277.

[2]*Govorov D.N., Zhivykh A.N.* Review of phytosanitary condition of crops in the Russian Federation in 2022 and forecast of development of harmful objects in 2023. Moscow: Pervaya Obraztsovaya Typographiya. 2023, pp. 574.

ly, when the weather conditions are favorable for the pathogen's further development, the disease is observed throughout the foliage. Particularly severe damage is noticeable on the lower leaves, often leading to the die-off of the lower tier of plants. In recent years, due to regional climate changes towards warming, there has been an increase in the frequency of outbreaks of foliar diseases [2]. Annual losses for winter barley from net blotch range from 15 to 50%. Under optimal meteorological conditions and when susceptible varieties are infected in production plantings, the pathogen's prevalence can reach 100%, with its development ranging from 50–90% [4].

In the Krasnodar Territory, a fairly large number of genetically diverse barley varieties approved for sowing in southern Russia are cultivated, with a wide range of quality characteristics. The best strategy to reduce the impact of plant diseases on crops is a comprehensive approach, including the use of crop rotation, the application of fungicides, and the introduction of resistant varieties [5]. In some cases, using resistant varieties is the only viable option for protecting crops due to the high demands of the region with recreational resources and a trend towards reducing the use of chemical pesticides in agriculture. Resistant varieties not only slow down the rate of infection but also reduce the accumulation of infection foci in the cenosis, which positively affects the phytosanitary situation in the agrocoenosis [6]. Fungicide treatment is the most common and effective method of combating foliar diseases, but it has a high pesticide load, which is complicated by the increasing resistance of pathogens. Using resistant varieties allows for a reduction in the frequency of chemical treatments, offers the possibility of using biological protection agents, ensures a predictable reduction in crop infection, which contributes to the timely detection of the economic threshold of harmfulness (ETH level) of the pathogen and the prevention of epidemics. Breeding strategies for agricultural crops for resistance to the most harmful diseases are based on information about the evolutionary potential of disease-causing populations and the genetic diversity of host plant resistance [7].

The purpose of the study is to conduct immunological assessment of the barley varieties sown in southern Russia in relation to net blotch of leaves.

MATERIAL AND METHODS

The study was carried out in 2020-2022 at the Federal Scientific Center for Biological Plant Protection (FSCBPP) using a unique scientific installation (USI) "Phytotron for the isolation, identification, study, and maintenance of races, strains, and phenotypes of pathogens" [https://ckp-rf.ru/catalog/usu/671925/] and objects of the FSCBPP bioresource collection "State collection of entomoacariphages and microorganisms" [https://ckp-rf.ru/catalog/usu/585858/]. The immunological assessment of winter barley varieties against net blotch of leaves in the juvenile phase was conducted under the conditions of a Binder KBWF 720 climate chamber (temperature 22 °C, humidity 80%, illumination 13,000 lx) on an artificial infection background. The evaluation in the adult plant phase was carried out at a field station on a natural infection background.

Nine varieties from Russian breeding centers: Vasya (P.P. Lukyanenko National Grain Center), Valery, Cousin, Storm (Stavropol Federal Agricultural Research Center), Artel, Vivat, Kvant, Marusya, Fox-1 (ANC "Donskoy") and one foreign-bred variety, Karioka (France) were selected for the study. Infectious material for inoculating plants with the fungus *P. teres* in the juvenile phase was selected in the year of adult plant assessment from production barley crops of the Krasnodar Territory and the Republic of Adygea, according to standard methods. Incubation of infected barley leaf areas occurred under natural light and a temperature of 25 °C on carrot-beet agar (120 ml beet, 120 ml carrot, 20 g agar, 1 l water).

For the immunological evaluation in the seedling phase, pots with a volume of 0.5 liters were sown with 12-15 seeds each and inoculated with a spore-mycelial suspension of *P. teres* (50,000 conidia/ml). A record was made after

7 days. Ranking of varieties for resistance was carried out according to the following criteria, scores: 0 - no disease, R - resistance (0.5-2.0), MR - moderate resistance (2-4), MS - moderate susceptibility (4.5-6.5), S - susceptibility (7-9).

In field conditions, varieties were sown on the plots without fungicidal treatments on a natural infectious background in three replicates on areas of 1 m^2 each. The forecrop was complete fallow. The Romans variety was sown as a susceptibility control. The first disease count was conducted from the moment of the primary manifestation of the disease - at the end of the tillering phase, with subsequent counts up to the milky-wax ripeness phase of the grain. The degree of the leaf blotch infection and ranking of varieties for resistance to pathogens was assessed on a scale, %: 0 - no disease, R - resistance (disease development up to 15), MR - moderate resistance (disease development from 15 to 30), MS - moderate susceptibility (damage up to 50), S - susceptibility (damage over 50). The average disease development was determined from the total number of plants in each replicate.

The soil of the infectious nursery is typical for the central zone of the Krasnodar Territory - leached chernozem. The depth of the humus horizon is 80-150 cm, humus content in the tillage layer up to 20 cm is 3.39% (GOST 2613-94), mobile phosphorus is 18.2 mg/100 g of soil (GOST 26204-91), mobile potassium compounds are 30.6 mg/100 g (GOST 26205-91), and soil reaction is slightly acidic (pH 5.5-6.5). There is no exchange acidity; hydrolytic acidity varies from 2 to 4 mg-equivalent/100 g of soil, soil base saturation degree is 85-95%. In the growing seasons of 2020 and 2021, moderate temperature and precipitation deficit were noted in May, so only occasional disease symptoms were observed on the leaves. In June, the weather conditions were favorable for the further development of the net blotch pathogen of barley, so the disease manifestation was noted universally on the foliage until the lower leaves died off in the sowings. Weather conditions in spring 2022 facilitated the widespread spread of the disease. Isolated spots, chaotically distributed on the leaf surface, were observed almost everywhere in production sowings of winter barley. In early summer, the weather conditions were unfavorable for the further development of the disease pathogen; high leaf damage on plants was not observed. Statistical processing was done using the Statistica software version 13.3.

RESULTS AND DISCUSSION

The results of the immunological evaluation of winter barley varieties in field infectious nursery conditions and in controlled climate chamber conditions on an artificial infectious background revealed a relatively low resistance against net blotch in varieties recommended for sowing in the south of Russia. It is worth noting that to create an artificial infectious background, material was selected from three agro-climatic zones of the region (southern foothill, central, and western Azov) from various production sites, which ensured a high level of pathogen population heterogeneity. On average, over 2 years of study in the seedling phase against leaf net blotch, resistance was found in the Viva variety, score (1.7) and Kvant (1.6) (see Table 1). Moderate resistance was identified in the following varieties, score: Artel (3.8), Karioka (2.7), and Fox-1 (2.3); varieties Valery (4.9), Vasya (4.2), Cousin (4.7), Marusya (4.3), and Storm (4.1) were determined as moderately susceptible in controlled conditions on an artificial infectious background.

As a result of field trials regarding resistance to leaf net blotch, it was found that 4 out of 10 studied varieties have moderate resistance to the pathogen in the adult plant phase, %: Viva (18.3), Kvant (26.6), Marusya (19.9), and Fox-1 (24.9) (see Table 2); varieties Artel (34.9), Valery (32.6), Karioka (41.6), Cousin (35.8), and Storm (45.8) showed moderate susceptibility. The Vasya variety (55.2%) was identified as susceptible to net blotch based on field evaluation (see Fig. 1).

[3]GOST 26205-91 Determination of mobile forms of phosphorus and potassium by Machigin method modified by CINAO.

Табл. 1. Иммунологическая оценка сортов ячменя относительно сетчатой пятнистости листьев в фазе всходов (ФНЦБЗР, 2021, 2022 г.)

Table 1. Immunological assessment of barley cultivars with respect to leaf net blotch in the phase of plant seedlings (FRCBPP, 2021, 2022)

Variety	Origin	Response of the varieties to *P. teres* infestation					
		Infestation, point			Degree of resilience		
		2021	2022	Average value	2021	2022	Average value
Artel	ASC "Donskoy"	5,5	2,0	3,8	MS	MR	MR
Valery	Stavropol FSAC	6,5	3,3	4,9	MS	MR	MS
Vasya	National Grain Center P.P. Lukyanenko	5,0	3,4	4,2	MS	MR	MS
Vivat	ASC "Donskoy"	2,5	0,9	1,7	MR	R	R
Karioka	France	2,0	3,4	2,7	MR	MR	MR
Kvant	ASC "Donskoy"	3,0	0,2	1,6	MR	R	R
Cousin	Stavropol FSAC	6,5	2,8	4,7	MS	MR	MS
Marusya	ASC "Donskoy"	6,3	2,3	4,3	MS	MR	MS
Fox-1	ASC "Donskoy"	3,0	1,7	2,3	MR	R	MR
Storm	Stavropol FSAC	5,7	2,4	4,1	MS	MR	MS
Romance (control)	National Grain Center P.P. Lukyanenko	7,0	5,0	6,0	S	MS	MS

Табл. 2. Иммунологическая оценка сортов ячменя относительно сетчатой пятнистости листьев в фазу взрослого растения (ФНЦБЗР, 2021, 2022 г.)

Table 2. Immunological assessment of barley cultivars with respect to the leaf net blotch in the adult plant phase (FRCBPP, 2021, 2022)

Variety	Origin	Response of the varieties to *P. teres* infestation					
		Infestation, point			Degree of resilience		
		2021	2022	Average value	2021	2022	Average value
Artel	ASC "Donskoy"	46,6	23,3	34,9	MS	MR	MS
Valery	Stavropol FSAC	49,3	15,9	32,6	MS	MR	MS
Vasya	National Grain Center P.P. Lukyanenko	73,3	37,2	55,2	S	MS	S
Vivat	ASC "Donskoy"	26,6	10,0	18,3	MR	R	MR
Karioka	France	46,6	36,7	41,6	MS	MS	MS
Kvant	ASC "Donskoy"	40,0	13,3	26,6	MS	R	MR
Cousin	Stavropol FSAC	50,0	21,7	35,8	MS	MR	MS
Marusya	ASC "Donskoy"	26,6	13,3	19,9	MR	R	MR
Fox-1	ASC "Donskoy"	36,6	13,3	24,9	MS	R	MR
Storm	Stavropol FSAC	70,0	21,7	45.8	S	MR	MS
Romance (control)	National Grain Center P.P. Lukyanenko	60,0	50,0	55,0	S	MS	S

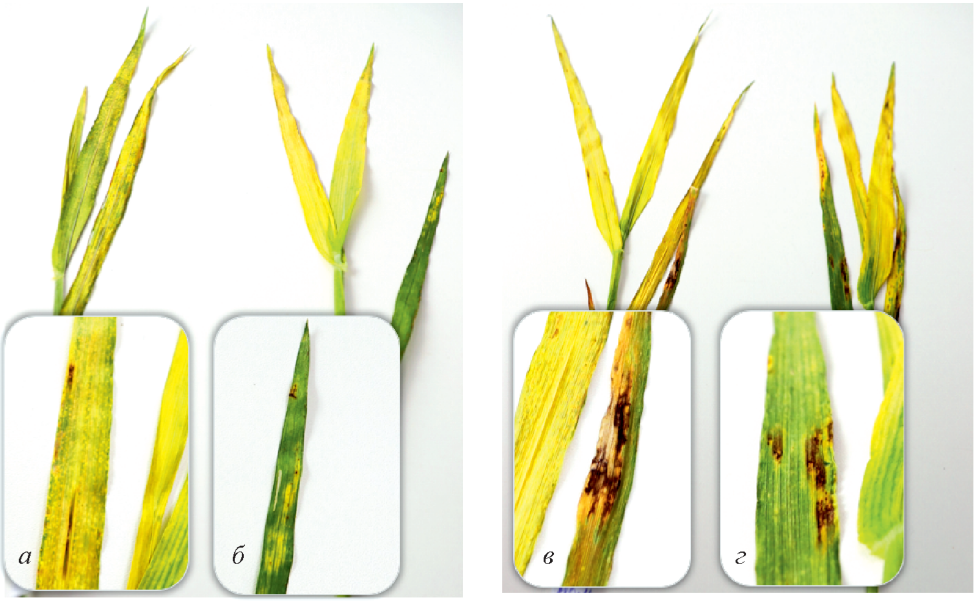

Рис. 1. Иммунологическая оценка сортов ячменя озимого к *P. teres* в полевых условиях:
а – Артель (MS); *б* – Виват (MR); *в* – Романс (S); *г* – Вася (S);
(4-дневные гербарные образцы (ФНЦБЗР, 2022 г., ориг.)

Fig. 1. Immunologic assessment of winter barley varieties to *P. teres* under field conditions:
а – Artel (MS); *б* – Vivat (MR); *в* – Romance (S); *г* – Vasya (S); (4-day herbarium samples, FRCBPP, 2022, orig.)

It was noted that the nature of the damage in different resistant varieties has somewhat different symptoms, which is consistent with the literature data, as in other plant diseases, the appearance of symptoms depends on the virulence of the pathogen, the genotype of the host, and the environment [5]. Net blotch exists in two different forms: *P. teres* f. *maculata* and *P. teres* f. *teres*. Although these two forms are identified as morphologically similar, they differ at the genetic and pathophysiological levels, and also produce toxins that vary in composition and amount [8]. The form *P. teres* f. *teres* creates dark-brown and longitudinal necrotic lesions transitioning to chlorotic ones, while *P. teres* f. *maculata* forms dark-brown round or elliptical spots with chlorosis on leaf tissues (see Fig. 2).

Interaction between the plant and the fungus involves physiological processes that manifest as external signs on the host plant due to the induction of various defense mechanisms [9]. On susceptible varieties, the infestation appears

а *б*

Рис. 2. Типичные симптомы поражения сетчатой пятнистостью листьев:
а – сорт Виват (MR); *б* – сорт Романс (S) (ФНЦБЗР, 2022 г., ориг.)

Fig. 2. Typical symptoms of lesions with leaf net blotch:
а – Vivat cultivar (MR); *б* – Romance cultivar (S) (FRCBPP, 2022, orig.)

as focal in the form of brown necrotic spots on infected tissues, which increase in size, forming elliptical or spindle-shaped lesions. They rapidly spread across the entire lamina, forming a characteristic net-like pattern with pronounced necrosis and broad chlorosis, which can lead to the death of the entire leaf [10]. The disease affects the upper tiers, increasing the area of necrotized leaf surface with chlorosis, and the lower tiers die off. On more resistant barley varieties, net blotch is observed as small dark round spots, with less pronounced chlorosis and without the typical net pattern. Often, the onset of infection begins at the edges of the leaf blade from mechanical damage to the plant during various agricultural practices or damage by phytophages.

1

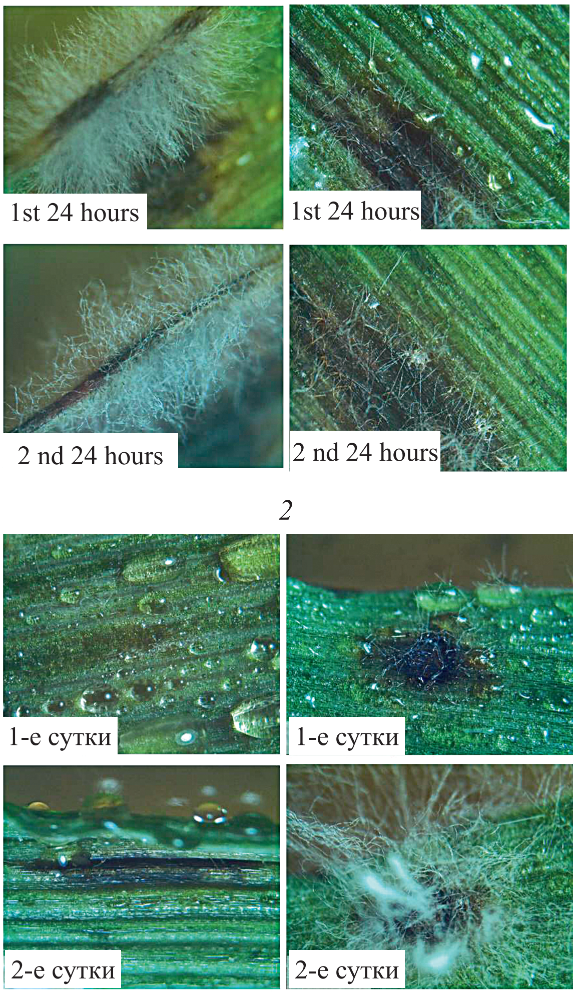

Рис. 3. Рост мицелий гриба *P. teres* на инфицированной ткани:
1 – сорт Романс (S); 2 – сорт Виват;
(MR) (ФНЦБЗР, 2022 г., ориг.)

Fig. 3. Mycelium growth of *P. teres* fungus on infected tissue:
1 – Romance cultivar (S); 2 – Vivat cultivar; (MR) (FRCBPP, 2022, orig.)

The plant's defense mechanisms determine the varying growth of *P. teres* colonies when placing infected plant sections on a nutrient medium (see Fig. 3). On the lamina of a susceptible variety, a well-structured white fluffy mycelium forms, which quickly grows, spreads across the leaf, and takes on a darker shade. On the infected tissue of a resistant variety, the fungus grows more slowly, the mycelium is fluffy and white. The formation of feathery white fungal structures has been observed, which, according to the literature, indicates a lack of nutrient resources [5].

CONCLUSIONS

1. Immunological evaluation of 10 winter barley varieties at the seedling stage in controlled conditions on an artificial infection background over 2 years of study revealed two varieties resistant to leaf net blotch: Vivat (1.7 points) and Kvant (1.6 points) bred by the ASC "Donskoy". Varieties Artel (3.8 points), Fox-1 (2.3 points) bred by the ASC "Donskoy", and the foreign-bred variety Karioka (2.7 points) showed moderate resistance.
2. Field moderate resistance to *P. teres* was identified in four winter barley varieties, %: Vivat (18.3), Kvant (26.6), Marusya (19.9), Fox-1 (24.9) bred by the ASC "Donskoy". This is important to consider in their territorial placement.
3. Pathophysiological processes of infection development depend on the resistance type of the variety. In resistant varieties, net blotch is marked as small dark round spots, with infection often resulting from mechanical damage to the lamina. Symptoms of net blotch disease on a susceptible variety have a characteristic net pattern with pronounced necrosis and extensive chlorosis.

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ЦЕЛЕСООБРАЗНОСТЬ ЗАЩИТЫ ПОСЕВОВ КУКУРУЗЫ ОТ ПРОГРЕССИРУЮЩИХ ФИТОФАГОВ

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Проведен в динамике мониторинг фитофагов посевов кукурузы в условиях Кабардино-Балкарии в степной засушливой зоне за 2000–2021 гг. Отмечено, что изменение климата в сторону потепления и значительное увеличение площадей посевов кукурузы изменили фитосанитарную ситуацию, что привело к формированию очагов высокой численности и вредоносности хлопковой совки. Изучены средства борьбы с хлопковой совкой и кукурузным мотыльком из различных групп химических и биологических соединений. Защитные мероприятия планировали и осуществляли, исходя из прогнозируемой и реально сложившейся фитосанитарной обстановки, чтобы получить экологически более чистую и биологически питательную зерновую продукцию. На основании многолетних наблюдений установлено, что вспышка хлопковой совки и стеблевого кукурузного мотылька периодична 5 ± 1 год. Это позволит проводить своевременное опрыскивание в годы максимальных вспышек указанных вредителей. Определение биологической эффективности и грамотная ротация группы химических инсектицидов позволят снизить их резистентность к прогрессирующим вредителям на посевах кукурузы. Значения биологической эффективности инсектицидов в вариантах препаратов Волиам Флекси, СК и Авант, КЭ соответствовали 97,1 и 95,6%. Хозяйственную эффективность инсектицидов оценивали по прибавке урожайности зерна, где Волиам Флекси, СК; Авант, КЭ и Лепидоцид, СК имели значения 1,1; 1,0 и 0,5 т/га соответственно. Многолетними исследованиями установлено, что урожайность зависит от степени повреждения початков и зерна кукурузы гусениц хлопковой совки. Резервом значительного повышения урожая зерна кукурузы на 0,5–1,1 т/га является использование эффективных инсектицидов химического происхождения с низкими нормами расхода (Волиам Флекси, СК; Авант, КЭ). Выявлено, что 2-кратное опрыскивание биоинсектицидами Лепидоцид, СК и Биослип, БТ, П по началу и массовому отрождению гусениц значительно снижало вредоносность указанных вредителей, биологическая эффективность которых составила 77,9 и 73,5% соответственно.

Ключевые слова: кукуруза, фитофаги, вредоносность, инсектициды, биоинсектициды, система интегрированной защиты, биологическая, хозяйственная, экономическая эффективность

EXPEDIENCY OF PROTECTING CORN CROPS FROM PROGRESSIVE PHYTOPHAGES

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Monitoring of phytophages of corn crops in the conditions of Kabardino-Balkaria in the steppe arid zone for 2000–2021 was carried out in dynamics. It was noted that climate change in the direction of warming and significant increase in the areas of corn crops changed the phytosanitary situation, which led to the formation of foci of high numbers and harmfulness of cotton budworm. Control agents against cotton budworm and corn borer from different groups of chemical and biological compounds were studied. Protective measures were planned and implemented based on the predicted and actual phytosanitary situation in order to obtain ecologically cleaner and biologically nutritious grain products. Based on long-term observations, the outbreak of cotton budworm and corn borer was found to be periodic for 5 ± 1 years. This will allow timely spraying in years of maximum outbreaks of these pests. Determination of biological efficacy and competent rotation of the group of chemical insecticides will reduce their resistance to progressive pests on corn crops. Values of biological efficiency of insecticides in the variants of Voliam Flexi, SC and Avant, EC preparations corresponded to 97.1 and 95.6%. The economic efficiency of the insecticides was evaluated by grain yield increment, where Voliam Flexi, SC, Avant, EC and Lepidocid, SC and had the values of 1.1; 1.0 and 0.5 t/ha, respectively. Long-term studies have established that yields depend on the degree of damage to cobs and corn grain by cotton budworm caterpillars. The reserve of significant increase of corn grain yield by 0.5–1.1 t/ha is the use of effective insecticides of chemical origin with low rates of consumption (Voliam Flexi, SC, Avant, EC). It has been revealed that 2-fold spraying with bioinsecticides Lepidocid, SC and Bioslip BT, P on the beginning and mass hatching of caterpillars significantly reduced the harmfulness of these pests, the biological efficiency of which amounted to 77.9 and 73.5%, respectively.

Keywords: corn, phytophages, harmfulness, insecticides, bioinsecticides, integrated protection system, biological, economical, economic effectiveness

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INTRODUCTION

The expansion of sown areas in recent times has led to changes in the phytosanitary situation in the corn agroecosystem. Consequently, there has been a significant increase in the population and harmfulness of the cotton budworm (*Helicoverpa armigera* Hb.) and the European corn borer (*Ostrinia nubilalis* Hb.). There arose a need to monitor them, followed by the development of effective elements in the integrated pest management system against these pests. Growing corn with a short rotation, and in some leased farms as a monoculture, has led to an increase in the population and harmfulness of the cotton budworm[1].

The purpose of the research is to conduct a comparative assessment of the economic, biological, and financial effectiveness of new-generation insecticides with a low application rate and prolonged action.

Research objectives:

– monitoring of the cotton budworm and the European corn borer from 2000 to 2021 in the steppe zone of Kabardino-Balkaria;

– determination of the economic, biological, and financial effectiveness of insecticides of biological and chemical origin for combating the larvae of the cotton budworm;

– comparative evaluation of the effectiveness of insecticides for the development of the elements of a biologized protection system against progressively harmful corn pests.

MATERIAL AND METHODS

Field trials were set up according to the existing methodologies in plant protection[2–4] [1, 2]. Trial variants were arranged using a randomized method in a rectangular form. There were 9 variants. The area of the experimental corn plots was 50 m², the accounting plots covered 25 m²,

[1]*Peresypkin V.F., Kovalenko S.N.* Practicum on the methodology of experimental work in plant protection. Moscow: Agropromizdat, 1989, 175 p.

[2]*Pospelov S.M., Arsenieva M.V., Gruzdev G.S.*; ed. by N.G. Berim. Plant protection. L.: Kolos, 1988, 432 p.

[3]*Eshchenko V.E., Trifonova M.F., Kopytko P.G., Soloviev A.M., Firsov I.P., Shevchenko V.A.* Fundamentals of experimental work in crop production. Moscow: KolosS, 2009, 264 p.

[4]*Goncharov N.R., Kolychev N.G., Cherkasov V.A.* Organization of plant protection. Moscow: Rosselkhozizizdat, 1985, 175 p.

with a three-fold repetition. The sowing pattern was wide-rowed, with a sowing depth of 6–10 cm. Pest accounting, determination of economic, biological, and financial effectiveness were conducted according to the methodologies [3]. Phytophage identification was carried out using an identification guidebook[5]. When determining the per hectare rate of insecticide application, the List of Pesticides and Agrochemicals permitted for use in the territory of the Russian Federation was used [4, 5].

Scientific-production tests were conducted in the steppe zone of the Kabardino-Balkarian Republic (KBR) on the Terek corn hybrid. Spraying was carried out using a Comfort-OE-12u backpack battery sprayer. The soil of the experimental plots was southern chernozem, situated in a relatively narrow strip between common chernozems and dark chestnut soils.

Southern chernozems are characterized by a low humus content in the A horizon (3.5–5.0%) and gradual distribution throughout the soil profile. Mainly, these soils are intensively used for cultivating cereal crops, sunflowers, and corn for grain and silage [6].

Soil treatment for the experimental corn sowing included autumn plowing, spring cultivation, and pre-sowing treatment. Corn sowing with a sowing rate of 55,000 seeds/ha was conducted in the first ten-day period of May, and harvesting was done when the grain moisture was 20%. Technological operations for crop care were carried out according to the standard corn cultivation system [7, 8].

The following biological and chemical insecticides were used to combat the cotton budworm (see Table 1).

Chemical insecticides were applied once during the mass emergence of the second-generation cotton budworm larvae; bio-insecticides were applied twice - at the beginning and during the mass emergence of the larvae, with a 7-day interval.

Табл. 1. Перечень использованных инсектицидов и удобрений в 2020, 2021 гг.

Table 1. List of insecticides and fertilizers used in 2020, 2021

Group of preparations	Name of preparations	Consumption rate, kg/ha; l/ha; tablet/ha
Bio insecticides	Fitoverm, SC (2 times)	0,2
	Leptocid, L (2 times)	3,0
	Actarophyt-E (2 times)	0,4
	Lepidocid, SC (2 times)	1,0
	Biosleep BT (2 times)	2,5
Chemical insecticides	Avant, EC	0,25
	Voliam Flexi, SC	0,4
	Decis Expert, EC	0,2
	Sharpey, OE	0,32

RESULTS AND DISCUSSION

In 2020 and 2021, scientific research continued on studying the progressing phytophages and their harmful effects in the maize agroecosystem. Such corn pests include the cotton budworm (*Heliothis armigera* Hb.) and the European corn borer (*Ostrinia nubilalis* Hb.).

In this context, the population dynamics of these pests on corn crops since 2000 in the steppe drought zone have been studied. Analysis of the data on the harmfulness of the cotton budworm and the European corn borer showed periodicity in their surges and declines. From 2000 to 2021, the intensity of corn plant colonization by European corn borer larvae was at or slightly above the threshold level (ETH 1-4% of the colonized plants). An exception was 2016, when 27% of plants were colonized. Given that this pest is in a depressed state, the periods of rise and decline in the number of European corn borer larvae are insignificant. Perhaps the corn borer has been in depression for 20 years (within ETH limits), but its harmfulness is increasing.

The figure clearly demonstrates a sharp decrease in the percentage of the damaged plants in 2007, 2008; 2016, 2017, and in 2020, indicating the periodicity of the harmfulness of the cotton budworm larvae.

According to long-term monitoring of dangerous pests, such as the cotton budworm and the European corn borer, an inverse relationship

[5]*Akhremovich M.B., Batiashvili I.D., Bei-Bienko G.Ya.* Determinator of agricultural pests by damage to cultivated plants. Leningrad, 1976, pp. 38-48.

of their harmfulness was identified. Analyzing the population dynamics of these pests, shown in the figure, it should be noted that the higher the number and harmfulness of the cotton bollworm, the lower the number and harmfulness of the European corn borer. For instance, in 2016, the highest percentage of damage from European corn borer larvae (27%) was recorded. In 2016, the percentage of the corn plants colonized by cotton budworm larvae significantly decreased (to 27%).

Bio-insecticides were used twice at the beginning and during the mass emergence of the cotton budworm larvae. The spraying times were slightly shifted. The accounting of the average density of colonization by cotton budworm larvae when using chemical insecticides was conducted 7 days later, and bio-insecticides – 14 days after the second spraying.

In 2020 and 2021, new generation insecticides with low usage rates and prolonged action were tested. A comparative evaluation of the biological effectiveness of the used insecticides was conducted 7 days after spraying against cotton budworm larvae (see Table 2).

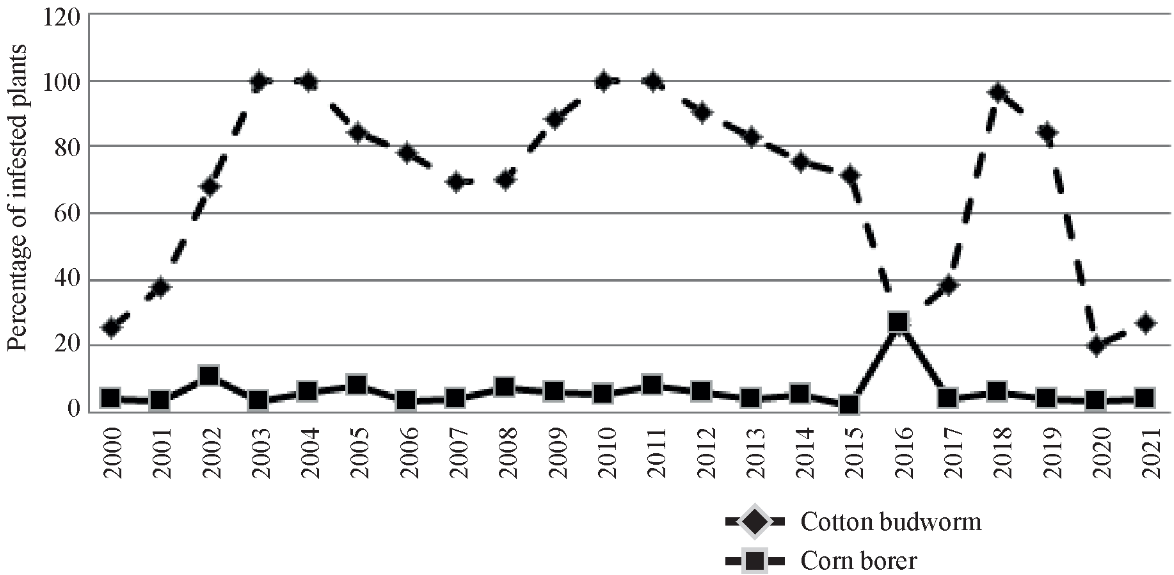
The new generation insecticides had a high value of biological effectiveness (BE) of 97.1% and 95.6% in the variants 7 (Voliam Flexi, SC) and 8 (Avant, EC) respectively. The bio-insecticide Lepidocide, SC (variant 2) proved itself as a good agent against the cotton budworm larvae over 2 years of trials, and its biological effectiveness was 77.9%.

The economic effectiveness (EE) of the insecticides was assessed by the increase in the corn grain yield compared to the control. Both in terms of economic and biological effectiveness, the same variants stood out: Voliam Flexi, SC (variant 7), Avant, EC (variant 8), and Lepidocide, SC (variant 2), where the yield increase was 1.1, 1.0, and 0.5 tons/ha respectively.

In variants 3 (Biosleep, BT, P), 4 (Leptocide, L), and 6 (Decis Expert, CE), the yield increase was 0.2, 0.1, and 0.3 tons/ha respectively. In variant 5 using Actarophyte-E, there was no yield increase (-0.03 tons/ha).

As a result, the insecticides Voliam Flexi, SC; Avant, EC; and Lepidocide, SC are promising in the fight against cotton budworm larvae (see Table 3).

One of the determining factors in corn production is economic and financial effectiveness [9]. The increase in corn grain yield compared to the control variant (without treatments) was evaluated as a result of testing insecticides against cotton budworm larvae. It was noted that the highest indicators of conditional net income were achieved by the new generation insecti-



Динамика численности и вредоносности хлопковой совки и стеблевого кукурузного мотылька на посевах кукурузы в степной зоне КБР, 2000–2021 гг.

Dynamics of the number and harmfulness of cotton budworm and corn borer on corn crops in the steppe zone of the KBR, 2000–2021.

Табл. 2. Биологическая и хозяйственная эффективность инсектицидов в борьбе с гусеницами хлопковой совки (степная зона КБР, 2020, 2021 гг.)

Table 2. Biological and economic effectiveness of insecticides in the fight against cotton budworm caterpillars (steppe zone of the KBR, 2020, 2021)

Experiment option	Average density of infestation before treatment, caterpillars/m^2	Average population density 7 days after the treatment, caterpillars/m^2	BE, %	EF, t/ha	
				Total	Yield increase
1. Control (without treatments)	3,5	6,8	–	4,6	–
2. Lepidocid, SC	2,7	1,5	77,9	5,1	0,5
3. Biosleep BT, P	4,0	1,8	73,5	4,8	0,2
4. Leptocid, L	4,6	2,5	63,2	4,7	0,1
5. Actarophyt-E	3,4	3,3	51,5	4,57	–0,03
6. Decis Expert, EC	2,4	1,7	75,0	4,9	0,3
7. Voliam Flexi, SC	3,0	0,2	97,1	5,7	1,1
8. Avant, EC	2,8	0,3	95,6	5,6	1,0
9. Sharpey, OE	3,7	1,8	73,5	5,0	0,4
LSD_{05}				0,42	

cides: Voliam Flexi, SC (variant 6); Avant, EC (variant 7); and the bio-insecticide Lepidocide, SC (variant 2). They amounted to 8520, 9620, and 5560 rubles/ha respectively.

The obtained numerical data on the economic efficiency of the tested preparations indicate the justification for the application of promising insecticides. This contributes to the development of new elements in the integrated protection system against the cotton budworm.

From the economic point of view, among biological insecticides, Lepidocide, SC turned out to be promising. The other bio-insecticides (Biosleep BT, P; Leptocide, L) weakly reduced the number and harmfulness of the cotton budworm, so the conditional net income was -550 and -2010 rubles/ha, respectively.

CONCLUSIONS

1. The expansion of corn cultivation areas changed the phytosanitary situation, leading to the formation of high-density and harmfulness hotspots of the cotton budworm.

2. The following dominant species were identified in the corn agroecosystem: the cotton budworm and the European corn borer.

3. The periodicity of the cotton budworm ‘s harmfulness has been determined, which is 5 ± 1 year.

4. Based on long-term monitoring (2000-2021), it was established that the higher the number and harmfulness of the cotton budworm, the lower the number and harmfulness of the European corn borer, i.e., an inverse relationship was identified.

Табл. 3. Экономическая эффективность инсектицидов в борьбе с гусеницами хлопковой совки на посеве гибрида кукурузы Терек (степная зона КБР, 2020, 2021 гг.)

Table 3. Economic efficiency of insecticides in the fight against cotton budworm caterpillars on the sowing of the Terek corn hybrid (Steppe zone of the KBR, 2020, 2021)

Experiment option	Consumption rate, kg/ha; l/ha	Yield increase, t/ha	Cost of preserved crops, rubles/ha	Additional costs, rubles/ha	Conditional net income, rubles/ha
1. Control (without treatments)		–	–	–	–
2. Lepidocid, SC (2 times)	2,0	0,5	6500	1940	5560
3 Biosleep BT, P (2 times)	2,5	0,2	2600	3150	–550
4. Leptocid, L (2 times)	3,0	0,1	1300	3310	–2010
5. Decis Expert, EC	0,2	0,3	3900	1622	2278
6. Voliam Flexi, SC	0,4	1,1	14300	5780	8520
7. Avant, EC	0,25	1,0	13000	3380	9620
8. Sharpey, OE	0,32	0,4	5200	1018	4185

5. The most promising insecticides in the fight against cotton budworm larvae have been identified: Voliam Flexi, SC; Avant, EC; and Lepidocide, SC.

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ЧУВСТВИТЕЛЬНОСТЬ СОРНЫХ РАСТЕНИЙ К ГЕРБИЦИДУ ЛЮМАКС И ЕГО ЭФФЕКТИВНОСТЬ В ПОСЕВАХ КУКУРУЗЫ НА ЗЕРНО

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Изучена чувствительность сорных растений к гербициду Люмакс в вегетационных условиях при до- и послевсходовом применении. Дана оценка биологической и хозяйственной эффективности гербицида Люмакс при разных сроках использования. Исследования проводили в 2020–2022 гг. в Приморье. Почва опытных участков лугово-бурая оподзоленная, содержащая в пахотном горизонте 3–4% гумуса. Агротехника – на основе безотвальной обработки почвы. Предшественник – соя. В полевых опытах использовали гибридную популяцию П 8521. Изучена чувствительность 16 видов сорняков при довсходовом внесении гербицида и 18 – при использовании по вегетирующим растениям на ранних стадиях их развития. Проведены визуальные наблюдения за развитием растений после проведенных обработок гербицидом Люмакс. При почвенном внесении препарат препятствовал прорастанию мари белой, ширицы запрокинутой, пикульника ладанного, проса куриного, череде трехраздельной, щетинникам сизому и зеленому, осоту полевому и бодяку щетинистому. Появившиеся всходы канатника Теофраста, горца почечуйного и акалифы южной на 7-е сутки полностью погибли. Умеренную чувствительность проявили амброзия полыннолистная, шерстняк мохнатый и коммелина обыкновенная. Гибискус тройчатый оказался устойчивым к данному гербициду. При использовании Люмакса по вегетирующим растениям 17 видов оказались высокочувствительными, относительную чувствительность проявил лишь шерстняк мохнатый. В полевых опытах в посеве кукурузы на зерно засоренность в среднем составила 531 растение/м^2 с общей надземной массой 3279 г/м^2. Гербицид применяли в три срока: до всходов, в фазы 2–3-го и 5–6-го листа кукурузы. При каждом сроке его использования были свои преимущества и недостатки. При довсходовом внесении он более активно подавлял однолетние злаки, при позднем (фаза 5–6-го листа) – многолетние двудольные. Применение гербицида в фазу 2–3-го листа кукурузы показало примерно равное действие на сорную растительность. Люмакс эффективно уничтожал коммелину обыкновенную и однолетние двудольные сорняки. Независимо от сроков внесения он способствовал сохранению 29,8–36,7 ц зерна кукурузы/га.

Ключевые слова: гербицид, сорняки, чувствительность, Люмакс, эффективность, урожайность

SENSITIVITY OF WEEDS TO HERBICIDE LUMAX AND ITS EFFECTIVENESS IN GRAIN MAIZE CROPS

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Sensitivity of weeds to Lumax herbicide under growing conditions with pre- and post-emergent application was studied. Evaluation of biological and economic efficiency of Lumax herbicide at different terms of use was given. The studies were conducted in 2020–2022 in the Primorsky Territory. The soil of the experimental plots is meadow-brown podzolized, containing 3–4% of humus in the arable horizon. The agricultural technique is based on no-tillage technology. The forecrop was soybeans. The hybrid population P 8521 was used in the field experiments. The sensitivity of 16 weed species was studied when used in pre-emergence applications and 18 when used on vegetative plants in the early stages of their development. Visual observations of plant development after treatments with Lumax herbicide were made. At soil application, the preparation inhibited the germination of lamb's-quarters, pigweed, hemp nettle, barnyard grass, bur beggar-ticks, yellow-foxtail grass and green bristle grass, field milk thistle and yellow thistle. Sprouts of China jute, common persicaria and copper leaf were completely dead by the 7th day. Moderate sensitivity was shown by ragweed, hairy cupgrass, and dayflower. Trailing hollyhock proved to be resistant to this herbicide. When using Lumax on vegetating plants, 17 species were highly sensitive, with only hairy cupgrass being relatively sensitive. In field experiments in the grain maize crop, weed infestation averaged 531 plants/m^2 with a total above ground mass of 3279 g/m^2. The herbicide was applied at three times: before sprouting, in the phases of the 2-3rd and 5th-6th of corn leaves. There were advantages and disadvantages with each term of its use. At preemergence, it more actively suppressed annual grasses, while at late (the 5th-6th leaf phase) it suppressed perennial dicotyledons. Application of the herbicide in the 2nd-3rd corn leaf phase showed approximately equal effect on the weeds. Lumax effectively eliminated dayflower and annual dicotyledonous weeds. Regardless of the timing of application, it contributed to saving 29.8-36.7 co of corn grain/ha.

Keywords: herbicide, weeds, sensitivity, Lumax, efficiency, yield

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INTRODUCTION

In agrarian practice, the degree of weed infestation in crops is one of the main factors influencing maize productivity [1]. Unlike other field crops, maize does not have specialized weeds. Due to its slow growth rates in the initial stages of development, it is the weakest competitor against weed plants in agrobiocenoses. During this period, its crops create favorable conditions for the growth of all biotypes of weed plants typical for a particular cultivation zone. The most harmful types of weeds are those whose biological development cycle closely aligns with that of maize [2].

In maize crops in the south of the Far East, the following species have been noted: barnyard grass (*Echinochloa crusgalli* (L.) *Beauv*.), yellow-foxtail grass (*Setaria glauca* (L.) *Beauv*.) and green bristle grass (*Setaria viridis* (L.) *Beauv*.), hairy cupgrass (*Eriochloa vilosa* (Thump.) *Kuth*), common ragweed (*Ambrosia artemisiifolia* L.), China jute (*Abutilon theophrasti Medik*), pigweed (*Amarantus retroflexus* L.), lamb's-quarters (*Chenopodium album* L.), sigesbeckia (*Sigesbeckia pubescens* Makino), copper leaf (*Acalypha australis* L.), common dayflower (*Commelina communis* L.), field milk thistle (*Sonchus arvensis* L.), yellow thistle (*Cirsium setosum* (Willd.) Bieb), and other.

Research conducted by the Far Eastern Research Institute of Plant Protection – Branch of Federal Scientific Center of Agricultural Biotechnology of the Far East named after A.K. Chaiki (FERIPP), found that maize grain yield decreases on average by 29% with weed infestation of barnyard grass at 12 plants/m^2, on most areas it grows at 50 plants/m^2 or more[1]. Common ragweed can accumulate up to 4 kg of vegetative mass per 1 m^2 in certain years. At a weed density of 10 plants/m^2, maize grain yield decreases by 34-41%; in drought years, the presence of 5 plants/m^2 reduced it by 55%[2]. In the Far Eastern federal district in 2021, during the survey of 51.75 thousand hectares, weed infestation was

[1] *Altukhova T.V., Kostyuk A.V.* Control of chicken millet in corn crops // Zemledelie. 2005, no. 6, pp. 32-33.

[2] Altukhova T.V., Kostyuk A.V., Spiridonov Y.Ya., Shestakov V.G., Ginevsky N.K. How to protect corn from wormwood ragweed // Plant Protection and Quarantine. 2005, no. 7, pp. 38-39.

detected on an area of 32.71 thousand hectares, including areas with a weed count exceeding the economic damage threshold – on 13.77 thousand hectares[3]. The fight against weeds in maize crops in the south of the Far East is very relevant. Achieving high maize yields under modern conditions is impossible without the use of herbicides. Chemically eradicating unwanted vegetation in crops is a crucial agronomic practice[4]. One of the factors that can influence the effectiveness of herbicide application is the developmental phase of the weeds and their condition. The varying phase sensitivity of different, albeit closely related, weed species of the same genus to herbicides, determined by both species and morphological differences in plants at a specific phase of their growth and development, should be taken into account when organizing chemical weeding [3, 4].

The modern assortment of herbicides for maize weed protection in the Russian Federation comprises over 200 products [5]. Literature provides sufficient information on the effectiveness of soil herbicides such as Merlin, Adengo, and Lumax, the application of which significantly reduced the weed infestation of maize crops and increased its productivity [6–9]. When developing new herbicides for post-emergence use, selectivity to the crop is a key factor [10].

Herbicides Adengo and Lumax are also highly effective when used in the early post-emergence period during the 2-3 leaf stage of maize [6–9, 11, 12]. Numerous articles have been published about the high activity of herbicides like Cordus Plus, Dublon Super, Master Power, as well as the tank mix of Egyda and Dublon when applied during the 5-6 leaf stage [13–16]. In dry weather conditions, the new herbicide Kreutzer provided a maximum reduction in the total mass of weeds, amounting to 98.8%. The phytomass of the dicotyledonous component of the weed cenosis decreased by 98.4%, and the monocotyledonous by 99.8% [17].

There are reports on late treatments in the 8-leaf stage of maize with herbicides Master Power and Kelvin Plus. During late treatments, weeds are well-developed and more resistant to the action of herbicides. Such treatments can only be justified in exceptional cases (for example, due to the inability to spray on time due to weather conditions or large areas to be treated) [18, 19].

The purpose of the study is to examine the sensitivity of weeds to the Lumax herbicide under vegetative conditions during pre- and post-emergence applications; to evaluate the biological and economic effectiveness of the Lumax herbicide at different times of use.

The scientific novelty of the work lies in the fact that, for the first time in the conditions of the south of the Far East, the sensitivity of weeds to the Lumax herbicide has been studied, as well as its effectiveness when used late (5-6 leaf stage).

MATERIAL AND METHODS

The research was conducted in a greenhouse in 2021 and 2022, as well as on the experimental fields of FERIPP in 2020-2022. The soil type was meadow-brown sod-podzolic medium loamy, containing 3-4% humus in the arable horizon with a pH of 5.0-5.9. Maize cultivation technology was based on non-till soil treatment. The sowing rate for the hybrid population P 8521 was 70,000 seeds/ha. At sowing, mineral fertilizers (nitroammonium phosphate) were applied at a rate of 100 kg physical mass/ha. The forecrop was soybean.

The vegetation periods from 2020-2022 were characterized by uneven precipitation. In 2020, only 70 mm of rain fell in July, while the standard amount was 140 mm. In 2021, during the second and third ten-day periods of June and throughout July, precipitation amounted to 35 mm, compared to the long-term average of 187 mm for this period. The daily air temperature during the second and third ten-day periods of July ranged from 28.1-36.3°C, with the daily average exceeding the norm by 4.6-5.5°C. In August, 74 mm of rain was recorded, which was half the

[3]Review of phytosanitary condition of crops in the Russian Federation in 2021 and forecast of development of harmful objects in 2022. Moscow, 2022, 477 p.

[4]*Kuznetsova S.V., Borsch T.I., Bagrintseva V.N.* Resistance of self-pollinated lines of maize to herbicides // Plant Protection and Quarantine. 2008, no. 1, pp. 44-45.

norm. In 2022, dry spells alternated with rainy periods. During the first and second ten-day periods of May, there was 12 mm of rain (standard 57 mm), the third ten-day period of May and the first of June received 104 mm (standard 66 mm), and during the third ten-day period of June and all of July, there was 214 mm (compared to a long-term average of 147 mm). In the first two ten-day periods of August, precipitation was 18 mm (standard 84 mm). The daily air temperature from the third decade of June until mid-August ranged from 29.3-33.7°C, except for a few days.

The herbicide Lumax was applied at a dose of 4 l/ha at three stages: before emergence, during the 2-3 leaf stage, and the 5-6 leaf stage of maize. A manual rod sprayer from the All-Russian Research Institute of Phytopathology (ARRIP) was used for application, with a working solution rate of 200 l/ha. The experimental plots had an area of 22.5 m^2, with a fourfold repetition and a randomized arrangement. The cobs were threshed after drying on a stationary thresher.

In the conditions of the greenhouse, experiments were laid out in plastic cups with a capacity of 300 g, filled with meadow-brown soil. Then, 10 seeds of one of the 16-18 species of weeds were sown in each cup. In 2021, the herbicide solutions were applied to the vegetating weed plants in their early stages of development, and in 2022, they were sprayed onto the soil surface using an OL-5 laboratory sprayer designed by ARRIP at the rates of 0.5; 1.0; 2.0; 3.0, and 4.0 l/ha. Soil moisture was maintained at 60-70% of field capacity through daily watering. The research was conducted according to the approved methodological guidance[5]. The numerical data were mathematically processed according to B.A. Dospekhov[6] and V.A. Koronevsky [20].

RESULTS AND DISCUSSION

The tested weeds responded differently to the herbicide Lumax applied to the soil surface and on growing plants. When applied to the soil, the herbicide prevented the emergence of lamb's-quarters, pigweed, hemp nettle (*Caleopsis ladanum* L.), barnyard grass, yellow-foxtail grass, and bur beggar-ticks (*Bidens tripartite* L.). On the sprouts of green bristle grass, yellow thistle, field milk thistle, copper leaf, and common persicaria, a developmental delay was noted, as well as leaf chlorosis starting from a herbicide dose of 1 l/ha. By the 6th day after emergence, at the application rates of 2, 3, and 4 l/ha, they had completely died, and significant suppression was observed in the others.

The emerged plants of China jute did not significantly differ from the control (without herbicides). However, on the 4th day, necroses appeared on the leaves at the maximum application rate, and by the 7th day, plants were drying up, starting from a herbicide dose of 1 l/ha. Using Lumax on common ragweed at an application rate of 3 and 4 l/ha, leaf chlorosis was observed right from emergence, and by the 4th day, it was present in all treatments. Starting from a dose of 2 l/ha, the sprouts of dayflower and hairy cupgrass significantly lagged in development, and by the 7th day, growth retardation was observed in other variants. Upon the emergence of the trailing hollyhock (*Hibiscus trionum* L.) at an application rate of 3 and 4 l/ha, leaf chlorosis was noted on some plants, and by the 7th day, necroses appeared on the leaves at a dose of 4 l/ha.

With post-emergence application of the Lumax preparation at recommended application rates of 3 and 4 l/ha, necroses appeared on the leaf edges of plants like pigweed, common persicaria, lamb's-quarters, elsholtzia (*Elsholtzia cristata* Wild), yellow thistle, field milk thistle, China jute, bur beggar-ticks, trailing hollyhock, siegesbeckia, hemp nettle, common ragweed, and copper leaf the very next day, while leaf chlorosis was observed on annual grassy weeds.

On the 7th day after treatment, severe necroses on the leaves were noted in barnyard grass, yellow-foxtail grass, green bristle grass, and dayflower. Partial leaf necrosis at application rates of 2, 3, and 4 l/ha was detected in hairy cupgrass plants.

[5]*Spiridonov Y.Ya., Larina G.E., Shestakov V.G.* Methodological guide to the study of herbicides used in crop production. Moscow: Printed City, 2009, 252 p.

[6]*Dospekhov B.A.* Methodology of field experience. Moscow: Kolos, 1979, 416 p.

Data from Table 1 indicate that the Lumax herbicide was most effective when used on the weeds in the early stages of their development. Of the 18 tested weeds, only hairy cupgrass showed moderate sensitivity under ideal greenhouse conditions. Its above-ground plant mass from the recommended consumption rates of 3 and 4 liters per hectare was reduced by 93–100%. All other weeds died from much smaller doses of Lumax.

When herbicide was applied to the soil surface at doses of 3 and 4 liters per hectare, moderate sensitivity was shown by ragweed, common dayflower, and hairy cupgrass, the above-ground mass of which was less than in the control by 95–100%. Trailing hollyhock turned out to be a resistant species to the action of Lumax herbicide, its vegetative mass was reduced only by 59–83%. In row crops, trailing hollyhock is easily destroyed by mechanical soil cultivation; it is sensitive to herbicides used in sowing in the early growth phases [20].

The weediness of the experimental plots in 2020–2022 averaged 531 weeds per square meter with a total above-ground mass of 3279 g/m^2 (see Table 2). In the middle of the growing season, perennial dicots increased the largest above-ground mass - 34%, mainly represented by field thistle. 28% and 26% respectively were annual dicots (mainly ragweed) and cereals (barnyard grass, bristlegrasses, and hairy cupgrass), 8% was common dayflower, and 4% was field horsetail.

Regardless of the application timing of the Lumax herbicide, the number of weeds was reduced to 248–398 per square meter, or 25–53%, and the above-ground mass growth – to 1498–1761 g/m^2, or 46–54%. Each application time had its own advantages and disadvantages. The main advantage of pre-emergence application was more active suppression of annual cereals by 57%, while late (5-6 leaf phase) was perennial dicots (field thistle) by 83%. With post-emergence use (2-3 and 5-6 leaf phases), annual

Табл. 1. Чувствительность сорных растений к гербициду Люмакс

Table 1. Susceptibility of weeds to herbicide Lumax

Dose per preparation, l/ha	Decrease in green mass of plants, % to the control							
	barnyard grass	green foxtail grass	hairy cupgrass	dayflower	ragweed	copper leaf	common persicaria	trailing hollyhock
In soil application (2022)								
Control	4,13	3,12	3,59	7,00	1,85	1,44	3,32	1,1
0,5	73	94	18	18	55	59	68	11
1,0	100	100	13	52	78	97	94	20
2,0	100	100	91	79	96	100	100	46
3,0	100	100	95	98	98	100	100	59
4,0	100	100	100	100	100	100	100	83
LSD_{05}	30	8	12	5	9	17	12	14
In post-germination application (2021)								
Control	0,96	0,77	1,48	1,79	0,83	0,64	0,14	0,70
0,5	75	65	8	27	55	100	100	100
1,0	99	79	60	79	85	100	100	100
2,0	100	100	82	100	100	100	100	100
3,0	100	100	93	100	100	100	100	100
4,0	100	100	100	100	100	100	100	100
LSD_{05}	13	6	15	15	14			

Note. Control - aboveground mass of plants, g.

Табл. 2. Эффективность гербицида Люмакс (4 л/га) в посеве кукурузы на зерно (среднее за 2020–2022 гг.)

Table 2. Efficiency of herbicide Lumax (4.0 k/ha) in grain maize crops (average 2020–2022)

Experiment option	Weediness										Grain yield, c/ha	Yield increase, c/ha
	Total quantity, pcs. /m^2	monocotyledonous		dicotyledons		Total above ground weight, g/m^2	monocotyledonous		dicotyledons			
		grain varieties	day-flower	annual	perennial		grain varieties	day-flower	annual	perennial		
Control (without herbicides)	531	279	25	151	33	3279	859	259	931	1118	11,3	–
Lumax: before sprouting	248	98	5	48	20	1584	368	60	223	816	45,7	34,4
2nd-3rd leaf stage	259	123	4	38	16	1498	550	16	56	481	48,0	36,7
5th-6th leaf stage	398	379	3	0	6	1761	1306	16	0	190	41,1	29,8
LSD_{05}											9,2	

dicots were destroyed by 94–100%, including ragweed by 96–100%, and common dayflower by 94%. With soil application, the herbicide was slightly less active – 76% and 77% respectively. It should be noted that from the group of annual dicot weeds, only southern copperleaf grew on the treated plots. In the variant of using Lumax in the 5-6 leaf phase, annual cereals, due to the absence of competition, accumulated vegetative mass, exceeding such in the control (without herbicides) by 52%. Its application in the 2-3 leaf phase of corn and at the early stages of weed development showed approximately equal action on weeds.

The herbicide Lumax, regardless of the application timing, ensured a preservation of 29.8–36.7 tons of corn grain per hectare, with a control yield of 11.3 c/ha. The highest amount of grain (48.0 c/ha) was obtained when it was applied during the 2–3 leaf stage of corn, which was 2.3 and 5.9 c/ha more than in the pre-emergence application and during the 5–6 leaf stage respectively.

CONCLUSIONS

1. In trials under greenhouse conditions, it was found that the weeds highly sensitive to the Lumax herbicide applied to the soil surface include barnyard grass, yellow-foxtail grass and green bristle grass, lamb's-quarters, China jute, pigweed, copper leaf, common persicaria, bur beggar-ticks, hemp nettle, yellow thistle, and field milk thistle (both from seeds). Moderate sensitivity was shown by ragweed, hairy cupgrass, and common dayflower. Trailing hollyhock can be considered resistant. When Lumax was applied to vegetative plants at early stages of their development, out of 18 species, only hairy cupgrass showed relative sensitivity; sigesbeckia, elscholtzia, and the aforementioned weeds are highly sensitive.

2. In maize grain sowing, it was revealed that with pre-emergence application, Lumax herbicide is more active in suppressing the development of annual grasses, and when used during the 5–6 leaf stage of the crop, it suppresses perennial dicots. Application of the herbicide during the 2–3 leaf stage of corn and at the early stages of weed development showed roughly equivalent action. At all application timings, Lumax effectively eradicated the common dayflower and annual dicotyledonous weeds, including ragweed. Regardless of the application timing, it ensured an additional yield amounting to 29.8–36.7 c/ha of corn grain.

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ВЗАИМОСВЯЗЬ ПОВЕДЕНЧЕСКОГО ТИПА САМЦОВ АМЕРИКАНСКОЙ НОРКИ С АКТИВНОСТЬЮ ПИЩЕВАРИТЕЛЬНЫХ ФЕРМЕНТОВ

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Доместикация американской норки (*Neovison vison*) приводит к проявлению такого признака, как ручное поведение. Отбор животных по этому признаку весьма привлекателен с позиций товарного производства. Поскольку работа с хищниками достаточно сложна, то селекция на ручное поведение представляется актуальной. Существует предположение, что гены, контролирующие поведение, в силу плейотропного действия могут быть вовлечены в процессы синтеза пищеварительных ферментов, что может приводить к снижению характеристик продуктивности. В связи с этим были проведены эксперименты по определению ферментативной активности протеаз, липаз и α-амилаз у особей агрессивного и ручного поведения. Установлено, что у агрессивных линий самцов американской норки активность протеаз и липаз выше, чем у ручных, тогда как амилолитическая активность у ручных зверей выше, чем у агрессивных.

Ключевые слова: американская норка, протеаза, липаза, амилаза, ручные норки, агрессивные норки, желудочно-кишечный тракт

RELATIONSHIP BETWEEN THE BEHAVIORAL TYPE OF AMERICAN MINK MALES AND THE ACTIVITY OF DIGESTIVE ENZYMES

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The domestication of the American mink (*Neovison vison*) leads to the manifestation of such a trait as “tame” behavior. The selection of animals on this basis seems to be very attractive from the standpoint of commodity production. Since work with predators is rather complicated, selection for the “tame” behavior of animals seems relevant. Assuming that the genes that control behavior, due to their pleiotropic action, can be involved in the synthesis of digestive enzymes, which can lead to a decrease in productivity characteristics. In this respect, experiments were carried out to determine the enzymatic activity of proteases, lipases, and α-amylases in aggressive and tame animals. It has been established that the activity of proteases and lipases is higher in aggressive lines of American mink males than in the tame ones, while the amylolytic activity in tame animals is higher than in the aggressive ones.

Keywords: American mink, protease, lipase, amylase, tame minks, aggressive minks, gastrointestinal tract

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BINTRODUCTION

As wild animals become domesticated, many of their inherent properties change. For example, mistrust and hostility towards humans in some parts of the population transform into tolerance and friendliness. In any wild population, there are highly aggressive, moderately aggressive, and easily tamed individuals [1]. The reactions that determine responses to external signals are based on the activity of the hypothalamic-pituitary-adrenal and sympathoadrenal systems[1] [2].

In cellular breeding of minks, selecting individuals of a calmer (tame) type is accompanied by a restructuring of many systems and functions in their organism: from nervous and hormonal [1-3] to digestive[2] [4, 5]. It has been established that selecting American minks for tame behavior leads to changes in coloration, growth and development of puppies, and the content of serotonin and catecholamines in the animal's brain cortex [5].

It is known that switching predators from natural diets to easily digestible meat-fish mince often results in restructuring their gastrointestinal tract, both morphologically[3] [6] and functionally [6-8]. For example, some species have seen an increase in intestine length to extend the digestion time of food with lower protein content. In canids, mutations have occurred in the genes responsible for lipid and carbohydrate metabolism. However, there is a significant lack of research on the influence of animal behavior on the physiology of the gastrointestinal tract.

We noticed that when raising mink offspring on the same diet, growth indicators in aggressive-type males were on average 16% higher compared to the tame-type representatives. Moreover, aggressive males consumed about 3% more feed. At the same time, no differences in feed consumption and average daily gain were observed between tame and aggressive-type females.

Given that feed consumption is associated with digestibility of nutrients, and digestibility is determined by the activity of gastrointestinal tract enzymes, an attempt was made to determine the activity of proteases, lipases, and amylases in the digestive tract of aggressive and tame males, which was the objective of this study.

MATERIAL AND METHODS

The study was conducted at the experimental fur farm of the Institute of Cytology and Genetics of the Siberian Branch of the Russian Academy of Sciences. The subjects of the study were male American minks (*Neovison vison*) with aggressive and tame behavior of the Standard dark brown (+/+) cellular breeding genotype. The selection based on the reaction to humans was carried out using the "hand catch test" method [9]. Animals scoring from +3 to +6 points were characterized by a peaceful attitude towards humans, while those scoring from -1 to -4 points showed aggression (see Fig. 1). It is worth noting that through specialized selection based on the defensive reaction to humans, a *de novo* unique tame behavior emerged, where the animals actively approached and investigated a human hand on their own initiative. Such individuals are scored at (+6) points.

As a result, four groups of 11-month-old male minks were selected for the study (see Table 1).

Animals with an aggression level of (-2) points attack the hand from hiding, (-3) attack regardless of hiding, (+3) show curiosity, do not hide, and reach out with their muzzles towards the hands, and (+6) confidently approach the hands, ready for contact with humans.

The evaluation of digestive enzyme activity was conducted at the Karelian Research Center of the Russian Academy of Sciences (located in Petrozavodsk). They determined the total proteolytic activity (TPA), lipase activity, and amylase activity in the pancreas, duodenum, and ileum using spectrophotometry.

TPA was determined based on the increase in tyrosine during the hydrolysis of hemoglobin, lipase activity based on the increase in

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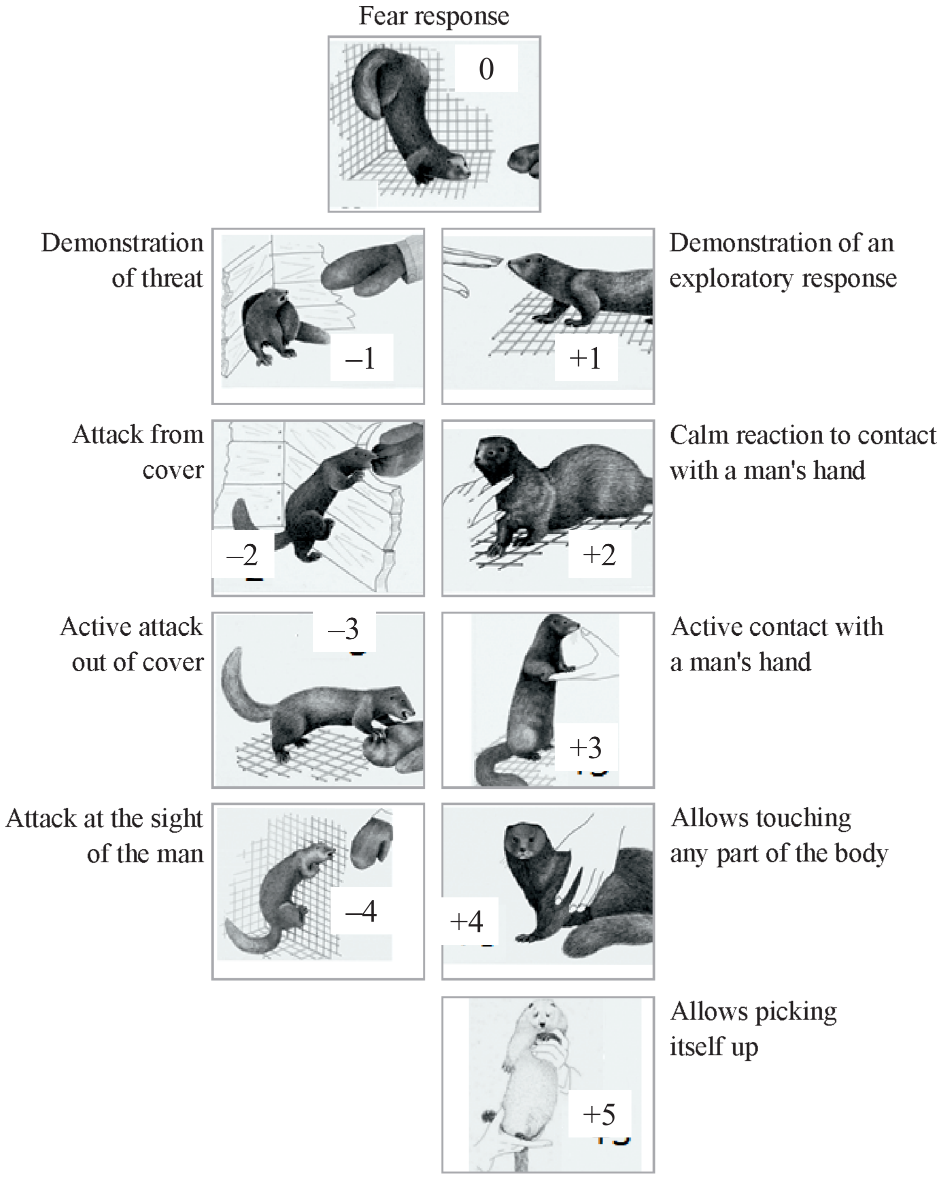

Рис. 1. Оценка оборонительной реакции самцов норки на человека в баллах

Fig. 1. Evaluation of the defensive reaction of male minks to humans in points

Табл. 1. Схема опыта

Table 1. Scheme of the experiment

Group	Aggressiveness score	Number of heads per group	Feed ration	Determinable indicators
1st – aggressors	−3	10	General	1) total proteolytic activity, µmol/min; 2) lipolytic activity, µmol/min; 3) amylolytic activity, mg min/g
2nd – aggressors	−2	10	»	
3rd – tame	+3	10	»	
4th – tame	+6	10	»	

glycerin during the hydrolysis of tributyrin, and α-amylase activity based on the decrease in starch according to the Smith and Roy method, as modified [10]. Enzyme activity is expressed in terms of the rate of hydrolysis of the products that were acted upon by the enzyme. The obtained data was processed using the Microsoft Excel software.

RESULTS AND DISCUSSION

It was determined that the total proteolytic activity of the gastrointestinal tract of minks with different behaviors significantly varies (see Fig. 2 *a*).

Both in tame and aggressive individuals, the highest protease activity is typical for the pancreas, decreasing in the duodenum and ileum. At the same time, the values of the total proteolytic activity in aggressive animals are significantly higher than in tame ones: in the pancreas 95–105 µmol/min compared to 85–87 µmol/min, and in the duodenum 8–10 µmol/min compared to 4–5 µmol/min. However, in the ileum, the protease activity in tame animals was higher by 14.3–16.7% than in aggressive ones. This might be due to the fact that aggressive individuals retain their "wild" type due to their diet, where the main nutrient is protein, and the high rate of food passage through the intestine provides them energy only with maximum hydrolysis activity of the nutrient in the upper part of the gastrointestinal tract[4,5] [11].

A similar pattern was observed when evaluating lipase activity (see Fig. 2 б). The lipolytic activity of the pancreas in aggressive males is higher by 30.5% than in tame ones from the 3rd group, and 69.2% higher than in the 4th group. In the duodenum, lipase activity drops to 0.4–0.45 µmol/min in aggressive animals and 0.25–0.15 µmol/min in tame ones. It should be noted that there were no differences in lipolytic activity in animals with different degrees of aggression (-2 and -3), whereas the group (+3) is characterized

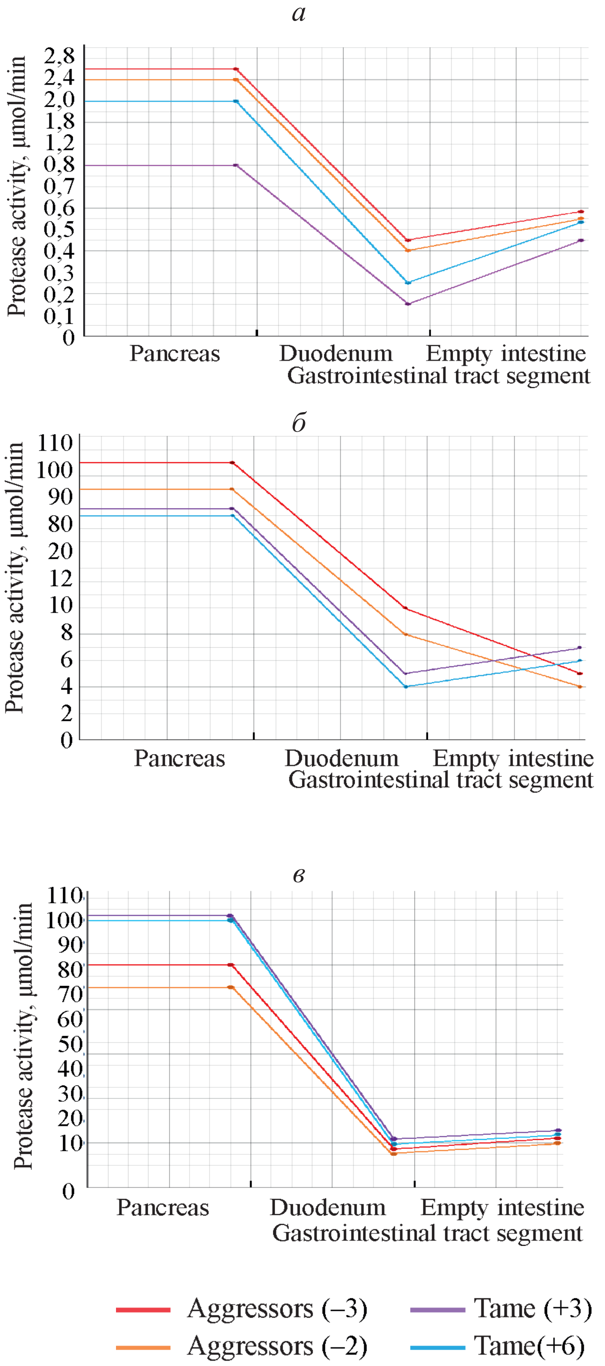

Рис. 2. Общая протеолитическая активность (*а*), активность липаз (*б*) и α-амилазы (*в*) желудочно-кишечного тракта у норок разного поведенческого типа

Fig. 2. Total proteolytic activity (*a*), lipase (*б*) and α-amylase (*в*) activity of the gastrointestinal tract in minks of different behavioral types

[4] *Skrede A., Berge G.M., Storebakken T., Herstad O., Aarstad K.G., Sundstol F.* Digestibility of bacterial protein grown on natural gas in mink, pigs, chicken and Atlantic salmon // Animal Feed Science and Technology. 1998, vol. 76, no. 1-2, pp. 103–116.

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by greater activity than the group (+6), especially in the pancreas.

The amylolytic activity of the enzymes is of real interest for practical fur farming activities, as it is the amylase that hydrolyzes plant-based feeds by breaking down sugars and starches. Therefore, increasing the proportion of grains in the animal diet without compromising productive qualities appears to be a profitable idea.

The data on the amylolytic activity of male minks of different behavioral types are presented in Fig. 2 *в*.

α-Amylase Activity in Tame Males was 22.7% higher in the pancreas. No differences in amylase activity were observed in the duodenum and ileum between both the 1st and 2nd groups (aggressors) and the 3rd and 4th groups (tame), as well as between the "aggressor-tame" lines. There was only a tendency towards increased amylase activity in the ileum among members of the 4th group.

It is known that carnivorous animals have low amylolytic activity. However, with the consistent inclusion of concentrated grain feeds in their diet, the activity of amylolytic enzymes increases[6,7] [12, 13]. In the current experiment, this is confirmed only for tame animals.

Thus, aggressive males have a higher activity of proteases and lipases (especially in the pancreas), while tame ones have higher α-amylase activity. This accounts for the more active growth of aggressive offspring since the biological value of hydrolyzed protein is higher for carnivores than the value of carbohydrates. High lipolytic activity provides animals with the necessary energy. The dependence of male growth on their behavioral type is reflected in Table 2.

From the data presented in Table 2, it can be seen that aggressive males at birth had a larger mass than males of domesticated, or tame, behavior.

When weaning the young at the age of 7 weeks, there was a difference in weight between the extreme forms of aggressive and tame behavior (-3 and +6) - the difference averaged 95.8 g per head.

Табл. 2. Влияние поведенческого типа на рост самцов американской норки

Table 2. Effects of behavioral type on the growth of male American minks

Group	Live weight, g		
	at birth	at weaning	at 11 months of age
1st	7,9 ± 0,18	619,5 ± 17,8	2030,0 ± 28,3
2nd		559,2 ± 8,1	2006,2 ± 14,9
3rd	6,9 ± 0,19	569,9 ± 27,7	1892,7 ± 68,5
4th		523,7 ± 15,8	1987,7 ± 36,2

A similar situation was observed at the age of 24 weeks. Males with extreme aggressive behavior (-3) were heavier than tame males (+6) by 42.3 g. Animals with moderate aggression (-2) outweighed tame males (+3) by 114.2 g.

The obtained results confirm the dominance in weight of aggressive males over males with tame behavior from birth until reaching sexual maturity.

CONCLUSIONS

1. The highest protease activity was observed in the pancreas of both tame and aggressive minks, with a reduction in the duodenum and ileum. Moreover, the overall proteolytic activity in aggressive individuals significantly exceeded that in tame animals.

2. The lipolytic activity of the pancreas in aggressive males was higher than in tame ones. Furthermore, no differences in lipolytic activity were detected between animals of varying degrees of aggressiveness (-2 and -3). However, the group of tame animals (+3) showed greater activity than the group (+6), especially in the pancreas.

3. α-Amylase activity was higher in the pancreas of tame male minks. No differences in amylase activity were detected in the duodenum and ileum between both the 1st and 2nd groups (aggressors) and the 3rd and 4th groups (tame). Only a tendency toward increased amylase activity in the ileum was observed in tame animals (+6).

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4. Assessing the average live weight dynamics of the males revealed differences in weight among extreme behavioral forms (-3 and +6 scores). At birth, aggressive males had a larger mass than tame ones. Both during weaning and at 11 months of age, tame animals also lagged behind aggressive ones in terms of live weight.

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ВЛИЯНИЕ ПОГОДНЫХ УСЛОВИЙ НА РАЗВИТИЕ И ПРОДУКТИВНОСТЬ ПЧЕЛИНЫХ СЕМЕЙ

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Полученные результаты показали, что определяющее влияние на интенсивность развития пчелиных семей и выход товарного меда оказывают погодные условия. Исследование проводили на пасеке, расположенной в Калужской области. Экологические условия в зоне продуктивного лета пчел оценены как благоприятные. Все пчелиные семьи, имевшиеся на пасеке, являлись представителями карпатской породы, рекомендованной для разведения на территории Калужской области. Данные, полученные за два смежных сезона (2021 и 2022 гг.), свидетельствуют о том, что медосборные условия 2022 г. по температурному режиму и количеству осадков были намного благоприятнее по сравнению с 2021 г. Несмотря на существенную разницу в минимальной и максимальной температуре в дневное время, в весенне-летний период 2022 г. резких перепадов температуры не наблюдалось, осадки были частыми, но кратковременными. В среднем в марте–августе 2021 г. зафиксировано всего 2 дня с осадками. В период медосбора установилась длительная засушливая погода, что оказало отрицательное влияние на выделение нектара растениями, развитие пчелиных семей и их продуктивность. Весной 2022 г. пчелиные семьи развивались интенсивнее, через месяц после весеннего осмотра сила пчелиных семей в среднем составила 9,27 улочек, что на 0,57 улочек больше по сравнению с 2021 г. В конце сезона общее количество пчелиных семей пасеки увеличилось на 11,7%. Выход товарного меда за сезон 2022 г. достиг 990 кг, что в 2,3 раза превышает показатели 2021 г. В расчете на одну пчелиную семью было получено в 2,2 раза больше товарного меда. Стоимость товарной продукции пасеки выросла в 2,35 раза.

Ключевые слова: погодные условия, развитие пчелиных семей, карпатская порода, товарный мед

INFLUENCE OF WEATHER CONDITIONS ON THE DEVELOPMENT AND PRODUCTIVITY OF THE BEE COLONIES

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The findings showed that weather conditions have a decisive influence on the intensity of bee colonies development and the yield of marketable honey. The study was conducted in the apiary located in the Kaluga region. Ecological conditions in the productive summer zone of bees are assessed as favorable. All bee colonies in the apiary were representatives of the Carpathian breed recommended for breeding in the Kaluga region. The data obtained for two adjacent seasons (2021 and 2022) indicate that the honey harvest conditions of 2022 were much more favorable compared to the previous year in terms of temperature and precipitation. Despite a significant difference in minimum and maximum temperatures during the day, there were no sharp temperature fluctuations during the spring-summer period of 2022, precipitation was frequent, but short-lived. On average, there were only 2 days of precipitation between March and August 2021. During the honey harvest period, there was prolonged dry weather, which had a negative impact on nectar production by plants, the development of bee families, and their productivity. Bee colonies developed more intensively in the spring of 2022; one month after the spring inspection, bee family strength averaged 9.27 beeways, an increase of 0.57 beeways over the previous year. At the end of the season, the total number of the apiary’s bee colonies increased by 11.7%. The yield of marketable honey for the 2022 season reached 990 kg, which is 2.3 times higher than in 2021. There was 2.2 times more marketable honey received per bee family. The value of marketable products of the apiary increased by 2.35 times.

Keywords: weather conditions, development of bee colonies, Carpathian breed, commercial honey

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INTRODUCTION

The honey bee (*Apis mellifera*) is a socially-living insect used by humans to obtain valuable food products and biologically active substances (honey, bee pollen, royal jelly, propolis, bee venom). However, the primary importance of bees lies in pollinating naturally growing and cultivated entomophilous plants. Bees maintain plant species diversity, and as a result, facilitate the production of plant-derived products.

At this stage, the climate is changing in all regions of the globe, which results in altered weather conditions both during the autumn-winter dormancy of bees and during their active life cycle. Climate change leads not only to global warming but also to an increase in precipitation, which is accompanied by a decrease in summer temperatures [1]. According to studies, due to global warming, the number of cloudy days in the central part of Russia has increased (+ 14), while the number of sunny days has decreased by the same amount [2].

During the main honey gathering period, unfavorable weather conditions shift the flowering times, reduce the nectar secretion by honey-producing plants, and require adjustments in the planned technological operations at the apiary [3-5]. The change in the flowering time of honey plants needs to be considered for timely preparation of bee colonies for honey collection and increased production of marketable honey [6, 7].

In adverse weather conditions during the main honey gathering, the amount of brood in the colonies is less than usual, and the egg-laying capacity of the bee queens decreases in the current season. However, this allows preserving the genetic potential of the queen's egg-laying capacity up to the third year of life [8].

There are two methods of maintaining bee colonies during the autumn-winter dormancy – indoor (in an apiary house) and "in the wild". Weather conditions during wintering directly affect the preservation of bee colonies. The main factors affecting wintering results include colony strength, food reserves, queen age, presence or absence of diseases, proper nest arrangement, hive quality, and their insulation [9].

For instance, the comfortable winter conditions of 2019/20 contributed to only one bee colony perishing at an apiary located in the Kaluga region when wintered "in the wild". In contrast, during the previous year, there was a significant loss of bee colonies during the winter, regardless of their strength [10].

The air temperature suitable for wintering bees "in the wild" ranges from −5 to 5 °C. In this case, it's especially important to insulate the hive's side walls thoroughly, which account for up to 70% of heat loss [11].

The optimal number of bees in the winter cluster depends on the climatic conditions. For example, for the Mid-Russian breed, this number ranges from 24 to 30 thousand [12]. During wintering, bee colonies consume feed 20 times less than during the spring-summer period. Minimal feed consumption is only possible at an optimal external temperature [13]. Increasing the number of bees in colonies when moving to colder climate zones convergently parallels the enlargement of homeothermic animals, achieving energy expenditure savings. Snow covering also aids in preserving warmth in bee nests [14].

Long periods of cold during winter and cold rainy weather in spring weaken bee colonies and reduce their resistance to diseases. To prevent bee diseases, routine veterinary and sanitary measures and monitoring targeting the assessment of changes in the apiaries' epizootic state are required[1].

Nosematosis is one of the most widespread and dangerous bee diseases. Nozemat is considered a highly effective drug in the treatment and prevention of this disease [15, 16]. Varroatosis is no less dangerous and frequent among bee colonies. The spread of this mite disease depends on the region, climatic conditions, the strength of bee colonies, and the veterinary treatment plan [17, 18].

In organic beekeeping, there is a stricter regulation regarding the use of drugs for treating bee colony diseases, including for the treatment and prevention of varroatosis. In this context, formic acid may be the most suitable remedy [19].

Studying the impact of weather conditions on the development and productivity of bee colonies in relation to changing natural and climatic conditions is a relevant research topic for various regions of Russia. This factor has the most significant effect on the vital activities of bee colonies. In the mid-zone conditions, the honey collection period lasts for an average of 4 months. With sharp temperature fluctuations, a large amount of precipitation, or conversely, drought-like conditions, plants' nectar productivity decreases, resulting in a lower yield of marketable honey.

The purpose of the research is to determine the influence of natural and climatic conditions on the development and productivity of bee colonies.

The objectives are:

1) assessment of weather conditions for the study period;

2) analysis of the number and strength of bee colonies at the beginning and end of the honey gathering period;

3) registration of the marketable honey yield and the value of the produced goods.

MATERIAL AND METHODS

The study was conducted from the autumn of 2020 to the autumn of 2022 at an apiary located in the Kaluga region. The total number of bee colonies during the study ranged from 43 to 67.

As part of the research work, the observation method[2] was used by conducting regular inspections, equipping bee nests, and recording daily air temperature. The results were logged in a bee colonies' status journal and a weather conditions diary. Bee colonies at the apiary were individually numbered.

The apiary territory is situated to the southwest of the regional center. The primary honey plants in this area are meadow grasses, shrubby, and woody plant species. An assessment of the site's honey plants showed that, under favorable weather conditions, bee colonies are fully self-sufficient in feed resources (nectar and pollen). The area within the bees' productive flight radius is environmentally sound (no fields treated with pesticides nearby, no roads with heavy traffic, etc.)[3].

For beekeeping production at the apiary, the Carpathian bee breed is used, which is recommended for breeding and well adapted to the climatic conditions of the Kaluga region. Carpathian bees are adapted to weak honey flow, unstable weather during the winter-spring period, and hot drought-like summer [20].

The bees were kept in single-chamber 12- and 14-frame hives with super extensions. The bee nests were insulated from the inside in the autumn.

The bees wintered "in the wild". For the wintering period, hives were insulated from the outside on three sides with foam sheets, and shields were installed in front of the entrances.

In the summer, for varroatosis prevention, scheduled treatments were carried out using acaricidal strips, and before wintering, a single treatment with bipin was done due to the negligible number of mites dropping in control hives. Preventive treatment for nosemosis was carried out in the autumn (when replenishing the bees'

[1]*Zelenina O.V.* Beekeeping: textbook. Moscow: Knorus, 2021. 128 p.

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feed reserves before wintering with sugar syrup) using the Nozemat drug.

To evaluate the research results, standard zootechnical, analytical, statistical, economic methods, and meteorological observation data were applied.

RESULTS AND DISCUSSION

The analysis of natural and climatic conditions was conducted using a method of comparing temperature regimes and the number of days with precipitation from March to August inclusive (see Table 1).

Observations showed that in March and April 2021, the average air temperature was higher compared to 2022, and there were significantly fewer days with precipitation. A more comfortable air temperature was recorded in May 2021, reaching 17.0°C compared to 12.9°C in 2022. Regarding precipitation, 2021 was a dry year. From late June to the first ten-day period of August, there was drought that led to a sharp reduction in nectar produced by plants. In April and May 2022, a significant number of rainy days (22 days each) were noted, which substantially reduced bee flight activity. From June to August, there was less rainfall and no prolonged rainy periods were observed.

According to the bee family count over two honey-harvesting seasons, 55 families each were kept for the winters of 2020/21 and 2021/22 (see Table 2). Compared to 2022, the bee family loss during the winter of 2021 was 39.6% higher. Additionally, in the spring of 2021, twice as many weak bee families were culled and combined. By mid-April 2021, the strength of bee families averaged 8.7 ± 0.28 bee streets, which is 6.6% less than the data for April 2022.

During the honey gathering period, bee families fully occupied either 12-frame or 14-frame hives, and supers were added to the hives for marketable honey collection. Frames with sealed brood were taken from very strong bee families in order to equalize the strength of bee families, and these brood frames were used for marketable honey collection.

In 2021, 60 bee families were kept for the winter, and in 2022, 67, which is 11.7% more. Bee families had a strength of 9.70 ± 0.21 beeways in the autumn of 2021 and 10.73 ± 0.16 in the autumn of 2022, representing a growth in strength of 10.6%.

The number of bee families during the honey gathering season peaks during the main nectar flow. The increase in the number of families in the apiary is achieved by forming nucleuses on fertile (purchased) or infertile (obtained in the apiary) queens, as well as swarms that emerged from the families not affected by swarm prevention techniques.

Swarming is one of the primary instincts of bee families. It's known that bee families show a propensity for swarming based on various factors. From a genetic perspective, swarming is not only a way for bee families to reproduce, but

Табл. 1. Погодные условия в период активной жизнедеятельности пчелиных семей
Table 1. Weather conditions during the period of active life of bee colonies

Year	Month						Average for the period
	March	April	May	June	July	August	
Average daily air temperature, °C ($M \pm m$)							
2021	1,0 ± 4,3	10,8 ± 5,3	17,0 ± 5,6	23,3 ± 5,1	25,5 ± 3,7	23,4 ± 3,4	16,8 ± 4,2
2022	0,0 ± 0,6	7,0 ± 0,8	12,9 ± 2,6	20,9 ± 0,8	22,9 ± 0,7	26,0 ± 0,8	15,0 ± 4,3
Minimum-maximum temperature value, °C							
2021	−11…9	4…21	5…30	15…32	21…32	15…32	−11…32
2022	−6,5…6	−0,5…16	7…18,5	13,5…30	17…29,5	18…34	−6,5…34
Number of days with precipitation							
2021	1	2	4	3	0	2	2,0
2022	8	22	22	15	19	8	15,7

Табл. 2. Характеристика пчелиных семей осенью и в начале активного сезона

Table 2. The number of bee colonies at the end and the beginning of the season

Indicator	2021	2022	Data correlation of 2022 and 2021, %
Number of families:			
remained in the autumn of the previous year, pcs.	55	55	100
dead during the wintering period, pcs.	7	5	39,6
of those that have gone into wintering, %	12,7	9,1	−3,6
culled and merged after spring revision, pcs.	10	5	50,0
available at the beginning of the season, pcs.	43	45	104,7
of those remained in the fall period, pcs.	60	67	111,7
The power of bee families, beeways:			
in the middle of April	8,70 ± 0,28	9,27 ± 0,27	106,6
in the autumn of the current year in preparation for wintering	9,70 ± 0,21	10,73 ± 0,16	110,6

also an adaptation to constantly changing environmental conditions [21].

To refresh the genetic resources of the bee families in the apiary and to form nucleuses, five Carpathian breed queens of the 77th line were purchased in May 2021. These queens were used to form early nucleuses; the new bee families with fertile queens provided an additional yield of commercial honey.

The number of bee families in the apiary increased by 17 units for the 2021 season and by 22 units for the 2022 season. Among them, two families were sold (see Table 3).

In 2022, the output of marketable honey amounted to 990 kg, which is 2.3 times higher than the previous season. The marketable honey yield per bee family in 2022 was 22 kg, compared to 10 kg in 2021.

The value of beekeeping products (marketable honey and bee families) for the 2022 season reached 455.5 thousand rubles, which is 2.35 times more than the previous year.

CONCLUSION

The assessment of weather conditions during the active life period of bee families showed that the honey-harvesting season of 2022 was more favorable in terms of precipitation and was characterized by the absence of prolonged drought periods. The daytime air temperature in the summer of 2022 was more comfortable, without sharp fluctuations.

Табл. 3. Изменение численности пчелиных семей, основные характеристики производства товарного меда

Table 3. Changes in the number of bee colonies, the main characteristics of marketable honey production

Indicator	2021	2022	Data correlation of 2022 and 2021, %
Number, pcs.:			
of bee families at the beginning of the season	43	45	104,7
of purchased prolific queens	5	–	–
of bee families sold	–	2	–
of bee families culled in the autumn	2	3	150,0
Increase in the number of bee families per season (including sales and culling), pcs.	17	22	129,4
Total volume of marketable honey produced, kg	430	990	230,2
Marketable honey yield per bee family (from available at the beginning of the season), kg	10,0	22,0	220,0
Production value, thousand rubles	193,5	455,5	235,4

The conditions favorable for honey collection contributed to a more intensive spring development of bee families. By mid-April 2022, the average strength of the bee families in the apiary reached 9.27 beeways, which means an increase of 6.6% compared to the previous season.

During the main honey-harvesting period, bees were more active in searching and collecting food. The production of marketable honey in the apiary in 2022 increased 2.3 times. The output of marketable honey per bee family was 22 kg, which is 2.2 times higher than the previous year's level. Moreover, enough backup brood frames with honey were left in the spare hives on the apiary grounds to replenish the food reserves of bee families in the spring of 2023. Such an opportunity was not available in the previous season due to weak honey collection and unfavorable weather conditions.

The increase in the number of bee families in the apiary, thanks to optimal honey collection and weather conditions in 2022, was 11.7% more than in 2021.

The overall output of commercial products for the summer season of 2022 increased by 263 thousand rubles. The bee families gained significant strength by the beginning of the wintering period of 2022/23, and the total number of families in the apiary grew.

Thus, the favorable honey-collecting conditions of the current season should be used to the fullest extent, not only for producing marketable honey and increasing the number of bee families in the apiary but also for collecting feed honey for the spring development of bee families in the next season.

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КОНЦЕПТУАЛЬНАЯ МОДЕЛЬ ПРОЦЕССА ВНЕСЕНИЯ В ПОЧВУ ЖИДКИХ ФОРМ МИНЕРАЛЬНЫХ УДОБРЕНИЙ

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Представлены материалы по формированию концептуальной модели процесса внесения в почву жидких форм минеральных удобрений. Базой данной модели является схема взаимодействия процессов в агроэкосистеме пшеницы на уровне концептуальной модели ресурсного цикла. В нее введены дополнительным блоком минеральное питание вегетирующих растений и соответствующее упорядочение внутренних связей системы. Установлено, что с учетом специфики научных исследований и технических возможностей для дальнейшего рассмотрения целесообразно использование модели «черный ящик». В основе данной модели лежит практическая деятельность человека, направленная на преобразование используемых объектов с помощью материальных, энергетических или информационных воздействий. Определены основные взаимодействующие блоки системы управления продукционным процессом посевов, связанные с обеспечением вегетирующих растений основными факторами их развития на уровнях надземной и корнеобитаемой частей агроэкосистемы, пространственным распределением жидких минеральных удобрений в зоне их внесения в соответствии с агротехническими требованиями, в том числе одновременно с посевом зерновых. Представлен блок азотно-фосфорного питания для вегетирующих растений, реализуемый посредством применения технологического и технического обеспечения для основных способов внесения жидких минеральных удобрений с использованием комплекса прицепных, навесных и монтируемых технологических машин на основе существующих почвообрабатывающих и посевных рабочих органов. Рекомендован принцип формирования машинно-тракторных агрегатов на его начальном этапе по минимуму энергетических затрат на их производство и эксплуатацию. Установлена перспектива использования пневматических систем для доставки и распределения жидких минеральных удобрений в зоне их внесения.

Ключевые слова: жидкие минеральные удобрения, неравномерность, дефлекторные распределители, шаг расстановки, крупнокапельный распыл, факел распыла, ширина захвата

CONCEPTUAL MODEL OF THE PROCESS OF APPLYING LIQUID FORMS OF MINERAL FERTILIZERS TO THE SOIL

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Materials on the formation of a conceptual model of the process of applying liquid forms of mineral fertilizers into the soil are presented. The basis of this model is the scheme of interaction of the processes in the agroecosystem of wheat at the level of the conceptual model of the resource cycle. Mineral nutrition of vegetative plants and corresponding ordering of internal relations of the system are introduced into it as an additional block. It has been found that given the specifics of scientific research and technical capabilities, it is appropriate to use the “black box” model for further consideration. This model is based on practical human activity aimed at transforming used objects by means of material, energy or informational influences. The main interacting blocks of the system of crop production process management related to the provision of vegetative plants with the main factors of their development at the levels of above-ground and root-inhabited parts of agroecosystem, spatial distribution of liquid mineral fertilizers in the zone of their application in accordance with agrotechnical requirements, including simultaneously with grain sowing, have been determined. The block of nitrogen-phosphorus nutrition for vegetative plants is presented, which is realized through the application of technological and technical support for the main methods of liquid mineral fertilizers application using a set of trailed, mounted and mounted technological machines on the basis of existing tillage and sowing working bodies. The principle of formation of machine-tractor aggregates at its initial stage on the minimum of energy costs for their production and operation is recommended. The prospect of using pneumatic systems for delivery and distribution of liquid mineral fertilizers in the zone of their application has been established.

Keywords: liquid mineral fertilizers, distribution, unevenness, deflector distributors, spacing, large - drop spray, spray cone, working width

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INTRODUCTION

One of the reserves for forming stable high yields of cereal crops is the improvement of their cultivation technology based on adaptive intensification of the sowing production process. An essential role in this task belongs to the application of liquid forms of nitrogen-phosphorus fertilizers in the form of liquid compound fertilizers and solutions of urea-ammonia mixture. Despite the thorough exploration of this direction, there remains a number of unresolved issues related to the dosing of small volumes of liquid forms of preparations, their transportation to the place of application, the clogging of holes (nozzles) with soil, and the rapid wear of the main lines supplying the working fluid. The lack of competitive domestic offerings in terms of machinery and equipment doesn't allow for the effective implementation of the advantages of precision farming technology and forces agricultural producers to purchase imported systems and agricultural machinery. However, even in this case, they mainly choose affordable configurations with minimal resource-saving and automation functions. Given the above, at this stage of the operation of systems for introducing mineral fertilizers into the soil, it is advisable to develop a conceptual model of the technical system of technological and technical support using liquid forms of mineral nutrition in the cultivation technologies of cereal crops.

The purpose of the research is to form an informational and methodological framework to justify prospective technological processes of cultivating cereals using liquid forms of nitrogen-phosphorus nutrition in cereal cultivation technologies.

The objective of the research is to develop a conceptual model of the process of introducing liquid forms of mineral fertilizers into the soil.

MATERIAL AND METHODS

The development of a conceptual model for technological and technical support using liquid forms of nitrogen-phosphorus nutrition in the forest-steppe zone of Western Siberia while improving cereal cultivation technologies is closely linked to the development strategy of the agricultural industry of the enterprise (see Fig. 1). These issues are most thoroughly addressed in the publications on the program-targeted approach to solving complex problems [1, 2].

Currently, there is a stable perception of three main types of conceptual models of technical systems: the “black box” model, the “machine” model, and the “organostructural” model. The choice of a conceptual model of a technical system is determined by the specifics of the research direction and the technical capabilities of its implementation.

In the “black box” model, its construction involves considering the properties of the technical system manifested in its behavior when interacting with the objects of the external environment [3, 4]. The “machine” conceptual model assumes that the set of the “machines” properties (and their models) includes a set of properties of the technical systems [5–11]. The organostructural model is most fully disclosed in the theory of solving inventive problems [11, 12]. It assumes that the performance of consumer functions (operation) should be provided by four functional parts interacting in a certain way (“engine”, “transmission”, “working tool”, and “control organ”).

Considering the aforementioned models, it was concluded that, given the specifics of scientific research and technical capabilities, it is appropriate to use the “black box” model. This model is based on human practical activity aimed at transforming used objects with material, energetic, or informational impacts. Moreover, these impacts, during any transformation, are carried out by humans and/or technical systems.

Thus, we are talking about the development of a conceptual model of the subject area. In this case, it is appropriate to speak about the model of the resource cycle within the framework of agricultural management, providing growing

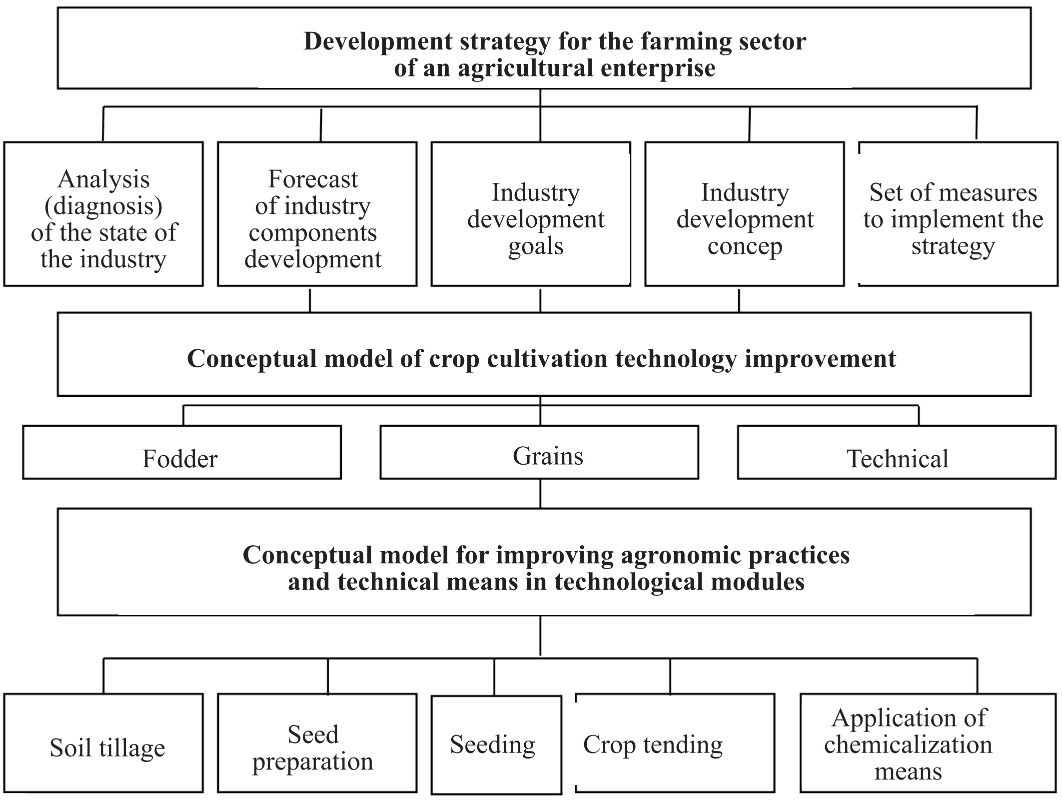

Рис. 1. Структура концептуальной модели совершенствования технологий возделывания зерновых культур и ее место в стратегии развития отрасли земледелия сельхозпредприятия

Fig. 1. The structure of the conceptual model of improvement of grain cropping technologies and its place in the strategy of development of the farming sector of an agricultural enterprise

plants with the required nutrition elements using the minimum and maximum laws of J. Liebig and E.A. Mitscherlich[1-3].

In our understanding, the resource cycle is the sum of spatial movements of a specific substance at all stages of its use in agricultural crop cultivation technologies. This includes preparation for use, spatial distribution of the substance in the soil horizon (in the seed placement zone) in terms of the width of the sown strip and the depth of seed placement, and creation of favorable conditions for the maximum realization of the substance's potential (mineral fertilizers). It also includes the use of the non-grain part of the harvest as an organic component of soil fertility.

Almost at all stages of the technical system's functioning (in this case, machine technology for cultivating grain crops), there is a loss of both resource potential and the yield of the cultivated crop. This encompasses yield losses from pests, diseases, development and spread of assimilants, disruptions in water and nutritional regimes, losses during transportation of nutrients, seeds, irreplaceable removal of nutrients from the soil, and more. Knowing such "pain" points of the technologies allows predicting a corresponding set of measures to eliminate the noted negative phenomena and the consequences associated with them.

In this regard, one of the main functions of the conceptual model of the technical system of subject activity is to identify and detail the cause-and-effect relationships characterizing these processes. The goal is to obtain, systematize, and structure the knowledge about the subject area and manage its condition using a technical support complex. The purpose of constructing this model is to consider the properties of the technical system as they manifest in its behavior when interacting with objects of the external environment[4]. That is, it allows evaluating the system's position in the external environment, identifying the necessary resource potential for its operation, assessing the influence of external environment factors, and what we expect at the output.

RESULTS AND DISCUSSION

Considering the above, to construct a conceptual model of the process of introducing liquid forms of mineral fertilizers into the soil, the interaction scheme of the processes in the wheat agroecosystem by G.Yu. Riznichenko (conceptual model of the resource cycle) [13] was adopted. An additional mineral nutrition block for vegetative plants has been introduced into the proposed scheme, and the internal connections of the system have been ordered accordingly (see Fig. 2).

The conceptual model of the process of introducing liquid forms of mineral fertilizers into the soil is presented in the form of four interrelated blocks. Blocks "A" and "B" are central and closely related to vegetative plants. Specifically, these two blocks provide plants with water, heat, the presence of oxygen in the soil, and soil air. Meanwhile, block "A" not only determines the microclimate, radiation regime, photosynthesis, and plant respiration, water-heat regime, and transport of nutrients, growth, development, distribution of assimilants but also has an ecological impact on the plants (pests, diseases, weeds).

Block "B" - the root-inhabited part of the agroecosystem - is determined by the soil's thermal and water regime and, through the block of nutrient movement and transformation taken from the nutrition block, provides favorable conditions for vegetation for the root system of plants.

The filling of the nutrition block of the root-inhabited part of the agroecosystem, among many components, is represented by the introduction of mineral fertilizers into the soil, implemented through appropriate technical equipment. Given the direction of scientific research, we only

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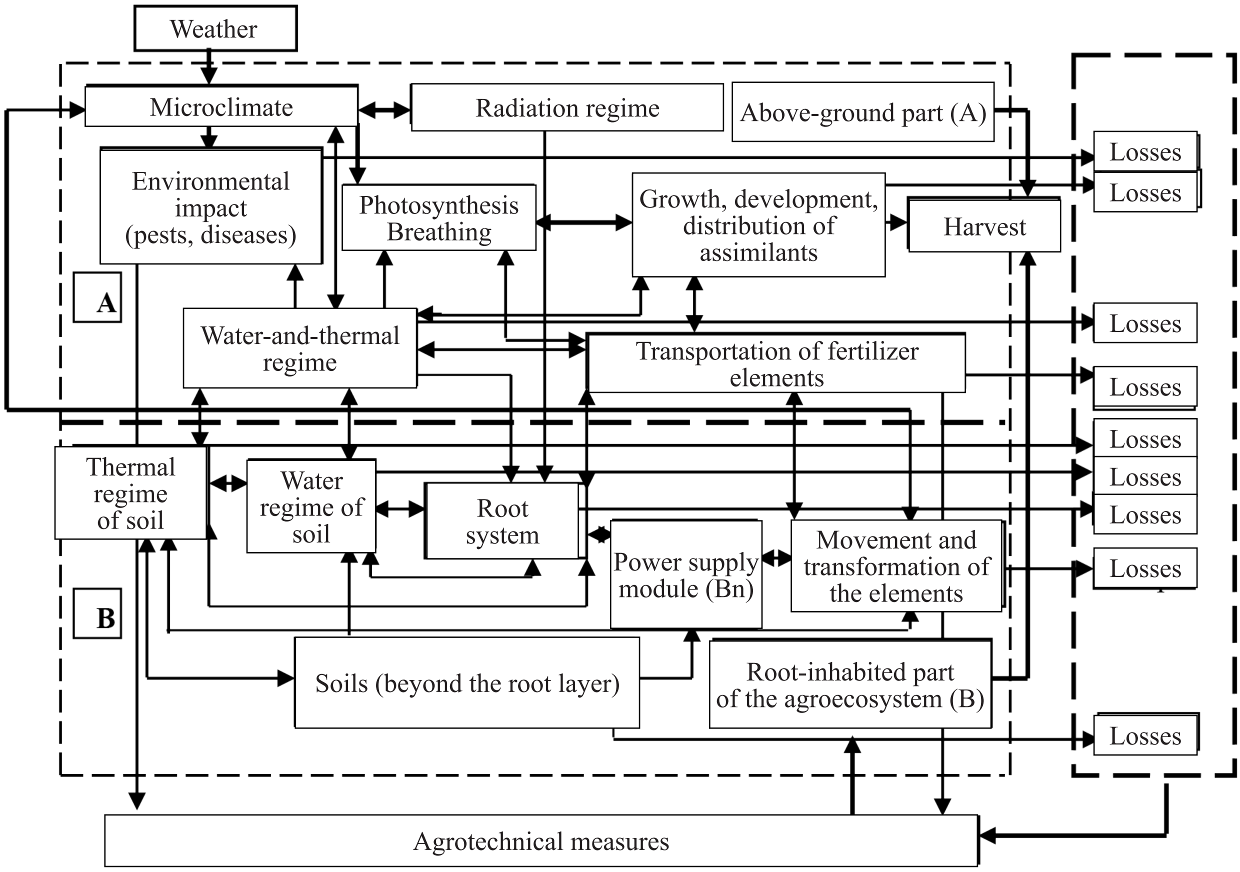

Рис. 2. Концептуальная модель ресурсного цикла
Fig. 2. Conceptual model of the resource cycle

consider the technical support for introducing liquid mineral fertilizers into the soil.

As practice shows, in recent years, farmers' interest, including in the Novosibirsk region, in liquid fertilizers has increased. The main ones are anhydrous liquid ammonia (82.0% N), aqueous ammonia (20.5% N), and urea-ammonium mixture (UAM), which, depending on the brand, contains 28-32% N. Liquid complex fertilizers (LCF) are also used, containing two or more nutrients in their composition. Such fertilizers can be obtained directly on farms by adding, for instance, salts of some microelements to solutions (provided no sediment is formed). The liquid complex nitrogen-phosphorus fertilizer produced by the "PhosAgro" company contains 11% N and 37% P_2O_5, and currently, the cost of liquid mineral fertilizers is at least 30% cheaper than solid fertilizers.

For the introduction of liquid forms of mineral fertilizers into the soil, various technological machines are used: Nitromaster unit for introducing anhydrous ammonia, KBA-8 "Strela" complex for introducing anhydrous ammonia, AVA-8 unit for introducing ammoniac water, OZP unit for introducing liquid mineral fertilizers and plant protection agents, AVG-8 herbicide application unit, OKZh-5.6 sprayer, APZh-12 machine for introducing liquid mineral fertilizers, "Real" complex for introducing liquid mineral fertilizers and plant protection agents, Duport's Liquiliser and GFI unit of Gustrower of various capacities, "Tuman 2" multi-injector, "Case Ih" nitrate application unit, "Lenta-B" herbicide tape application equipment, "RSM AF-3800" plant-feeder applicator, "RSM AP" plant-feeder applicator, "KU-3(6.2) A" cultivator with equipment for fertilizer application, "Agridjet 2x2" machine for introducing liquid fertilizers, "John Deere 2510H (C)" nutrient application machine, "Agridjet-03" towed feeder, liquid fertilizer feeders series "PZhU", liquid fertilizer feeder "Ammoniac", mounted feeder "PMT-480", feeder for introducing liquid mineral fertilizers (UAS, LCF) and ammoniac water "AVU-4500", LINUS liquid fertilizer application system, liquid fertilizer application systems (SVZhU), complex for introducing liquid and granulated fertilizers simultaneously with sowing based on PK JOHN DEER, complex for introducing liquid and granulated fertilizers simultaneously with sowing based on PK BOURGAULT, UA-ZhU ground application unit for UAS on PK with an intermediate capacity, UA-ZhU ground application unit for two types of liquid fertilizers on PK SALFORD with a towed capacity of 2x5000 l, STUURMAN RONDO mobile unit for introducing liquid fertilizers.

The above and many other types of technological machines are available in trailed, mounted, and installable versions. Practice shows that the choice of technical equipment is quite large, and agricultural producers face the task of choosing an effective variant of machine-tractor aggregate (MTA) for the production of the technological process of introducing liquid forms of mineral fertilizers into the soil.

Issues of machine-tractor aggregate composition in the cultivation of agricultural crops are currently of particular importance. This is due to the technical re-equipment of the agricultural sector, the improvement of the equipment itself, and the resulting increase in its cost. In addition, the range of both mobile power means and technological machines, implemented in the corresponding technologies, has significantly expanded. All of this poses a challenge to agricultural producers in choosing effective technical support for cultivation technologies of the required crops with minimal operating costs.

In general, nowadays agricultural producers independently decide on the configuration of Machine-Tractor Aggregates (MTA) in terms of timing, method of aggregation, productivity, and the use of comprehensive (multi-operation) MTA, depending on the soil and climatic zone in which the farm is located, and financial stability. However, another aspect of the problem draws attention. The main document regulating the production process of any agricultural crop is the technological map. It reflects the main technological processes and their components, raw materials, equipment, machines, and technological modes, the time required for product manufacturing, and worker qualifications. When calculating direct operating costs, the productivity of the aggregate and the price of the equipment play a determining role, as these indicators are used to determine labor payment costs for service personnel and costs for repair and maintenance of the purchased equipment. To determine the minimum level of direct operating costs in the cultivation technology of agricultural crops, repeated calculations are required when changing both mobile power sources and technological machines that make up the aggregate. Therefore, at the initial stage of forming a machine-tractor aggregate, it is advisable to make a choice based on the minimum energy costs for their production and operation. The basis for such calculations is laid out in the relevant sources of scientific and technical information [13–19]. However, considering the aspects of energy conservation when using technological aggregates, it is necessary to consider that all work in the corresponding technological module must be carried out within certain time frames, which determines the configuration of high-performance aggregates, ensuring the performance of the required amount of work within the specified time. The arising dual task requires further logical solution based on an assessment of the significance of factors influencing the choice of machine technologies in crop production.

The material outlined above is presented in a canonical form (see Fig. 3). The conceptually presented model of the process of introducing liquid forms of mineral fertilizers into the soil should be referred to as complex models, in which blocks "A" and "B" contain the main links of interacting yield factors: microclimate, radiation regime, environmental impact (pests, diseases) acting as external influences on the agroecosystem and at the same time ensuring growth, development, spread of assimilants, photosynthesis and respiration of plants, water-thermal regime, and transport of nutrients (above-ground part) and a complex of interactions in the root-inhabited part of the agroecosystem.

The interaction of the designated blocks is quite fully described in the sources of scientific and technical information, so we will not provide it. In accordance with the direction of scientific research, we will indicate the main connections between the components.

Internal direct connections

1. A **(**the aboveground part of the agroecosystem) → B (the root-inhabited part of the agroecosystem) → Bp **(**the feeding unit of the root-inhabited part of the agroecosystem) → Ст **(**technical support of liquid fertilizer application: C_{T1} – machines for mineral fertilizer application: C_{T2}, C_{T12}**)** → C_{TM} (technological machines: C_{TM1}, C_{TM2}, C_{TM3}, C_{TM4}) → D_K **(**MTA equipment**:** D_{K1}, D_{K2}, D_{K3}, D_{K4}, D_{K5}, D_{K6}, D_{K7});
2. Ca (agrotechnical measures: Ca_1, Ca_2, Ca_3,) → Can **(**the methods of application of the LMF: Ca_1, Ca_2, Ca_3, Ca_{11}, Ca_{12}, Ca_{13}, Ca_{14}) → Ст **(**technical support of liquid fertilizer application: C_{T1} – machines for mineral fertilizer application**:** C_{T2}, C_{T12}) → C_{TM} (technological machines: C_{TM1}, C_{TM2}, C_{TM3}, C_{TM4}) → D_K (MTA equipment: D_{K1}, D_{K2}, D_{K3}, D_{K4}, D_{K5}, D_{K6}, D_{K7});
3. Bp (B_{P1}, B_{P2}) (power supply unit;) → C_{TM} (technological machines: C_{TM1}, C_{TM2}, C_{TM3}, C_{TM4}) → D_K (MTA equipment: D_{K1}, D_{K2}, D_{K3}, D_{K4}, D_{K5}, D_{K6}, D_{K7}).

Reverse connections: block “A” and block “B”; Bp and block Ст, $Ст_{12}$ and block Стм.

Further development of the conceptual model of the process of application of liquid forms of mineral fertilizers into the soil will be carried out in the direction of development and improvement of labor means for implementation of the main ways of their application into the soil.

CONCLUSIONS

1. To justify prospective technological processes of using liquid forms of nitrogen-phosphorus nutrition in cereal cultivation technologies, it is advisable to use information and methodological support, which consists in considering the cause-and-effect relationships of the technical system interacting with the external environment, their influence on the formation of planned output indicators, taking into account the resource potential for its functioning.
2. When developing a conceptual model of the technological process of introducing liquid forms of mineral fertilizers into the soil, it is advisable to use the conceptual model of the resource cycle of cereal cultivation with an additionally introduced block of mineral nutrition of vegetating plants with ordered internal connections of the system.
3. The developed conceptual model operates in the main blocks: block “A” - the aboveground part of the agroecosystem; block “B” - the root-inhabited part of the agroecosystem; block “Ca” - agrotechnical measures, ensuring through the blocks “Ct” (technical provision for introducing LCF), “C_{TM}” (technological machines), and “D_K” (MTA equipment) - a set of necessary agrotechnical measures for plants with the aim of obtaining a given volume of agricultural products of the required quality.

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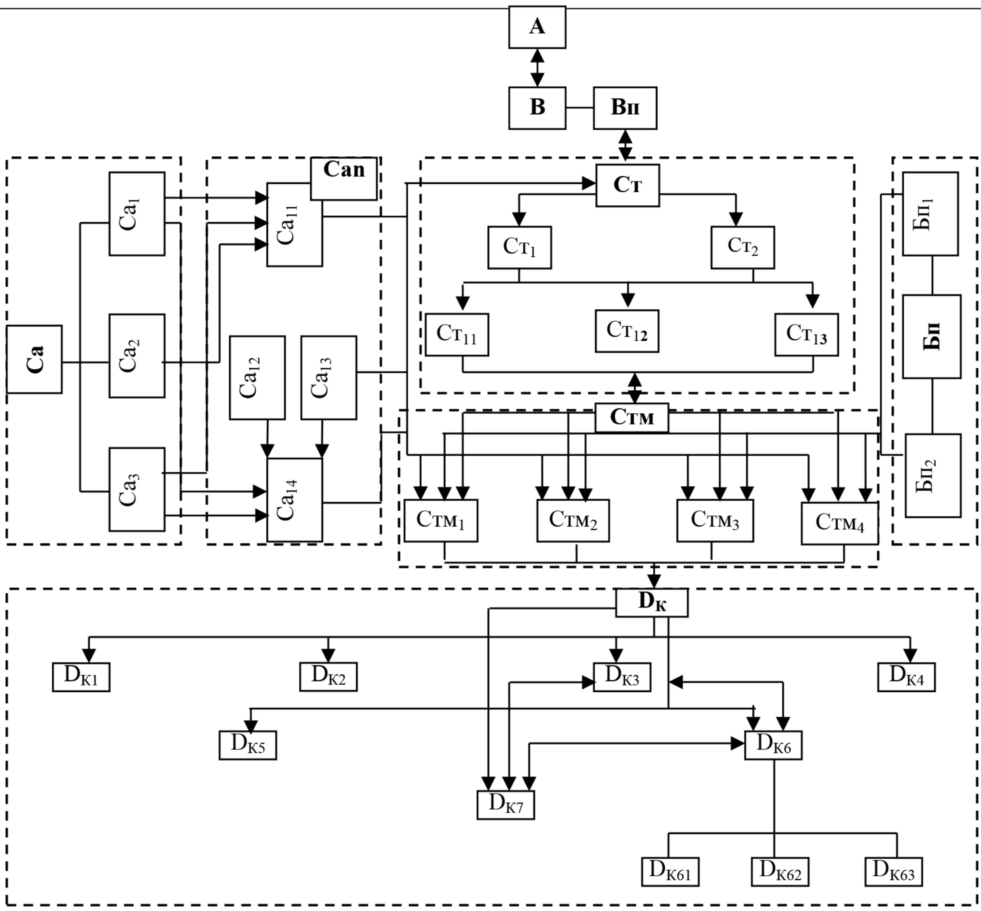

Рис. 3. Концептуальная модель процесса внесения в почву жидких форм минеральных удобрений:

А – надземная часть агроэкосистемы; В – корнеобитаемая часть агроэкосистемы; Вп – блок питания корнеобитаемой части агроэкосистемы; Са – агротехнические мероприятия; Сап – способ внесения ЖМУ; $Са_1$ – основное внесение; $Са_2$ – припосевное внесение; $Са_3$ – подкормка; $Са_{11}$ – внутрипочвенное внесение; $Са_{12}$ – внесение одновременно с семенами; $Са_{13}$ – внесение в междурядье; $Са_{14}$ – поверхностное внесение; $С_Т$ – техническое обеспечение внесения ЖМУ; $С_{Т1}$ – машины для внесения минеральных удобрений; $С_{Т2}$ – машины для внесения органических удобрений; $С_{Т11}$ – машины для внесения твердых удобрений; $С_{Т12}$ – машины для внесения жидких удобрений; $С_{Т13}$ – машины для внесения пылевидных удобрений; $С_{ТМ}$ – технологические машины; $С_{ТМ1}$ – технологические машины навесные; $С_{ТМ2}$ – технологические машины прицепные; $С_{ТМ3}$ – технологические машины монтируемые; $С_{ТМ4}$ – технологические машины самоходные; $Б_П$ – блок питания; $Б_{П1}$ – блок азотного питания; $Б_{П2}$ – блок фосфорного питания; $D_К$ – комплектование МТА; $D_{К1}$ – комплектование МТА по срокам внесения ЖМУ; $D_{К2}$ – комплектование МТА по способу агрегатирования; $D_{К3}$ – комплектование МТА по производительности; $D_{К4}$ – комплектование МТА по удельному сопротивлению машин; $D_{К5}$ – комплектование МТА по использованию комплексных (многооперационных) МТА; $D_{К6}$ – комплектование МТА перспективными РО ($D_{К61}$ – распределитель малых объемов ЖМУ при внутрипочвенном внесении; $D_{К62}$ – вращающийся пневматический распылитель ЖМУ при поверхностном внесении; $D_{К63}$ – пневмокапельный распылитель ЖМУ при внутрипочвенном внесении); $D_{К7}$ – комплектование энергосберегающих МТА

Fig. 3. Conceptual model of the process of applying liquid forms of mineral fertilizers to the soil A – the above-ground part of the agro-ecosystem; B – the root-inhabited part of the agro-ecosystem; Bp – the feeding block of the root-inhabited part of the agro-ecosystem; Ca – agrotechnical measures; Can – the method of application of LMF; Ca_1 – main application; Ca_2 – application at seeding; Ca_3 – top dressing; Ca_{11} – in-soil application; Ca_{12} – application simultaneously with seeds; Ca_{13} – inter-row application; Ca_{14} – surface application; C_T – technical support of liquid fertilizer application; C_{T1} – machines for mineral fertilizer application; C_{T2} – machines for organic fertilizer application; C_{T11} – machines for solid fertilizer application; C_{T12} – machines for liquid fertilizer application; CT_{13} – machines for dust fertilizer application; C_{TM} – technological machines; C_{TM1} – lift-type technological machines; C_{TM2} – trailed technological machines; C_{TM3} – mounted technological machines; C_{TM4} – self-propelled technological machines; B_P – power supply unit; B_{P1} – nitrogen power supply unit; B_{P2} – phosphorus power supply unit; D_K – MTA equipment; D_{K1} – MTA equipment by timing of liquid fertilizer application; D_{K2} – MTA equipment by method of aggregation; D_{K3} – MTA equipment by productivity; D_{K4} – MTA equipment by specific resistance of machines; D_{K5} – MTA equipment by use of complex (multi-operational) MTAs; D_{K6} – MTA equipment with perspective ROs (D_{K61} – a distributor of small volumes of LMF for in-soil application; D_{K62} – a rotating pneumatic atomizer of LMF for surface application; D_{K63} – a pneumatic drip atomizer of LMF at in-soil application); D_{K7} – completion of energy-saving MTAs

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ВЛИЯНИЕ СОРТА И НОРМЫ ВЫСЕВА НА ПАРАМЕТРЫ ПРОДУКТИВНОСТИ СОИ В МОСКОВСКОЙ ОБЛАСТИ

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Изучено влияние сортовой специфики и нормы высева на формирование листовой поверхности растений, элементы структуры урожая, число генеративных признаков, урожайность сортов сои. Исследования выполнены в Московской области в 2021 и 2022 гг. В эксперименте было заложено 12 вариантов: четыре нормы высева (400, 500, 600 и 700 тыс. шт./га) для трех сортов (Бара – стандарт, Hidaka, Сибирячка). В 2021 г. интенсивнее шло развитие листового аппарата на растениях сорта Hidaka, площадь листьев увеличивалась с уменьшением нормы высева. В среднем за 2021 и 2022 гг. максимальная площадь листьев у сорта Бара сформировалась в варианте с нормой высева 600 тыс. шт./га – 33,09–40,81 тыс. м^2/га. Максимальное число цветков зафиксировано у всех вариантов с нормой высева 400 тыс. шт./га. У сорта Бара цветки формировались равномерно по вариантам относительно года исследования. Различия на 2–3 шт. на одно растение отмечены в вариантах с нормой высева 500 и 700 тыс. шт./га. В 2022 г. количество бобов у растений сорта Бара превышало показатель 2021 г. на 6,9% при норме высева 600 тыс. шт./га, на 28,8% при норме высева 400 тыс. шт./га. Превышение массы 1 тыс. семян у сорта Hidaka относительно стандарта составило 43,2–48,4%. Максимальная масса 1 тыс. семян получена в оба года исследования в варианте с нормой высева 400 тыс. шт./га – 220,5 и 218,9 г соответственно. Максимальная урожайность отмечена у сорта Hidaka при норме высева 400 тыс. шт./га – 4,18 т/га. Прибавка по сравнению с контролем составила 18,75%. В результате исследований установлено, что больший положительный эффект на показатели продуктивности сои оказала норма высева 400 тыс. шт./га.

Ключевые слова: соя, сорт, семена, урожайность, норма высева

VARIETY AND SEEDING RATE INFLUENCE ON THE PARAMETERS OF SOYBEAN PRODUCTIVITY IN THE MOSCOW REGION

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The influence of varietal specificity and the seeding rate on the formation of leaf surface of plants, elements of the yield structure, number of generative traits, and the yield of soybean varieties were studied. The research was carried in the Moscow region in 2021, 2022. 12 variants were planted in the experiment: four seeding rates (400, 500, 600 and 700 thousand pieces/ha) for three varieties (Bara –

standard, Hidaka, Sibiryachka). In 2021, leaf apparatus development was more intensive on Hidaka plants, and the leaf area increased with a decrease in the seeding rate. On average for 2021 and 2022, the maximum leaf area of the Bara variety was formed in the variant with a seeding rate of 600 thousand pieces/ha – 33.09–40.81 thousand m^2/ha. The maximum number of flowers was recorded in all the variants with a seeding rate of 400 thousand seeds/ha. In the Bara variety, the flowers were formed uniformly across the variants relative to the year of the study. Differences by 2–3 pieces per plant were noted in the variants with seeding rates of 500 and 700 thousand pieces/ha. In 2022, the number of beans in the plants of the Bara variety exceeded the index of 2021 by 6.9% at a seeding rate of 600 thousand pieces/ha, by 28.8% at a seeding rate of 400 thousand pieces/ha. Excess weight of 1 thousand seeds in the Hidaka variety relative to the standard amounted to 43.2–48.4%. Maximum weight of 1 thousand seeds was obtained in both years of the study in the variant with a seeding rate of 400 thousand seeds/ha – 220.5 and 218.9 g, respectively. The maximum yield was observed in the variety Hidaka at a seeding rate of 400 thousand pieces/ha – 4.18 tons/ha. The gain compared to the control amounted to 18.75%. As a result of the research it was found that the seeding rate of 400 thousand pieces/ha had a greater positive effect on soybean productivity indicators.

Keywords: soy, variety, seeds, yield, seeding rate

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Conflict of interest

The authors declare no conflict of interest.

INTRODUCTION

Over the past 10-15 years, there has been intensive growth in soybean production both in Russia and in other countries. In 2020 and 2021, approximately 353.9 million tons of soybeans were harvested worldwide. Brazil is considered one of the leaders in this field, producing up to 136.0 million tons annually[1]. In the Russian Federation, gross soybean production is relatively small compared to the global volume, averaging around 6 million tons per year[2]. Soybeans are classified as globally-strategic crops because they are currently a crucial source of vegetable oil and protein. Soybean grains contain 30-45% high-quality protein with essential amino acids and 15-22% oil with a favorable ratio of linoleic to linolenic acid (6:7)[3]. Additionally, it is a high-yield crop in demand in various industries[4]. For example, soybeans are widely used in the food industry for producing bread, sausages, margarine, baby food, and more. Furthermore, they are actively used in animal feed production (silage, meal, cake, various concentrates, etc.)[5].

The number of seeds per unit area is the primary factor determining crop yield [1]. Research conducted in the United States (Oklahoma state) on the Pioneer variety and late-maturing breeding samples demonstrated that the maximum potential soybean yield ranges from 7250 to 11,000 kg/ha. Grain yield of soybeans is determined as the average seed mass obtained per unit area, assuming optimal plant density and the preservation of all reproductive plant organs. Harvesting such a volume is only possible when optimal sowing rates are observed, and there is no stress

[1]https://www.fao.org/faostat/ru/#home.

[2]https://www.rosstat.gov.ru.

[3]*Singh G.* The Soybean: Botany, Production and Uses. Wallingford, 2010, 494 p.

[4]*Krasovskaya A.V., Veremey T.M.* Leguminous crops in the subtaiga of Western Siberia // Leguminous crops - an emerging trend in Russia: collection of proceedings of the conference Omsk, 2016, pp. 76-78.

[5]*Petibskaya B.C., Baranov V.F., Kochegura A.V., Zelentsov S.V.* Soybean: quality, utilization, production. Moscow: Agrarian Science, 2001, 64 p.

throughout the entire growing season [2].

In essence, crop yield depends on the number of flowers that form on the plant during the flowering period. Soybeans typically bloom for an average of 20 to 40 days, sometimes up to 90 days, but the majority of flowers are formed within a narrower range[6]. The quantity of flowers formed during the vegetative growth, first flowering, and full flowering stages determines the yield, and conversely, the number of underdeveloped flowers directly limits the yield[7]. The vegetative growth stage deserves special attention as it marks the transition from vegetative growth to reproductive growth. During this time, flowers developing on previously established nodes mature into reproductive organs, ultimately determining the final number of seeds and, in turn, the yield [1].

Recently, farmers have been offered many new soybean varieties that may not always realize their biological potential under existing cultivation conditions[8] [3, 4]. Research continues to identify the optimal sowing rate and plant density for soybean crops, especially in new growing regions [5–7].

Studies on the impact of plant density on seed yield have not yielded consistent results: in some cases, there was no response[9, 10], while in others, the response was quite clear[11] [8, 9]. Plant density in the conducted studies ranged from 70,000 to 600,000 plants per hectare[12] [8, 10].

According to many authors, the response of different varieties to changes in the sowing rate can vary significantly depending on their genetic biological characteristics. Analyzing the contribution of variety and sowing rate factors in the formation of productivity parameters is of practical interest.

Therefore, the purpose of our study was to determine the variability of soybean seed productivity in the Moscow region, taking into account the variety-specificity and sowing rate. The objectives also included studying the parameters of seed productivity (number of flowers, pods, and seeds, weight of 1,000 seeds), yield, and photosynthetic activity of crops depending on the sowing rate.

MATERIAL AND METHODS

The research was conducted on an experimental plot of the All-Russian Research Institute of Vegetable Growing, located in the Ramensky District of the Moscow Region, in the Moscow River floodplain. The plot belongs to the southern forest zone of the European province in the central part of the Russian Plain and falls within the humid zone.

The soils of the plot are alluvial meadow soils with medium loamy moisture. The depth of the plow layer is approximately 27 cm, and the groundwater level is more than 2 meters deep. The soil is well-cultivated and has a high level of natural fertility. The soil pH ranges from 5.8 to 6.1 (potentiometrically), humus content in the plow layer is between 3.15% to 3.22% (according to Tyurin), total nitrogen content is 0.23% to 0.28% (according to Kjeldahl), nitrate nitrogen is 1.4 to 4.1 mg/100 g (according to Grandval – Leaju), available phosphorus is 25.0 to 27.0 mg/100 g (according to Chirikov), and potassium is 10.0 to 15.0 mg/100 g (according to Maslova).

The sum of active temperatures in the Moscow Region (above 10°C) is 2055°C. The dura-

[6] *Zheng S.-H., Nakamoto H., Yoshikawa K., Furuya T., Fukuyama M.* Influences of High Night Temperature on Flowering and Pod Setting in Soybean // Plant Production Science. 2002, no. 5 (3), pp. 215–218.

[7] *Peterson C.M., Mosjidis C.O'H., Dute R.R., Westgate M.* A Flower and Pod Staging System for Soybean // Annals of Botany. 1992, no. 69 (1), pp. 59–67.

[8] *Barsukov S.S.* Soybean productivity depending on variety and plant density in crops // Agrarian Science. 2000, no. 6, pp. 25-27.

[9] *Board J.E., Kang M.S., Harville B.G.* Path analyses of the yield formation process for late-planted soybean // Agronomy Journal. 1999, vol. 91 (1), pp. 128–135.

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[11] *Walker E.R., Mengistu A., Bellaloui N., Koger C.H., Roberts R., Larson J.* Plant population and row-spacing effects on maturity group III soybean // Agronomy Journal. 2010, vol. 102 (3). pp. 821–826.

[12] *Holshouser D.L., Whittaker J.P.* Plant population and row-spacing effects on early soybean production systems in the Mid-Atlantic USA // Agronomy Journal. 2002, vol. 94 (3), pp. 603–611.

tion of the period with temperatures above 10°C is 135 days. The total hours of sunshine per year are 1574. Weather conditions in 2021 were generally favorable for the growth and development of soybeans. In the third ten-day period of April and May, precipitation was 42% higher than the multi-year average, and the average daily air temperature did not exceed 14.5°C, which slightly delayed seed germination. From June to August, the average daily air temperature was higher than the multi-year average, staying at around 20°C, which contributed to good plant growth and development. August and the first half of September were warm, with precipitation in this period being 15-20% higher than the multi-year averages, but this did not hinder the timely and full harvest. Weather conditions in 2022 were characterized by elevated temperatures and a clear lack of moisture. The average daily temperature during the growing season exceeded multi-year averages by 3.3-6.5°C. Precipitation during the three summer months was only 54% of the multi-year norm.

12 variants were established in the experiment: four sowing rates (400, 500, 600, and 700 thousand seeds per hectare) for three varieties (Bara, Krasnodar region; Hidaka, Japan; Sibiryachka, Omsk Agrarian Scientific Center). The standard was the Bara variety, which is widely cultivated in the Central region.

For the variety "Bara," the following biological characteristics are typical. The plant exhibits a semi-determinate to indeterminate growth type, with medium height, ranging from upright to semi-upright, and has gray pubescence.

The leaves are rounded-ovate in shape. The flowers are violet in color. The seeds are of medium size, roundly-flattened, yellow, with a gray hilum.

The "Sibiryachka" variety is an early-maturing variety with a growth type that varies from semi-determinate to indeterminate. The pubescence of the main stem is reddish-brown. The leaves are pointed-ovate. Flowers are violet in color. The seeds are of medium size, elongated, yellow, with a dark brown hilum.

The "Hidaka" variety is also early-maturing and has determinant growth type plants. The bush's shape is broad. The pubescence of the main stem is reddish-brown. Leaves are pointed-ovate, and flowers are violet. Pods are evenly distributed on the plant. Seeds are elongated, yellow, with a dark brown hilum[13].

The experimental plot had an area of 2.5 m^2, and the experiment was repeated four times. Manual seeding was performed when favorable meteorological conditions were present, on May 18, 2021, and May 21, 2022. Row length was 5 meters, and the spacing between the rows was 50 cm. At sowing rates of 400, 500, 600, and 700 thousand seeds per hectare, the distance between seeds in the row was 5.0, 4.0, 3.3, and 2.8 cm, respectively.

Harvesting was done manually in warm and dry weather conditions when the soybeans were fully ripe. The "Hidaka" variety showed early maturity, with a vegetation period of 106 days in 2021 and 100 days in 2022. Harvesting was done 7-8 days earlier than other samples (on September 2, 2021, and August 29, 2022). The "Bara" and "Sibiryachka" varieties, with vegetation periods of 114 and 106 days in 2021 and 2022, respectively, were harvested on September 10 and 5, respectively.

Phenological observations during the plant's growing season were conducted in accordance with the methodology of the State Commission for Variety Testing of Agricultural Crops (1985)[14]. The dynamics of plant development and above-ground biomass accumulation by growth stages, as well as changes in leaf surface area, were tracked using the methodology of A.A. Nichiporovich[15]. Study of the yield structure elements was carried out according to the methodology of A.F. Bukharov et al.[16] The statistical analysis of the experimental data and the

[13] *Shafigullin D.R.* Agrobiological and physiological-biochemical aspects of introduction of vegetable soybean (*Glycine max* L.) in the conditions of the Central region of the Non-Chernozem zone: PhD in agricultural sciences thesis. Moscow, 2019, 195 p.

[14] Methodology of state variety testing of agricultural crops. Moscow: Selkhozizdat, 1989, vol. 2, 194 p.

[15] *Nichiporovich A.A., Strogonova L.E., Chmora S.N., Vlasova M.P.* Photosynthetic activity of plants in crops: methods and tasks of accounting in connection with the formation of yield. Moscow: USSR Academy of Sciences Publishing House, 1961, 135 p.

[16] *Bukharov A.F., Baleev D.N., Bukharova A.R.* Morphometry in the system of seed quality testing: educational method. manual. Moscow, 2020, 80 p.

assessment of the relationships between parameters were based on the Pearson correlation coefficient. The significance of differences between variants and the contribution of factors to trait variability were determined according to B.A. Dospekhov (1985)[17].

RESULTS AND DISCUSSION

It is known that the productivity of a variety largely depends on the intensity of assimilation apparatus formation. The primary indicator characterizing the photosynthetic activity of soybean crops is leaf area [11]. Leaf area is influenced by the biological characteristics of varieties and applied agronomic practices [12].

In 2021, the development of the leaf apparatus on the Hidaka variety plants was more intensive. While differences with the Bara variety during the budding and flowering stages were insignificant, during seed filling, the leaf area of the Hidaka variety was already 1.5-1.8 times higher than the standard. The most developed leaf area for both Bara and Hidaka varieties was observed in the variant with a sowing rate of 400 thousand seeds per hectare. In the conditions of 2022, the intensity of leaf area formation in Hidaka variety plants decreased compared to 2021 (due to hot weather and insufficient moisture). On average across the experiment, it was found that as the number of plants per hectare increased, the leaf area per plant decreased. Therefore, the seeding rate influences the formation of the photosynthetic leaf area of soybean plants (see Table 1).

On average for 2021 and 2022, the maximum leaf area for the Bara variety plants in the variant with a sowing rate of 600 thousand seeds per hectare ranged from 33.09 to 40.81 thousand m²/ha. For the Hidaka variety, the leaf area increased after reducing the seeding rate. In the case of the Sibiryachka variety, there was a reverse reaction, with the highest leaf area recorded at a seeding rate of 700 thousand seeds per hectare.

Табл. 1. Влияние нормы высева и сортовой специфики на показатели фотосинтетической активности посевов

Table 1. Influence of the seeding rate and varietal specificity on the indicators of photosynthetic activity of crops

Variety	Seeding rate, thousand pcs/ha	Leaf area, thousand m^2/ha		Photosynthetic potential, thousand m^2 - day/ha		Net photosynthetic productivity, g/m^2		Economic effectiveness coefficient, %	
		2021	2022	2021	2022	2021	2022	2021	2022
Bara	400	32,89	32,54	1743,2	1610,7	4,97	5,07	26,6	36,2
	500	32,44	39,55	1719,3	1957,7	4,98	5,67	29,2	30,7
	600	33,09	40,81	1753,8	2020,1	5,10	4,95	32,9	32,3
	700	27,49	43,70	1457,0	2163,2	5,57	4,96	34,0	26,3
Hidaka	400	51,15	54,54	2503	2508,8	4,21	3,99	29,1	35,6
	500	50,87	51,29	2493	2359,3	3,91	3,84	33,7	35,3
	600	47,93	51,01	2349	2346,5	3,72	3,89	34,6	34,5
	700	47,92	51,27	2348	2358,4	3,86	3,53	31,1	34,3
Sibiryachka	400	–	40,01	–	1980,5	–	4,90	–	32,6
	500	–	44,27	–	2191,4	–	3,98	–	39,1
	600	–	49,59	–	2454,7	–	3,59	–	38,2
	700	–	44,28	–	2191,9	–	3,86	–	38,1

[17] *Dospekhov B.A.* Methodology of field experiment (with the basics of statistical processing of research results). Moscow: Alliance, 2011, 350 p.

The net productivity of photosynthesis varied in all the experimental variants depending on the variety, seeding rate, and the year's conditions. Intensive photosynthetic activity of the leaves was observed in both years of the study for the Bara variety in all experimental variants.

On average across all the variants, a greater number of flowers were formed in 2022 (see Fig. 1, *a*). The number of plants per unit area and their degree of illumination influence branching and the formation of generative organs (see footnote 15). The maximum number of flowers in our study was recorded in all the variants with a seeding rate of 400 thousand seeds per hectare. For the Bara variety, flowers were evenly formed across the variants in both years of the study. A difference of 2-3 flowers per plant was observed in the variants with seeding rates of 500 and 700 thousand seeds per hectare.

For the Hidaka variety, in 2022, the formation of generative organs, including flowers, increased compared to 2021, indicating the variety's responsiveness to more favorable growing conditions. The maximum number of flowers was observed for the Sibiryachka variety in 2022. The number of flowers on plants varied depending on the seeding rate. The highest number of flowers was formed in the variant with a seeding rate of 400 thousand seeds per hectare, with 79.0 flowers per plant, exceeding the standard by 40.0%.

Thus, it is evident that the seeding rate has the greatest influence on flower formation. According to our data, the most productive seeding rate is 400 thousand seeds per hectare. At this seeding rate, all experimental variants produced high results: in 2021 and 2022, the Bara variety produced 48.8 and 48.2 flowers per plant, respectively; the Hidaka variety produced 41.1 and 42.4 flowers; the Sibiryachka variety produced 43.4 flowers.

The number of pods per plant was influenced by all three studied factors: seeding rate, year's conditions, and the responsiveness of the varieties. A reduction in the seeding rate to 400 thousand seeds per hectare contributed to the formation of a greater number of pods in all experimental variants (see Fig. 1, б). In 2022, the number of pods on the Bara variety plants exceeded the 2021 figures, ranging from 6.9 (with a seeding rate of 600 thousand seeds per hectare) to 28.8% (400 thousand seeds per hectare). An exception for this variety was the variant with a seeding rate of 700 thousand seeds per hectare: the number of pods in this variant remained consistent in both years (23.3 pods per plant in 2021 and 22.9 pods in 2022), due to the dense plant spacing per unit area and insufficient moisture.

In terms of the considered characteristic, the Hidaka variety behaved as an extensive one. Over the course of two years of research, this variety displayed consistent responsiveness to growing conditions and formed a slightly varying number of pods across the different variants. The maximum number of pods was recorded in 2022 in the variant with a seeding rate of 400 thousand seeds per hectare, amounting to 21.5 pods per plant. For the Sibiryachka variety, the number of pods across all seeding rates was lower than the standard by 0.8 to 3.7 pods.

Clearly, the positive influence of the growing conditions and the good responsiveness of the varieties contributed to an increase in the number of seeds per plant (see Figure 1, b, *в*).

By analyzing the diagrams in Figure 1, *б*, *в*, it can be noted that there is a positive relationship between the number of pods and seeds per plant. The Sibiryachka variety obtained the highest number of seeds, surpassing the standard level and achieving the maximum result in the experiment with a seeding rate of 400 thousand seeds per hectare, amounting to 79.0 seeds per plant.

The weight of 1,000 seeds for all varieties was more dependent on the seeding rate (see Fig. 1, *г*). As the seeding rate decreased, the weight of 1,000 seeds increased. On average across the experiment, the Hidaka variety produced large, well-formed seeds in all the variants. The weight of 1,000 seeds for this variety exceeded the standard by 43.2% to 48.4%. The maximum weight of 1,000 seeds was observed in the variant with a seeding rate of 400 thousand seeds per hectare, reaching 220.5 grams in 2021 and 218.9 grams in 2022.

The yield of different soybean varieties is determined by the year's conditions and the seeding rate. In 2021, the Hidaka variety had a noticeable advantage over the standard depending

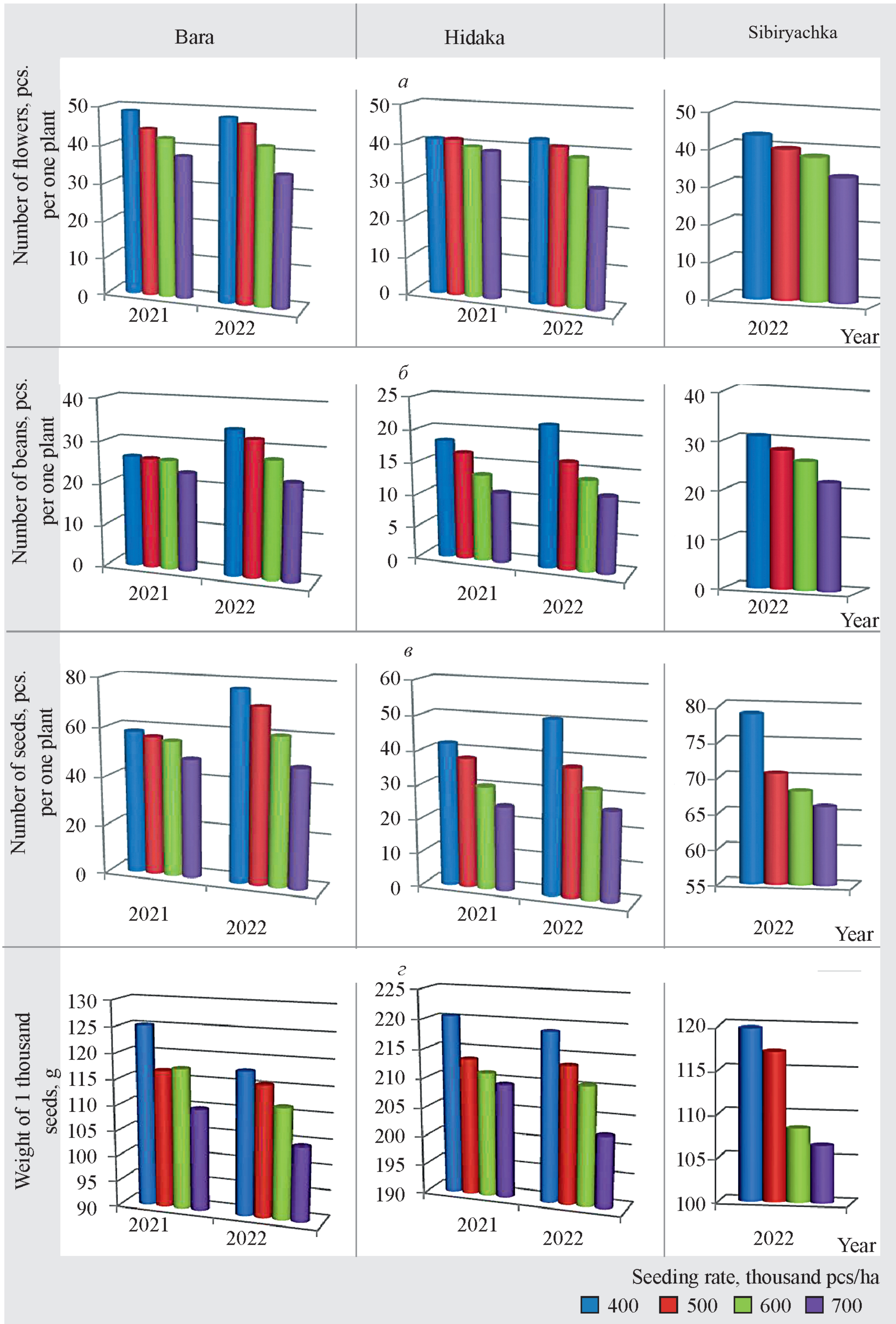

Рис. 1. Влияние нормы высева, условий года и сорта на число цветков (*а*), бобов (*б*), семян (*в*) и массу 1 тыс. семян (*г*)

Fig. 1. Influence of the seeding rate, conditions of the year and the variety on the number of flowers (*а*), beans (*б*), seeds (*в*) and a thousand-seed weight (*г*)

on the seeding rate (see Table 2). The yield of this variety significantly exceeded the standard in the variants with seeding rates of 400 and 500 thousand seeds per hectare. With a seeding rate of 400 thousand seeds per hectare, the yield of the Hidaka variety was higher than the standard by 0.88 tons per hectare, and with a seeding rate of 500 thousand seeds per hectare, it exceeded the standard by 0.85 tons per hectare.

In 2022, the studied varieties realized their biological potential most fully, with yields varying between 3.28 (the Bara variety, seeding rate of 700 thousand seeds per hectare) and 4.18 tons per hectare (Hidaka variety, seeding rate of 400 thousand seeds per hectare). The yield of the Sibiryachka variety significantly exceeded the standard in all experimental variants. The highest yield was recorded for the Hidaka variety with a seeding rate of 400 thousand seeds per hectare, amounting to 4.18 tons per hectare (compared to the standard of 3.52 tons per hectare), resulting in an increase of 18.75% compared to the control.

Табл. 2. Изменение урожайности сои под влиянием нормы высева и сортовой специфики, т/га

Table 2. Change in the soybean yield under the nfluence of the seeding rate and varietal specificity, t/ha

Variety	Seeding rate, thousand pcs/ha			
	400	500	600	700
2021				
Bara	2,68	2,97	3,42	3,21
Hidaka	3,56	3,82	3,51	3,27
LSD_{05}	0,22			
2022				
Bara	3,52	3,96	3,76	3,28
Hidaka	4,18	3,72	3,66	3,32
Sibiryachka	3,68	3,97	3,91	3,75
LSD_{05}	0,14			

Research conducted in a three-factor experiment system (4 × 4 × 2) revealed that the variety factor (A), seeding rate factor (B), and year factor, as well as their first-order interactions, had a significant impact on seed yield at the 0.01% significance level, while the second-order interactions had a 0.05% significance level (see Table 3).

The contribution of the variety factor to the variability of the yield was 29.4%, the agronomic factor (seeding rate) contributed 29.9% (see Fig. 2).

The ecological factor (year conditions) accounted for 26.1% of the variability in seed yield. Pairwise interactions of the variety and seeding rate factors contributed 3.5% of variability, variety and year conditions contributed 6.8%, seeding rate and year conditions contributed 3.3%. The effect of the interaction of all three factors did not exceed 0.7%. Random factors accounted for 0.3% of variability.

Табл. 3. Дисперсионный анализ показателя урожайности (т/га) в системе многофакторного опыта (2021, 2022 гг.)

Table 3. Variance analysis of the yield index (t/ha) in the system of multifactorial experience (2021, 2022)

Dispersion	Sum of squares	Degree of freedom	Mean square	F_{act}	$F_{05\,(01)}$
Variety (A)	5,4712	2	2,7356	107,6	3,09 (4,82)
Seeding rate (B)	8,3528	3	2,7843	109,4	2,70 (3,98)
Year conditions (C)	2,4327	1	2,4327	95,7	3,94 (6,90)
Interaction:					
A : B	1,9613	6	3,269	12,9	2,19 (2,99)
A : C	1,2567	2	0,6282	24,7	3,09 (4,82)
B : C	1,9474	6	0,3079	12,1	2,19 (2,99)
A : B : C	0,4357	6	0,07262	2,86	2,19 (2,99)
Remaining balance	1,6783	66	0,02428	–	–

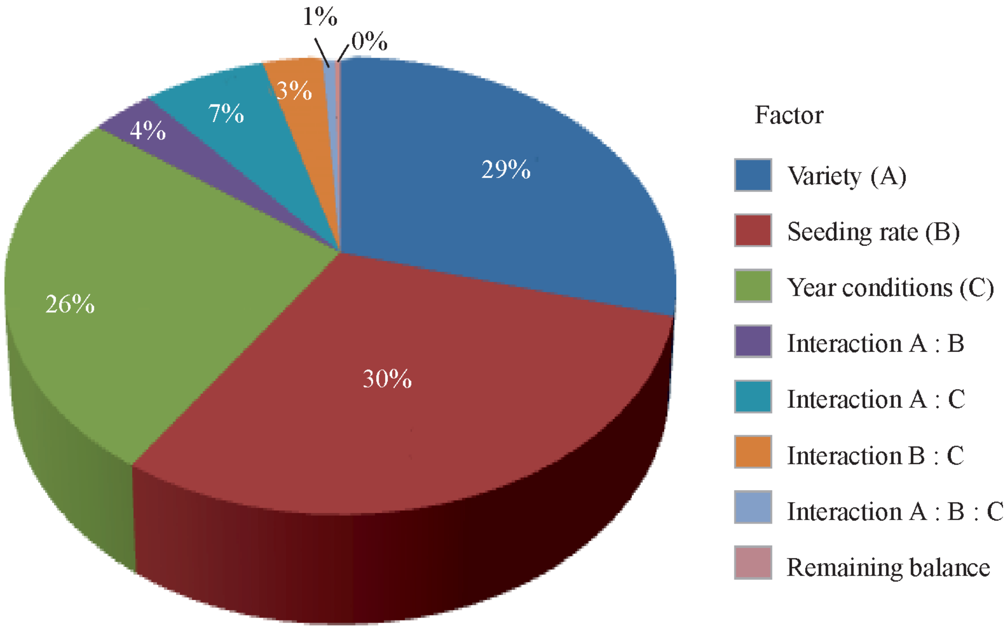

Рис. 2. Вклад изучаемых факторов в развитие признака «урожайность семян» в системе многофакторного опыта (2021, 2022 гг.)

Fig. 2. Contribution of factors to the development of the seed yield trait in the system of multifactorial experience (2021, 2022)

CONCLUSION

The specificity of the variety, year conditions, and seeding rate influenced the growth and development of plants, productivity elements, and the yield of the studied soybean varieties under the conditions of the Moscow region. It was found that as the number of plants per hectare increased, the leaf surface area per plant decreased. The most developed leaf surface was observed in the Bara and Hidaka varieties in the variant with a seeding rate of 400 thousand seeds per hectare in 2021. Intensive photosynthetic activity of the leaves was observed in both years of the study for the Bara variety in all experimental variants.

It was established that the seeding rate has the greatest impact on flower formation. According to the obtained data, the most productive seeding rate is 400 thousand seeds per hectare. With this seeding rate, a higher number of pods per plant was obtained. For the Bara variety, this indicator was 26.3 pods in 2021 and 33.9 pods in 2022. For the Hidaka variety, it was 18.3 and 21.5 pods, respectively, and for the Sibiryachka variety, it was 30.9 pods. A reduction in the seeding rate led to an increase in the weight of 1,000 seeds. Variants with the minimum seeding rate were characterized by high yields. The maximum positive effect on soybean productivity indicators was achieved with the minimum seeding rate of 400 thousand seeds per hectare.

The Bara variety achieved the highest yield at seeding rates of 500–600 thousand seeds per hectare, and the Sibiryachka variety showed a similar trend (based on one-year data). The Hidaka variety, which tends to branch more with lower planting density, had higher yields in variants with seeding rates of 400–500 thousand seeds per hectare.

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