https://doi.org/10.26898/0370-8799-2023-11-4
УДК: 631.524.01
Тип статьи: оригинальная
Type of article: original

НАСЛЕДОВАНИЕ ЦЕННЫХ ПРИЗНАКОВ ПРОДУКТИВНОСТИ ГИБРИДНЫХ КОМБИНАЦИЙ МЕСТНЫХ И ИНОСТРАННЫХ СОРТОВ ОВСА В УСЛОВИЯХ ЗАУРАЛЬЯ

(✉)**Любимова А.В.[1], Ерёмина Д.В.[2]**
[1]*Научно-исследовательский институт сельского хозяйства Северного Зауралья – филиал Федерального исследовательского центра «Тюменский научный центр Сибирского отделения Российской академии наук»*
Тюменская область, п. Московский, Россия
[2]*Государственный аграрный университет Северного Зауралья*
Тюмень, Россия
(✉)e-mail: ostapenkoav88@yandex.ru

Представлены результаты изучения характера наследования ценных признаков гибридов первого поколения, полученных от скрещивания иностранных и отечественных сортов овса в условиях Северного Зауралья. Эксперимент проводили на опытном поле Научно-исследовательского института сельского хозяйства Северного Зауралья в 2019 и 2020 гг. Объектом исследования являлись 18 гибридных популяций F1 и шесть родительских сортов: Талисман, Отрада, Фома, Sang, Solidor и Ensiler. Оценку элементов продуктивности осуществляли согласно методике Всероссийского института генетических ресурсов растений им. Н.И. Вавилова. Для статистической обработки данных использовали методику Б.А. Доспехова. Характер наследования фенотипических признаков определяли по G.M. Beil, R.E. Atkins. Анализ элементов структуры урожая продемонстрировал отсутствие преимущества сортов иностранной селекции перед генотипами, полученными в Северном Зауралье. Установлено, что по озерненности метелки и массе 1000 зерен сорт Отрада не уступает сортам Sang, Solidor и Ensiler, а Фома – превосходит их. Определено, что скрещивания между сортами местной и иностранной селекции имеют высокий процент удачи (42–68%), что обусловливает их перспективность в селекционном процессе. Выявлено, что 50% гибридных комбинаций характеризуются депрессией по признаку «высота растений» – степень фенотипического доминирования в данном случае варьирует от −22,2 до −3,1 ед. Скрещивание Фомы с иностранными сортами обеспечило сверхдоминирование по высоте метелки, ее озерненности и массе 1000 зерен. По степени фенотипического доминирования элементов продуктивности выделены следующие перспективные гибридные комбинации: Ensiler × Отрада, Sang × Отрада, Фома × Sang. У перечисленных комбинаций отбор высокопродуктивных генотипов можно проводить со второго поколения. Осуществлять отбор перспективных линий среди гибридных комбинаций, где одной из родительских форм являлся сорт Фома, рекомендуется в более поздних поколениях. Гибриды первого поколения, полученные от скрещивания сорта Талисман с сортами Ensiler, Sang и Solidor, не имеют преимуществ перед родительскими формами и неперспективны для селекционного процесса.

Ключевые слова: гибридизация, характер наследования, элементы продуктивности, гетерозис, генетическая депрессия, модель сорта

INHERITANCE OF VALUABLE PRODUCTIVITY TRAITS OF HYBRID COMBINATIONS OF LOCAL AND FOREIGN OAT VARIETIES IN THE CONDITIONS OF THE TRANS-URAL REGION

(✉)**Lyubimova A.V.[1], Eremina D.V.[2]**
[1]*Scientific Research Institute of Agriculture for Northern Trans-Ural Region – Branch of the Federal Research Center of the Tyumen Scientific Centre of the Siberian Branch of the Russian Academy of Sciences*
Moskovsky, Tyumen region, Russia
[2]*State Agrarian University of the Northern Trans-Urals*
Tyumen, Russia
(✉)e-mail: ostapenkoav88@yandex.ru

The results of studying the character of inheritance of valuable traits of the first-generation hybrids obtained from crossing foreign and domestic varieties of oats in the conditions of the Northern

Trans-Urals are presented. The experiment was conducted on the experimental field of the Scientific Research Institute of Agriculture for Northern Trans-Ural Region in 2019 and 2020. The object of the study were 18 F1 hybrid populations and 6 parent varieties: Talisman, Otrada, Foma, Sang, Solidor and Ensiler. Productivity elements were evaluated according to the methodology of the N.I. Vavilov All-Russian Institute of Plant Genetic Resources. B.A. Dospekhov's methodology was used for statistical data processing. Inheritance of phenotypic traits was determined according to G.M. Beil and R.E. Atkins. Analysis of the yield structure elements demonstrated the lack of advantage of foreign selection varieties over the genotypes obtained in the Northern Trans-Urals. It has been established that the Otrada variety is not inferior to Sang, Solidor and Ensiler varieties in terms of panicle ear grain content and the thousand-kernel weight, and Foma is superior to them. It has been determined that crosses between the varieties of local and foreign selection have a high percentage of success (42–68%), which makes them promising in the breeding process. It has been revealed that 50% of hybrid combinations are characterized by depression in the trait "plant height" – the degree of phenotypic dominance in this case varies from –22.2 to –3.1 units. Crossing of Foma with foreign varieties ensured overdominance in the panicle height, its grain content and the thousand-kernel weight. According to the degree of phenotypic dominance of the productivity elements, the following promising hybrid combinations have been identified: Ensiler × Otrada, Sang × Otrada, Foma × Sang. In the above combinations, selection of high-yielding genotypes can be carried out from the second generation onwards. It is recommended to select promising lines among hybrid combinations, where one of the parental forms is the Foma variety, in the later generations. Hybrids of the first generation obtained from crossing the Talisman variety with Ensiler, Sang and Solidor varieties have no advantages over the parental forms and are unpromising for the breeding process.

Keywords: hybridization, nature of inheritance, elements of productivity, heterosis, genetic depression, variety model

Для цитирования: *Любимова А.В., Ерёмина Д.В.* Наследование ценных признаков продуктивности гибридных комбинаций местных и иностранных сортов овса в условиях Зауралья // Сибирский вестник сельскохозяйственной науки. 2023. Т. 53. № 11. С. 32–45. https://doi.org/10.26898/0370-8799-2023-11-4

For citation: Lyubimova A.V., Eremina D.V. Inheritance of valuable productivity traits of hybrid combinations of local and foreign oat varieties in the conditions of the Trans-Ural region. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2023, vol. 53, no. 11, pp. 32–45. https://doi.org/10.26898/0370-8799-2023-11-4

Конфликт интересов
Авторы заявляют об отсутствии конфликта интересов.
Conflict of interest
The authors declare no conflict of interest.

Благодарность
Работа выполнена в рамках государственного задания № 122011300103-0 и при поддержке Западно-Сибирского межрегионального научно-образовательного центра мирового уровня.
Acknowledgements
The work was carried out according to the state task No. 122011300103-0 and with the support of the world-class West Siberian Interregional Research and Education Center.

INTRODUCTION

The foundation of any country's food security lies in the adequate provision of agricultural produce, including feed for livestock and poultry farming. Therefore, grain forage crops are currently as significant as wheat, rice, soy, and corn. In the last 70 years, the yield of agricultural crops has increased more than threefold thanks to the implementation of a scientifically based system of agriculture. Such significant achievements in the agro-industrial complex were only possible with the transition to modern intensive varieties, whose genetic potential for productivity is incomparably higher.

According to Rosstat (Russian Federal State Statistics Service), in 2022, the sown area of oats in the Russian Federation was 2.16 million hectares, including 235.5 thousand hectares in the Ural Federal District. To meet the growing needs of livestock and poultry farming, it is

necessary to significantly increase the gross oat harvest. Consequently, an increase in sown areas and enhancement of agricultural crop yields will be required. However, the most fertile fields are currently occupied by strategic or marginal crops, and reducing their sown areas is impractical. Therefore, the expansion of oat sowing areas or other grain forage crops is possible only through the plowing of less fertile lands. Increasing yields through the use of agrochemicals (including mineral fertilizers) is the most promising approach in the modern world. The solution to increasing grain harvest lies in creating new varieties capable of forming high yields and utilizing the bioclimatic potential of the region.

In the State Register of Breeding Achievements, foreign oat varieties account for 10%. These varieties are characterized by high yield and grain quality. Modern domestic oat varieties also possess high potential productivity, almost equal to that of foreign varieties. However, the actual yield in different regions of the country remains quite low, not to mention the quality of the harvested grain. There are many reasons for this, but overall they boil down to non-compliance with cultivation technology and the lack of variety plasticity to a wide range of soil and climatic conditions. According to G.A. Batalova et al.[1], the reason for the low productivity of modern oat varieties also lies in their incorrect zoning by admission regions. One way to solve the problem of low oat yields is to use local breeding varieties as parental forms, which are characterized by good resistance to unfavorable soil and climatic conditions, high ecological plasticity, as well as high-yielding foreign varieties possessing the necessary economically valuable properties (high ear grain content of the panicle and grain size, short-stemmedness, etc.).

A modern variety should effectively realize its genetic potential under various natural and anthropogenic environmental factors, possessing significant resistance to stress of both abiotic and biotic nature [1].

The purpose of the research is to create promising hybrid populations by crossing oats of foreign and domestic breeding, followed by their evaluation for key economically valuable properties.

MATERIAL AND METHODS

The study was conducted at the Research Institute of Agriculture for Northern Trans-Ural Region, in the forest-steppe zone of the Trans-Urals, according to the methodology of state varietal testing[2]. The soil of the experimental site was dark gray forest podzolized, with typical regional morphological characteristics and primary physical-chemical properties [2, 3]. The soil and climatic conditions of the site closely resemble the agricultural zone of the Ural Federal District, allowing for an assessment of the potential of hybrid combinations and oat varieties involved in the breeding work.

Six varieties of local and foreign breeding were used in the experiment (see Table 1). The combinations for crossings were selected based on the principle of eco-geographical remoteness of the parent forms.

Hybridization was conducted in field conditions. During the beginning of the panicle emergence phase (when two to three spikelets appear from the leaf sheath), mechanical castration was performed. The upper and lower spikelets were removed from the panicle, leaving four to six of the most developed spikelets in the middle part. Castration was done in the morning, from 5 to 8 a.m. local time. On the 4th to 5th day, forced pollination was carried out according to the hybridization scheme. Pollen was collected on the day of pollination, from 9 a.m. to 12 p.m. Three mature anthers were placed in each flower. The panicle was then enclosed in a paper isolator. Crossing was carried out on ten panicles of each variety. The seeds of hybrid combinations were sown the following year according to the scheme ♀ – F1 – ♂ in three replications. Ten seeds of parent varieties and hybrids were placed on each

[1] *Batalova G.A., Lisitsyn E.M., Changzhong Ren, Andreev N.P., Tuliakova M.V., Shevchenko S.N., Malco A.M.* Breeding oats in the European North-East of Russia // Achievements of science and technology of AIC, 2016, vol. 30, N 1, pp. 21-24.

[2] Methodology of state variety testing of agricultural crops. Moscow, 1985, Issue 1, 270 p.

Табл. 1. Сорта овса отечественной и иностранной селекции, используемые в гибридизации
Table 1. Oat varieties of domestic and foreign selection used in hybridization

Number in the experiment	Variety	Sort	Country of origin	Source of description
1	Ensiler	*mutica*	USA	4
2	Sang	»	Sweden	4
3	Solidor	»	Germany	4
4	Otrada	»	Russia	5
5	Talisman	»	»	6
6	Foma	»	»	7

row. The distance between the rows was 20 cm, and the sowing depth was 5–6 cm. The sowing period was the second ten-day period of May. Agronomic practices in the experiments were standard for the northern forest-steppe of the Trans-Urals [8].

Phenological observations, assessment of crop condition, and recording of yield structure elements were conducted according to methodological instructions for studying the world collection of barley and oats[3].

The inheritance of traits was calculated using the formula by G.M. Beil, R.E. Atkins:

$$hp = (F1 - MP)/(HP - MP),$$

where *hp* is the degree of phenotypic dominance; *F*1 is the trait expression in F1 plants; *MP* is the average trait expression of both parental forms; *HP* is the most expressed trait of the parental form.

Hybrid grouping according to the degree of phenotypic trait expression was done using the classification by G.M. Beil, R.E. Atkins[4], according to which the following types of gene interactions are possible: $hp > 1$ – heterosis (positive over-dominance); $0.5 < hp < 1.0$ – positive dominance; $-0.5 < hp < 0.5$ – intermediate inheritance; $-1 \leq hp \leq -0.5$ – negative dominance; $hp < -1$ – depression (negative over-dominance).

For statistical analysis of the research results, the method of variance analysis was used in accordance with the methodology of B.A. Dospekhov[5].

RESULTS AND DISCUSSION

The hybridization of domestic and foreign oat varieties was conducted in 2019, a year characterized by favorable weather conditions throughout the entire vegetation period. As a result, 18 hybrid combinations were obtained (see Table 2). The success rate was quite high for oats, varying from 42% (Solidor × Talisman) to 68% (Otrada × Solidor).

It was noted that when using the Ensiler variety as the maternal plant in crossing with local varieties, the formation of hybrid seeds was maximal (61–68%), while using the same variety as the paternal plant resulted in a significantly lower outcome of 51–57% ($F_{fact} > F_{theor}$). The lowest success rate (42–48%) was recorded in the combinations where the Solidor variety was used as the maternal plant. However, when used in combinations with Talisman and Otrada as the paternal plant, the seed setting increased to 60 and 68%, respectively. In the Foma × Solidor combination, the success rate remained low.

The highest seed set (55–68%) was observed in the combinations where local varieties served as maternal plants. However, varietal characteristics were evident: Foma (♀) when pollinated by foreign varieties had a lower seed set (47–51%), while Otrada's rate varied from 55 to 68%.

[3]Methodological guidelines for the study of the world collection of barley and oats. St. Petersburg, 2012, 64 p.

[4]*Beil G.M., Atkins R.E.* Inheritance of guantitative characters in grain sorghum // Iowa State Journal Science, 1965, vol. 39, N 6, pp. 165–179.

[5]*Dospekhov B.A.* Methods of field experiment (with the basics of statistical processing of research results). 5th ed., supplemented and revised. Moscow: Agropromizdat, 1985, 351 p.

Табл. 2. Гибридные комбинации
Table 2. Hybrid combinations

Crossbreeding catalog	Hybrid combination (♀ × ♂)	Percentage of luck
1 × 4	Ensiler × Otrada	65
1 × 5	Ensiler × Talisman	68
1 × 6	Ensiler × Foma	61
2 × 4	Sang × Otrada	54
2 × 5	Sang × Talisman	51
2 × 6	Sang × Foma	60
3 × 4	Solidor × Otrada	45
3 × 5	Solidor × Talisman	42
3 × 6	Solidor × Foma	48
4 × 1	Otrada × Ensiler	57
4 × 2	Otrada × Sang	55
4 × 3	Otrada × Solidor	68
5 × 1	Talisman × Ensiler	56
5 × 2	Talisman × Sang	52
5 × 3	Talisman × Solidor	60
6 × 1	Foma × Ensiler	51
6 × 2	Foma × Sang	47
6 × 3	Foma × Solidor	50

There are many reasons for the reduction in hybrid seed set. Primarily, this includes unsuitable weather conditions: during the flowering period of oats in Siberia, the weather is usually hot and dry, leading to premature pollen sterilization. In our case, hybridization occurred within short periods, neutralizing the weather differences. According to G.L. Petrov and E.Y. Petrova[6], the success of oat hybridization also depends on the anatomical features of the flower structure.

Plant height is an important phenotypic trait used in the breeding of cereal crops. For oats, this trait is significant, as it affects the plants' resistance to lodging [9]. Modern research has shown a direct correlation between short-stemmedness and grain productivity [10]. Therefore, breeders need to balance between resistance to lodging and oat yield.

The average height of the local varieties was 77–80 cm, with significant variation: Otrada ranged from 72 to 98 cm, Talisman from 75 to 85 cm (see Fig. 1). The Foma variety had the smallest height range, from 74 to 80 cm.

Foreign varieties did not significantly differ in height from local genotypes. Average heights were as follows: Ensiler – 82 cm, Solidor – 85 cm, and Sang – 87 cm. However, the range of height variation in the experiment was significantly smaller, being ± 5% of the average values.

The first-generation hybrid populations (F1) exhibited varying heights relative to each other and to the parent forms. The tallest were hybrid combinations 6 × 3; 4 × 1; 4 × 3; 6 × 1; 3 × 6; 2 × 6; 5 × 3; 1 × 6, where the inheritance of this trait followed the pattern of over-dominance (h_p > 1.0). The height of such hybrids ranged from 88 cm (Otrada × Solidor) to 105 cm (Talisman × Solidor), with the degree of phenotypic dominance being 3.4 and 7.8 units, respectively.

Depression, caused by the effect of negative over-dominance (h_p < -1), was noted in F1 of the following hybrid combinations: 1 × 5; 2 × 5; 3 ×5; 5 × 2; 4 × 2; 6 × 2; 5 × 1, which could indicate the expression of the short-stemmedness gene. In the crosses of Ensiler × Talisman and Sang × Talisman, the highest degree of depression was observed: h_p was equal to -5.0 and -3.5 units, respectively. The height of these hybrids was 70 and 78 cm, respectively.

Hybrids obtained by crossing local varieties (♀) with the Sang variety (♂) maintained height at the level of the maternal forms, making them promising for further breeding in the conditions of Western Siberia [11]. A similar effect was noted in combinations 1 × 4 and 2 × 4, where Otrada served as the male parent. The height of

[6]*Petrov G.L., Petrova E.Yu.* Study of flowering biology and pollination methods of oats in the conditions of the Northern Trans-Urals // Natural and Technical Sciences, 2017, N 2 (104), pp. 13-14.

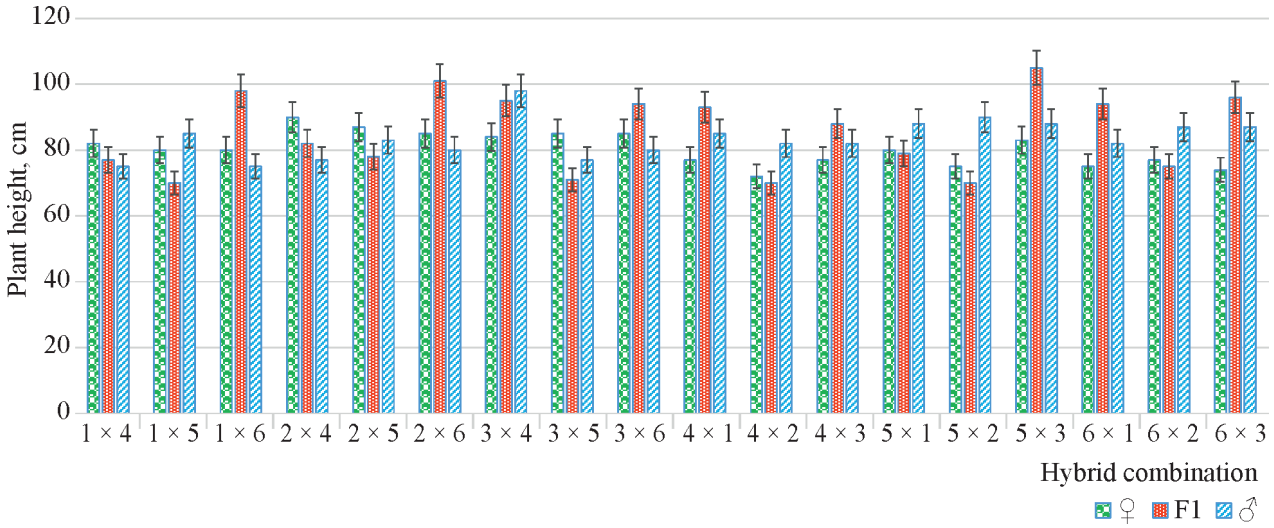


Рис. 1. Высота растений у родительских сортов и гибридов первого поколения при 5%-й погрешности
Fig. 1. Plant height of the parent varieties and hybrids of the first generation of oats at a 5% error limit

these hybrids was 77 and 82 cm, respectively. The degree of phenotypic dominance was −0.4 and −0.2 units, which corresponds to intermediate inheritance and makes these combinations promising for the breeding process.

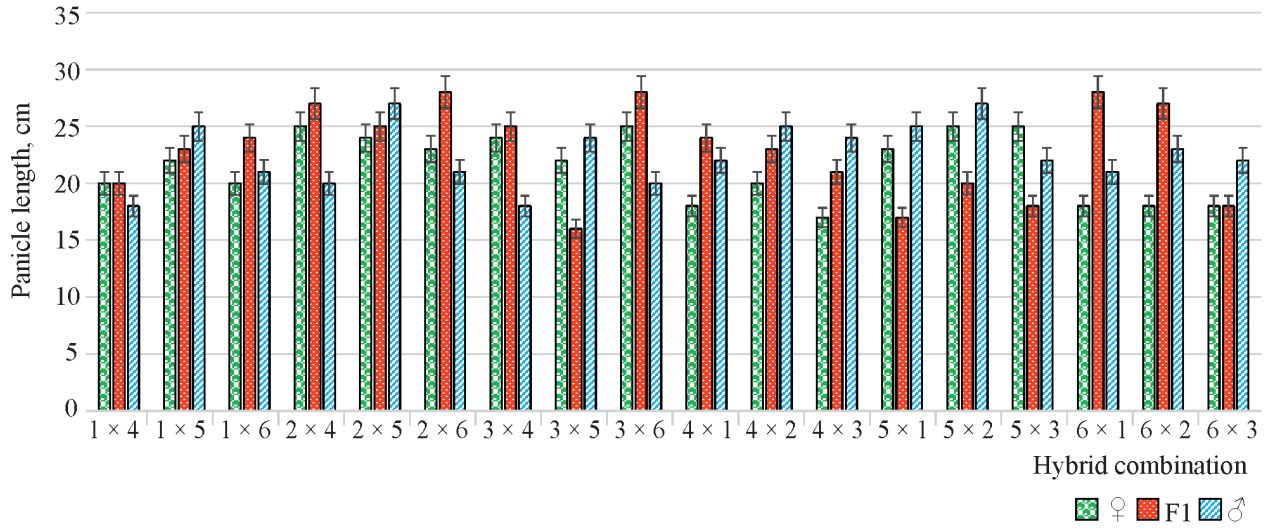
The panicle length of the Talisman variety varied from 23 to 27 cm (average in the experiment – 25 cm), which was the maximum result among the studied local varieties (see Fig. 2). The Otrada and Foma varieties had shorter panicle lengths – from 17 to 20 cm (average in the experiment – 19 cm). The Ensiler variety, in terms of the phenotypic trait "panicle length," was close to Talisman: the indicator ranged from 20 to 25 cm, with an average panicle length in the experiment of 22 cm. The Sang variety recorded the maximum average panicle length of 25 cm, varying from 23 to 27 cm, identical to the local variety Talisman. Solidor differed significantly in panicle length variation – from 18 to 24 cm, which is undesirable for modern intensive varieties. The average panicle length was 21 cm.

The first-generation hybrids obtained in the study exhibited a wide range of panicle lengths. The minimum length (16 cm) was observed in the hybrids of Solidor × Talisman, where the effect of negative over-dominance was manifested. A similar expression of depression (h_p < -1) was noted in the hybrid combinations 3 × 5; 5 × 1; 5 × 2; 5 × 3; 6 × 3. Hybrids with a heterosis effect (h_p > 1), whose panicle length significantly exceeded that of the parent varieties ($F_{fact} > F_{theor}$), included combinations 1 × 4; 3 × 4; 2 × 4; 4 × 1; 3 × 6; 6 × 2; 6 × 1; 2 × 6; 1 × 6. The greatest phenotypic over-dominance effect was observed in hybrid combinations where Foma was one of the parents – 6 × 1; 2 × 6 and 1 × 6, with panicle lengths ranging from 24 to 28 cm.

Intermediate inheritance of panicle length was identified in hybrids resulting from crosses of Ensiler × Talisman, Sang × Talisman, Otrada × Solidor, and Otrada × Sang. The panicle length of these hybrids varied from 21 to 25 cm, which was comparable to the Talisman variety.

M.N. Fomina et al. [11] have proven that oat yield is closely correlated with the “ear grain content of the main panicle” indicator. Therefore, breeders pay significant attention to this trait in creating new varieties for Western Siberia [12].

The average ear grain content of the main panicle of Talisman in the experiment was 33 pcs., with a variation range of 28–38 pcs. The modern variety Otrada showed higher values: the ear grain content of the main panicle reached 35–42 pcs., with an average value of 39 pcs. The maximum ear grain content of the main panicle among the local varieties was recorded for Foma – 43 pcs., with a value range from 38 to 47



Puc. 2. Длина метелки у родительских сортов и гибридов первого поколения при 5%-й погрешности
Fig. 2. Panicle length of the parent varieties and hybrids of the first generation of oats at a 5% error limit

pcs., which was significantly higher than Otrada (LSD_{05} = 3 pcs.).

Foreign selection varieties in the forest-steppe conditions of Zauralye did not have an advantage over local genotypes in terms of ear grain content in the panicle. The minimum grain count was noted for Ensiler and Sang – 34 and 32 grains, respectively. These varieties also stood out for their large range of variation in grain count in the panicle – 8 and 12 grains, respectively. The Solidor variety was at the level of Otrada in terms of ear grain content, both in average value and in the range of variation.

Regarding the "ear grain content of the main panicle" trait, more than half of the hybrids showed over-dominance ($h_p > 1$). The maximum degree of phenotypic dominance was noted in combinations 2 × 6; 3 × 4 and 6 × 3 (see Fig. 3). The ear grain content of the main panicle of these hybrids varied from 44 to 57 pcs. The hybrid population resulting from the cross of Ensiler and Foma was particularly interesting, as it managed to maintain the ear grain content of the panicle at the level of the local variety. The degree of phenotypic dominance was equal to 1.0 units.

First-generation hybrids of combinations 5 × 1; 3 × 5; 2 × 5; 5 × 3, and 4 × 3 were characterized by negative over-dominance ($h_p < 1.0$). The maximum effect of genetic depression was recorded in hybrids of Talisman × Ensiler, Solidor × Talisman, and Sang × Talisman, with h_p values of -4.31 and -3.91, respectively. It's important to note the combination 4 × 3, where Otrada and Solidor were used as parent forms: in this case, the ear grain content of the panicle remained at the level of the local variety.

First-generation hybrids obtained from crossing Otrada and the foreign variety Sang (4 × 2; 2 × 4) were characterized by positive dominance ($0.5 < h_p < 1.0$) and intermediate inheritance of the trait ($-0.5 < h_p < 0.5$), allowing their inclusion in the breeding process from the second generation [13].

Similarly, the combination 5 × 2, where Talisman was used as the female parent, produced hybrids that had the same ear grain content as the parent forms.

Grain weight per panicle, a trait directly correlated with productivity, is always considered in developing models for cereal and legume varieties [14, 15]. Among the studied oat varieties, Talisman had the lowest grain weight per panicle (1.0 g) with good uniformity of values (see Fig. 4).

The difference between the minimum and maximum was 0.2 g. Otrada and Foma had higher values – 1.5 and 1.8 g, respectively (LSD_{05} = 0.2). The average grain weights per panicle for the foreign varieties varied slightly – from 1.4 (Sang) to 1.6 g (Ensiler). They also differed in a larger range of values – a variation range of 0.5 g.

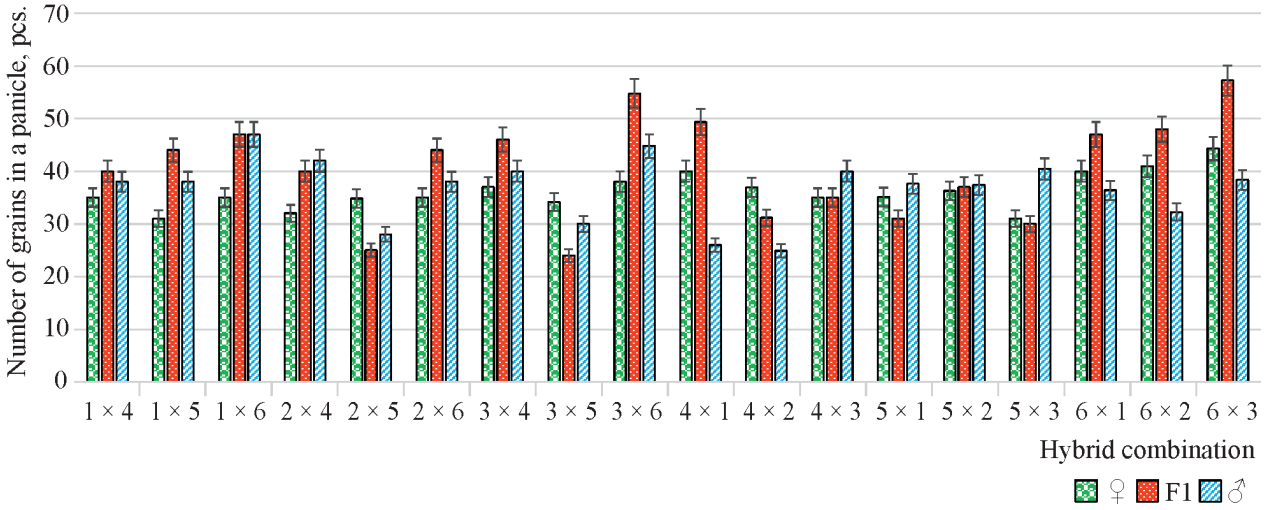


Рис. 3. Озерненность главной метелки у родительских сортов и гибридов первого поколения при 5%-й погрешности

Fig. 3. Grain content of the main panicle of parent varieties and hybrids of the first generation of oats at a 5% error limit

Inheritance of the "grain weight per main panicle" trait in 11 out of 18 F1 hybrid populations followed a pattern of over-dominance – h_p ranged from 1.0 (2 × 5; 3 × 4) to 7.0 (1 × 6). It's noteworthy that true heterosis was observed when crossing any foreign variety with Foma: the degree of phenotypic dominance varied from 3.0 to 7.0 units.

Additionally, three hybrid combinations (4 × 3; 5 × 3; 3 × 5) with negative dominance were identified, where h_p ranged from −1.00 to −2.12 units. In these combinations, the variety Solidor was used as one of the parental forms. Negative dominance was also observed in hybrids from combinations 5 × 1; 1 × 5, and 5 × 2, where the local variety Talisman was one of the parental forms.

In oat breeding, it's important to use genotypes with large grains. According to several scientists[7] [16, 17], grain size and its geometri-

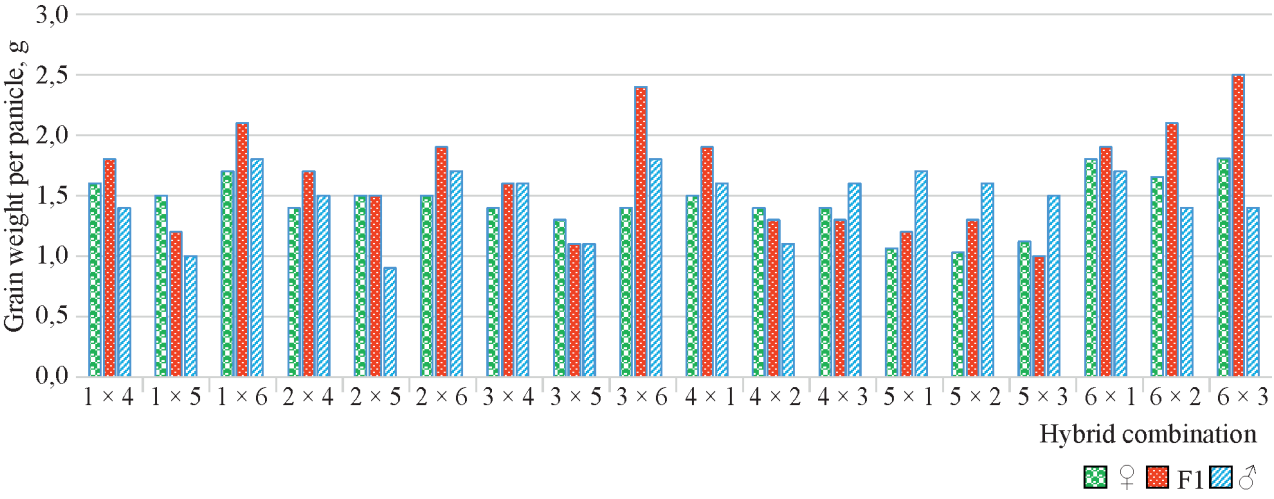


Рис. 4. Средняя масса зерна с метелки у родительских форм и гибридов первого поколения

Fig. 4. Average grain weight per panicle in parental forms and hybrids of the first generation

[7] *Ivanova Yu.S., Fomina M.N., Loskutov I.G.* Source material for the creation of high-protein varieties of oats in the zone of the Northern Trans-Urals // Proceedings on applied botany, genetics and breeding, 2017, vol. 178, N 2, pp. 38-47.

cal characteristics are 70-75% dependent on the genotype. The weight of 1000 grains not only determines the feed value of a variety but also its food value for humans. Moreover, cultivating large-grain oat varieties significantly reduces harvest and sorting losses [18]. In risky farming conditions, sowing oats with a weight of 1000 grains more than 35 g ensures uniform germination, helping to mitigate the negative impact of abiotic factors [19, 20]. This is particularly relevant for the Ural Federal District, where oat acreage is gradually increasing.

The variety Talisman used in the experiment was characterized by a low weight of 1000 grains (see Fig. 5). On average, this indicator was 29.1 g, varying from 27.3 to 30.4 g. Although Talisman had a consistent weight of 1000 grains, Otrada, despite having a higher weight (35.3 g), had a wider range between its minimum and maximum values.

Among the local varieties, Foma was the largest-grained – the average weight of 1000 grains was 40.7 g with minor variation (39.5–42.0 g). Such outstanding indicators characterize Foma as an intensive type variety.

The grain of foreign varieties was larger than that of the local genotypes. In the forest-steppe conditions of the Trans-Urals, the Solidor variety had an average weight of 1000 grains of 36.9 g, varying from 36.9 to 38.1 g. Sang and Ensiler belong to large-grained oat varieties: in their case, the average weight of 1000 grains was 43.4 and 46.2 g. The identified variability of values is considered low, so these varieties can be classified as intensive types.

First-generation hybrids, which showed clear signs of heterosis and a high degree of phenotypic dominance ($h_p > 1.0$), had a very large weight of 1000 grains – ranging from 43.7 (6 × 3; 3 × 6) to 48.7 g (6 × 2; 2 × 6). These hybrid combinations involved the local variety Foma and two foreign varieties – Sang and Solidor.

During hybridization, populations (4 × 3; 3 × 4; 5 × 1; 5 × 2) were obtained, which exhibited the effect of negative overdominance ($h_p < -1$). Their weight of 1000 grains was initially lower than the values of the parent forms – from 27.4 to 33.9 g. Maximum depression was noted in the offspring of the varieties Otrada and Solidor. In the hybridization of Otrada (♀) with Solidor and Sang (♂), hybrids with intermediate inheritance were obtained, caused by the additive effect of genes: h_p was −0.4 and 0.18 respectively. Hybrid combinations 1 × 5; 5 × 3; 3 × 5 were characterized by negative dominance – the weight of 1000 grains of first-generation hybrids was close to the paternal parental forms (Talisman and Solidor).

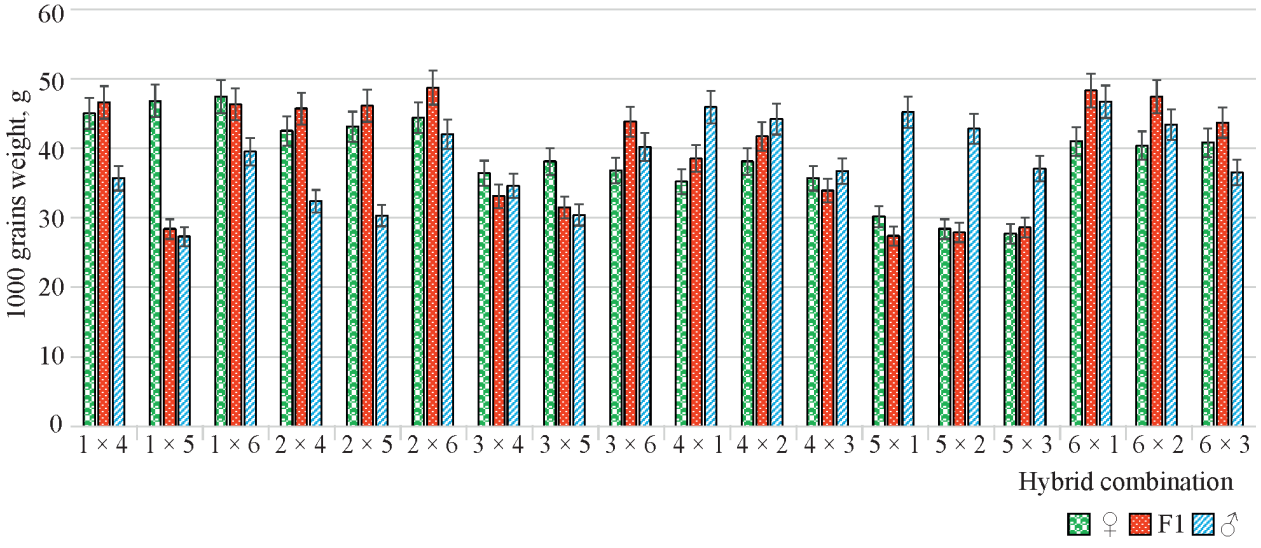


Рис. 5. Масса 1000 зерен у родительских сортов и гибридов первого поколения при 5%-й погрешности

Fig. 5. Thousand kernel weight of the parent varieties and hybrids of the first generation of oats at a 5% error limit

The conducted studies showed that the most valuable combinations in oat breeding are those where the first-generation hybrids dominate traits related to productivity and plant height.

According to the correlation analysis of the degree of phenotypic dominance, the main productivity indicators of oats (weight of 1000 grains, ear grain content per panicle, weight of grain per panicle) do not have a close dependence on plant height – $r = 0.19…0.33$ (see Table 3).

Therefore, the selection of hybridological material can be guided by productivity elements, taking into account their potential short-stemmed shape. Hybrids of the first generation obtained by crossing foreign and local oat varieties were selected based on a complex of traits. The most promising for the selection process were: Ensiler × Otrada (1 × 6), Sang × Otrada (2 × 4), Foma × Sang (6 × 2). These hybrid combinations had a lower height compared to the parental forms and predominantly showed a heterosis effect on productivity elements. Hybrid populations from the crossings Solidor × Foma (3 × 6), Foma × Ensiler (6 × 1), Foma × Solidor (6 × 3), Solidor × Foma (3 × 6) and Sang × Foma (2 × 6) were significantly taller than the parental forms, but also characterized by positive overdominance of yield structure elements, making them promising for breeding in the forest-steppe conditions of the Trans-Urals.

Other first-generation hybrids obtained during the study can be considered as sources of individual economically valuable traits. The least valuable were the hybrids obtained by crossing Otrada (♀) with the Solidor (♂) variety, as well as Talisman with all foreign varieties.

Табл. 3. Степень фенотипического доминирования по некоторым показателям продуктивности у гибридов овса первого поколения

Table 3. The degree of phenotypic dominance for some indicators of productivity in the hybrids of the first-generation oats

Crossbreeding catalog	Hybrid combination	Plant height, cm	Panickle length, cm	Number of grains in a panickle, pcs.	Grain weight per panicle, g	Weight of 1000 grains, g
1 × 6	Ensiler × Otrada	–0,4	1,0	2,3	3,0	11,0
1 × 5	Ensiler × Talisman	–5,0	–0,3	2,7	–0,2	–0,3
1 ×4	Ensiler × Foma	8,2	7,0	1,0	7,0	8,8
2 × 4	Sang × Otrada	–0,2	1,8	0,6	5,0	2,0
2 × 5	Sang × Talisman	–3,5	–0,3	–1,9	1,0	–10,3
2 × 6	Sang × Foma	7,4	6,0	5,0	3,0	11,7
3 × 4	Solidor × Otrada	0,6	1,3	5,0	1,0	2,5
3 × 5	Solidor × Talisman	–2,5	–7,0	–3,9	–1,0	–8,7
3 × 6	Solidor × Foma	4,6	2,2	4,0	4,0	2,9
4 × 1	Otrada × Ensiler	3,0	2,0	2,3	6,1	3,7
4 × 2	Otrada × Sang	–1,4	0,2	0,0	0,3	–0,4
4 × 3	Otrada × Solidor	3,4	0,1	–1,0	–2,1	1,9
5 × 1	Talisman × Ensiler	–1,3	–7,0	–4,3	–0,6	–3,0
5 × 2	Talisman × Sang	–1,7	–6,0	0,3	–0,1	–4,6
5 × 3	Talisman × Solidor	7,8	–3,7	–1,2	–1,6	–0,1
6 × 1	Foma × Ensiler	4,4	5,7	4,9	3,0	2,1
6 × 2	Foma × Sang	–1,4	2,6	2,6	4,5	8,2
6 × 3	Foma × Solidor	2,4	–1,0	5,3	4,4	3,7

CONCLUSION

It was established that the foreign and local varieties used in the study cross well and produce viable seeds. The overall success rate was 45-65%. The most successful crosses occurred when using Ensiler and Otrada as the female parent – 65% and 60%, respectively. The lowest success rate was noted when using Solidor and Foma as the female parent variety – 45% and 49%, respectively. As a result, the most promising hybrid combinations for further breeding work were identified: Ensiler × Otrada, Sang × Otrada, Foma × Sang, where selection of highly productive genotypes can be carried out from the second generation. The degree of phenotypic dominance of these hybrids varied in the range of 3.0 to 5.0, corresponding to positive overdominance. The number of grains per main panicle was 40-48, with a weight of 1000 grains being 45.7-47.4 g. In combinations such as Ensiler × Foma, Foma × Ensiler, Solidor × Foma, Sang × Foma, selection would be more effective in later generations. The hybrids obtained exhibited a pronounced heterosis effect only for individual yield structure elements. The weight of grain per main panicle in these hybrids varied from 1.9 to 2.4 g, and the number of grains from 44 to 55. Crossbreeding Talisman with foreign varieties (Ensiler, Sang, Solidor) is not promising, as the F1 hybrids obtained do not demonstrate an effect of improving economically valuable properties in the first generation. In hybrid combinations where Talisman was one of the parental forms, negative overdominance was observed for the main productivity indicators: number of grains, weight of grain per plant, and weight of 1000 grains. Other hybrid oat combinations can be used only in breeding for individual traits and properties.

СПИСОК ЛИТЕРАТУРЫ

1. *Сапега В.А., Турсумбекова Г.Ш.* Урожайность и адаптивность сортов яровой пшеницы различных групп спелости в условиях лесостепи Северного Зауралья // Вестник Новосибирского государственного аграрного университета. 2022. № 3 (64). С. 67–75. DOI: 10.31677/2072-6724-2022-64-3-67-75.
2. *Каюгина С.М., Еремин Д.И.* Физико-химические свойства серых лесных почв восточной окраины Зауральского плато // Журнал Сибирского федерального университета. Серия: Биология. 2022. Т. 15. № 4. С. 471–490. DOI: 10.17516/1997-1389-0399.
3. *Каюгина С.М., Еремин Д.И.* Гумусовое состояние темно-серых лесных почв Северного Зауралья // Вестник Красноярского государственного аграрного университета. 2022. № 10 (187). С. 35–42. DOI: 10.36718/1819-4036-2022-10-35-42.
4. *Ахадова Э.Т., Баташева Б.А., Блинова Е.В., Лоскутов И.Г.* Каталог мировой коллекции ВИР. СПб., 2019. Вып. 897: Овес: агробиотехнологическая характеристика образцов в условиях Дагестанского филиала ВИР. 36 с. DOI: 10.30901/978-5-907145-27-6.
5. *Любимова А.В., Еремин Д.И., Мамаева В.С., Брагин Н.А., Белоусов С.А., Брагина М.В., Кочнева Д.А., Таутекенова А.К.* Каталог биохимических паспортов сортов овса посевного сибирской селекции // Вестник Красноярского государственного аграрного университета. 2022. № 5 (182). С. 73–83. DOI: 10.36718/1819-4036-2022-5-73-83.
6. *Любимова А.В., Иваненко А.С.* Овес в Тюменской области: монография. Тюмень, 2021. 172 с.
7. *Наумов И.В., Полковская М.Н.* Анализ сортоиспытаний ярового овса в Иркутской области // Вестник Иркутской государственной сельскохозяйственной академии. 2021. № 102. С. 35–44. DOI: 10.51215/1999-765-2021-102-35-44.
8. *Перфильев Н.В., Вьюшина О.А.* Влияние систем обработки на агрофизические параметры темно-серой лесной почвы в Северном Зауралье // Земледелие. 2023. № 1. С. 27–31. DOI: 10.24412/0044-3913-2023-1-27-31.
9. *Моисеева М.Н., Еремин Д.И.* Проблема полегания и урожайности овса при различном уровне минерального питания в лесостепи Зауралья // Известия Оренбургского государственного аграрного университета. 2022. № 4 (96). С. 46–50.

10. *Loskutov I.G.* Advances in cereal crops breeding // Plants. 2021. Vol. 10. N 8. P. 1705. DOI: 10.3390/plants10081705.
11. *Фомина М.Н., Иванова Ю.С., Брагин Н.А., Брагина М.В.* Качество зерна перспективных линий овса на заключительном этапе селекционного процесса в условиях Северного Зауралья // Достижения науки и техники АПК. 2023. Т. 37. № 3. С. 34–38. DOI: 10.53859/02352451_2023_37_3_34.
12. *Полонский В.И., Герасимов С.А., Сумина А.В., Зюте С.А.* Адаптивный потенциал образцов овса по химическим и физическим характеристикам зерна // Труды по прикладной ботанике, генетике и селекции. 2022. Т. 183. № 1. С. 57–75. DOI: 10.30901/2227-8834-2022-1-57-75.
13. *Lyubimova A.V., Tobolova G.V., Eremin D.I., Loskutov I.G.* Dynamics of the genetic diversity of oat varieties in the Tyumen region at avenin-coding loci // Vavilov Journal of Genetics and Breeding. 2020. Vol. 24. N 2. P. 123–130. DOI: 10.18699/VJ20.607.
14. *Таутекенова А.К., Мамаева В.С., Еремин Д.И.* Модель сорта как основа маркерной селекции овса посевного для Западной Сибири (аналитический обзор) // Эпоха науки. 2022. № 31. С. 188–194. DOI: 10.24412/2409-3203-2022-31-188-194.
15. *Казак А.А., Логинов Ю.П.* Научные основы разработки модели сорта яровой мягкой пшеницы для Западной Сибири // Вестник Курганской государственной сельскохозяйственной академии. 2019. № 3 (31). С. 9–12.
16. *Еремин Д.И., Любимова А.В., Таутекенова А.К., Кочнева Д.А.* Элементы продуктивности и характер их наследования гибридами F1 овса ярового (*Avena sativa* L.) в Западной Сибири // Достижения науки и техники АПК. 2022. Т. 36. № 7. С. 25–30. DOI: 10.53859/02352451_2022_36_7_25.
17. *Иванова Ю.С., Фомина М.Н., Пай О.А.* Морфологические особенности и геометрическая характеристика зерна голозерных образцов овса // Молекулярная генетика, микробиология и вирусология. 2019. Т. 37. Спецвыпуск. С. 29.
18. *Тулякова М.В., Баталова Г.А., Пермякова С.В.* Адаптивный потенциал генофонда овса пленчатого по массе 1000 зерен // Зерновое хозяйство России. 2021. № 5 (77). С. 3–8. DOI: 10.31367/2079-8725-2021-77-5-3-8.
19. *Снигирева О.М., Ведерников Ю.Е.* Влияние сроков сева и уборки на урожайность и посевные качества семян ярового овса Сапсан // Аграрная наука Евро-Северо-Востока. 2019. Т. 20. № 3. С. 230–237. DOI: 10.30766/2072-9081.2019.20.3.230-237.
20. *Еремин Д.И., Моисеева М.Н., Любимова А.В.* Генетические и агротехнологические особенности формирования посевных качеств овса при различном уровне минерального питания // Аграрный вестник Урала. 2022. № 8 (223). С. 27–38. DOI: 10.32417/1997-4868-2022-223-08-27-38.

REFERENCES

1. Sapega V.A., Tursumbekova G.Sh. Yield and adaptability of spring wheat varieties of different maturity groups under forest-steppe conditions of the Northern Trans-Urals. *Vestnik Novosibirskogo gosudarstvennogo agrarnogo universiteta = Bulletin of NSAU*, 2022, no. 3 (64), pp. 67–75. (In Russian). DOI: 10.31677/2072-6724-2022-64-3-67-75.
2. Kayugina S.M., Eremin D.I. Physicochemical properties of gray forest soils on the eastern outskirts of the Trans-Ural Plateau. *Zhurnal Sibirskogo federal'nogo universiteta. Seriya: Biologiya = Journal of Siberian Federal University. Biology*, 2022, vol. 15, no. 4, pp. 471–490. (In Russian). DOI: 10.17516/1997-1389-0399.
3. Kayugina S.M., Eremin D.I. Dark gray forest soils humus state of the Northern Trans-Urals. *Vestnik Krasnoyarskogo gosudarstvennogo agrarnogo universiteta = Bulletin of KrasSAU*, 2022, no. 10 (187), pp. 35–42. (In Russian). DOI: 10.36718/1819-4036-2022-10-35-42.
4. Akhadova E.T., Batasheva B.A., Blinova E.V., Loskutov I.G. *Catalogue of the VIR global collection*. St. Petersburg, 2019, Is. 897: Oats: agrobiological characteristics of accessions for the environments of the Dagestan branch of VIR, 36 p. (In Russian). DOI: 10.30901/978-5-907145-27-6.
5. Lyubimova A.V., Eremin D.I., Mamaeva V.S., Bragin N.A., Belousov S.A., Bragina M.V.,

Kochneva D.A., Tautekenova A.K. Siberian oat varieties' biochemical passports catalog. *Vestnik Krasnoyarskogo gosudarstvennogo agrarnogo universiteta = Bulletin of KrasSAU*, 2022, no. 5 (182), pp. 73–83. (In Russian). DOI: 10.36718/1819-4036-2022-5-73-83.
6. Lyubimova A.V., Ivanenko A.S. *Oats in the Tyumen region*. Tyumen, 2021, 172 p. (In Russian).
7. Naumov I.V., Polkovskaya M.N. Analysis of variety testing of spring oats in the Irkutsk region. *Vestnik IrGSKhA = Vestnik IrGSHA*, 2021, no. 102, pp. 35–44. (In Russian). DOI: 10.51215/1999-765-2021-102-35-44.
8. Perfil'ev N.V., V'yushina O.A. Influence of tillage systems on agrophysical parameters of dark grey forest soil in the Northern Trans-Urals. *Zemledelie = Zemledelie*, 2023, no. 1, pp. 27–31. (In Russian). DOI: 10.24412/0044-3913-2023-1-27-31.
9. Moiseeva M.N., Eremin D.I. The problem of lodging and productivity of oats at different levels of mineral nutrition in the forest-steppe of the Trans-Urals. *Izvestiya Orenburgskogo gosudarstvennogo agrarnogo universiteta = Izvestia Orenburg State Agrarian University*, 2022, no. 4 (96), pp. 46–50. (In Russian).
10. Loskutov I.G. Advances in cereal crops breeding. *Plants*, 2021, vol. 10, no. 8, P. 1705. DOI: 10.3390/plants10081705.
11. Fomina M.N., Ivanova Yu.S., Bragin N.A., Bragina M.V. Grain quality of promising oat lines at the final stage of the breeding process in the conditions of the northern Trans-Urals. *Dostizheniya nauki i tekhniki APK = Achievements of Science and Technology of AIC*, 2023, vol. 37, no. 3, pp. 34–38. (In Russian). DOI: 10.53859/02352451_2023_37_3_34.
12. Polonskiy V.I., Gerasimov S.A., Sumina A.V., Zute S.A. Adaptive potential of oat accessions in the context of their chemical and physical grain characteristics. *Trudy po prikladnoi botanike, genetike i selektsii = Proceedings on applied botany, genetics and breeding*, 2022, vol. 183, no. 1, pp. 57–75. (In Russian). DOI: 10.30901/2227-8834-2022-1-57-75.
13. Lyubimova A.V., Tobolova G.V., Eremin D.I., Loskutov I.G. Dynamics of the genetic diversity of oat varieties in the Tyumen region at avenin-coding loci. *Vavilov Journal of Genetics and Breeding*, 2020, vol. 24, no. 2, pp. 123–130. DOI: 10.18699/VJ20.607.
14. Tautekenova A.K., Mamaeva V.S., Eremin D.I. The model of the variety as the basis of marker selection of oats for Western Siberia (analytical review). *Epokha nauki = Era of Science*, 2022, no. 31, pp. 188–194. (In Russian). DOI: 10.24412/2409-3203-2022-31-188-194.
15. Kazak A.A., Loginov Yu.P. Scientific areas of spring soft wheat for Western Siberia. *Vestnik Kurganskoi GSKhA = Bulletin of the Kurgan State Agricultural Academy*, 2019, no. 3 (31), pp. 9–12. (In Russian).
16. Eremin D.I., Lyubimova A.V., Tautekenova A.K., Kochneva D.A. Elements of productivity and the nature of their inheritance by F1 hybrids of spring oat (Avena sativa L.) in Western Siberia. *Dostizheniya nauki i tekhniki APK = Achievements of Science and Technology of AIC*, 2022, vol. 36, no. 7, pp. 25–30. (In Russian). DOI: 10.53859/02352451_2022_36_7_25.
17. Ivanova Yu.S., Fomina M.N., Pai O.A. Morphological features and geometric characteristics of grain of naked oat samples. *Molekulyarnaya genetika, mikrobiologiya i virusologiya = Molecular genetics, microbiology and virology*, 2019, vol. 37, special edition, p. 29. (In Russian).
18. Tulyakova M.V., Batalova G.A., Permyakova S.V. Adaptive potential of the hulled oats gene pool according to 1000-grain weight. *Zernovoe khozyaistvo Rossii = Grain Economy of Russia*, 2021, no. 5 (77), pp. 3–8. (In Russian). DOI: 10.31367/2079-8725-2021-77-5-3-8.
19. Snigireva O.M., Vedernikov Yu.E. Influence of sowing and harvesting time on productivity and sowing qualities of spring oat Sapsan seeds. *Agrarnaya nauka Evro-Severo-Vostoka = Agricultural Science Euro-North-East*, 2019, vol. 20, no. 3, pp. 230–237. (In Russian). DOI: 10.30766/2072-9081.2019.20.3.230-237.
20. Eremin D.I., Moiseeva M.N., Lyubimova A.V. Genetic and agrotechnological features of the formation of sowing qualities of oats at different levels of mineral nutrition. *Agrarnyi vestnik Urala = Agrarian Bulletin of the Urals*, 2022, no. 8 (223), pp. 27–38. (In Russian). DOI: 10.32417/1997-4868-2022-223-08-27-38.

ИНФОРМАЦИЯ ОБ АВТОРАХ

(✉)**Любимова А.В.,** кандидат биологических наук, заведующая лабораторией; **адрес для переписки:** Россия, 625501, Тюменская область, п. Московский, ул. Бурлаки, 2; e-mail: ostapenkoav88@yandex.ru

Ерёмина Д.В., кандидат сельскохозяйственных наук, доцент

AUTHOR INFORMATION

(✉)**Anna V. Lyubimova,** Candidate of Science in Biology, Laboratory Head; **address:** 2, Burlaki St., Moskovsky, Tyumen Region, 625501, Russia; e-mail: ostapenkoav88@yandex.ru

Diana V. Eremina, Candidate of Science in Agriculture, Associate Professor

Дата поступления статьи / Received by the editors 08.08.2023
Дата принятия к публикации / Accepted for publication 25.09.2023
Дата публикации / Published 15.12.2023