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ECOLOGICAL-GEOGRAPHIC APPROACHES TO THE STUDY OF GENETIC DIVERSITY OF BARLEY AND OAT FROM THE VIR COLLECTION

© I.G. Loskutov, L.Yu. Novikova, O.N. Kovaleva, N.N. Ivanova, E.V. Blinova, G.V. Belskaya

Federal Research Center "N.I. Vavilov All-Russian Institute of Plant Genetic Resources", St. Petersburg, Russia

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❀ Under conditions of climate change, the assessment of the stability of genotypes is of particular importance. To conduct directed selection of genotypes with a narrow or broad reaction rate, it is necessary to assess their stability already in the early stages of breeding. The aim of the study was to study the stability of breeding significant traits of oat and barley samples in contrasting ecological and geographical conditions. 25 oat samples and 25 barley samples were studied over 3 years under contrasting conditions in St. Petersburg and the Tambov Region. Varieties are characterized by average values of economically valuable traits and genotype regression coefficients on the influence of the bi environment according to Eberhart and Russell. The most sensitive to a change in the ecological and geographical situation were the durations of the germination—heading, germination—harvest periods and grain yield. These characters varied to a greater extent depending on the cultivation conditions than on the genotype. According to regression coefficients for environmental conditions, significant differences in genotypes were only in yield. Contrasting groups of varieties were distinguished by regression coefficients on environmental conditions, genotypes with high productivity. The durations of "germination—heading", "germination—harvest", the plant height reacted to the change in the environment the same in different varieties. The duration of the growing season was determined by the sum of effective temperatures above 15 °C. The reduction of the growing season in both crops was 3 days with an increase in the sum of effective temperatures above 15 °C by 100 °C.

❀ **Keywords:** oats; barley; ecological-geographical tests; ecological plasticity; agroclimatic regression model.

ЭКОЛОГО-ГЕОГРАФИЧЕСКИЕ ПОДХОДЫ К ИЗУЧЕНИЮ ГЕНЕТИЧЕСКОГО РАЗНООБРАЗИЯ ЯЧМЕНЯ И ОВСА ИЗ КОЛЛЕКЦИИ ВИР

© И.Г. Лоскутов, Л.Ю. Новикова, О.Н. Ковалёва, Н.Н. Иванова, Е.В. Блинова, Г.В. Бельская

ФГБНУ «ФИЦ Всероссийский институт генетических ресурсов растений им. Н.И. Вавилова», Санкт-Петербург

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❀ В условиях климатических изменений особое значение приобретает оценка стабильности генотипов. Для ведения направленной селекции генотипов с узкой или широкой нормой реакции необходима оценка их стабильности уже на ранних этапах селекции. Цель исследования — изучение стабильности селекционно значимых признаков образцов овса и ячменя в контрастных эколого-географических условиях. В течение 3 лет в контрастных погодных условиях Санкт-Петербурга и Тамбовской обл. были изучены 25 образцов овса и 25 — ячменя. Сорта охарактеризованы средними значениями хозяйственно ценных признаков и коэффициентами регрессии генотипа на влияние среды bi по Эберхарту и Расселу. Наиболее чувствительными к смене эколого-географической обстановки оказались продолжительности периодов «всходы—колошение», «всходы—созревание» и урожайность зерна. Эти признаки в большей степени варьировали в зависимости от условий возделывания, чем от генотипа. По коэффициентам регрессии на условия среды достоверные различия генотипов были только по урожайности. Выделены контрастные группы сортов по коэффициентам регрессии на условия среды, генотипы с высокой урожайностью. Периоды «всходы—колошение» и «всходы—созревание», а также высота растения реагировали на изменение среды одинаково у разных сортов. Продолжительность вегетационного периода определялась суммой эффективных температур выше 15 °С. Сокращение вегетационного периода у обеих культур составило 3 сут при увеличении суммы эффективных температур выше 15 °С на 100 °С.

❀ **Ключевые слова:** овес; ячмень; эколого-географические испытания; экологическая пластичность; агроклиматическая регрессионная модель.

INTRODUCTION

The traditional direction of investigations conducted in the Federal Research Center N. I. Vavilov All-Russian Institute of Plant Genetic Resources (VIR) is large-scale geographic experiments [1]. By organizing geographic oriented evaluation, N.I. Vavilov et al. first sought to determine probable geographic limits of mutability and spread of agricultural plants; their results laid the foundation of practical actions aimed at regulating sowings in the country. Scientists sought to trace the dependence of individual genotype mutability on ecological and geographical factors. Geographic experiments aimed to determine how morphological and physiological traits change, identify the characteristics of plant chemistry, analyse the traits that are conservative and suitable for taxonomic goals, and examine how environment and heredity are correlated with each other [2].

Currently, under the climate change conditions, an estimation of genotype stability has become especially valuable [3]. Strengthened ecological firmness is considered the most important condition to realize the potential productivity growth of agricultural crops [4–6]. To maintain directed breeding of genotypes with narrow or wide reaction ranges to a certain set of environments, scientists require information concerning general and specific adaptability [7]. Adaptive breeding considers genotype–environment interactions. Selection in certain conditions may not ensure genotype advantages in other conditions, so we must have information on genotypes and environments at early stages of breeding [7–9].

In this respect, studies on contrasting ecological and geographical conditions involving great diversity of accessions of different origins, which are base material for the breeding of agricultural crops, are critical [10, 11]. The whole system of studying accessions from the global collection of VIR is based on a geographic principle. The net of experiment stations, where the accessions undergo 3-year studies, is located in various ecological–geographical zones in our country. Such genotypes with valuable traits are singled out based on the results of 3 years of studies [12].

To evaluate the adaptability of varieties, scientists evaluate and characterize varieties in contrasting environmental conditions (years and locations) to differentiating ability [5, 6]. This technique allows them to evaluate the varieties by average value of a sign and by sensitivity to environmental conditions, which are under independent genetic control and relatively independent themselves [5, 13]. Investigations on contrasting ecological and geographical conditions allow analysts to not only determine average characteristics but also to distinguish genotypes of a wide habitat with general adaptability.

The aim of this work was to study accessions of oat and barley from the VIR global collection under contrasting ecological and geographical conditions and to evaluate the genotypes on the basis of the stability of traits important for breeding.

MATERIALS

Objects of studies were 25 accessions of oat and 25 accessions of barley of various ecological and geographical origins from the Federal Research Center N. I. Vavilov All-Russian Institute of Plant Genetic Resources (VIR) global collection. Studies were held in a field with contrasting ecological and geographical conditions of Pushkin (Saint Petersburg) and Ekaterinino (Tambov region) branches of VIR. Studies on accessions of spring barley and oat by morphological, economic, and biological characteristics in accordance with *Methodic directions on studying and storage of the global collection of barley and oat* [14]. Standards for studies on oat were zoned in the Leningrad region variety Privet (k-14787, Moscow region) and in the Tambov region Horizon (k-12113, Ukraine). Standards for studies on barley were zoned in the Leningrad region variety of spring barley Belogorsky (k-22089, Leningrad region) and in the Tambov region Dvoran (k-19913, the Czech Republic).

The following valuable characteristics were studied: duration of the period germination–heading (days), duration of period germination–harvest (days), plant height (cm), 1000 grains weight (g), grain productivity from 1 m^2 (g), resistance to lodging (score), and resistance to illnesses (score) [14].

Soil and climate conditions

Soils of the experiment field of the Pushkin branch of VIR (PB) are sod-podzolic, loamy, sandy-loam, well, or medium cultured with neutral or weakly acidic reaction. Soils of the Ekaterinino branch of VIR (EB) were leached chernozems (black soil) of medium loamy constitution and acidity close to neutral.

Climate conditions of the region where PB is located are characterized by transition of sea to temperate continental climate. The sum of active temperatures is 1600 °C–2000 °C. The average yearly amount of precipitation is 500–600 mm, and 65%–75% of the precipitation falls during the warm season.

Climate of the Tambov region where EF is located is characterized as sharply continental. The sum of active temperatures is 2300 °C–2600 °C. The yearly amount of precipitation is 500–550 mm, and 70%–75% of it falls during the warm season.

Studies of the oat and barley accessions on the PB fields were conducted from 2013 to 2017 (Fig. 1). The weather conditions differed considerably in the years of studies. In 2013, they were favorable for the growth and development of barley during the vegetation period. The air temperature during all vegetation stages exceeded average long-term values. The high air temperature combined with high humidity caused abundant precipitation. The abundance of moisture led to increased plant height. In 2014, the period from germination to heading (May–June) occurred in warm and humid weather with a redundant amount of precipitation. The second stage of vegetation from heading to harvest coincided with hot dry weather. The amount of precipitation in July was three times less than normal, thereby influencing the quality and quantity of the obtained cereals. Thus, the weather conditions of 2015 were favorable for the growth and development of crops. The air temperature did not exceed the long-term average. Sufficient amounts of heat and moisture favored filling grains.

The weather conditions of 2016 did not differ considerably from long-term average. The weather was warm, and the amount of precipitation was sufficient for good development of plants. Redundant moisture provoked the development of panicle blight, lodging of some accessions, and complicated harvesting.

The year 2017 considerably differed from the long-term average. Deficiency in warmth in the beginning and middle of vegetation lengthened the vegetation period. The temperature in August was the highest for many years. Nevertheless, abundant precipitation delayed harvesting. The weather conditions were conducive to fungal diseases.

On the EB fields, the accessions of oat and barley were studied from 2016 to 2018 (Fig. 1). Sowing was conducted at the optimal time, namely, in the end of April (April 25–29). In 2016, the vegetation period coincided with high temperature and abundant precipitation. 2017 was favorable for plant growth and development. Planting was conducted in warm weather with sufficient soil moisture. The weather conditions in 2018 were characterized by above-average air temperature and uneven precipitation. Planting was conducted in warm weather in the end of April, when the soil was humid. The Tambov

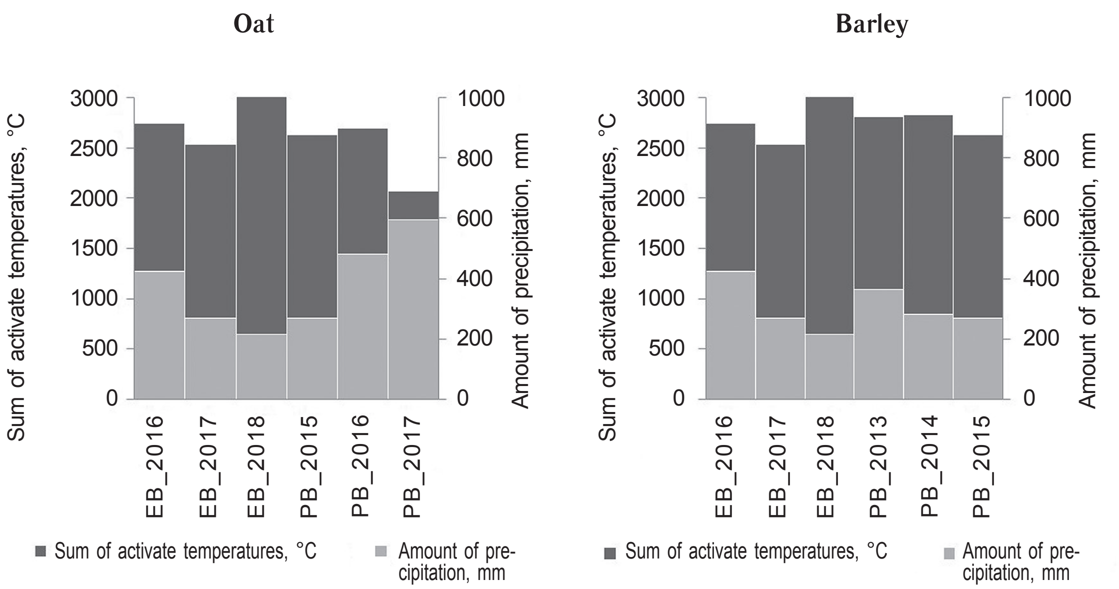

Fig. 1. Agrometeorological conditions of ecological and geographical trials of accessions

region belongs to a zone of insufficient moisture, so the years of abundant precipitation (2016 and 2017) brought richer grain crops than typically observed.

METHODS

Objects of studies were breeding valuable characteristics of oat and barley accessions; they included duration of periods germination—heading and germination—harvest, plant height, 1000 grains weight, and productivity from 1 m^2 [14]. The influence of factors such as geographical location, and environment (geographical location × year) via analysis of variance in the Statsoft Statistica 13.3 was investigated. According to the method of S.A. Eberhart and W.A. Russell [15, 16] there were calculated the interaction genotype × environment, where "environment" refers to six combinations of geographical sight × year. The varieties were characterized by average indices of economically valuable traits and indicators of plasticity (regression coefficient of genotype to environment = b_i). Remarkable differences in plasticity indicators for both cereals were obtained only for productivity. Genotypes of the upper quartile of the productivity distribution were considered the best based on productivity. Quartiles of the plasticity distribution served as contrasting plasticity groups. Regression models of the duration of periods germination—heading and germination—harvest were built for both cereals. The significance level was set at 5%.

RESULTS

Genotype characteristics of oat and barley at two investigation sites

There was revealed a set of reliable differences between genotype characteristics of oat and barley at 2 investigation sites on the basis of data from 3 years of observations. Compared with PB, the germination—heading period was reliably 2 days (p = 0.005) longer, the germination—harvest period was 5 days (p = 0.000) shorter, and the grain yield from 1 m^2 increased to 371 g (p = 0.000) for oat on the fields of EB. No reliable differences were fixed in average plant height (p = 0.825) and 1000 grains weight (p = 0.499). EB showed lower middle score of resistance to lodging (8.4) than PB (8.8). In 2016, 2017, and 2018, the fungal disease Helminthosporium was registered at EB (middle scores of 7, 8, and 8, respectively). In 2016 and 2017, crown rust was registered at EB (6 and 8 points, respectively). At PB in 2015, 2016, and 2017, Helminthosporium (7, 8, and 6 points, respectively), stem rust (5, 8, and 9 points, respectively), and barley yellow dwarf virus (7, 9, and 9 points, respectively) were registered [14].

Compared with PB, barley at EB exhibited a germination—heading period that was 5 days longer (p = 0.000), germination—harvest period that was 6 days longer (p = 0.000), plant height that was 6 cm smaller (p = 0.007), and productivity that was 308 g higher (p = 0.000). 1000 grains weight did not differ between PB and EB (p = 0.164). Barley resistance to lodging at the observed sites did not differ, and the average score was 8.2. At EB, Helminthosporium was registered in 2016 (average of 6 score) and 2017 (average of 7 score) [14].

Each genotype in studies was investigated under 6 conditions (environments) for 3 years at 2 sites. The environmental conditions were contrasting (Table 1, Fig. 2, and Fig. 3). The environmental factors remarkably influenced each studied trait.

The highest average productivity of both cereals was registered in 2017 at EB, whereas the lowest for oat and barley at PB was registered in 2016 and 2014, respectively.

Investigation of varieties plasticity

There were calculated indices of plasticity and stability of the investigated agrobiological indicators and F-criterion to evaluate the significance of factors such as genotype and environment (attachment 1). Attachments 2 and 3 show the average values and standard errors for all characteristics investigated. Significant differences between genotypes were registered for all breeding valuable traits, except barley productivity. In reactions to the environmental conditions, on the contrary, no significant differences were revealed for most traits, except productivity of both cereals and 1000 grains weight of barley. Coefficient b_i, which characterizes the reaction of genotype productivity to environmental condition changes, is given in attachments 2 and 3.

There were also calculated the percentage of dispersion for the factors investigated: genotype, environment, interaction genotype × environment, and residual error. For traits such as duration of the period germination—heading and germination—harvest, the

Table 1

Characteristics of the study environment (location × year)

Environment	Duration of germination–heading, days	Duration of germination–harvest, days	Plant height, cm	1000 grains weight, g	Grain yield from 1 m², g
Oat					
EB_2016	51.6 ± 0.6	79.0 ± 0.7	105.5 ± 4.5	31.6 ± 1.2	532.0 ± 44.9
EB_2017	50.6 ± 0.8	86.2 ± 0.6	117.8 ± 4.7	37.7 ± 0.9	963.4 ± 61.4
EB_2018	47.8 ± 0.9	74.2 ± 0.6	79.6 ± 3.6	31.1 ± 0.6	575.7 ± 34.5
PB_2015	46.6 ± 0.5	85.8 ± 0.5	95.2 ± 4.1	38.5 ± 1.1	322.2 ± 22.4
PB_2016	44.2 ± 0.6	80.1 ± 0.7	101.0 ± 3.5	32.4 ± 1.0	236.6 ± 13.9
PB_2017	52.9 ± 0.7	88.7 ± 1.3	109.2 ± 3.5	31.5 ± 1.0	398.3 ± 26.2
Average	48.9 ± 0.4	82.3 ± 0.5	101.4 ± 1.9	33.8 ± 0.5	504.7 ± 24.4
LSD_{05}	1.9	2.2	11.0	2.7	103.8
Barley					
EB_2016	50.0 ± 0.6	77.5 ± 0.6	82.7 ± 2.7	51 ± 0.8	450.6 ± 29.8
EB_2017	52.9 ± 0.7	89.0 ± 0.5	88.6 ± 1.4	57.2 ± 1	903.2 ± 34.1
EB_2018	48.1 ± 0.4	74.2 ± 0.6	70.5 ± 1.2	46.0 ± 0.5	667.4 ± 23.6
PB_2013	45.6 ± 1.0	70.2 ± 0.4	78.5 ± 2.3	53.6 ± 0.5	317.1 ± 18.5
PB_2014	48.1 ± 0.8	79.2 ± 0.9	90.1 ± 1.9	45.3 ± 0.9	223.2 ± 15.9
PB_2015	41.6 ± 0.6	71.8 ± 0.7	91.6 ± 2.6	51.5 ± 0.6	554.0 ± 15.7
Average	47.7 ± 0.4	77.0 ± 0.6	83.7 ± 1.0	50.8 ± 0.5	519.3 ± 20.8
LSD_{05}	2.0	1.8	5.9	2.2	66.6

Note. LSD_{05} is the least significant difference for 5% level of significance.

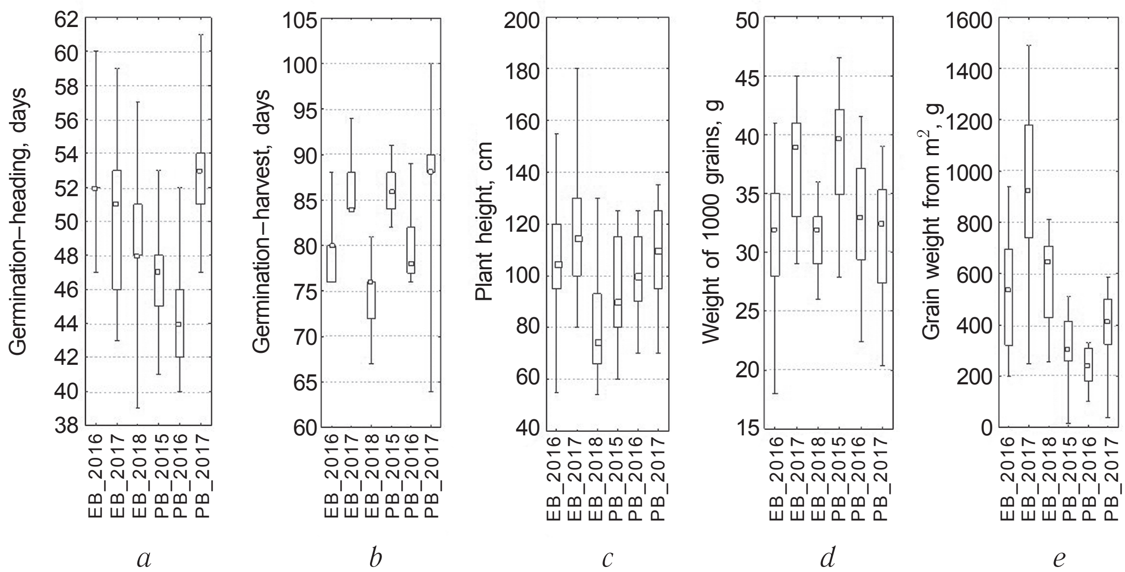

Fig. 2. Agrobiological data for 25 accessions of oat. Minimum, maximum, median, and quartiles are shown: *a* – germination–heading; *b* – germination–harvest; *c* – plant height; *d* – 1000 grains weight; *e* – grain yield from 1 m²

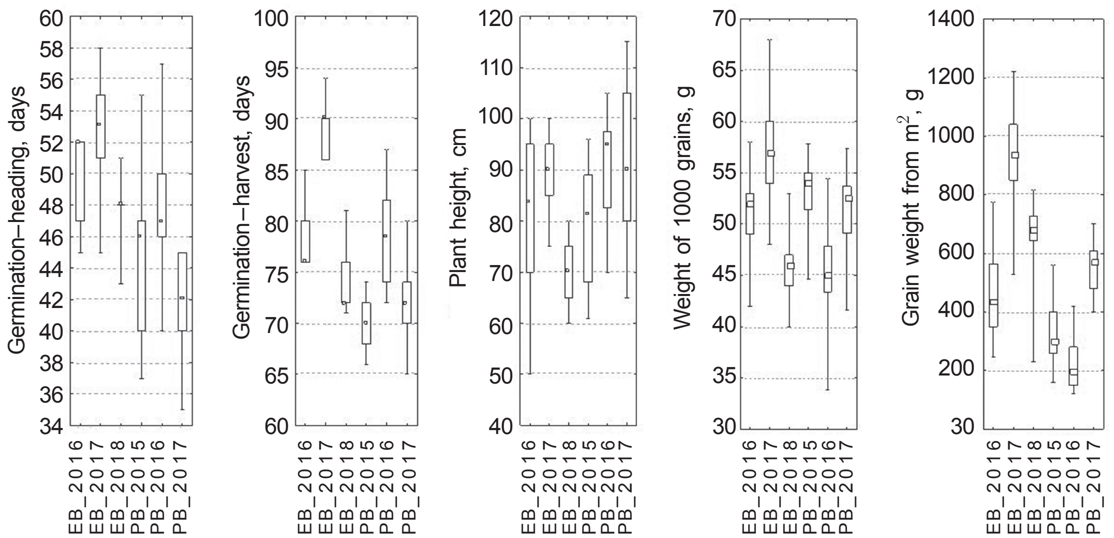

Fig. 3. Agrobiological data for 25 accessions of barley. Minimum, maximum, median, and quartiles are shown: *a* — germination—heading; *b* — germination—harvest; *c* — plant height; *d* — 1000 grains weight; *e* — grain yield from 1 m²

largest contribution to variance was made by differences in environments, i.e., site and year of investigation. The contribution of conditions of growing for oat and barley in the variability of the traits was as follows: 43.7% and 52.1% for the duration of the period germination—heading, respectively, and 62.1% and 79.7% for the duration of the period germination—harvest, respectively. At the same time, the differences in b_i were not significant, and all genotypes reacted similarly. The data obtained proved the results of analysis of long-term observations of the standard cultivars of oat and barley [17], which showed similar reaction in duration of vegetation and plant height to weather—climate changes.

Plant height was found to be more dependent on genotype than on growth conditions. The contribution of genotype was 54.9% for oat and 36.8% for barley. Varieties of both cereals did not differ in terms of b_i. Thus, analysis of variance confirmed the uniformity of the reaction of plant height to the growth conditions.

The 1000 grains weight did not differ between the investigation sites, but the contribution of the environment was more valuable than that of genotype for barley. Accessions differed in their reaction to the environment ($F = 2.103$ with $F_{05} = 1.628$). The environment contributed 55.8% of variability to this trait, whereas the genotype contributed 18.2%. The probable reason was contrasting reactions to weather condition changes in 2017 and 2018 at EB. Analysis of data on oat accessions showed the contrary: the contribution of the environment was less (28.5%) than that of the genotype (51.5%).

Productivity varied more depending on the environment than on genotype: the contribution of the environment for oat was 62.4%, whereas that for barley was 78.6%.

Characteristics of the varieties

According to yield plasticity, varieties of the intensive type were differ manifested themselves better under favorable conditions ($b_i > 1$). Such genotypes are better in the narrow range of favorable environments but decrease productivity when they deviate from the narrow optimum zone [5, 7, 16]. Extreme groups, namely, the lower and upper quartiles of distribution of regression coefficients, were marked (Table 2).

In the oat accessions, b_i varied from 0.2 to 1.8. The lower quartile of plasticity embraced 6 varieties with $b_i \leq 0.7$, whereas the upper quartile encompassed 6 varieties with $b_i \geq 1.3$. Stability of a variety is often associated with low productivity [16]. Nevertheless, among the singled-out stable accessions of oat, some varieties had a set of positive traits in comparison with the average in the sampling: shortened period germination—harvest and large productivity for Z 0585 (k-15521, China, 81 days, 567.7 g, $b_i = 0.5$) and Oberon (k-15513, Germany, 80 days, 592.3 g, $b_i = 0.7$), high 1000 grains

Table 2

Oat and barley cultivars distinguished by low or high coefficients of yield response to environmental changes

Number of VIR catalog	Cultivar name	Origin	Germination–heading. days	1000 grains weight. g	Grain yield from 1 m². g	b_i – regression coefficient
O a t						
Stable cultivars						
15440	Piband	Russia, Leningrad region	87.7 ± 3.1	29.4 ± 1.1	294.7 ± 79.3	0.19
15524	Bai yan 7	China	85.0 ± 2.5	34.8 ± 1.4	473.7 ± 98.5	0.31
15521	Z 0585	China	80.8 ± 1.4	32.7 ± 1.1	567.7 ± 71.7	0.54
15513	Oberon	Germany	79.8 ± 2.3	37.0 ± 1.5	592.3 ± 94.8	0.65
15519	Din yan 3	China	83.8 ± 2.0	26.0 ± 2.0	330.2 ± 82.7	0.71
15507	Buggy	Germany	84.2 ± 3.7	31.3 ± 2.5	457.0 ± 100.2	0.72
Plastic cultivars						
15509	Flocke	Germany	82.2 ± 2.8	38.9 ± 1.6	588.5 ± 152.6	1.35
15520	Din yan 4	China	82.5 ± 2.3	28.9 ± 2.1	411.2 ± 161.1	1.39
15499	Vilensky	Sakha	83.8 ± 2.3	31.8 ± 2.4	529.7 ± 165.4	1.43
15502	Zhitomirsky	Ukraine	84.7 ± 2.8	37.9 ± 2.1	644.7 ± 162.9	1.54
15504	Svitanok	Ukraine	76.8 ± 3.2	37.6 ± 2.3	636.2 ± 177.2	1.59
15508	Carron	Germany	81.2 ± 2.7	36.9 ± 1.9	623.3 ± 201.3	1.81
B a r l e y						
Stable cultivars						
31322	Stratus	Poland	77.8 ± 2.6	51.7 ± 2.5	473.8 ± 71.8	0.40
31241	Quench	Denmark	80.0 ± 3.6	47.8 ± 1.4	507.2 ± 56.3	0.47
31320	Sylphide	France	77.2 ± 3.0	48.6 ± 2.5	508.3 ± 75.8	0.68
31170	Calcule	Germany	81.0 ± 3.4	47.1 ± 1.5	455.3 ± 79.1	0.73
31321	Serval	Poland	78.7 ± 3.0	50.1 ± 2.3	458.2 ± 82.4	0.74
31169	Evergreen	Denmark	80.2 ± 2.7	51.4 ± 2.0	507.5 ± 89.9	0.80
Plastic cultivars						
31315	Susyn	Kazakhstan	76.0 ± 3.1	51.2 ± 2.3	604.7 ± 130.7	1.18
31135	Saule	Kazakhstan	74.0 ± 2.8	47.4 ± 2.3	571.3 ± 126.7	1.21
31325	Wiebke	Germany	78.2 ± 3.2	53.1 ± 4.0	570.0 ± 133.3	1.24
31136	Medikum 108	Kazakhstan	74.0 ± 2.7	50.3 ± 1.8	486.2 ± 134.5	1.32
31317	Zhan	Kazakhstan	77.2 ± 3.1	50.2 ± 1.6	603.8 ± 146.5	1.42
31316	Akzhol	Kazakhstan	74.2 ± 3.2	54.7 ± 2.8	600.3 ± 154.8	1.51

weight for Bai yan 7 (k-15524, China, 1000 grains weight = 34.8 g, $b_i = 0.3$). The leader among plastic varieties was the naked variety Svitanok (k-15504, Ukraine), which had a shorter duration of vegetation period (77 days), higher grain yield from 1 m² (636.2 g), and $b_i = 1.6$ compared with the average values.

In barley accessions, the regression coefficient varied from 0.4 to 1.5. Among the investigated genotypes with low regression coefficient, there were no accessions with high productivity, but 2 varieties had high 1000 grains weight: Stratus (k-31322, Poland, 1000 grains weight = 52 g, $b_i = 0.4$) and Evergreen (k-31169, Denmark,

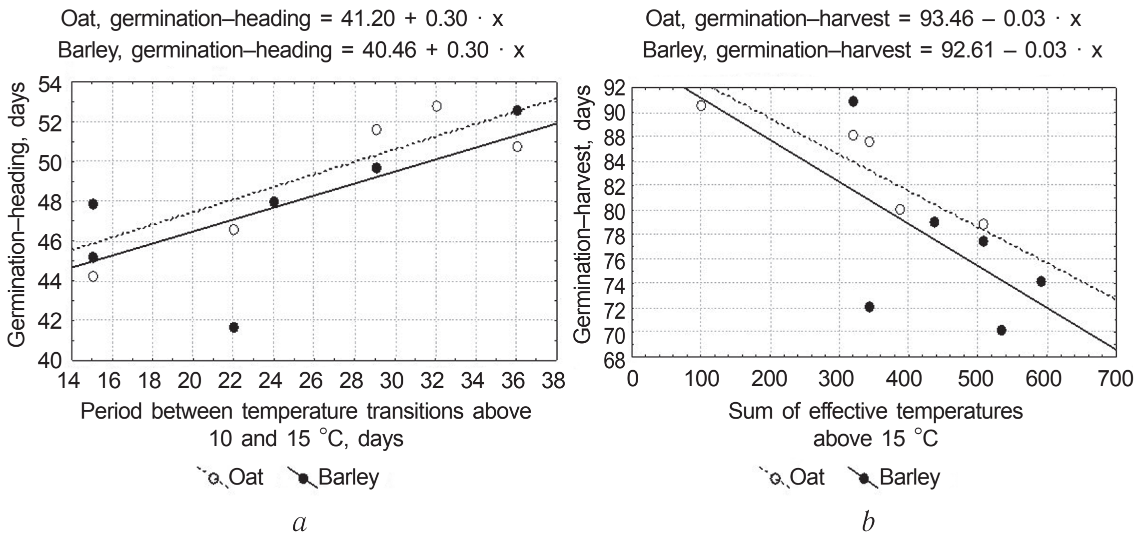

Fig. 4. Agrometeorological dependence of duration of vegetation periods for oat and barley: *a* — germination—heading on duration of the period between dates of stable transition of temperatures above 10 °C and 15 °C; *b* — germination—harvest on the sum of effective temperatures above 15 °C

1000 grains weight = 51 g, b_i = 0.8). Four of the 6 accessions with high coefficient of productivity reaction to environmental conditions b_i were characterized by high productivity, and 2 varieties had a shorter vegetation period, greater 1000 grains weight, and higher productivity than the average: Susyn (k-31315, Kazakhstan, vegetation period = 76 days, 1000 grains weight = 51 g, grain yield from 1 m^2 = 604.7 g, b_i = 1.2) and Akzhol (k-31316, Kazakhstan, vegetation period = 74 days, 1000 grains weight = 55 g, grain yield from 1 m^2 = 600.3 g, b_i = 1.5).

Correlation of agrobiological indicators with weather conditions

To estimate the weather and climate factors, there were calculated mean values of each trait for each of the cereals in 6 trials (environment index) and correlation coefficients with average monthly characteristics and generalized indicators: the sum of temperatures above 10 °C and 15 °C and durations of periods between dates of temperature transition upper these limits. We have previously identified dependencies with characteristics of periods between the dates of stable transition of temperatures above 10 °C and 15 °C. The conditions of the experiment were contrasting, so we disclosed a set of reliably strong correlations. The 1000 grains weight and the grain yield from 1 m^2 had no reliable connections with the investigated weather and climate characteristics. Durations of inter-phase periods and total vegetation period were the most thermosensitive of all the tested characteristics.

Duration of the period germination—heading for oat was positively correlated with the duration of the spring period between the dates of stable transition of temperatures over 10 °C and 15 °C ($r = 0.84$); duration of the vegetation period was negatively correlated with the temperature in July ($r = -0.89$) and sum of effective temperatures higher than 15 °C ($r = -0.93$, Fig. 4). As shown by the regression equations of traits influenced by the environment, the reaction rates of the investigated accessions of oat and barley were similar. This finding agreed with the results of analysis of variance.

For barley, the duration of the vegetation period was negatively correlated with average June temperatures ($r = -0.88$) but positively correlated with the duration of the period of 10 °C—15 °C in spring ($r = 0.88$).

The plant height for oat was positively correlated with the duration of the period of 10 °C—15 °C in spring ($r = 0.86$). The plant height for barley was negatively correlated with the sum of effective temperatures higher than 15 °C ($r = -0.88$).

Resistance to lodging for oat was positively correlated with the plant height ($r = 0.84$) and duration of the vegetation period ($r = 0.85$). Meanwhile, correlations with these indicators were lower for barley than for oat.

CONCLUSIONS

The sampling sites and contrasting weather conditions allowed us to obtain remarkable differences in all investigated traits, except 1000 grains weight and plant height for oat.

The conducted analysis of variance of plasticity of the genotypes according to Eberhart and Russell [15] showed that the traits most sensitive to changes in ecological and geographical environment were as follows: duration of the period germination–heading, duration of the period germination–harvest, and grain productivity. The contribution of the growth conditions to trait variability was as follows: 43.7% and 52.1% for germination–heading for oat and barley, respectively; 62.1% and 79.7% for germination–harvest for oat and barley, respectively; and 62.4% and 78.6% for productivity for oat and barley, respectively. These traits varied in high degree depending on the growth conditions than on genotype. The plant height in the investigated accessions was dependent more on genotype than on the growth conditions, specifically 54.9% for oat and 36.8% for barley. The 1000 grains weight for oats was determined mainly by the genotype peculiarities (51.5%), whereas that for barley was mainly due to the environment (55.8%).

Of all the selected traits, the genotypes of both cereals differed only in grain productivity plasticity, as evidenced by the regression coefficient to the environmental conditions. The plant height, duration of the period germination–heading and germination–harvest reacted to the environmental changes the same in different varieties. This result agreed with our previous investigation on long-term variability of these traits. The regression coefficient of 1000 grains weight to changes in environmental conditions differed for varieties of barley but not for varieties of oat.

There were distinguished groups of genotypes with heightened and lowered plasticity. Varieties of heightened plasticity were recommended for growth in a wide range of ecological and geographical conditions, whereas varieties of lowered plasticity were suitable in a narrow range of conditions close to those of EB and PB in 2017 with high levels of heat and moisture.

Some stable genotypes of oat exhibited shorter germination–harvest period and higher grain productivity then the average in the sampling; these genotypes were Z 0585 (k-15521, China, 81 days, 567.7 g, $b_i = 0.5$) and Oberon (k-15513, Germany, germination–harvest period = 80 days, grain productivity = 592.3 g, $b_i = 0.7$). Variety Bai yan 7 demonstrated a high 1000 grains weight (k-15524, China, 1000 grains weight = 34.8 g, $b_i = 0.3$). The plastic genotypes generally showed high productivity. In particular, the naked variety Svitanok (k-15504, Ukraine) had a short vegetation period (77 days) and heightened grain productivity from 1 m^2 (636.2 g) with the regression coefficient $b_i = 1.6$.

The regression coefficient for the studied barley accessions varied from 0.4 to 1.5. Among accessions with low regression coefficient, there were no varieties of high productivity, but 2 varieties had high 1000 grains weight: Stratus (k-31322, Poland, 52 g, $b_i = 0.4$) and Evergreen (k-31169, Denmark, 51 g, $b_i = 0.8$). Among genotypes with high coefficient of productivity reaction to the environmental conditions, four were characterized by high productivity. Two varieties from Kazakhstan, namely, Susyn (k-31315, vegetation period = 76 days, 1000 grains weight = 51 g, grain yield from 1 m^2 = 604.7 g, $b_i = 1.2$) and Akzhol (k-31316, vegetation period = 74 days, 1000 grains weight = 55 g, grain yield from 1 m^2 = 600.3 g, $b_i = 1.5$), had shorter vegetation period and 1000 grains weight and higher productivity than average in the sampling.

The investigation revealed the weather–climate factors that had the greatest influence on the duration of the period germination–heading and germination–harvest for both cereals. Duration of the period germination–heading was determined by duration of the spring period with temperature of 10 °C–15 °C, and the whole vegetation period – by the sum of effective temperatures higher than 15 °C. The reaction rates of the studied cereals to changes in these factors were similar to one another. The germination–heading period was shortened at 0.3 days when the period with temperatures 10 °C–15 °C in spring was shortened by 1 day. The shortening of germination–harvest period was 3 days when the sum of effective temperatures (higher than 15 °C) was increased by 100 °C.

The investigation was conducted within the state task No 0662-2019-0006.

Attachment 1

Analysis of variance of genotype and environment influence [15]

Dispersion component	d_f	Germination–heading				Germination–harvest				Height				1000 grains weight				Productivity			
		SS	*MS*	*F*	% *SS*	*SS*	*MS*	*F*	% *SS*	*SS*	*MS*	*F*	% *SS*	*SS*	*MS*	*F*	% *SS*	*SS*	*MS*	*F*	% *SS*
Овес																					
Total	149	3099.6			100	5989.3			100	79459.3			100	4917.6			100	13330512.6			100
Genotype	24	893.2	37.2	4.949	28.8	903.3	37.6	3.830	15.1	43655.5	1819.0	17.350	54.9	2530.6	105.4	13.268	51.5	1711209.6	71300.4	3.525	12.8
Environment	1	1355.9			43.7	3720.9			62.1	21558.9			27.1	1402.6			28.5	8316771.3			62.4
Genotype × environment	24	98.3	4.1	0.545	3.2	382.2	15.9	1.620	6.4	3760.6	156.7	1.495	4.7	189.7	7.9	0.995	3.9	1279581.9	53315.9	2.636	9.6
Deviation from regression	100	752.1	7.5		24.3	982.9	9.8		16.4	10484.3	104.8		13.2	794.7	7.9		16.2	2022949.9	20229.5		15.2
Barley																					
Total	149	3536.7			100	7204.1			100	24047.1			100	4621.1			100	9663810.916			100
Genotype	24	504.0	21.0	2.050	14.2	711.3	29.6	4.400	9.9	8847.1	368.6	6.573	36.8	843.2	35.1	4.407	18.2	318462.5642	13269.3	1.099	3.3
Environment	1	1842.8			52.1	5745.1			79.7	8195.7			34.1	2578.2			55.8	7595120.562			78.6
Genotype × environment	24	165.5	6.9	0.673	4.7	74.1	3.1	0.459	1.0	1396.1	58.2	1.037	5.8	402.4	16.8	2.103	8.7	542365.9913	22598.6	1.871	5.6
Deviation from regression	100	1024.3	10.2		29.0	673.6	6.7		9.4	5608.2	56.1		23.3	797.2	8.0		17.3	1207861.799	12078.6		12.5

Note. d_f – number of freedom degrees; *SS* — sum of squares of declinations; *MS* — middle sum of squares of declination; *F* — Fisher criterion. F_{05} = 1,628.

Attachment 2

Characteristics of the studied oar cultivars

Number of VIR catalog	Cultivar name	Origin	Germination–heading. days	Germination–harvest. days	Plant height, cm	1000 grains weight. g	Yield of 1 m^2. g	b_i — regression coefficient of genotype to environment
15440	Piband	Leningrad region	55.0 ± 1.8	87.7 ± 3.1	76.7 ± 7.8	29.4 ± 1.1	294.7 ± 79.3	0.19
15496	Stipler	Ulyanovsk region	49.3 ± 1.3	80.7 ± 2.4	114.3 ± 6.4	35.5 ± 1.5	595.8 ± 121.1	1.04
15497	Atlet	Yekaterinburg region	49.2 ± 1.6	81.8 ± 2.7	102.5 ± 6.2	37.7 ± 1.9	628.8 ± 121.8	1.04
15499	Vilensky	Sakha	48.7 ± 1.7	83.8 ± 2.3	99.7 ± 8.9	31.8 ± 2.4	529.7 ± 165.4	1.43
15501	Vizit	Ukraine	52.0 ± 1.7	86.7 ± 2.7	115.8 ± 6.8	27.0 ± 2.1	375.7 ± 118.6	1.04
15502	Zhitomirsky	Ukraine	50.5 ± 1.6	84.7 ± 2.8	111.5 ± 5.1	37.9 ± 2.1	644.7 ± 162.9	1.54
15503	Rannostygly	Ukraine	44.3 ± 1.1	78.7 ± 2.8	95.2 ± 5.5	39.5 ± 2.1	557.2 ± 139.7	1.32
15504	Svitanok	Ukraine	48.0 ± 1.8	76.8 ± 3.2	97.3 ± 5.9	37.6 ± 2.3	636.2 ± 177.2	1.59
15505	Avgol	Ukraine	48.2 ± 2.0	81.3 ± 2.5	96.2 ± 7.0	26.1 ± 1.5	383.5 ± 83.7	0.74
15507	Buggyy	Germany	51.3 ± 2.0	84.2 ± 3.7	71.7 ± 4.4	31.3 ± 2.5	457.0 ± 100.2	0.72
15508	Carron	Germany	47.7 ± 1.7	81.2 ± 2.7	85.0 ± 5.2	36.9 ± 1.9	623.3 ± 201.3	1.81
15509	Flocke	Germany	46.3 ± 2.3	82.2 ± 2.8	95.3 ± 6.6	38.9 ± 1.6	588.5 ± 152.6	1.35
15510	Kaplan	Germany	48.0 ± 2.5	81.0 ± 2.8	96.8 ± 7.5	35.3 ± 1.9	533.8 ± 102.8	0.87
15511	Kurt	Germany	51.0 ± 1.9	84.5 ± 4.0	68.2 ± 3.9	33.2 ± 1.7	434.2 ± 107.9	0.97
15512	Max	Germany	44.8 ± 0.9	79.2 ± 2.0	91.8 ± 3.4	37.4 ± 2.1	552.3 ± 117.8	1.08
15513	Oberon	Germany	44.8 ± 0.9	79.8 ± 2.3	97.0 ± 12.0	37.0 ± 1.5	592.3 ± 94.8	0.65
15515	Simon	Germany	47.7 ± 1.6	81.7 ± 1.4	97.2 ± 2.2	37.3 ± 1.5	603.7 ± 135.4	1.28
15516	Zorro	Germany	49.0 ± 1.7	82.7 ± 2.2	85.2 ± 3.9	35.6 ± 1.3	592.0 ± 116.9	1.10
15517	Dakar	Switzerland	49.0 ± 1.4	80.7 ± 2.6	94.2 ± 11.2	30.6 ± 1.3	427.9 ± 110.2	0.78
15518	Din yan 6	China	50.5 ± 1.6	84.7 ± 2.2	120.0 ± 6.7	29.8 ± 1.4	309.0 ± 86.7	0.75
15519	Din yan 3	China	49.8 ± 1.5	83.8 ± 2.0	120.8 ± 7.6	26.0 ± 2.0	330.2 ± 82.7	0.71
15520	Din yan 4	China	50.2 ± 1.2	82.5 ± 2.3	115.8 ± 7.9	28.9 ± 2.1	411.2 ± 161.1	1.39
15521	Z 0585	China	46.3 ± 2.0	80.8 ± 1.4	119.7 ± 6.8	32.7 ± 1.1	567.7 ± 71.7	0.54
15523	Bai yan 6	China	49.8 ± 1.6	82.3 ± 2.1	137.5 ± 10.4	37.5 ± 1.3	474.8 ± 86.4	0.74
15524	Bai yan 7	China	52.2 ± 2.3	85.0 ± 2.5	129.2 ± 2.7	34.8 ± 1.4	473.7 ± 98.5	0.31
LSD_{05}			3.1	3.6	11.7	3.2	162.5	–

Note. Mean value ± standard error of the mean, LSD_{05} is the least significant difference for 5% level of significance.

Attachment 3

Characteristics of the studied barley cultivars

Number of VIR catalog	Cultivar name	Origin	Germination–heading. days	Germination–harvest. days	Plant height, cm	1000 grains weight. g	Yield of 1 m². g	b_i — regression coefficient of genotype to environment
31124	Asem	Kazakhstan	49.0 ± 1.5	76.5 ± 2.3	88.3 ± 5.7	47.9 ± 1.4	537.7 ± 119.8	1.13
31135	Saule	Kazakhstan	47.0 ± 1.3	74.0 ± 2.8	88.5 ± 4.5	47.4 ± 2.3	571.3 ± 126.7	1.21
31136	Medikum 108	Kazakhstan	45.8 ± 2.4	74.0 ± 2.7	92.0 ± 4.8	50.3 ± 1.8	486.2 ± 134.5	1.32
31137	Karagandinsky	Kazakhstan	46.7 ± 1.7	75.8 ± 2.3	99.0 ± 4.8	50.6 ± 1.6	485.7 ± 97.1	0.87
31138	Medikum 11	Kazakhstan	46.8 ± 2.3	74.0 ± 2.7	95.2 ± 5.5	51.3 ± 2.1	468.8 ± 110.3	1.08
31139	Medikum 125	Kazakhstan	43.0 ± 2.1	73.5 ± 2.8	87.2 ± 2.5	51.7 ± 3.4	480.0 ± 112.6	1.08
31140	Medikum 176	Kazakhstan	46.2 ± 1.8	75.3 ± 2.6	90.2 ± 6.6	52.0 ± 1.9	475.0 ± 129.8	0.87
31169	Evergreen	Denmark	50.0 ± 2.9	80.2 ± 2.7	75.2 ± 4.9	51.4 ± 2.0	507.5 ± 89.9	0.80
31170	Calcule	Germany	48.5 ± 2.7	81.0 ± 3.4	76.0 ± 5.3	47.1 ± 1.5	455.3 ± 79.1	0.73
31195	Maali	Estonia	48.0 ± 2.3	79.5 ± 2.9	79.0 ± 3.1	52.3 ± 2.0	533.5 ± 123.4	1.18
31241	Quench	Denmark	48.7 ± 2.7	80.0 ± 3.6	75.9 ± 5.3	47.8 ± 1.4	507.2 ± 56.3	0.47
31300	Vodogray	Ukraine	46.7 ± 1.9	77.5 ± 3.2	85.6 ± 2.8	55.9 ± 2.0	503.9 ± 108.4	1.07
31311	Chudovy	Ukraine	46.8 ± 2.1	76.8 ± 2.4	78.8 ± 4.5	51.4 ± 1.9	583.0 ± 102.7	0.95
31312	Oboyan	Ukraine	46.2 ± 2.3	76.4 ± 3.1	92.2 ± 5.0	54.1 ± 1.9	558.2 ± 95.7	0.90
31314	Turan 2	Kazakhstan	46.5 ± 2.0	75.3 ± 3.1	86.8 ± 4.3	48.6 ± 3.4	515.5 ± 119.6	1.18
31315	Susyn	Kazakhstan	48.3 ± 1.9	76.0 ± 3.1	87.7 ± 4.2	51.2 ± 2.3	604.7 ± 130.7	1.18
31316	Akzhol	Kazakhstan	44.8 ± 1.7	74.2 ± 3.2	90.3 ± 4.8	54.7 ± 2.8	600.3 ± 154.8	1.51
31317	Zhan	Kazakhstan	47.3 ± 1.2	77.2 ± 3.1	87.7 ± 3.7	50.2 ± 1.6	603.8 ± 146.5	1.42
31318	Sever 1	Kazakhstan	48.3 ± 1.5	76.8 ± 3.2	88.0 ± 3.9	51.4 ± 2.0	508.3 ± 106.4	0.96
31320	Sylphide	France	49.7 ± 1.4	77.2 ± 3.0	79.0 ± 3.9	48.6 ± 2.5	508.3 ± 75.8	0.68
31321	Serval	Poland	48.0 ± 2.4	78.7 ± 3.0	74.5 ± 4.1	50.1 ± 2.3	458.2 ± 82.4	0.74
31322	Stratus	Poland	51.3 ± 2.0	77.8 ± 2.6	76.5 ± 5.9	51.7 ± 2.5	473.8 ± 71.8	0.40
31323	Katy	Denmark	49.8 ± 2.3	80.7 ± 3.2	74.8 ± 2.7	52.5 ± 1.3	480.3 ± 120	1.14
31324	Vendela	Czech Republic	50.3 ± 1.4	78.7 ± 3.1	72.2 ± 3.5	46.4 ± 1.7	504.7 ± 98.4	0.90
31325	Wiebke	Germany	49.0 ± 1.3	78.2 ± 3.2	71.3 ± 3.4	53.1 ± 4.0	570.0 ± 133.3	1.24
LSD_{05}	–	–	3.7	3.0	8.6	3.2	125.6	–

Note. Mean value ± standard error of the mean. LSD_{05} is the least significant difference for 5% level of significance.

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❀ Authors and affiliations

Igor G. Loskutov — Doctor of Biological Sciences, Chief Researcher, Acting Head of the Department of Genetic Resources of Oats, Rye, Barley. Federal Research Center "N.I. Vavilov All-Russian Institute of Plant Genetic Resources", Saint Petersburg, Russia. SPIN: 2715-2082. E-mail: i.loskutov@vir.nw.ru.

❀ Информация об авторах

Игорь Гадиславович Лоскутов — д-р биол. наук, главный научный сотрудник, и. о. заведующего отделом генетических ресурсов овса, ржи, ячменя. ФГБНУ «ФИЦ Всероссийский институт генетических ресурсов растений им. Н.И. Вавилова», Санкт-Петербург. SPIN: 2715-2082. E-mail: i.loskutov@vir.nw.ru.

❀ Authors and affiliations

Lyubov Yu. Novikova — Doctor of Agricultural Science, Leading Researcher, Acting Head of the Department of Automated Information Systems for Plant Genetic Resources. Federal Research Center "N.I. Vavilov All-Russian Institute of Plant Genetic Resources", Saint Petersburg, Russia. E-mail: l.novikova@vir.nw.ru.

Olga N. Kovaleva — Candidate of Biological Science, Leading Researcher, Department of Genetic Resources of Oats, Rye, Barley. Federal Research Center "N.I. Vavilov All-Russian Institute of Plant Genetic Resources", Saint Petersburg, Russia. E-mail: o.kovaleva@vir.nw.ru.

Nadezhda N. Ivanova — Senior Researcher, Department of Genetic Resources of Oats, Rye, Barley. Federal Research Center "N.I. Vavilov All-Russian Institute of Plant Genetic Resources, Saint Petersburg", Russia. E-mail: n.ivanova@vir.nw.ru.

Elena V. Blinova — Candidate of Agricultural Sciences, Senior Researcher, Department of Genetic Resources of Oats, Rye, Barley. Federal Research Center "N.I. Vavilov All-Russian Institute of Plant Genetic Resources", Saint Petersburg, Russia. E-mail: e.blinova@vir.nw.ru.

Galina.V. Belskaya — Candidate of Agricultural Science, Senior Researcher, Head of the Laboratory of Cereal Crops, Yekaterinino Experimental Station. Federal Research Center "N.I. Vavilov All-Russian Institute of Plant Genetic Resources", Yekaterinino, Tambow Region, Russia. E-mail: belskaigalin@yandex.ru.

❀ Информация об авторах

Любовь Юрьевна Новикова — д-р с.-х. наук, ведущий научный сотрудник, и. о. заведующего отделом автоматизированных информационных систем генетических ресурсов растений. ФГБНУ «ФИЦ Всероссийский институт генетических ресурсов растений им. Н.И. Вавилова», Санкт-Петербург. E-mail: l.novikova@vir.nw.ru.

Ольга Николаевна Ковалева — канд. биол. наук, ведущий научный сотрудник отдела генетических ресурсов овса, ржи, ячменя. ФГБНУ «ФИЦ Всероссийский институт генетических ресурсов растений им. Н.И. Вавилова», Санкт-Петербург. E-mail: o.kovaleva@vir.nw.ru.

Надежда Николаевна Иванова — старший научный сотрудник отдела генетических ресурсов овса, ржи, ячменя. ФГБНУ «ФИЦ Всероссийский институт генетических ресурсов растений им. Н.И. Вавилова», Санкт-Петербург. E-mail: n.ivanova@vir.nw.ru.

Елена Владимировна Блинова — канд. с.-х. наук, старший научный сотрудник отдела генетических ресурсов овса, ржи, ячменя. ФГБНУ «ФИЦ Всероссийский институт генетических ресурсов растений им. Н.И. Вавилова», Санкт-Петербург. E-mail: e.blinova@vir.nw.ru.

Галина Владимировна Бельская — канд. с.-х. наук, старший научный сотрудник, заведующая лабораторией зерновых культур, Екатерининская опытная станция. ФГБНУ «ФИЦ Всероссийский институт генетических ресурсов растений им. Н.И. Вавилова», Екатеринино, Тамбовская область. E-mail: belskaigalin@yandex.ru.