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АДАПТИВНЫЙ ПОТЕНЦИАЛ СЕЛЕКЦИОННЫХ ЛИНИЙ ЯРОВОГО ЯЧМЕНЯ В УСЛОВИЯХ КУЗНЕЦКОЙ КОТЛОВИНЫ

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Изучены адаптивные свойства ярового ячменя в условиях Кузнецкой котловины. Объекты исследований – пять среднеспелых селекционных линий ярового ячменя. Изучение селекционных линий проведено в питомнике конкурсного сортоиспытания в 2016–2020 гг. Почва опытного участка – выщелоченный чернозем, тяжелосуглинистый по гранулометрическому составу, средней мощности. Повторность четырехкратная, норма высева (оптимальная для ярового ячменя в зоне возделывания) – 450 шт./м^2. Срок посева 29 апреля – 5 мая, уборка комбайном Сампо 130 в фазу полной спелости образцов ярового ячменя (12–15 августа). Эксперимент проведен в сравнении со стандартным сортом Биом. Параметры экологической пластичности (b_j), стабильности (S^2d_j), индекс условий среды (Ij) рассчитаны по методике, разработанной S.A. Eberchart и W.A. Russel, где рассматривается положительный отклик генотипа на улучшение условий выращивания. При контрастных условиях выращивания ярового ячменя в годы проведения исследований установлено, что значительное влияние на урожайность имеет фактор среда – 82,6%, доля влияния генотипа составила 1,4%. Средняя урожайность за годы исследования ярового ячменя по питомнику конкурсного сортоиспытания составила 5,51 т/га, максимальный показатель средней урожайности имеет селекционная линия КМ-198/11 – 6,45 т/га. Выделены генотипы с наиболее высокими адаптивными свойствами: КМ-198/11 (b_i = 0,24, S_i^2 = 2,59), Nutans 12/16 (b_i = 0,24, S_i^2 = 2,18) при вариабельности урожайности 25,9–29,2% (стандарт Биом – 46,1%). Среднеспелая селекционная линия ярового ячменя КМ-198/11, имея адаптивные свойства выше средних показателей, подготовлена для передачи на государственное сортоиспытание в 2021 г. как сорт Кузбасский юбилейный. Выявлены основные достоинства сорта: высокая засухоустойчивость, устойчивость к полеганию и поражению головневыми грибами, высокая продуктивность (6,45–8,50 т/га), крупная зерновка (53,2 г), средняя степень реакции на стрессовые факторы (снижение продуктивности). Содержание сырого протеина в зерне 13,6–14,1%, пленчатость 8,4%, натурная масса 620 г/л.

Ключевые слова: яровой ячмень, селекционные линии, сорт, стабильность, пластичность, урожайность, агроэкологические условия

ADAPTIVE POTENTIAL OF BREEDING LINES OF SPRING BARLEY IN CONDITIONS OF KUZNETSK DEPRESSION

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Adaptive properties of spring barley in the conditions of the Kuznetsk depression have been studied. The objects of the research are five medium-ripening breeding lines of spring barley. The breeding lines were studied in a nursery of competitive varietal trials in 2016-2020. The soil of the experimental plot is leached chernozem, heavy loam with a medium granulometric composition. The repetition was fourfold, the seeding rate (optimal for spring barley in the cultivation zone) 450 pcs / m^2. The sowing dates were April 29 - May 5, the harvesting was done with a Sampo 130 combine at the stage of full ripeness of spring barley samples (August 12-15). The experiment was carried out in comparison with the standard cultivar Biom. The parameters of environmental plasticity (bj), stability (S2dj), the environmental conditions index (Ij) were calculated according to the method developed by S.A. Eberchart and W.A. Russel, which examines the positive response of the genotype to the improved growing conditions. Under contrasting growing conditions of spring barley in the years of research, it was found that the environment factor had a significant influence on the yield - 82.6%, the share of genotype influence was 1.4%. The average yield over the years of the study of spring barley in the nursery of competitive variety trials was 5.51 t/ha, the maximum average yield has a breeding line KM-198/11 - 6.45 t/ha. Genotypes with the highest adaptive properties were identified: KM-198/11 (bi = 0.24, Si2 = 2.59), Nutans 12/16 (bi = 0.24, Si2 = 2.18) with yield variability of 25.9-29.2% (Biom standard - 46.1%). The medium-maturing selection line of spring barley KM-198/11, having above-average adaptive properties, is prepared for submission for state variety testing in 2021 as the variety Kuzbass Jubilee. The main advantages of the variety were revealed: high drought tolerance, resistance to lodging and blight, high productivity (6.45-8.50 t/ha), large grain size (53.2 g), medium reaction to stress factors (reduced productivity). Grain crude protein content was 13.6-14.1%, the film content 8.4%, the natural weight 620 g/l.

Keywords: spring barley, breeding lines, variety, stability, plasticity, yield, agroecological conditions

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Conflict of interest

The authors declare no conflict of interest.

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INTRODUCTION

Spring barley is a key forage and fodder crop that generates higher yields than other cereal crops due to its early maturity and drought tolerance [1-3]. Barley grain is used for processing in the food and brewing industries [4, 5].

In Western Siberia with contrasting soil and climatic conditions it is necessary to cultivate varieties that can effectively use the bioclimatic potential in specific soil and climatic conditions [6]. Creation of high-yielding plastic varieties of spring barley will increase the efficiency of grain production, using the bioclimatic resources of the region [7].

Taking into account climatic factors and production demands, breeding for increased productivity and adaptability to local natural and climatic factors is currently relevant, especially in a changing climate [8–10]. The complex-ity of yield formation lies in the interaction of multiple traits that appear during plant development under the influence of environmental conditions [11–13].

Successful varieties must be adapted to a wide range of environmental conditions in order to realize their genetic potential in a sustainable manner and to use their cultivation technology effectively. Differences in the response of varieties to changes in soil and climatic conditions are due to the interaction between the genotype and the environment. This interaction greatly complicates the process of selecting the best genotypes, so this information is of paramount importance in the breeding process [14, 15].

The aim of the research is to evaluate the breeding lines of spring barley for adaptability under the conditions of Kuznetsk Depression.

MATERIAL AND METHODS

The research was conducted in 2016-2020 at the Laboratory of Selection and Agrotechnics of Field Crops of the Kemerovo Research Institute of Agriculture - Branch of the Siberian Federal Scientific Centre of Agrobiotechnologies of the Russian Academy of Sciences (Kemerovo NIISKh - Branch of SFSCA RAS). The objects of the research are five medium-ripening breeding lines of spring barley. The breeding lines were studied in the nursery of competitive variety trials under the conditions of Kuznetsk Depression. Repeatability is fourfold, the location of plots is randomized, the accounting plot area is 15 m^2, the seeding rate (optimal for spring barley in the area of cultivation) is 450 pcs/m^2. The sowing date was 29 April - 5 May, harvesting by Sampo 130 combine in the phase of full ripeness of spring barley samples was conducted on 12-15 August. The counting and phenological observations of barley growth and development and yield accounting were conducted according to the method of M.A. Fedin, Y.A. Rogovsky, L.V. Isayev[1]. Statistical processing of the obtained data was carried out by methods of variation, correlation, variance analysis by the method of B.A. Dospekhov[2] in processing of computer programs by O.D. Sorokin[3].

The parameters of ecological plasticity (bj), stability (S2dj), environment index (Ij), theoretical yield (Xij) were calculated according to the methodology developed by S.A. Eberchart and W.A. Russel[4], which considers the positive response of the genotype to improved growing conditions.

The soil on which the research was conducted is leached chernozem, heavy loamy in granulometric composition, of medium thickness. The humus content is 8.0%, soil solution reaction is close to neutral, pH 6.0. $N\text{-}NO_3$ content in 0-40 cm horizon is 27.2 mg/kg, P_2O_5 is 128 mg/kg, K_2O is 98 mg/kg.

Spring barley yields are largely determined by the hydrothermal regime during the first vegetation period. In 2017, conditions during this period were defined as unfavorable (high temperatures and lack of moisture). Spring barley plants had a lack of moisture in the periods of sowing - sprouting and sprouting - emerging, HTC in May was 0.40, in June - 0.46 on the background of increased temperatures by one and three degrees, respectively (see Table 1). Precipitation in the second half of the growing season had a favorable effect on the further development of barley plants, HTC during earing - waxy ripeness is 1.8.

Unfavorable conditions in 2018 occurred during the growth and development of spring barley from sowing to full tillering with a decrease in average daily temperatures to 4.8 °C and a significant amount of rainfall (186% of the norm). A large overwetting was recorded in June and July, with HTC of 2.41 and 1.92, respectively. The harvesting period is characterized as favorable with low precipitation (33% of the norm, HTC = 0.42).

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Табл. 1. Метеоусловия в период вегетации ярового ячменя
Table 1. Weather conditions during the vegetation of spring barley

Indicator	Month				
	May	June	July	August	September
2017					
HTC	0,40	0,46	1,8	1,1	2,3
Precipitation amount, deviation from the norm, %	54	39	161	89	154
Average daily air temperature, deviation from the norm, °C	+1	+3	0	+1	–1
2018					
HTC	0,0	2,41	1,92	0,42	0,36
Precipitation amount, deviation from the norm, %	186	212	167	33	133
Average daily air temperature, deviation from the norm, °C	–3	+3	–1	0	+1
2019					
HTC	1,37	1,12	1,23	1,12	1,95
Precipitation amount, deviation from the norm, %	91	81	111	97	156
Average daily air temperature, deviation from the norm, °C	0	0	0	+2	+1
2020					
HTC	1,50	0,46	2,44	0,81	1,90
Precipitation amount, deviation from the norm, %	156	33	227	72	146
Average daily air temperature, deviation from the norm, °C	+4	–0,3	+0,4	+2,5	+0,6

Favorable conditions prevailed in 2019, with average daily temperatures in May, June and July in line with the long-term average.

In August, there was an increase in average daily temperatures by 2°C with moderate moisture content, HTC = 1.12-1.37. In 2020, lack of moisture was present during tillering - earing of spring barley, HTC = 0.46. In May, during the sprouting - heading period, high temperatures (4 °C above the norm) were accompanied by precipitation of 67 mm (156% of the annual average). During spring barley grain ripening period, significant overwatering was recorded, HTC = 2,44 (145 mm of precipitation) with average daily temperatures ranging from 16,7 to 21,4 °C (+0,4 °C to the norm).

RESULTS AND DISCUSSION

Under contrasting growing conditions of spring barley in the years of research, it was found that a significant influence on the yield has a factor of environment - 82.6%, the share of genotype influence was 1.4%. The analysis of environment indices revealed favorable years (2020 and 2019), when Ij was 1.09 and 1.96, and unfavorable years (2017 and 2018, Ij equal -2.7 and -0.33, respectively) (see Table 2). The average yield for the years of research of spring barley in the nursery of competitive variety trials was 5.51 t/ha, the maximum average yield has a breeding line KM-198/11 (6.45 t/ha). The average yield under different growing conditions characterizes the ability of plants to withstand the negative effects of the environment, i.e. the compensatory ability of genotypes, it is an indicator of genetic flexibility (GF) [16]. In agroecological conditions 2017-2020, breeding lines KM-209/11, Nutans 26/18 (GY = 5.52 t/ha), Nutans 12/16 (GY = 5.47 t/ha) have genetic flexibility, the Biom standard indicator is 5.00 t/ha. Compared with the standard, the KM-198/11 breeding line has the greatest genetic flexibility, with an excess in yield of 1.45 t/ha.

The regression coefficient bi was used to assess the adaptability of spring barley breeding lines. The selection line KM-198/11 had above-average adaptability, bi = 0.24, at high average yield in the experiment. The greatest responsiveness to improvement of environmental con-

Табл. 2. Влияние условий выращивания на продуктивность селекционных линий ярового ячменя
Table 2. Influence of growing conditions on productivity of breeding lines of spring barley

Variety, line	Yield, t/ha. Experiment year 2017	2018	2019	2020	Yield sum of the *i*-variety under *j*- conditions, $\sum Y_i$, t/ha	Average variety yield in the j-year of experiment Y_i, t/ha	Regression coefficient b_i
Biom, standard	2,0	4,4	7,0	6,6	20,0	5,00	0,31
KM-209/11	2,2	5,2	7,7	7,0	22,1	5,52	0,43
KM-198/11	4,9	5,3	7,1	8,5	25,8	6,45	0,24
Nutans 12/16	3,5	6,0	7,3	5,1	21,9	5,47	0,24
Nutans 26/18	1,8	5,6	7,8	6,9	22,1	5,52	0,47
Nutans 27/18	2,4	4,6	7,9	5,5	20,4	5,10	0,39
$\sum Y_{ij}$ (the yield sum of all varieties in the *j*- year of experiment)	16,8	31,1	44,8	39,6	132,3		
Yi – average variety yield in the j-year of experiment	2,80	5,18	7,47	6,60	22,0	5,51	
Ij – environmental index	–2,7	–0,33	1,96	1,09			

ditions was shown by samples KM-209/11 and Nutans 26/18, bi = 0.43 and 0.47, respectively.

The less variation in yield under the influence of external conditions, the higher the stress tolerance of the variety and the wider the range of its adaptive capacity. The response of breeding lines to external conditions was evaluated by the coefficient of variation (V, %). The breeding lines KM-198/11 (25.9 %), Nutans 12/16 (29.2%) and the standard Biom (46.1%) had the lowest rate of variability of yield in spring barley (see table 3). Yields in breeding line KM-198/11 ranged from 4.9 to 8.5 t/ha. The greatest influence of environment among breeding lines was observed in KM-209/11 (44.4%), Nutans 27/18 (44.6), Nutans 26/18 (47.8%). Stability coefficients (S_i^2) were calculated based on theoretical yield and deviations from actual yield values.

The high and most stable grain yield was observed in the breeding lines Nutans 12/16 and KM-198/11 (S_i^2 = 2.18 and 2.59 respectively), the Biom standard had S_i^2 = 4.23 (see Table 4).

The breeding line KM-198/11 with the highest yield among the genotypes studied has above-average adaptive properties (bi = 0.24, S_i^2 = 2.59).

The selection line of spring barley KM-198/11 has been prepared for state variety testing in 2021 as the variety Kuzbass Jubilee.

Spring barley Kuzbass Jubilee.

The variety of spring barley Kuzbass Jubilee was created in Kemerovo Research Institute of Agriculture (NIISKh) - a branch of SFSCA RAS. It was bred by individual selection from a hybrid population (KM-81 × Grosso) with breeding work on the selection of forms immune to dust brand with stable productiv-

Табл. 3. Вариабельность урожайности селекционных линий ярового ячменя
Table 3. Yield variability of breeding lines of spring barley

Variety, line	Parameter: Average variety yield in the j-year of experiment Yi, t/ha	Size of yield variation, (min-max), t/ha	Variation coefficient *V*, %
Biom, standard	5,00	2,0–7,0	46,1
KM-209/11	5,52	2,2–7,7	44,4
KM-198/11	6,45	4,9–8,5	25,9
Nutans 12/16	5,47	3,5–7,3	29,2
Nutans 26/18	5,52	1,8–7,8	47,8
Nutans 27/18	5,10	2,4–7,9	44,6

Табл. 4. Теоретическая урожайность и стабильность селекционных линий ярового ячменя
Table 4. Theoretical yield and stability of breeding lines of spring barley

Variety, line	Theoretical yield X_{ij}, t/ha				Deviation of the actual yield from theoretical d_{ij}, t/ha				S_i^2
	Experiment year								
	2017	2018	2019	2020	2017	2018	2019	2020	
Biom, standard	4,16	4,90	5,60	5,34	–2,16	–0,5	+1,4	+1,26	4,23
KM-209/11	4,36	5,38	6,36	5,99	–2,16	–0,18	+1,34	+1,01	3,20
KM-198/11	5,80	6,37	6,92	6,71	–0,9	–1,07	+0,18	+1,79	2,59
Nutans 12/16	4,82	5,39	5,94	5,73	–1,32	+0,61	+1,36	–0,63	2,18
Nutans 26/18	4,25	5,37	6,44	6,03	–2,45	+0,23	+1,36	+0,87	4,33
Nutans 27/18	4,05	4,87	6,02	5,61	–1,65	–0,27	+1,88	–0,11	3,16

ity. The variety showed high resistance to dust brand (Ustilago nuda (Jens) Kell et Swing) and practical resistance to head smut (Ustilago hordei (Pers) Kell et Swing).

The variety belongs to the nutans variety group, a medium-maturing variety with a growing season of 85 days. The average yield is 6.45 t/ha and the maximum yield is 8.50 t/ha. The grain is large, the weight of 1,000 grains is 53.2 g, the number of grains in an ear is 20.9 units, productive tillering capacity is 1.9. It forms an aligned stem with a plant height of 86.8 cm, and is highly resistant to lodging and tilting of the ear (9 points). Crude protein content in grain: 13.6-14.1%; hoodness: 8.4%; natural weight: 620 g/l.

The main advantages of the variety are high drought tolerance, resistance to lodging and smut fungus, and high productivity. The variety reacts moderately to stress factors by reducing productivity.

CONCLUSION

As a result of a comparative study of spring barley selection lines in Kuznetsk Depression the most adaptive genotypes were singled out: KM-198/11 (bi = 0.24, S_i^2 = 2.59), Nutans 12/16 (bi = 0.24, S_i^2 = 2.18). The lowest rates of variability of the spring barley yield were observed for the selection lines KM-198/11 (25.9 %), Nutans 12/16 (29.2 %) and for the standard Biom - 46.1 %. The KM-209/11 (bi = 0,43) and Nutans 26/18 (bi = 0,47) samples had the greatest responsiveness to improvement of environmental conditions with a significant variation in yield depending on environmental conditions (V = 44,4-47,8%).

The selection line of spring barley KM-198/11 has been prepared for submission to state variety testing in 2021 as the Kuzbass Jubilee variety.

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