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Selection of parent pairs for the breeding process based on adaptive ability and environmental sustainability of spring barley varieties

A.V. Shabalkin, *A.A.* Andreev, *M.K.* Dracheva*, and *I.A.* Kutepova

Tambov Research Institute of Agriculture - Branch of FSBSI "I.V. Michurin Federal Research Center", Russia, Tambov region, Rzhaksinsky district, Zhemchuzhny settlement, Zelenaya Str., 10

Abstract. Varietal diversity and study of the source material for the breeding process is an important condition when creating a new variety with the necessary economically valuable characteristics, considering the requirements of agricultural producers and the processing industry. The task of breeders at the first stage of cultivar creation is to select from a collection nursery set high-yielding varieties resistant to pests and diseases, able to withstand various climatic stresses, to determine the adaptive ability to identify the positive and negative sides of genotypes, and creatively apply them in the breeding process. During 2018-2021, 94 varieties of spring barley of various ecological and geographical origin were studied. As a result of scientific research and mathematical calculations of the adaptability indicators of varieties, genotypes with a positive combination of high yield and their resistance to biotic and abiotic environmental factors were selected. Depending on the tasks set before breeding, varieties with positive adaptive abilities should be used in crosses: Azov (Russia), Lun (Russia), Medicum 336 (Russia), Corona (Ukraine), Effect (Ukraine), Grace (Germany), Delphine (France), Leon (Germany), Desnina (Germany), Collil (UK).

1 Introduction

Barley is a high-yielding crop, but depending on weather conditions and cultivation technology, fluctuations in yield and gross yields over the years are quite high. A successful solution to the problem of barley grain production in the volumes necessary for the needs of animal husbandry and processing industry is possible with a comprehensive solution to the problem. First, it is possible to increase grain production by expanding the areas under barley and observing scientifically sound crop cultivation technologies, and above all, creating environmentally plastic, high-yielding varieties that are adaptive to regional abiotic and biotic environmental stressors. Therefore, the main task facing the breeding is the continuous improvement of varieties, considering the changing conditions of cultivation and specifics of the soil and climatic features of the zone. Currently widely cultivated

* Corresponding author: drasheva_m@mail.ru

barley varieties have a high productivity potential of up to 50-70 c/ha. Nevertheless, not only the maximum capabilities of the variety are important for production, but also the stability of yield over the years [1-4]. This is an equally important feature that breeders pay less attention to. Meanwhile, with an increase in the average yield level, its variation over the years not only does not decrease, but even increases. To create stable varieties, a source material with such characteristics is needed, since in breeding work the selection of parent pairs for crossing is one of the fundamental creative stages. This is the most difficult question, which depends on the subjective factor. The success of hybridization largely depends on the correct selection of parents. It is possible to predict the results of hybridization if the hereditary features of the original forms and the patterns of trait inheritance are known. In many agricultural plants, positive and negative traits are genetically linked and are usually transmitted to the hybrid generation together. Parental forms should have a minimum of negative traits, moreover, the negative traits of the maternal and paternal genotype (low winter hardiness, low yield, fine grain, weak resistance to diseases) should by no means coincide. One of the principles of parental genotype selection is a mathematical analysis of varieties by a set of traits, which can serve as a basis for searching for sources of economically valuable traits in collections. Based on the data obtained, we can classify samples according to informative features that optimize the process of selecting parent forms for crosses. The decision on whether a particular variety of the collection is a source of an economically valuable trait should be justified by a detailed assessment of all analysable variation sources by methods of variance analysis. When assessing the initial forms and hybrids based on economically valuable traits, it is necessary to consider the effects of the "genotype-year" interaction and random variation depending on the analyzed trait.

2 Materials and methods

In 2018-2021, research on the study of barley varieties was conducted on the basis of the Tambov Agricultural Research Institute - branch of the "I.V.Michurin Federal Research Center", located in the northeastern part of the Central Chernozem region. The research material was 94 varieties of spring barley from the world collection of the FSBSI Federal Research Center All-Russian Institute of Plant Genetic Resources named after N.I. Vavilov. The field of the experimental site is located on soils with the following characteristics: the content of mobile phosphorus in the arable layer (0-30 cm) is 11.0, exchangeable potassium – 14.3 mg per 100 g of soil, humus – 8.24%, the reaction of soil solution (pHsol) – 5.5 mmol per 100 g of soil. The experiment was laid in accordance with the methodology of field experiment. Sowing was carried out at the optimal period with a breeding seeder SSFK 10. The samples were sown without repetition in plots of 5m2. The seeding rate of spring barley is 5.0 million germinating seeds per 1 ha. The technology of spring barley cultivation corresponded to zonal farming systems for the Tambov region [5]. Records, observations, and evaluation of the studied varieties were carried out according to the methodology of the State Variety Testing of agricultural crops [6] and methodological guidelines for the study of the world collection of VIR [7]. Grain quality assessment was carried out according to the following methods: protein content in grain GOST108460- 91; determination of gluten quantity and quality in grain GOST 13586.1- 68. The index of environmental conditions (I), plasticity (b1), and stability (b) were determined using the mathematical model of S.A. Eberhart, W.A. Russell [8]. Resistance of varieties to stress (U2-U1) and genetic flexibility according to the equations of A.A. Rossielle, J. Hamblin as presented by A.A. Goncharenko [9]; homeostasis according to V.V. Hangildin [10]. The distribution of varieties into groups and the definition of source varieties according to Merezhko A.F. [11], Lakin G.F. [12].

Mathematical processing of the research results was carried out according to the method of B.A. Dospekhov [13].

3 Results and discussion

During the period of research on the study of spring barley varieties, meteorological conditions were characterized by different temperature conditions and moisture provision. This made it possible to more objectively assess the studied varieties based on the prevailing environmental conditions. According to the amount of precipitation and temperature regime, 2018 was characterized by a dry and hot year. In total, 72.6 mm of precipitation fell during the growing season, or 43.0% of the long-term indicators, and the air temperature was 18.40 C, which is 12.5% higher than normal. Especially arid conditions developed during the tillering – earing – ripeness period, the hydrothermal coefficient in these development phases was 0.1-0.4, which corresponds to a severe drought. The growing season conditions in 2019 were humid and hot. During the growing season, precipitation fell by 39.4% higher than long-term indicators and the average air temperature was 17.50 C, 1.40 C above normal. The growing season of 2020 was characterized by generally dry and hot weather conditions. If we consider the weather conditions according to the barley plant development phases, it should be noted that in the first periods of growth (seedlings, tillering) took place in favorable humidification conditions, the air temperature in these phases of barley development was 1.0-3.6 0C lower than long-term values. During the barley earing and ripening, hot weather developed. The year 2021 was dry and hot. The average air temperature was 21.2 oC or 4.9 oC above the long-term average. 73.3 mm of precipitation fell, or 44.7% of the long-term indicators. All periods of barley growth and development took place with a lack of moisture. From barley sowing to tillering (18 days), 15.4 mm of precipitation fell, which is 2.3 times less than the average long-term indicators. From tillering to ripening (53 days), 57.9 mm of precipitation fell, which is 45.2% of the long-term values. The calculation of the environmental conditions index by year showed that of the four years of study, 2020 was the most favorable for barley growth and development, the environmental conditions index was +9.0. In 2018, 2019, and 2021, the environmental conditions index had negative values, which characterizes these years as unfavorable for obtaining a high yield of barley.

The problem of assessing the source material and identifying valuable forms is very difficult. From 94 varieties of various ecological and geographical origin studied in the experiment, 15 high-yielding cultivars were selected according to the confidence interval, which provided productivity above the average varietal yield from 18% to 54% (Table 1).

Table 1. Grain yield of spring barley varieties in the collection nursery (2018-2021).

No.	Variety	Origin	Yield, c/ha			Excess over the average for variety, %
			U_1 (max)	U_2 (min)	Average (2018-2021)	
1	Tokada	Russia	43.3	28.7	36.0	19
2	Medicum 336	Russia	41.3	34.0	35.7	18
3	Azov	Russia	41.6	29.3	36.2	20
4	Lun	Russia	44.0	38.7	39.4	30
5	Grace	Germany	41.3	30.8	37.0	22
6	Scarlet	Germany	48.0	23.5	35.6	18
7	Leon	Germany	40.7	32.7	37.4	24
8	Fabiona	Germany	73.3	30.7	46.4	54
9	Desnine	Germany	38.0	33.0	36.5	21
10	Magutny	Belarus	89.0	21.0	42.2	40
11	Batka	Belarus	59.3	26.7	39.4	30

12	Korona	Ukraine	43.7	32.0	35.7	18
13	Effect	Ukraine	47.1	29.0	38.7	28
14	Delphine	France	40.7	31.3	36.5	22
15	Collil	UK	39.3	32.0	35.5	18

The maximum and minimum yields of varieties varied widely from 21.0 to 89.0 c/ha (Table 1). This shows the different degree of their reaction to growing conditions. On average, over 4 years of the study, the best yield indicators were noted in the varieties of Magutny (Belarus) – 42.2 c/ha, Batka (Belarus) – 39.4 c/ha, Lun (Russia) – 39.4 c/ha, Fabiona (Germany) – 46.4 c/ha.

With the help of a mathematical assessment of genotypes, a selection of parent pairs for the breeding process was carried out according to several adaptive indicators. This made it possible to see and to assess the positive and negative traits of the varieties. Genotypes differed significantly in the rate of reaction to changes in environmental conditions. This feature is considered as the interaction of genotype x environment (IGE).

Over the years of testing of varietal samples from various places of origin, information was obtained on the reaction of varieties to environmental conditions. According to the plasticity parameters, it is possible to predict the behavior of the variety in the field conditions. Varieties with a coefficient value bi>1 have greater responsiveness to growing conditions, which can be attributed to intensive varieties. Such varieties are demanding to a high level of agricultural technology and under favorable weather conditions will give maximum return. The higher the value of the bi coefficient, the higher responsiveness this variety has. Such varieties include – Magutny (bi= 4.87), Scarlett (bi= 1.43), Batka (bi= 2.22), Fabiona (bi=2.87) (Table 2).

If bi=1 or slightly higher or lower than this indicator, then such varieties can be characterized as semi-intensive. These genotypes have a complete correspondence of the change in the yield of the variety to the change in growing conditions. The samples with average ecological plasticity include the Effect (bi=1.14), Korona (bi=0.81), Lun (bi=0.59) varieties (Table 2).

Varieties with a coefficient of plasticity significantly lower than one, belong to the extensive type. Such genotypes do not form high yields, respond poorly to changes in environmental factors, but, as a rule, are more stable. In conditions of intensive farming, extensive-type varieties cannot form high yields, but under adverse weather conditions, productivity indicators decrease less compared to intensive and semi-intensive varieties. This type includes varieties Tokada (bi=0.07, b=58.27), Medicum 336 (bi=0.05, b=25.63), Grace (bi=0.06, b=21.96), Delphine (bi=0.36, b=18.64), Leon ((bi=0.41, b=9.26), Collil (bi=0.38, b=9.47), Azov (bi=0.24, b=35.83), Desnina (bi=0.23, b=26.22) (Table 2).

The difference in yield in a favorable and unfavorable year is one of the indicators of plant resistance to stressful conditions. The smaller the gap between favorable and unfavorable conditions, the more stress-resistant the variety is. In our example, the stress-resistant varieties include - Medicum 336 (-7.3), Leon (-8.0), Collil (-7.3), Lun (-5.3), Desnina (-5.0). Such genotypes as Magutny (-68.0), Batka (-32.6), Fabiona (-43.0) belong to unstable weather conditions. The remaining varieties are medium-resistant - Effect (-18.1), Tokado (-14.6), Grace (-10.5), Korona (-11.7), Delphine (-9.4), Scarlett (-24.5), Azov (-12.3) (Table 2).

Table 2. Indicators of mathematical calculation of adaptive potential of spring barley (2018-2020).

No.	Variety	Origin	Plasticity	Resistance to stress	Genetic flexibility	Stability	Homeostasis	Breeding value
1	Tokada	Russia	0.02	-14.6	36.0	58.27	6.36	23.86
2	Medicum 336	Russia	0.05	-7.3	37.7	21.96	25.63	28.26
3	Azov	Russia	0.23	-12.3	35.5	35.89	21.07	25.42

4	Lun	Russia	0.59	-5.3	41.4	20.66	39.58	28.99
5	Grace	Germany	0.06	-10.5	36.1	29.35	44.42	27.59
6	Scarlett	Germany	1.43	-24.5	35.8	47.39	7.79	17.38
7	Leon	Germany	0.41	-8.0	36.7	3.26	73.93	30.04
8	Fabiona	Germany	2.87	-43.0	51.8	59.59	5.49	19.18
9	Desnina	Germany	0.23	-5.0	35.5	26.22	120.67	31.69
10	Magutny	Belarus	4.87	-68.0	55.0	101.10	2.01	9.95
11	Batka	Belarus	2.22	-32.6	43.0	3.15	23.34	17.73
12	Korona	Ukraine	0.81	-11.7	37.9	20.80	36.99	26.17
13	Effect	Ukraine	1.14	-18.1	38.1	35.88	20.09	23.82
14	Delphine	France	0.36	-9.4	36.0	18.64	42.62	28.30
15	Collil	UK	0.38	-7.3	35.7	9.17	57.75	28.90

Resistance to stress is complemented by the genetic flexibility indicator, which characterizes the average yield of varieties in contrasting (stressful and non-stressful) conditions. High values of this indicator indicate a greater degree of dependence between the genotype of the variety and environmental factors. When determining significant differences in genetic flexibility according to the confidence interval, all varieties showed average genetic flexibility, i.e. the interaction of variety and environmental conditions was almost the same (Table 2).

Breeders are paying more and more attention to highly productive and stable crop varieties under adverse weather conditions. Stability can be associated with a number of features and is determined by their high plasticity [1]. The varieties Delphine (b=18.64), Leon (b=9.26), Collil (b=9.17), Batka (b=3.15) showed high stability.

Stability and plasticity are based on homeostasis. According to Hangildin V.V., the evaluation of varieties using the regression model of Eberhart S.A., Russell W.A. do not give a complete and objective characteristic of the compared genotypes [6]. According to the author, the limiting factor of yield is not potential productivity, but resistance to adverse weather conditions, i.e. homeostaticity. The higher the homeostasis indicators, the higher the biological productivity of plants. The results of the homeostaticity analysis showed that Leon (Hom=73.93), Collil (Hom=57.75), Desnina (Hom=120.67) have high homeostasis. Low results of homeostaticity were found in the varieties Tokada (Hom=6.36), Magutny (Hom=2.01), Scarlett (Hom=7.79), Fabiona (Hom=5.49). The remaining varieties occupied an intermediate position (Table 2).

The breeding value of the variety is the ability to combine productivity and stability in the genotype. The method of determining the breeding value of the variety was proposed by R.V. Hangeldin, where the average yield of the variety limits the selection possibilities by two backgrounds (optimal and limiting). The varieties – Medicum 336 (Sc=28.26), Leon (Sc=30.04), Lun (Sc=28.97), Delphine (Sc=28.30), Collil (Sc=28.90), Desnina (Sc=31.69) showed high breeding value. Low indicators of breeding value are in the varieties of Magutny (Sc=9.95), Scarlett (Sc=17.38), Batka (Sc=17.73), Fabiona (Sc=19.18) (Table 2).

Based on the data obtained, genotypes were identified that combined both positive and negative adaptive traits. In the breeding process, special attention should be paid to genotypes that have more positive properties and fewer negative ones. The following pattern can be traced in the experiment. Intensive varieties from Germany (Fabiona), Belarus (Batka, Magutny) had more negative adaptive properties. Whereas the extensive varieties Tokada (Russia), Medicum 336 (Russia), Azov (Russia), Lun (Russia), Grace (Germany), Leon (Germany), Desnina (Germany), Delphine (France) had high and medium adaptability (Table 3).

Table 3. Characteristics of spring barley varieties with positive and negative aspects of adaptive potential.

No.	Variety	Origin	Intensive	Semi-intensive	Extensive	Resistance to stress	Genetic flexibility	Stability	Homeostasis	Breeding value
1	Tokada	Russia			-	I	I	-	-	I
2	Medicum 336	Russia			-	+	I	I	I	+
3	Azov	Russia			-	I	I	I	I	I
4	Lun	Russia			-	+	I	I	I	+
5	Grace	Germany			-	I	I	I	I	I
6	Scarlett	Germany		I		I	I	-	-	-
7	Leon	Germany			-	+	I	+	+	+
8	Fabiona	Germany	+			-	I	-	-	-
9	Desnina	Germany			-	+	I	I	+	+
10	Magutny	Belarus	+			-	I	-	-	-
11	Batka	Belarus	+			-	I	+	I	-
12	Korona	Ukraine		I		I	I	I	I	I
13	Effect	Ukraine		I		I	I	I	I	I
14	Delphine	France			-	I	I	+	I	+
15	Collil	UK		I		+	I	+	+	+

Note: + high indicators;
I medium indicators;
- low indicators.

4 Conclusions

As a result of the assessment of the adaptability of varieties for the breeding process, genotypes with more positive combinations of high yields and their resistance to biotic and abiotic environmental factors were selected. Depending on the tasks assigned to the breeding, varieties with positive adaptive abilities were identified: Azov (Russia), Lun (Russia), Medicum 336 (Russia), Korona (Ukraine), Effect (Ukraine), Grace (Germany), Delphine (France), Leon (Germany), Desnina (Germany), Collil (UK).

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