

Adaptability of prospective spring barley cultivars bred in Federal Agricultural Research Center of the North-East

*Irina N. Shchennikova*¹, *Olga N. Shupletsova*¹, *Irina Yu. Zaytseva*^{1,*}, *Larissa P. Kokina*¹ and *Rimma I. Vyatkina*²

¹Federal Agricultural Research Center of North-East, 166-a Lenin Street, Kirov, 610007, Russian Federation

²Perm Research Institute of Agriculture – Branch of the Perm Federal Research Center of the Ural Branch of the Russian Academy of Sciences, 12 Kultury street, 614532, Perm Territory, Perm district, Lobanovo village, Russian Federation

Abstract. Based on the statistical assessment of long-term field studies, in competitive variety tests, barley cultivars were identified adaptive to the conditions of the region, promising for transfer to the State variety test. As a result of the studies, a promising breeding material was created. The efficiency of using various methods of creating a new initial material, in particular, the cell culture method, is shown. A statistically significant correlation was established between the value of the hydrothermal coefficient (GTK) in the period "leaf tube formation - heading" and the yield capacity of a cultivar ($r = 0.520$). High variability ($V = 24.4\%$) in the duration of the inter-stage period "leaf tube formation - heading" was revealed in the cultivars of competitive variety testing. Cultivars 94-13 and 38-15 are distinguished by a high yield potential (up to 6.4... 6.9 t/ha) and the duration of inter-stage periods, at which the main stages of organogenesis occur at the most favorable combination of heat and moisture for the potential development of plant features and properties. Cultivars 207-15, 38-15, and regenerant 550-08, characterized by high annual average yield capacity (5.9...5.7 tons/ha) and adaptability, are promising for transfer to the Russian Federation State variety test.

1 Introduction

The main task of breeding is to create cultivars characterized by high and stable yield capacity, independent to a large extent of changing growing conditions. Studies of many authors [1, 2, 3] have shown that with an increase in the cultivar potential yield capacity its ecological stability tends to decrease. Application of intensive agricultural technologies makes it possible to increase significantly the plant productivity but cannot fully offset fluctuations of weather conditions during growing season [1]. The solution to this problem is possible with more extensive application of ecological breeding methods to create

* Corresponding author: irina-zajjceva30@rambler.ru

agroecologically targeted cultivars adapted equally to changing soil and climatic conditions and regional cultivation technologies [4].

Barley is the main grain crop, which is proven and highly reliable, using its biological potential as much as possible in various soil and climatic conditions for the formation of stable yields [5]. In terms of grain production, barley occupies the second place in Russia; in world production, the part of Russian barley is 10-13% [6]. In recent years, in the Kirov region there has been a tendency to increase the sowing area occupied by barley. In 2020, they amounted to 104.7 thousand hectares, occupying more than 30% of the areas occupied under cereals [7].

Targeted breeding for reduce the reaction of cultivars to contrasting weather conditions and, above all, to extreme ones, will increase their adaptability. A feature of adaptive breeding is the control of ecological plasticity and stability of genotypes, if possible, at all stages of the breeding process. According to the data of [8], the need for these studies is explained by the fact that the shortage of yields in the years unfavorable by the conditions of growing season brings more significant economic losses than the profit from an increase in yields in favorable ones.

Culture of plant cells and tissues *in vitro* on artificial nutrient media is an additional tool to increase the efficiency of adaptive breeding. Introduction into the medium of selective agents that mimic the effects of natural stressors (hydrogen, aluminum ions, heavy metals, osmotics) allows to purposefully select stable callus cultures (somaclones), and subsequently plant-regenerants. The presence of useful mutations among somaclonal lines allows them to be used as a promising breeding material. *In vitro* cell culture does not destroy the valuable genetic sequences achieved in the previous breeding. Only certain parts of the genome are changed, which are based on somaclonal variability, due to the imbalance of the genetic and epigenetic programs of plant tissue when removing ontogenetic control. Thus, somaclonal variability is useful for creating a new initial material for adaptive breeding [9].

The purpose of the research is to distinguish barley cultivars adaptive to the conditions of the region, promising for transfer to the Russian Federation State variety testing, based on a statistical assessment of long-term field studies in competitive field tests.

2 Materials and methods

Research was carried out in 2018-2020 in the FARC of the North-East (Kirov, Russian Federation). The objects of research were spring barley cultivars zoned in the Volga-Vyatka region and new promising ones bred in FARC of the North-East: Rodnik Prikamiya, Pamiaty Rodinoy, Dobryak, Boyarin, 52-12, 94-13, 550-08, 38-15, 205-16, 207-16 and 208-16. The cv. Belgorodsky 100 recommended by the Russian Federation State Commission for Variety Testing was used as a standard. All the presented cultivars were obtained by crossing, with the exception of 550-08 regenerant, created using cell selection on an acidic selective medium with an increased content of aluminum ions (40 mg/l Al³⁺ at pH 4.0).

Field observations, estimates and accounting of yield were carried out in accordance with the methodology of the Russian State Commission for variety testing of agricultural crops [10]. The study was carried out in a competitive variety test on plots with an accounting area of 10 m², in 4 repetitions. Sowings were located in breeding crop rotation. The soil of experimental sites is sod-podzolic with low humus content, a low capacity of the organic matter horizon with a low pH in a significant part, typical of the Kirov region. Basic and pre-sowing soil treatment was carried out in accordance with zonal recommendations [11, 12]. Sowing was carried out at an optimally early time, mineral fertilizers were introduced before sowing at a dose of N₄₈P₁₀K₁₄.

Ecological stability of a cultivar was evaluated in accordance with the procedure described by A.A. Goncharenko [13]. According to it, the difference between the minimum and maximum yield of a cultivar over the years of study ($Y_{\min} - Y_{\max}$) reflects the level of cultivar resistance to stress factors; the lower the gap between values, the higher the stress resistance of a cultivar. The average yield of a cultivar in years contrasting in growth conditions, $x = (Y_{\min} + Y_{\max})/2$, characterizes the genetic flexibility of a cultivar; the higher the correspondence between the genotype and various environmental factors, the higher this indicator.

Hydrothermal coefficient (GTK) of G.T. Selyaninov was used to estimate moisture availability during plant vegetation, calculated by formula:

$$GTK = \Sigma P / (\Sigma t * 0.1), \tag{1}$$

where ΣP - the sum of precipitation for the considered period

ΣT - the sum of active temperatures higher than 10 °C, collected for the same period reduced by 10 times.

In general, soil and climatic conditions helped to identify the potential of cultivars. Statistical methods in the presentation of B.A. Dospekhov [14] were used in the work.

3 Results and discussion

Biological basis of stable high yield of barley cultivars in different growing conditions is "genotype x environment" interaction, which is expressed in different norm of genotype response, and change of their ranks in different medium conditions [4]. The norm of a cultivar reaction is manifested in the presence of certain environmental factors that limit the realization of a cultivar potential. Earlier studies [15] on the assessment of the ecological stability of barley cultivars of competitive tests in the Volga-Vyatka region using various statistical methods found that the ranking of cultivars was stable in most cases (tab. 1); this confirms the possibility of using any of these methods to obtain objective data. For further evaluation, we selected the method proposed by A.A. Goncharenko (2005).

Table 1. Ranking of cultivars of competitive testing by environmental stability using different assessment methods.

Estimation method			
S.A. Eberhart, W.A. Russell, 1966 [16]	S.P. Martynov, 1989 [17]	A.V. Kil'chevsky, 2005 [18]	A.A. Goncharenko, 2005
Pamiaty Rodinoy	Pamiaty Rodinoy	Pamiaty Rodinoy	Pamiaty Rodinoy
Tandem	Tandem	Tandem	Tandem
Rodnik Prikamiya	Novichok	Novichok	Rodnik Prikamiya
Novichok	Rodnik Prikamiya	Rodnik Prikamiya	Novichok

Weather conditions during the years of research varied significantly in the periods of plant development. The most favorable conditions developed in 2018 (data averaged by cultivars), when sufficient precipitations was observed throughout the growing season ($1.0 \leq GTK \leq 2.0$). In 2020, arid conditions ($GTC \leq 0.5$) were noted, starting from the tillering stage to complete heading. In 2019, in the inter-stage period "tillering – leaf tube formation" the GTK was more than 3.0, which means overwetting (fig. 1).

Studied barley cultivars differed both in the duration of the entire growing season and in its individual stages. Cv. Dobryak (growing season 79 days) and 208-16 (79 days) matured 4 days earlier than the standard Belgorodsky 100 (83 days, $LSD_{05} = 3$ days, $p = 1.25\%$). In other cultivars, the duration of the growing season was at the standard level and ranged from 82 (Pamiaty Rodinoy) to 85 (94-13) days. At the same time, cultivars differed

significantly in the time of the onset of the development stages and in accordance with the growing conditions prevailing in the inter-stage periods. As a result, the experiment showed differences between cultivars in the value of GTK in the inter-stage periods (tab. 2). The calculation of the coefficient of variation [14] (V, %) showed that the largest differences between cultivars by GTK were observed in the inter-stage period "leaf tube formation - heading" (V = 24.4%), when the number of spikelets and grains per ear is formed; during the remaining periods the differences between cultivars were insignificant.

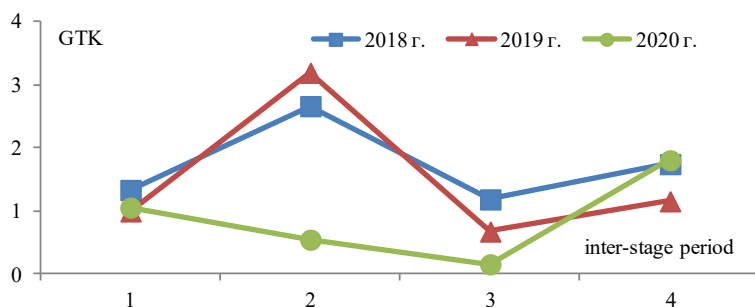


Fig. Hydrothermal coefficient (GTK) by plant growth stages: 1 - germination; 2 – tillering - leaf tube formation; 3 - leaf tube formation - heading; 4 – heading - ripening.

Table 2. Growth conditions (GTK) of some cultivars of competitive testing, 2018-2020.

Cultivar	GTK value in inter-stage period			
	Germination - tillering	Tillering – leaf tube formation	Leaf tube formation - heading	Heading - ripening
Belgorodsky 100	1.10	2.30	0.74	1.56
Rodnik Prikamiya	1.13	2.09	0.58	1.58
Pamiaty Rodinoy	1.11	2.04	0.72	1.62
Dobryak	1.13	2.08	0.67	1.65
Boyarin	1.11	2.35	0.48	1.56
52-12	1.10	2.14	0.79	1.61
550-08	1.14	2.15	0.55	1.61
94-13	1.10	2.14	0.95	1.50
38-15	1.14	1.88	0.94	1.35
205-16	1.14	2.12	0.48	1.62
207-15	1.14	2.15	0.56	1.61
208-16	1.14	2.15	0.56	1.52
Average	1.12	2.13	0.67	1.57

Cultivars 38-15 and 94-13 had duration of all studied inter-stage periods the most favorable for the growth and development of barley plants; only for these cultivars during the period "leaf tube formation - heading" growth conditions developed close to optimal in moisture availability (GTK = 0.94... 0.95). A statistically significant correlation was established between the GTK value during the "leaf tube formation - heading" period and yield capacity ($r = 0.520$). The cultivars Boyarin, 205-16, regenerant 550-08 and 207-15 are distinguished in which the period of "leaf tube formation - heading" took place under exact lack of moisture (GTK = 0.48... 0.56); however, these cultivars formed a fairly high yield capacity, showing their adaptive properties.

The adaptability of a cultivar was evaluated by the degree of decrease in the average value of the yield capacity attribute. The stability of cultivar in a variety of weather

conditions is an indicator of adaptability and ecological plasticity, and is defined as the difference between the minimum and maximum value of the characteristic ($Y_{\min} - Y_{\max}$). This indicator has a negative sign, and the lower in absolute value, the higher the stress resistance, that is, the wider the range of adaptability of a cultivar. Cultivars 205-16, 208-16, Belgorodsky 100, 207-15 and regenerate 550-08 had high stress resistance, with a minimum difference in yield capacity. According to the average yield capacity, cultivars 207-15, 38-15, regenerant 550-08 and Boyarin (tab. 3) were distinguished in years contrasting on growing conditions ($x = (Y_{\min} + Y_{\max})/2$).

Table 3. Adaptive potential of zoned and prospective barley cultivars, 2018-2020.

Cultivar	Yield capacities, t/ha			
	Y_{\min}	Y_{\max}	$Y_{\min} + Y_{\max}$	$(Y_{\min} + Y_{\max})/2$
Belgorodsky 100	4.4	6.2	-1.8	5.30
Rodnik Prikamiya	3.9	7.0	-3.1	5.45
Pamiaty Rodinoy	3.7	5.9	-2.2	4.80
Dobryak	3.8	7.4	-3.6	5.60
Boyarin	4.5	6.9	-2.4	5.70
52-12	4.4	6.5	-2.1	5.45
550-08	4.7	6.7	-2.0	5.70
94-13	2.8	6.4	-3.6	4.60
38-15	4.7	6.9	-2.2	5.80
205-16	4.7	5.7	-1.0	5.20
207-15	4.9	6.9	-2.0	5.90
208-16	4.7	6.2	-1.6	5.45

At the same time, it should be noted that in the selected cultivars this level of yield capacity was formed due to the high yield in different years according to the conditions of growth. While in the cv. Dobryak and Rodnik Prikamiya it was primarily due to its maximum manifestation in favorable conditions, the presence of a significant gap between values under unfavorable and favorable conditions, indicating the reaction to growing conditions, led to a decrease in their stress resistance relative to other cultivars.

The presence of varieties in competitive barley testing created using methods of crossing and of cell selection suggests the feasibility and/or possibility of combined approaches in the creation of adaptive breeding material. It should also be noted that cultivar-regenerant 550-98, created as a result of the selection of callus cells on selective media with aluminum toxicity and subsequent plant regeneration, was adapted to drought conditions in the field. This phenomenon can be a manifestation of nonspecific resistance formed in callus culture [19]. Callus cells, being in a state of physiological stress on selective backgrounds *in vitro*, show excessive metabolic activity, which leads to the possible formation of general adaptive mechanisms for adverse effects and, as a result, the appearance of resistance to a stressor that is not part of the direction of cell selection. There is a possibility that along with the manifestation of nonspecific resistance at the level of isolated tissue, this mechanism can be activated at the level of an adult regenerate plant. However, such effects are not predictable [20].

4 Conclusions

A promising breeding material has been created for further use in adaptive breeding. The efficiency of using various methods of creating a new initial material, in particular, the cell culture method, is shown. High variability ($V = 24.4\%$) of the duration of the inter-stage period "leaf tube formation - heading" was revealed in the cultivars of competitive testing. Cultivars 94-13 and 38-15 differ in high yield potential (up to 6.4... 6.9 t/ha) and the

duration of inter-stage periods, at which the main stages of organogenesis occur at the combination of heat and moisture most favorable for the potential development of plant features and properties. Cultivars 207-15, 38-15 and regenerant 550-08 characterized by high annual average yield capacity (5.9... 5.7 tons/ha) and adaptability are promising for transfer to the Russian Federation State variety test.

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