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COMPLEX EVALUATION OF PRODUCTIVITY AND ENVIRONMENTAL PLASTICITY OF THE WINTER WHEAT BREEDING MATERIAL FOR THE CONDITIONS OF THE SUBMONTANE ZONE OF CENTRAL CAUCASUS

Irina Rafikovna MANUKYAN[1], Madina Ahsarbekovna BASIEVA[1], Anna Nikolaevna GNEUSH[2], Gayane Yur'evna ARUTYUNOVA[3], Majya Mugdinovna UDYCHAK[3], Denis Anatolevich YURIN[4]

[1]North Caucasian Research Institute for Montane and Submontane Agriculture, Branch of the Vladikavkaz Scientific Centre of the Russian Academy of Sciences, Vilyamsa Street, 1, Mikhailovskoye, 363110, Russian Federation, Phone/Fax: +7(8672)23-04-20; E-mails: miririna.61@mail.ru, basievane@rambler.ru
[2]Kuban State Agrarian University named after I.T. Trubilin, Kalinina Street, 13, Krasnodar, 350055, Russian Federation, Phone/Fax: +7 (861) 221-59-42, Email: gneush.anna@yandex.ru
[3]Maikop State Technological University, Pervomaiskaya Street, 191, Maykop, 385000, Russian Federation, Phone/Fax: +7 499 3227595, Emails: naden8277@mail.ru, aledana2207@mail.ru
[4]Krasnodar Research Centre for Animal Husbandry and Veterinary Medicine, Pervomaiskaya Street, 4, Znamensky village, Krasnodar, 350055, Russian Federation, Phone/Fax: +(861) 260-87-72, Email: 4806144@mail.ru

Corresponding author: miririna.61@mail.ru

Abstract

The paper reports on the results of the study of eleven cultivars and strains of winter soft wheat tested in the conditions of the submontane zone of the Central Caucasus. The average annual yield (2016-2018) varied from 0.66 to 1.05 kg/m^2. A comprehensive assessment of the parameters of environmental plasticity and adaptability using various methods was carried out. According to the results of variance analysis, the genotypes of the studied samples (the "cultivar" factor) had the highest impact on the overall variability of productivity – their proportion was 50%. The proportion of variability caused by the influence of environmental conditions (the "year" factor) was 26.5%. To identify adaptive genotypes by productivity, regression, and correlation analyses were performed and various selection indices were calculated.

Key words**:** *productivity, cultivar, winter wheat, ecological plasticity, adaptability, selection indices*

INTRODUCTION

The nature of the interaction of the genotype and the environment is one of the main directions of research in selection. Adaptive properties of cultivars are described by a number of parameters: plasticity, stability, resistance, etc. They reflect the dynamics of the genotype reaction to changes in environmental conditions or, in other words, the range of modification variability within the normal reaction of the genotype [13].
The value of adaptive cultivars depends not only on the absolute values of yield, but also largely on the environmental plasticity, i.e. the ability to generate productivity close to the potential in a wide range of soil and climatic conditions, to be resistant to diseases and damage by pests, to have the ability to quickly respond to improved growing conditions. For a comprehensive assessment of adaptability (a number of adaptive properties of the organism) and the selection of a valuable initial breeding material, a set of techniques is used to establish the significance of the observed differences and obtain the necessary information about the potential productivity and ecological plasticity of plants [1, 2].
Account must be taken of the fact that the assessment of sustainability parameters is, in part, relative, as it depends on the selected set of analyzed cultivars and may have a different

absolute value when compared with other strains. To identify the mechanisms of plasticity and stability of new genotypes, it is necessary to focus on known cultivars with different types of resistance and plasticity – most often, these are well-accepted regional cultivars [10].

MATERIALS AND METHODS

Studies were conducted in 2016-2018 in the laboratory of selection and seed production of grain crops of the North Caucasian Research Institute for Montane and Submontane Agriculture of the Vladikavkaz Scientific Centre of the Russian Academy of Sciences. The aim of the study was to assess the productivity and adaptability of the winter wheat breeding material to the cultivation conditions. Three recognized cultivars of winter wheat and eight strains from the collection of Vavilov Research Institute of Plant Industry were used for the research.

The soil of the experimental plot was medium-heavy clay-loam leached chernozem, underlain by pebbles.

Meteorological conditions during the years of research changed (temperature and moisture conditions were different), which made it possible to evaluate the adaptive properties of winter wheat cultivars.

The climatic conditions of 2016 (hydrothermal index = 1.5) were characterized as favorable for grain crops.

The climatic conditions of 2017 (hydrothermal index = 1.62) were hotter and more humid than usual since the spring vegetation period, which contributed to the development of diseases, including Fusarium head blight and Septoria blight.

In 2018 (hydrothermal index = 1.73), in early March and April, the moisture availability for the crops was lower than usual, the productive moisture reserves in the soil were 20-27 mm in the arable layer, which is not enough for plants during the period of ear initiation. In May, rainfall exceeded the norm by 135%. The crops were well supplied with heat and moisture.

The method of S.A. Eberhart and W.A. Russell (1966) [6] (as presented by V.Z. Pakudin and L.M. Lopatina (1984) [14]) was used to evaluate the adaptive properties, stability parameters, and environmental plasticity. The linear regression coefficient (bi) or plasticity coefficient and standard dispersion (S2i) or stability variance were calculated. Ecological plasticity means the average response of a cultivar to changes in environmental conditions, and stability means the deviation of empirical data in each environmental condition from this average response. Cultivar resistance to stress (Ymin – Ymax) and genetic flexibility ((Ymax + Ymin)/2) were determined using the method described by A.A. Rossielle and J. Hemblin (1981) [15] (as presented by A.A. Goncharenko (2005) [8]). When assessing the genotype-environment interaction using quantitative indicators of productivity, selection indices found in literature sources were used [5, 17, 19, 21]: Mexican index (Mx) – grain weight per head (g)/plant height (cm); head linear density index (HLD) – the number of grains in the head/head length; Canadian index (Ki) – grain weight in the head/head length; new plant productivity index (Vi), which is the ratio of the number of grains in the head times the grain weight in the head to the head length [11]. Homeostaticity (Hom) and breeding value (Sc) were calculated using the method described by V.V. Khangildin and N.A. Litvinenko (1981) [9], adaptive ability (Yi) was calculated using the method described by L.A. Zhivkova et al. (1994) [20], stability index (SI) was calculated using the method described by R.A. Udachin, A.P. Golovchenko (1990) [18].

To determine the nature of the correlative relationships, the ranking described by V.F. Dorofeev and A.F. Melnikov (1976) [3] was used: relationship is weak – $r < 0.30$; moderate – $r = 0.31$-0.50; significant – $r = 0.51$-0.70; strong – $r = 0.71$-0.90; very strong, close to functional – $r > 0.90$.

Mathematical processing of the experimental data was performed according to the method described by B.A. Dospekhov (1985) [4]. Field experiments, phenological observations, surveys and measurements of plants were carried out in accordance with the Methodology of State Variety Testing (1985) [7].

RESULTS AND DISCUSSIONS

For the correct calculation of the adaptability parameters using the yield parameters, we performed a quantitative assessment of the "genotype – environment" interaction using variance analysis.

The results of the variance analysis confirmed the significant influence of environmental conditions and "genotype – environment" interactions on the yield of the studied group of cultivars (Fact > Ftheor) (Table 1).

The highest contribution to the overall productivity variability was made by the genotypes of the studied cultivars (the "cultivar" factor), their proportion was 50%. The proportion of variability caused by the influence of environmental conditions (the "year" factor) was 26.5%. The proportion of other factors was 23.5%..

Table 1. The results of the variance analysis of the yield parameters for the cultivars

Type of variance	Sum of squared deviations	Number of degrees of freedom	Mean square (variance)	Factor contribution proportion, %	Ratio of variances (F)	
					actual value	reference value (P=0,95)
General	0.68	32	0.021	–		
The "year" factor A	0.18	2	0.9	26.5	112.5	5.9
The "cultivar" factor B	0.34	10	0.034	50.0	42.5	2.4
Residual	0.16	20	0.008	23.5		

Source: Compiled by the authors based on the findings from an expert survey conducted by them.

To identify the response to changes in growing conditions, we calculated regression coefficients (bi), that characterize the average response of cultivars to changes in environmental conditions and show their plasticity, as well as indicators of stress resistance, genetic flexibility of the cultivar, homeostaticity, and variance of cultivars stability (Table 2).

Table 2. Average yield and adaptability parameters of winter wheat cultivars for 2016-2018

Cultivar	Yield, kg/m2			Average Xi	Adaptability indicators				
	2016	2017	2018		Hom	Уmin–Уmax	(Уmax + Уmin)/2	bi	S2i
Alyans	0.63	0.54	0.8	0.66	4.0	-0.26	0.67	1.46	0.14
Zluka	0.6	0.73	0.64	0.66	8.7	-0.13	0.66	0.3	0.01
Gordovita	0.67	0.74	0.78	0.73	13.3	-0.04	0.72	0.46	0.03
Lazurnaya	0.65	0.6	0.91	0.72	4.0	-0.31	0.75	1.91	0.24
Areal	1.0	0.94	1.21	1.05	9.8	-0.27	1.1	1.61	0.14
Malvina	0.87	0.83	0.91	0.87	2.3	-0.08	0.87	0.41	0.01
Antonina	0.83	0.74	1.0	0.86	7.2	-0.26	0.87	1.46	0.15
Kuma	0.72	0.7	0.81	0.74	13.7	-0.11	0.75	0.67	0.03
List 25	0.6	0.64	1.0	0.75	3.42	-0.4	0.80	2.49	0.2
Don 107 st.	0.76	0.74	0.8	0.77	2.63	-0.06	0.77	0.34	0.01
Zira	0.77	0.75	0.82	0.78	20.3	-0.07	0.78	0.41	0.002
Average Xj	0.74	0.72	0.88	**0.78**	$F_{act} > F_{theor}$				
Conditions index (lj)	-0.04	-0.06	0.10						

Source: Compiled by the authors based on the findings from an expert survey conducted by them.

To characterize the growing conditions, we calculated indices of environmental conditions (lj). Indices of environmental conditions can possess positive and negative values. Positive environmental index values show the best conditions for the growth and development of genotypes, and negative values show the worst conditions. The best conditions for the formation of productivity were in 2018 (lj = 0.1), less favorable environmental conditions were in 2016 and 2017 (lj = -0.04 and -0.06) (Table 2).

Stress tolerance of cultivars and lineages is an important indicator of adaptability and environmental plasticity, which is calculated as the difference between the minimum and maximum yield. The highest stress tolerance (Ymin – Ymax) was observed in the Gordovita (-0.04), Don 107 (-0.06), and Zira (-0.07) cultivars. The Zluka cultivar is characterized by the lowest responsiveness to the improvement of environmental conditions in the studied set of cultivars.

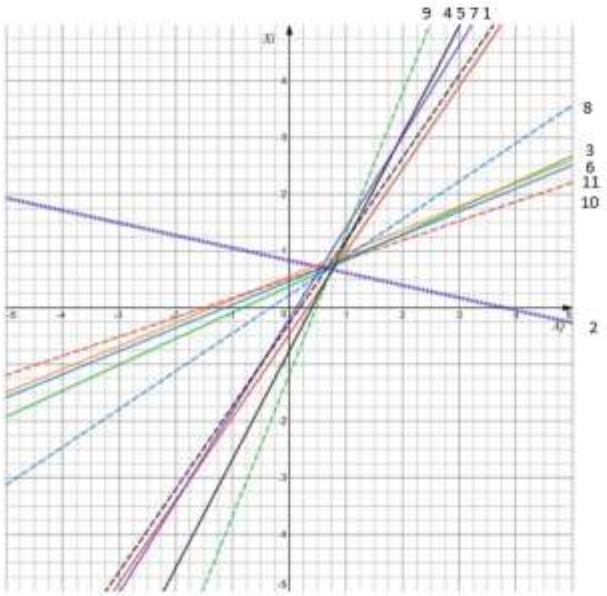
The indicator (Ymax + Ymin)/2 reflects the average yield of the cultivar in contrasting (stressful and non-stressful) conditions and characterizes the genetic flexibility of the cultivar, its compensatory ability. The higher this indicator, the higher the degree of correspondence between the cultivar genotype and environmental factors [16]. The following cultivars had the most genetically flexible genotypes: Areal, Antonina, and Malvina, with index values of 1.1, 0.87, and 0.87, respectively. These cultivars have a high degree of correspondence between the genotype and environmental factors.

The relationship between homeostaticity and variation coefficient characterizes the stability of the trait in changing environmental conditions (stability). The cultivars with high homeostaticity (Hom = 20.3, 13.7, and 13.3) include Zira, Kuma and Gordovita.

The linear regression coefficient bi of the cultivars yields shows their response to changes in growing conditions. The higher the coefficient bi > 1, the more responsive cultivar is. Such cultivars demand a high level of agricultural technology, as only in this case they will give the maximum yield. If bi < 1, then the cultivar's reaction to changes in environmental conditions is weaker. Such cultivars are best used on an extensive background, where they will give the maximum yield at the lowest cost. If bi = 1, then there is the full correspondence of changes in the cultivar yield and changes in growing conditions [12].

The slope of the regression lines provides visual information about the behavior of cultivars relative to each other and in comparison, with the average response of cultivars to changes in growing conditions (Figure 1).

Of practical interest are those cultivars, whose regression lines rise high on the right side of the graph (favorable conditions), which characterizes their high responsiveness to the improvement of conditions, and slightly decrease on the left side (severe conditions), which indicates buffering of genotypes in unfavorable conditions of cultivation.



*1 – Alyans; 2 – Zluka; 3 – Gordovita; 4 – Lazurnaya; 5 – Areal; 6 – Malvina; 7 – Antonina; 8 – Kuma; 9 – List 25; 10 – Don 107; 11 – Zira

Fig. 1. Yield regression lines (Xi) of winter wheat cultivars for environmental indices (Xj)
Source: compiled by the authors on the basis of the obtained results (Submontane zone of the Central Caucasus, average for 2016-2018)

The following cultivars are the most demanding for a high agricultural background, they can be referred to as the intensive type: Alyans (bi = 1.46, S2i = 0.14), Lazurnaya (bi = 1.91, S2i = 0.24), Areal (bi = 1, 61, S2i = 0.14), Antonina (bi = 1.46, S2i = 0.15), List 25 (bi = 2.49, S2i = 0.2). The next group of cultivars has a less plastic and stable genotype and is characterized by a fairly high yield and responsiveness to growing conditions: Gordovita (bi = 0.46, S2i = 0.03), Malvina (bi = 0.41, S2i = 0.01), Kuma (bi = 0.67, S2i = 0.03), Don 107 (bi = 0.34, S2i = 0.01), Zira (bi = 0.41, S2i = 0.002). These cultivars are best used on an extensive background, where they will give the maximum yield at the lowest cost.

At the earliest stages of the selection process, it is important to know not only the reaction of the genotype and its responsiveness to environmental conditions, but also the level of potential productivity of the selection specimen. Of practical interest in this matter are selection indices and coefficients that serve as markers of plant productivity. According to the results of the correlation analysis, the closest connection with plant productivity was shown for the SI stability index (r = 0.93), the new plant productivity index Vi that we developed (r = 0.75), the adaptability coefficient Yi (r = 0.73) and the breeding value factor Sc (r = 0.71) (Table 3).

Table 3. The relationship of the yield of winter wheat cultivars with breeding indexes

Cultivar	Yield, kg/m^2	SI	Yi, %	Sc	Vi	LED	Ki
Alyans	0.66	1.06	82.3	0.44	7.0	5.24	0.26
Zluka	0.66	1.06	91.0	0.54	6.8	4.73	0.15
Gordovita	0.73	1.31	94.2	0.63	8.4	4.12	0.17
Lazurnaya	0.72	1.26	91.4	0.47	8.0	6.9	0.3
Areal	1.04	2.63	134.5	0.81	9.7	5.4	0.22
Malvina	0.87	1.84	112.3	0.80	8.0	4.4	0.16
Antonina	0.85	1.76	115.7	0.63	7.4	4.62	0.17
Kuma	0.74	1.34	97.0	0.64	6.9	4.32	0.18
List 25	0.74	1.34	95.0	0.44	6.8	4.22	0.20
Don 107 st.	0.76	1.41	99.0	0.70	7.3	5.11	0.20
Zira	0.78	1.48	100.1	0.71	7.7	4.73	0.23
Correlation coefficient, r		0.93	0.73	0.71	0.75	0.25	0.38

Source: Compiled by the authors based on the findings from an expert survey conducted by them.

The main element of productivity that determine the yield of a particular plant in an ecosystem is the grain weight per head, which consists of the number and the weight of grains. The elements of productivity have different variability depending on the interaction of the genotype and environment factors. Based on the obtained results, the following cultivars and strains have high productivity (in descending order): Areal, Malvina, Antonina, Zira, Don 107 (standard), Kuma, List 25, Gordovita, Lazurnaya, Zluka, Alyans. Based on the specific yield of a head (Canadian index), three cultivars with the highest values (which were 0.26-0.23 g/cm, (Table-3)) were selected in comparison with the standard cultivar Don 107: Alyans, Zira, and Areal.

The grain weight per head is formed during the entire growing season and is determined not only by the number of grains, but also by the weight of each grain. Therefore, the linear density index, which is the ratio of grain weight per head (g) to the head length (cm), provides a large amount of data on the relationship between genotype and environment. Based on the linear head density index values 6.9, 5.4, 5.24, and 5.11 units/cm, the following cultivars were chosen: Lazurnaya, Areal, Alyans, and Don 107.

Based on the results of a comprehensive assessment of the parameters of adaptability for the cultivars (breeding material), the following were considered highly plastic, stable, and demanding of a high level of agricultural technology: Alyans (bi = 1.46, S2i = 0.14), Lazurnaya (bi = 1.91, S2i = 0 , 24), Areal (bi = 1.61, S2i = 0.14), Antonina (bi = 1.46, S2i = 0.15), List 25 (bi = 2.49, S2i = 0.2). Low-plastic but stable, with a weaker reaction to changes in environmental conditions than the average for the entire set of studied cultivars, were the following: Gordovita (bi = 0.46, S2i = 0.03), Malvina (bi = 0.41, S2i = 0.01), Kuma (bi = 0.67, S2i = 0.03), Don 107 (bi = 0.34, S2i = 0.01), Zira (bi = 0.41, S2i = 0.002). The following cultivars showed the highest average productivity over the years: Areal, Malvina, Antonina, Gordovita. Don 107, Kuma. Alyans and Zluka showed the smallest values.

When calculating the environmental plasticity, it should be kept in mind that the absolute values of the adaptability indicators for each studied cultivar obtained as a result of dispersion and regression analyzes, are to some extent relative, as they can change as the set of studied cultivars changes. For a more complete characterization of the economically valuable characteristics of the breeding material, one can additionally use indicators, the calculation of which does not require dispersion and average values for the whole experiment. For example, Vi is the plant productivity index (r = 0.75). In any set of cultivars, it has a close correlation with productivity; it is calculated based on "individual" plant productivity (number of grains, grain weight, and head length) and may indirectly indicate the resistance of the selection specimen to diseases.

CONCLUSIONS

The following strains are of the intensive type: Alyans (bi = 1.46, S2i = 0.14), Lazurnaya (bi = 1.91, S2i = 0.24), Areal (bi = 1.61, S2i = 0.14), Antonina (bi = 1.46, S2i = 0.15), List 25 (bi = 2.49, S2i = 0.2). The following have less plastic and stable genotypes: Gordovita (bi = 0.46, S2i = 0.03), Malvina (bi = 0.41, S2i = 0.01), Kuma (bi = 0.67, S2i = 0.03), Don 107 (bi = 0.34, S2i = 0.01), Zira (bi = 0.41, S2i = 0.002). The following cultivars and strains have high productivity: Areal (1.05 kg /m2), Malvina (0.87 kg/m2), Antonina (0.85 kg/m2), Zira (0.78 kg/m2), Don 107 (0.76 kg/m2). The closest correlation with productivity was shown for the SI stability index (r = 0.93), the new plant productivity index Vi that we developed (r = 0.75), the adaptability coefficient Yi (r = 0.73) and the breeding value factor Sc (r = 0.71). It should be kept in mind that the results of dispersion and regression analyses are to some extent relative, as they can change as the set of studied cultivars changes.

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