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ORIGINAL ARTICLE

The adaptability of soft spring wheat (*Triticum aestivum* L.) varieties

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Soft wheat is one of the leading food crops grown in large areas on all continents. However, with the rapid growth of the world's population, increasing grain production remains the main task of all agricultural producers. Recently in Ukraine, due to the shortage of organic fertilizers, the soil's humus content has dropped sharply to 2.5-1.5%. As a starting material, we used ten samples of *Triticum aestivum*, obtained from the National Center for Plant Genetic Resources of Ukraine (NCGRRU). These samples had economically valuable features and were introduced from different ecological and geographical areas. We used the method of A.V. Kilchevsky and L.V. Khotylova to determine the environment parameters, phenotypic stability, and adaptive potential. We established the highest general adaptive ability in the samples of Swedish, Russian, and Ukrainian selection: Sunnan, Prokhorovka, and Kharkivska 30. We suggested that the level of combination of assessments of adaptability or stability by different methods should be a reliable indicator of predicting the variety's behavior and help the breeder choose the most appropriate and informative parameters that fit the stability concept.
Keywords: spring wheat, genotype, adaptability, stability, environment, yield.

Introduction

Spring wheat could be used for food, fodder, and technical grain. Spring wheat grain produced the best varieties of pasta. Moreover, wheat is the world's most nutritious crop. Improving the adaptability of spring wheat varieties is currently one of the essential areas in selecting spring wheat. Selection for high adaptability is one of the effective means of minimizing the effects of global climate change. Frequent droughts in the steppe and forest-steppe zones of Ukraine, where most of the spring cereals' crops are concentrated, cause constant crop shortages.

Research in different environmental conditions plays a vital role in selecting the best varieties and agronomic measures for future use after assessing varietal stability. Some researchers have used the definition of rank correlation between different stability parameters in an empirical database (Pielpho, Lotito, 1992; Adugna, Labuschagne, 2003). In most cases, biometric methods are used to assess phenotypic stability (Becker, Leon, 1988; Hussein, 2000).

Although none of these methods can adequately explain the genotypic manifestation of stability due to environmental conditions, the comparative method is widely used when studying the genotype-environment interaction (G × E) in different cultures (Hussein, 2000; Mohammadi et al., 2008). In cereals, most breeders use the term "stability" to describe genotypes that form a relatively stable crop regardless of environmental conditions.

In order to conduct a comprehensive assessment of the ecological stability and plasticity of samples with a different ecological and geographical origin, the indicators of the level of adaptability of promising samples of soft and hard spring wheat in the forest-steppe of Ukraine were developed as reflected in previous publications (Adugna, Labuschagne, 2003).

Materials and methods

Differentiated assessment of genotypes of soring soft wheat (*Triticum aestivum* L.) in phenotypic stability and adaptive potential when changing growing conditions. As a starting material, we used ten samples of the species *Triticum aestivum*. The source material was obtained from the National Center for Plant Genetic Resources of Ukraine (NCGRRU) and had some economically valuable features. Samples were introduced from different ecological and geographical areas (Table 1).

Table 1. Characteristics of the studying *Triticum aestivum* varieties

	National catalog number	Sample number	Variety	Country of origin
Triticum aestivum				
1	UA 0100098	Sunnan	*var. lutescens*	SWE*
2	UA 0101113	Prokhorovka	*var. lutescens*	RUS
3	UA 0104110	Kharkiv 30	*var. lutescens*	UKR
4	UA 0106145	L-501	*var. lutescens*	RUS
5	UA 0110938	Simkodamironovskaya	*var. lutescens*	UKR
6	UA 0111008	Yrym	*var. erythrospermum*	KAZ
7	UA 0105661	CIGM.250-	*var. erythrospermum*	MEX
8	UA 0110937	Phyto 14/08	*var. erythrospermum*	UKR
9	UA 0110936	Phyto 33/08	*var. erythrospermum*	UKR
10	UA 0111123	L 685-12	*var. lutescens*	UKR

* SWE – Sweden; RUS – Russia; UKR – Ukraine; KAZ – Kazakhstan; MEX – Mexico.

The research was conducted in Kharkiv National Agrarian University V.V. Dokuchaev (KhNAU) in 2018–2019. Sowing was carried out in the optimal time for the eastern part of the Forest-Steppe of Ukraine (April I-II), collection samples were sown by hand under a marker, rows were 1 m long with a row spacing of 0.15 m, at the rate of 100 grains per running meter. All phenological observations were performed following the guidelines for the study of wheat collections (Methods…, 2003): predecessor - black steam. The placement of plots is standard. To assess the intraspecific and interspecific ecological variability of spring wheat, 30 plants of each sample were analyzed annually. Accounting and observation were carried out under the appropriate state variety testing (Methodology…, 2003; Methods…, 2003).

To determine the environment's parameters, phenotypic stability, and adaptive potential, we used A.V. Kilchevsky and L.V. Khotylova (1997) method. We calculated the general adaptive capacity ($GAA = Vi$), the variance of the specific adaptive capacity, $\sigma^2\ Vi$, the variance of genotype-environment interaction, $\sigma^2\ (G \times E) / gi$, relative stability, *Sgi*, compensation coefficient, *Kgi*, and selection value of the genotype, *STsGi* (Eberhart, 2006).

The hydrothermal coefficient was used to detect the effect of abiotic factors on spring wheat during the study years.

Results

Considering the hydrothermal resources of the vegetation period of 2018, we observed the evidence of excess moisture (GTK>1.5) in the third decade of June - 1.5, and eight dry decades (GTK<0.5): the second and third decades of April – 0.33 and 0.37, first and third decade of May - 0, first and second decade of June - 0.12 and 0.29, first and third decade of July - 0.3 and 0.12 (Fig. 1).

Analyzing the hydrothermal resources of the 2019 vegetation period, we registered significant excess moisture (GTK > 1.5): the first decade of May - 1.79, and seven dry decades (GTK <0.5): the first, second, and third decade of April – 0, 0.1, and 0.07, the second decade of May - 0.19, the second and third decade of June – 0 and 0.1, the second decade of July - 0.

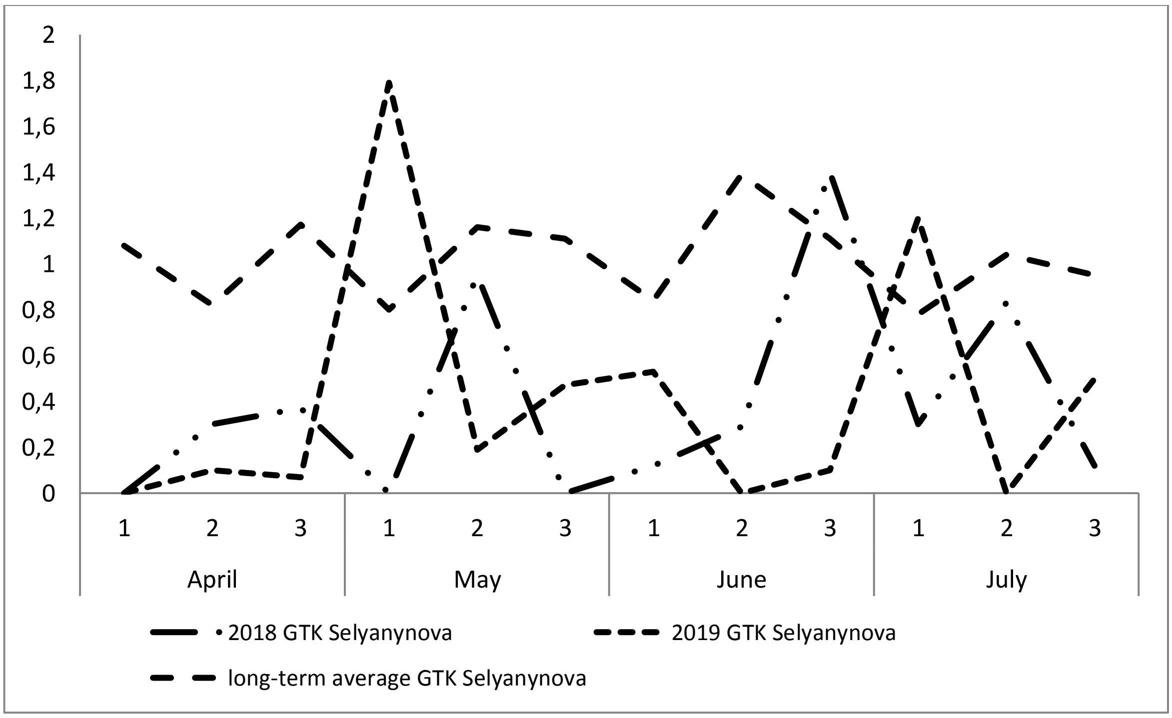

Fig. 1. Selyaninov hydrothermal coefficient dynamics during the growing spring wheat season (Educational Research and Production Center "Experimental Field" of KhNAU, 2018-2019).

According to the parametric approach, the environment was evaluated by quantitative indicators. The method determines several main parameters that characterize the suitability of the environment for selecting genotypes, namely: typicality, ability to detect genotypic differences, the productivity of the environment, interannual repeatability of the analyzed parameters.
In our research, we considered the adaptive ability as the genotype's ability to maintain its inherent phenotypic expression of the trait in certain environmental conditions. The general adaptive ability characterizes the average value of environment parameters and specific - deviation from *Vi* in a particular environment. On average, in 2018–2019, one ear's highest weight was observed in Sunnan, Prokhorovka, and Kharkivska 30 – this was 1.75, 1.34, and 1.29 g. Comparison of indicators of the general adaptive ability and weight of one ear was revealed a specific difference between these sizes at some genotypes. The highest effects of *Vi* were recorded in samples Sunnan - (0.58), Phyto 33/08 (0.34), and sample CIGM.250- (0.26), while in the sample Simkodamironovskaya (0.07) and sample Yrym (0.05), overall adaptive capacity was at the level of less productive genotypes. The stability of a particular trait can be considered in both broad and narrow senses. In the narrow sense, a genotype is stable with a stable realization of its potential, and it is characterized by a reaction to the improvement or deterioration of environmental conditions. In a broad sense, the stable genotype is a genotype that almost does not depend upon environmental conditions changes (Eberhart, 2006) (Table 2).

Table 2. Parameters of adaptive ability and phenotypic stability of spring wheat genotypes (2018–2019)

Sample name	Mass of one ear, g	V_i	σ^2Vi	$\sigma^2(G{\times}E)g$	S_{gi}	I_{gi}	K_{gi}	STsGi
Sunnan	1.75	0.58	0.14	0.001	8.00	0.02	1.6	1.19
Prokhorovka	1.34	0.18	0.10	0.010	10.41	0.56	1.0	1.74
Kharkiv 30	1.29	0.12	0.10	0.009	10.85	0.50	1.0	1.69
L-501	0.97	0.20	0.46	0.223	14.43	1.04	12.2	0.87
Simkodamironovskaya	1.24	0.07	0.10	0.016	11.29	1.53	0.6	1.64
Yrym	1.11	0.05	0.10	0.010	12.56	0.56	1.0	1.51
CIGM.250-	0.90	0.26	0.10	0.010	15.47	0.56	1.0	1.30
Phyto14/08	1.20	0.04	0.01	0.010	11.62	0.56	1.0	1.24
Phyto 33/08	0.82	0.34	0.01	0.010	16.97	0.56	1.0	0.86
L 685-12	1.02	0.15	0.01	0.013	13.73	0.76	1.0	1.06

The degree of stability of genotypes of spring wheat based on "mass of one ear" in a broad sense can be assessed by the variance of specific adaptive capacity (σ^2Vi); its lower values corresponded to greater stability. The highest stability was observed in breeding samples of Phyto 14/08 (0.01), Phyto 33/08 (0.01), and sample L 685-12 (0.01). The relative stability of the genotype (*Sgi*) indicates the trait's stability in the narrow sense. According to this indicator, the most stable samples were the Sunnan (*Sgi* = 8.0%), Prokhorovka (*Sgi* = 10.41%), and Kharkiv 30 (*Sgi* = 10.85%). In essence, the genotype's relative stability is analogous to the coefficient of variation (*Cv*). The genotype's relative stability is based on a fundamental biological basis and determines the degree of adaptability of genotypes to different environmental situations. According to the stability parameters classification, the indicator *Sgi* belongs to group A (stability type 1) and can be inherited. The variance of genotype-environment interaction, which refers to one genotype, should not be considered a parameter of ecological (phenotypic) stability. Thus, this indicator characterizes the typicality of the genotype's reaction rate and the ability to predict the environment's reaction. Among the analyzed genotypes of spring wheat, the sample L 501, according to the indicator σ^2 *(G × E) gi*, (0.22) should be considered with ten the least predictable reaction to environmental conditions changes the highest ability to interact with them.
The complex value for assessing the genotype by combining yield and stability is the most suitable selection value of the genotype (*STsGi*). In our studies, this figure ranged from 0.86 (Phyto 33/08) to 1.74 (Prokhorovka). In most cases, the collection contains genotypes with high overall adaptive capacity: Kharkiv 30 and Sunnan - respectively 1.69 and 1.19. At the same time, three genotypes with the same *Vi* 0.04, 0.05, and 0.07 showed different selection values - from 1.24 (Phyto 14/08) to 1.64 (Simkodamironivska), and the least productive genotype was the worst in terms of selection value. To establish the compensating and destabilizing effects of the genotype using the compensation factor (*Kgi*). At *Kgi* → 0, the compensating effects of the genotype-environment interaction predominate; at *Kgi* = 1, the effects of compensation and destabilization are in equilibrium, and at *Kgi* > 1, the effects of destabilization were more significant (Table 2). One studied sample of soft spring wheat had a compensating effect (*Kgi* = 0.6), and other samples - destabilizing effects (*Kgi* = 1.10-1.0) (Table 2).
We observed the highest number of grains per ear in the samples of Prokhorovka, Sunnan, and L-501 – 31.63, 29.00, and 27.93 pcs, respectively (average for 2018–2019. Comparing indicators of the general adaptive ability and quantity of grains from one ear, we revealed a specific difference between these sizes at some genotypes. The highest effects of *Vi* were recorded in the samples of Prokhorovka (8.36) CIGM.250- (7.89) and the sample Yrym (6.57), while in the sample of Phyto 14/08 (0.69), the overall adaptive capacity was at the level of less productive genotypes (Table 3).

Table 3. Parameters of adaptive ability and phenotypic stability of spring wheat genotypes (2018−2019)

Sample name	grains per ear	V_i	$\sigma^2 Vi$	$\sigma^2(G\times E)g$	S_{gi}	I_{gi}	K_{gi}	STsGi
Sunnan	27.93	4.66	0.74	1.83	2.65	3.36	0.25	17.07
Prokhorovka	31.63	8.36	0.98	1.92	2.34	1.96	0.45	17.25
Kharkiv 30	27.88	4.61	1.01	1.93	2.65	1.86	0.48	13.06
L-501	29.00	5.73	1.04	0.02	2.55	0.02	0.51	13.74
Simkodamironovskaya	27.49	4.21	1.10	1.95	2.69	1.59	0.57	11.35
Yrym	16.70	6.57	1.29	1.90	4.43	1.14	0.77	2.23
CIGM.250-	15.39	7.89	1.34	1.83	4.81	1.01	0.84	35.04
Phyto14/08	22.59	0.69	0.91	1.90	3.28	2.27	0.39	9.23
Phyto 33/08	17.03	6.24	1.29	1.90	4.35	1.14	0.77	1.90
L 685-12	17.09	6.19	1.27	1.91	4.33	1.17	0.75	1.55

The degree of stability of genotypes of spring wheat, based on "the number of grains per ear," can be assessed by the variance of specific adaptive capacity ($\sigma^2 Vi$); its lower values corresponded to greater stability. The highest stability was observed in breeding samples of Sunnan (0.74), Phyto 14/08 (0.91), and Prokhorovka (0.98). According to the relative stability of the genotype (*Sgi*), the most stable samples were Prokhorovka (*Sgi* = 2.34%), L-501 (Sgi = 2.55%), and the Kharkiv 30 (*Sgi* = 2.65%). The Simkodamiron sample, according to the index $\sigma^2 (G \times E) / gi$ value of 1.95, should be considered the least predictable reaction to environmental changes and the highest ability to interact with them. The index of genotype selection value (*STsGi*) ranged from 1.55 (L 685-12) to 35.04 (CIGM.250). In most cases, genotypes with high overall adaptive capacity were identified: the Sunnan and Prokhorovka samples had significant selection value - 17.25 and 17.07, respectively. To establish the compensating and destabilizing effects of the genotype, we used the compensation factor (*Kgi*). All studied spring soft wheat samples had destabilizing effects (*Kgi* = 0.25–0.84) (Table 3).

We observed the highest grain weight from one ear was in samples of the Sunnan, Prokhorovka, and Kharkivska - 1.24, 1.02, and 0.99 g, respectively (average for 2018-2019). Comparing indicators of the general adaptive ability and weight of grain from one ear, we revealed a distinct difference between these sizes at some genotypes. The highest *Vi* effects were recorded in Sunnan (0.43) and CIGM.250- (0.52) samples, while in the Phyto 14/08 sample, the overall adaptive capacity was at the level of less productive genotypes (0.05). The degree of stability of spring wheat genotypes, based on "grain weight from one ear," can be assessed by the variance of specific adaptive capacity (σ^2CAS); its lower values correspond to high stability. According to the genotype relative stability (*Sgi*), the most stable samples were the Sunnan (Sgi = 4.82%), Prokhorovka (Sgi = 5.85%), and Kharkiv 30 (Sgi = 6.03%). The index of $\sigma^2 (G \times E) / gi$ was 1.27 in the sample of Simkodamironovskaya. When comparing the entire collection (10 samples), this population had the least predictable response to environmental changes and was characterized by the highest ability to interact with environmental factors. In our studies, the genotype selected value (*STsGi*) ranged from 0.08 (in CIGM.250-) to 2.91 (in L-501) (Table 4).

To establish the compensating and destabilizing effects of the genotype, we used the compensation factor *(Kgi*). At *Kgi* → 0, the compensating effects of genotype-environment interaction predominated; at *Kgi* = 1, the effects of compensation and destabilization are in equilibrium, and at *Kgi* >1, the effects of destabilization are more significant. We registered the compensatory effects in two studied samples of soft spring wheat (*Kgi* = 25.0 in L 501 and 8.0 in L 685-12), whereas we determined the destabilizing effects in other samples (*Kgi* = 0.91-0.99) (Table 4).

Table 4. Parameters of adaptive ability and phenotypic stability of spring wheat genotypes based on "grain weight from one ear" (2018−2019)

Sample name	grains per ear	V_i	$\sigma^2 Vi$	$\sigma^2(G\times E)g$	S_{gi}	I_{gi}	K_{gi}	STsGi
Sunnan	1.24	0.43	0.06	0.0005	4.82	0.10	0.91	0.87
Prokhorovka	1.02	0.21	0.07	0.003	5.85	0.66	0.99	0.58
Kharkiv 30	0.99	0.18	0.06	0.0005	6.03	0.10	0.91	0.62
L-501	0.67	0.14	0.35	0.1274	8.89	1.02	25.0	2.91
Simkodamironovskaya	0.96	0.15	0.06	0.0013	6.25	0.27	0.96	0.58
Yrym	0.61	0.20	0.06	0.0013	9.84	0.27	0.96	0.23
CIGM.250-	0.52	0.29	0.07	0.0033	11.4	0.66	0.99	0.08
Phyto14/08	0.76	0.05	0.07	0.0155	7.89	3.23	0.96	1.20
Phyto 33/08	0.60	0.21	0.07	0.0033	9.92	0.66	0.99	0.16
L 685-12	0.72	0.09	0.20	0.0243	8.33	0.61	8.00	1.98

We observed the highest productivity in terms of grain weight per 1m^2 in samples of L-501, Simkodamironivska, and Prokhorovka - 479.91, 455.86, and 299.54 g (average for 2018−2019. We revealed a certain difference between these sizes at some genotypes compared to the indicators of the general adaptive ability and weight of grain from 1 m2. The highest effects of *Vi* were recorded in samples L-501 (479.91), Simkodamironovskaya (455.86), while in the sample of CIGM.250, the overall adaptive capacity was at the level of less productive genotypes (3.43). The degree of spring wheat genotype stability, based on "grain weight per 1m2", can be assessed by the variance of specific adaptive capacity (Q^2Vi): its lower values correspond to the higher stability. According to the genotype relative stability (*Sgi*), the most stable samples were L-501 (*Sgi* = 3.21%), Simkodamironovskaya (*Sgi* = 3.38%), and Prokhorovka 30 (*Sgi* = 5.14%).

The value of $\sigma^2(G\times E)/gi$ in a sample of L-501 was 8864.3. We supposed that this sample's reaction should be considered a predictable response to environmental changes and the highest ability to interact with them. The index of genotype selection value (*STsGi*) ranged from 168.9 (Simkodamironovskaya) to 577.85 (Prokhorovka). To establish the compensating and destabilizing effects of the genotype, we used the compensation factor (*Kgi*).

At *Kgi* → 0, the compensating effects of the genotype-environment interaction predominated; at *Kgi* = 1, the effects of compensation and destabilization are in equilibrium, and at *Kgi* > 1, the effects of destabilization are more noticeable. Two studied samples of soft spring wheat are in equilibrium (*Kgi* = 6.40 in L 501 and 4.11 in Simkodamironovskaya), while the other samples have destabilizing effects (*Kgi* = 0.06–0.98) (Table 5).

Table 5. Parameters of adaptive ability and phenotypic stability of spring wheat genotypes based on grain weight per 1 m^2 (2018−2019)

Sample name	Mass of grains/1m^2	V_i	σ^2Vi	$\sigma^2(G\times E)g$	S_{gi}	I_{gi}	K_{gi}	STsGi
Sunnan	263.38	29.8	15.41	-889.3	5.85	3.75	0.18	130.91
Prokhorovka	299.54	6.36	32.37	292.45	5.14	0.28	0.82	577.85
Kharkiv 30	295.48	2.30	24.49	1144.3	5.21	1.91	0.47	506.04
L-501	479.91	186.7	90.67	8864.3	3.21	1.08	6.40	299.7
Simkodamironovskaya	455.86	162.7	72.67	2248.8	3.38	0.43	4.11	168.9
Yrym	266.22	26.96	29.43	704.14	5.79	0.81	0.67	519.25
CIGM.250-	289.75	3.43	8.77	2392.7	5.32	31.1	0.06	214.37
Phyto14/08	229.43	63.75	24.53	1144.5	6.72	1.90	0.47	440.34
Phyto 33/08	167.60	125.6	26.65	1154.8	9.19	1.63	0.55	396.73
L 685-12	184.65	108.5	35.39	867.02	8.34	0.69	0.98	488.93

We determined the highest productivity in weight of 1000 seeds in samples of Sunnan, Yrym, and Kharkiv 30; it was 49.10, 47.20, and 39.42 g, respectively (average for 2018-2019). Comparing indicators of the general adaptive ability and weight of 1000 seeds, we revealed a certain difference between these sizes at some genotypes. The highest effects of *Vi* were recorded in samples of Sunnan (11.96), Yrym - (10.06), and CIGM.250 (7.34), while in sample L-501 (1.16), the overall adaptive capacity was at the level of less productive genotypes. The degree of spring wheat genotype stability based on the mass of 1000 seeds can be assessed by the variance of specific adaptive capacity (σ^2Vi); its lower values correspond to higher stability. According to the relative stability of the genotype (*Sgi*), the highest values were registered in CIGM.250- (*Sgi* = 5.34%), L 685-12 (*Sgi* = 5.08%), and Phyto 14/08 (*Sgi* = 5.06%). The index $\sigma^2(G\times E)gi$ of the Simkodamironovskaya sample was 34.95; this sample's reaction was the least predictable reaction changes in environmental conditions and the highest ability to interact them. In our studies, the *STsGi* ranged from 4.49 (L-501) to 165.52 (Yrym). To establish the compensating and destabilizing effects of the genotype, we used the compensation factor (*Kgi*).

At *Kgi* → 0, the compensating effects of the genotype × environment interaction predominate; at *Kgi* = 1, the effects of compensation and destabilization are in equilibrium, and at *Kgi*>1, the effects of destabilization were more significant. We revealed the compensatory effects of *Kgi in* two studied samples of soft spring wheat; these were 2.99 (Yrym) and 2.64 (Kharkiv 30), while we registered the destabilizing effects in other samples (*Kgi* = 0.05–0.99) (Table 6).

Table 6. Parameters of adaptive ability and phenotypic stability of spring wheat genotypes based on "mass of 1000 seeds" (2018−2019)

Sample name	Weight of 1000 seeds	V_i	σ^2Vi	$\sigma2(G\times E)g$	S_{gi}	I_{gi}	K_{gi}	STsGi
Sunnan	49.10	11.96	1.59	28.59	3.24	11.17	0.07	31.03
Prokhorovka	32.25	4.89	1.31	61.01	4.93	35.16	0.05	17.36
Kharkiv 30	39.42	2.28	9.77	26.30	4.03	0.28	2.64	150.46
L-501	35.98	1.16	3.56	5.37	4.42	0.42	0.35	4.49
Simkodamironovskaya	39.90	2.76	4.76	32.55	3.98	1.44	0.63	14.20
Yrym	47.20	10.06	10.41	34.95	3.37	0.32	2.99	165.52
CIGM.250-	29.80	7.34	5.93	9.58	5.34	0.27	0.97	97.20
Phyto14/08	31.42	5.72	4.14	32.25	5.06	1.88	0.47	15.64
Phyto 33/08	35.03	2.11	5.61	29.85	4.54	0.95	0.87	28.74
L 685-12	31.30	5.84	5.98	22.07	5.08	0.62	0.99	36.67

Conclusions

We registered the highest general adaptive ability based on "weight of one ear" in samples of Swedish, Russian, and Ukrainian selection: Sunnan, Prokhorovka, and Kharkiv 30. The Sunnan, Prokhorovka, and Kharkivska 30 showed high stability of one ear's mass when evaluating specific adaptive capacity. According to the genotype's relative stability, the highest stability had joined breeding samples of Simkodamironovskaya and Yrym.

The genotype's selection value, which combines productivity and stability, was the highest in genotypes with high overall adaptability. At the same time, three genotypes had different *Vi* values: L-501, Irym, and CIGM.250-; we also determined that the least productive of them was CIGM.250- according to this parameter. We suggested that the best-adapted spring soft wheat varieties were the Sunnan, Prokhorovka, and Kharkivska 30.

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