Scientific Papers. Series A. Agronomy, Vol. LXVIII, No. 1, 2025
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

YIELD STABILITY AND ITS ELEMENTS IN COMMON WINTER WHEAT VARIETIES UNDER PAZARDZHIK REGION CONDITIONS

Evgeniy DIMITROV[1], Hristina NEDEVA[2], Rangel DRAGOV[3], Teodora ANGELOVA[4], Zlatina UHR[4], Blagoy ANDONOV[4]

[1]Institute of Plant Genetic Resources "K. Malkov", 2 Druzhba Street, Sadovo, Bulgaria
[2]Agricultural Experimental Station of Irrigative Agriculture, 4407, Pazardzhik, Village of Ivaylo, Bulgaria
[3]Field Crops Institute, 2 G. Dimitrov Street, Chirpan, Bulgaria
[4]Institute of Plant Genetic Resources, 2 Druzhba Street, Sadovo, Bulgaria

Corresponding author email: genipd@abv.bg

Abstract

In the period 2019-2023 in the field of irrigated agriculture experimental station Pazardzhik on cinnamon forest soil at humus 1.2-1.5% and pH 5.5-6 is set trial, which includes 9 varieties of common winter wheat selection of IPGR Sadovo. The stability of yields and its elements -1000 grains weight, and test weight, kg/hl Yield stability and grain physical properties of the varieties were evaluated using the stability variants σi2 and Si2 of Shukla (1972), the ecovalance Wi of Wricke (1962) and the phenotypic stability criterion (Ysi) of Kang (1993). IPCSSVKYSI (Interactive program for calculating Shukla`s stability index (Ysi)) developed by Kang and Magari (1995) was used to determine the stability index. The objective of our study was to evaluate the stability of common winter wheat cultivars grown in the Pazardzhik region. The results of this study will enable us to make an even more complete evaluation of the varieties of the IPGR Sadovo breeding of common winter wheat. Phenotypic stability is particularly important for practice.

Key words: *winter wheat, stability, yield, yield traits, climate change.*

INTRODUCTION

Wheat is one of the most important crops grown globally and plays a critical role in ensuring global food security (Gooding & Shewry, 2022; Gooding, 2023). Different forms of this species are cultivated, which are also related to its intended use and further uses. In the temperate climate of Central Europe, the most popular form is winter wheat, characterized by high yields and good baking properties (Oleksiak et al., 2022).
Despite continued progress in breeding new varieties, wheat yield remains highly dependent on the interaction between genotype and environment. Climate change, driven by global warming, exerts a substantial influence on agricultural production, particularly in areas reliant on rain-fed agriculture (Farrell et al., 2023). These areas are particularly susceptible to climatic conditions (Jiang et al., 2022). Climate warming directly alters the water cycle and precipitation patterns, resulting in increased dry-wet annual variability of precipitation (Malakouti, 2023; Zhang & Zhou, 2020). Therefore, gaining insight into the dynamics of meteorological factors and their impact on agricultural productivity is of importance for predicting future climatic trends and devising sustainable agricultural production strategies (Gu et al., 2017).
According to the World Bank of Development Report (WBDR), namely, The Changing Nature of Work published in early 2019, Bulgarian agriculture will be strongly influenced by climatic changes now and in the next 20-30 years. According to the ex-perts, agriculture plays a key yet disproportionate role in the socioeconomic fabric of rural Bulgaria (World bank, 2019).
In Bulgaria, there are regional differences in the likelihood of negative impacts from drought and flooding, as well as differences in the vulnerability, resilience and adaptive capacity of rural populations to climate change (Georgieva et al., 2022).
Genotype × environment (GE) interaction means that varieties respond differently to changes in growing conditions. Relative ranking of the performance of a group of cultivars under different environmental conditions gives

different results. Even among specific, regionally adapted breeding forms, it is difficult to select the best genotype because of the variability of yields in different years of observation and under different environmental conditions

In general, potential yield in dry years is strongly influenced by rainfall. Furthermore, inter-annual variations in rainfall are the main determinants of winter wheat yield in specific growing seasons without supplemental irrigation (Wang et al, 2025). Genotype × environment (GE) interaction means that varieties respond differently to changes in growing conditions. Relative ranking of the performance of a group of cultivars under different environmental conditions gives different results. Even among specific, regionally adapted breeding forms, it is difficult to select the best genotype because of the variability of yields in different years of observation and under different environmental conditions

In general, potential yield in dry years is strongly influenced by rainfall. Furthermore, inter-annual variations in rainfall are the main determinants of winter wheat yield in specific growing seasons without supplemental irrigation (Wang et al., 2025). Current winter wheat varieties will maintain their potential productivity, but actual yields will be strongly influenced by the duration of drought periods (Kazandjiev et al., 2023) GxE interactions have been used in various methods to characterize the response of genotypes to changing environments along with the average value of quantitative traits tested (Mohammadi et al., 2009; Christov et al., 2010; Hilmarsson et al., 2021). Research on this interaction is crucial for the stability and adaptability of varieties to different agro-climatic conditions. Genotype-environment interaction is defined as the variation in performance of different genotypes caused by specific environmental conditions. This phenomenon makes direct selection of high-yielding varieties difficult, as genotypes may show different behaviour depending on the location and year of cultivation. Various statistical and graphical methods are used to analyse the G×E interaction. Among the most common are: AMMI (Additive Main Effects and Multiplicative Interaction) analysis, a method that combines analysis of variance with principal components to identify stable genotypes (Gauch, 2020). GGE Biplot analysis, a graphical method that represents genotype and environment interaction effects, allowing identification of the most productive and stable varieties (Yan & Tinker, 2019).

The objective of our study was to evaluate the stability of common winter wheat cultivars grown in the Pazardzhik region. The results of this study will enable us to make an even more complete evaluation of the varieties of the IPGR Sadovo breeding of common winter wheat. Phenotypic stability is particularly important for practice.

MATERIALS AND METHODS

In the period 2019-2023 on the field of irrigated agriculture experimental station Pazardzhik on cinnamon forest soil at humus 1.2-1.5% and pH 5.5-6 is set trial, which includes 9 varieties of common winter wheat breeding of IPGR Sadovo. It is located in southern Bulgaria, in the central part of the Upper Thracian Lowland, north of the Rhodope Mountains, along the Maritsa River. It was laid out using the long strip method in four replications with a harvest plot size of 10 m^2. The sowing rate is 550 gs/m^2. Fertilization was with phosphorus (20 kg/da), applied as triple superphosphate presowing. The entire nitrogen fertilizer rate was applied as N_{12} (applied as ammonium nitrate). The stability of yields and its elements -1000 grains weight, g by weighing two samples of 500 grains (BSS ISO 520:2003) and test weight, kg/hl according to BSS ISO 7971:2000 of varieties of common winter wheat were determined.

Analysis of variance (ANOVA) and variational analysis was performed to determine the significance and influence of individual factors. The coefficient of variation was calculated. It is accepted that the variation is considered weak if the coefficient of variation is up to 10%, medium - when it is greater than 10% and less than 20%, strong - when it is over 20% (Dimova & Marinkov, 1999).

Yield stability and grain physical properties of the varieties were evaluated using the stability variants σi^2 and Si^2 of Shukla (1972), the ecovalance Wi of Wricke (1962) and the phenotypic stability criterion (Ysi) of Kang (1993). IPCSSVKYSI (Interactive program for calculating Shukla's stability index (Ysi)) developed by Kang & Magari (1995) was used to determine the stability index.

RESULTS AND DISCUSSIONS

Multilocation trials - used for breeding of varieties with high adaptability in different agro-ecological conditions (Bhatta et al., 2022). Different climatic conditions - temperature, rainfall, soil characteristics - have a significant impact on yield. Studies have shown that, high temperatures can reduce yield by up to 20% due to shortening of the growing season (Lobell et al., 2018). Moisture deficiency leads to reduced biomass and poor grain quality (Yang et al., 2020). High soil fertility promotes varietal resistance under stress conditions (Sharma et al., 2023). Modern breeding programs aim to develop varieties with higher yield stability under different environmental conditions. Genetic selection combined with molecular markers allows identification of genes associated with drought and temperature stress tolerance (Singh et al., 2019). In addition, integrating predictive models of G×E interactions helps develop cultivars that exhibit greater stability. Research on genotype-environment interactions in common wheat is essential for improving breeding programs and ensuring stable yields under changing climates. The development of new methodologies for analyzing G×E interactions, combined with advances in genetics, will play a key role in the future selection of high-yielding, resistant varieties.

Table 1 presents the tracking data for precipitation and monthly mean temperature for the period 2019-2023. Deviations are observed for both monitored indicators. For average monthly temperatures from October to February inclusive, there is a trend of: an increase compared to the norm of the 70-year period, and for the months of March to May a decrease from minus 0.7 to minus 4.1°C. There is a shift of the 'winter or cool months. For the indicator rainfall sum, in two of the five years the values are lower than the norm (2018/2019; 2022/2023), with a difference of more than 135 mm in the growing season 2022/2023. In 2019/2020, rainfall is close to normal. In 2020/2021 and 2021/2022, more precipitation fell, but it was unevenly distributed. In all five years of the study, lower than normal rainfall during the phases heading, flowering and beginning of grain filling.

Table 1. Deviations in precipitation and average monthly temperatures for the period 2019-2023

Months/ Year	X	XI	XII	I	II	III	IV	V	VI
rainfall deviation, mm									
2018-2019	-28.3	20.1	-24.8	-16.5	-19.1	-34.4	14.6	-29.1	72.5
2019-2020	-31.7	56.2	-32	-34.1	-9.3	76	34.8	-32	-22.1
2020-2021	24.4	-38.2	1.7	44.6	-8.5	-2.3	30	-17.4	17.6
2021-2022	121	-35.5	20.6	5	17.1	-17	4.8	-48.6	-5.7
2022-2023	-35.6	-20.4	-17.8	-5.9	-28.1	-4.5	10.1	-19.6	-14.5
deviation at mean monthly temperature, ^{0}C									
2018-2019	0.9	0.3	0.2	2	2.1	3.6	-0.3	-1.6	1.8
2019-2020	1.8	3.3	1.9	2.8	4	2.1	-0.9	-1.8	0.3
2020-2021	2	-0.1	3.3	2.8	2.9	-0.7	0.1	-1.9	0.5
2021-2022	-1.7	0.9	1.5	2.5	2.5	-1.4	0	-0.8	1.7
2022-2023	1.3	2.7	3.4	5	3.2	1.7	-0.7	-4.1	0.8

The yield and quality based performance of all tested genotype in breeding experiments is the result of the interaction among genotypes, and environmental factors (Akcura & Kaya, 2008). Therefore, evaluating and increasing the yield potential of genotypes in different ecologies in variable climatic conditions is given high importance as an important selection criteria in Turkish wheat breeding programs (Bilgin et al., 2016). Besides these, many other factors like crop rotation, tillage, fertilization, genotype, biotic and abiotic factors could also affect yield and grain yield potential of wheat varieties in a region (Pepo & Kovacevic, 2011). Therefore would be new varieties are tested in different environments, to facilitate recommending them for different regions (Yaşar et al., 2020) depending on their compatiblity with local ecologies. Kaya & Akcura (2014) and Nehe et al. (2019) suggest that genotypes and environment including precipitation have the main effect on grain yield and quality characteristics of bread wheat are very important in multilocation experiments.

Table 2 presents the grain yield results for the wheat varieties studied. The data from our table show that the highest average yield for the study period was recorded in the variety Sashets - 652.2 kg/da, and the lowest result was shown by the variety Pobeda - 547.0 kg/da. In eight genotypes there was an excess of the trait compared to the standard, but the differences were not mathematically signifficant. Comparing the individual yield values in different years, it can be seen that in the 2022 crop year the lowest average yields were recorded - 438.7 kg/da, while the maximum grain yield was recorded in 2020, with three wheat varieties recording yields of over 700 kg/da.

Table 2. Average yield of winter common wheat for the period 2019-2023

№	Genotyp	Grain yield, kg/da						± D	Sign.	% to standard
		2019	2020	2021	2022	2023	$\bar{x}$			
1	Sadovo 1 – st.	606.7	655.9	576.0	442.0	631.0	582.3			100
2	Pobeda	587.9	583.4	539.0	414.0	610.5	547.0	-35.3	n.s.	93.9
3	Murgavets	632.3	698.8	630.0	407.0	645.5	602.7	20.4	n.s.	103.5
4	Boryana	659.6	704.4	714.0	469.0	603.0	630.0	47.7	n.s.	108.2
5	Geya	689.1	727.1	658.0	456.0	595.0	625.0	42.7	n.s.	107.3
6	Fermer	535.5	597.7	674.0	452.0	586.5	569.1	-13.2	n.s.	97.7
7	Gizda	662.7	769.5	713.0	447.5	570.0	632.5	50.2	n.s.	108.6
8	Nikibo	679.4	633.6	621.0	435.0	579.0	589.6	7.3	n.s.	101.2
9	Ginra	646.3	666.4	669.0	433.0	625.5	608.1	25.7	n.s.	104.4
10	Nadita	640.0	672.0	664.0	447.0	601.0	604.8	22.5	n.s.	103.9
11	Sashets	685.0	730.0	732.0	423.0	691.0	652.2	69.9	n.s.	112.0
Mean		638.6	676.3	653.6	438.7	612.5	603.9			
Minimum		535.5	583.4	539.0	407.0	570.0	547.0			
Maximum		689.1	769.5	732.0	469.0	691.0	652.2			
Std. Dev.							30.7			
Coef. Var.							9.3			
Standard error							5.1			
GD 5.0%=74.6; GD 1.0%=98.7; GD 0.1%=127.3										

+ -,+ + - -,+ + + - -, signifficant at GD 5.0%, GD 1.0% and GD 0.1%; n.s. - not significant

For the milling industry, the so-called milling qualities of wheat are of crucial importance. This concept covers a complex of physical particularityof the grain, such as test weight (density), large (size), vitreous, etc., which have a significant influence in the process of preparation and milling of the grain and determine the yield and quality of the flour (Tsenov et al., 2015; Nazarenko et al., 2020). Determination of the test weight is adopted by all state standards as an important trait of the quality of grain raw materials. A grain with a high test weight is well developed, plump and contains relatively more endosperm and less shell. Determination of grain density is an indicator of the overall quality and initial evaluation of the grain. (Bern & Brumm, 2009). The reported mean values of test weight (Table 3) ranged from 69.28 (Geya) to 75.60 (Pobeda) kg/hl. Three genotypes were above the standard level and their difference with Sadovo 1 was mathematically assured. In the 2020 crop year, the genotypes studied realized the highest average value of the trait - 78.01 kg/hl, while the lowest test weight was recorded in 2022 -71.50 kg/hl.

The 1000 kernel weight is an important indirect trait that characterizes the grain size, its milling quality (therelative content of endosperm, as well as the potential yield of flour with a low ash content), and determines its quality as seed material (Taneva et al., 2014; Ivanov, 2019). The hereditary validity of individual quality parameters is undoubtedly an established fact. The varietal determination of the grainweight is strongly manifested. It is believed that a larger and heavier grain is distinguished by a greater potential for flour yield, although this dependence has not been mathematically significant (Ivanov, 2019; Nazarenko et al., 2020).

The results obtained for the trait 1000 grains weight (Table 4) ranged from 33.20 (Gizda) to 44.24 g (Geya). On four wheat varieties, the reported value of the trait exceeded that of the standard, and in two of them the difference was mathematically significant. In 63.6% of the total varieties tested, the 1000 grains weight was above 40 g. The highest mean values were recorded in 2019 (44.98 g), while the most unfavorable year for the studied trait appeared to be 2022 with a mean value of the trait of 33.13 g.

Table 3. Test weight of common winter wheat varieties for the period 2019-2023

№	Genotyp	Test weight, kg/hl						± D	Sign.	% to standard
		2019	2020	2021	2022	2023	$\bar{x}$			
1	Sadovo 1 – st.	73.26	77.84	72.58	73.90	73.10	74.14			100
2	Pobeda	75.48	78.84	75.46	73.00	75.20	75.60	1.46	+++	102.0
3	Murgavets	72.78	78.12	73.12	70.80	72.50	73.46	-0.67	---	99.1
4	Boryana	71.01	80.40	74.07	72.80	72.20	74.10	-0.04	n.s.	99.9
5	Geya	68.66	73.35	68.19	67.10	69.10	69.28	-4.86	---	93.4
6	Fermer	72.94	77.88	72.60	72.40	73.00	73.76	-0.37	--	99.5
7	Gizda	74.65	78.89	73.56	72.00	74.80	74.78	0.64	+++	100.9
8	Nikibo	71.39	75.07	71.70	70.10	71.90	72.03	-2.10	---	97.2
9	Ginra	73.79	78.82	75.77	71.20	73.10	74.54	0.40	+++	100.5
10	Nadita	73.10	79.06	74.14	71.80	72.50	74.12	-0.02	n.s.	100.0
11	Sashets	73.20	79.80	73.86	71.40	72.70	74.19	0.06	n.s.	100.1
Mean		72.75	78.01	73.19	71.50	72.74	73.64			
Minimum		68.66	73.35	68.19	67.10	69.10	69.28			
Maximum		75.48	80.40	75.77	73.90	75.20	75.60			
Std. Dev.							1.69			
Coef. Var.							0.51			
Standard error							2.3			
GD 5.0%=0.22; GD 1.0%=0.30; GD 0.1%=0.38										

+ -,+ + - -,+ + + - -, signifficant at GD 5.0%, GD 1.0% and GD 0.1%; n.s. - not significant

Table 4. Weight per 1000 grains of common winter wheat varieties for the period 2019-2023

№	Genotyp	1000 grains weight, g						± D	Sign.	% to standard
		2019	2020	2021	2022	2023	$\bar{x}$			
1	Sadovo 1 – st.	48.42	43.30	38.20	36.40	43.20	41.90	0.00		100
2	Pobeda	43.30	38.30	39.20	32.28	43.30	39.28	-2.63	---	93.7
3	Murgavets	43.22	42.46	41.10	35.20	45.20	41.44	-0.47	n.s.	98.9
4	Boryana	46.56	44.38	42.14	34.62	42.40	42.02	0.12	n.s.	100.3
5	Geya	49.34	44.66	44.26	33.52	49.40	44.24	2.33	+++	105.6
6	Fermer	45.32	40.88	37.92	33.84	41.40	39.87	-2.03	+++	95.2
7	Gizda	35.84	34.94	33.10	26.32	35.80	33.20	-8.70	---	79.2
8	Nikibo	46.28	43.50	42.14	38.50	44.70	43.02	1.12	+	102.7
9	Ginra	44.72	43.06	41.06	31.80	42.80	40.69	-1.22	-	97.1
10	Nadita	45.51	36.52	36.92	30.16	40.30	37.88	-4.02	---	90.4
11	Sashets	46.30	42.20	45.16	31.84	45.40	42.18	0.28	n.s.	100.7
Mean		44.98	41.29	40.11	33.13	43.08	40.52			
Minimum		35.84	34.94	33.10	26.32	35.80	33.20			
Maximum		49.34	44.66	45.16	38.50	49.40	44.24			
Std. .Dev.							3.01			
Coef.Var.							0.91			
Standard error							7.4			
GD 5.0%=0.22; GD 1.0%=0.30; GD 0.1%=0.38										

+ -,+ + - -,+ + + - -, signifficant at GD 5.0%, GD 1.0% and GD 0.1%; n.s. - not significan

The calculated coefficient of variation for thestudied traits shows that the variation is estimated to be low (CV>10%) according Dimova & Marinkov (1999).

Analysis of genotypex interaction is particularly import ant for the breeding process (Yan & Hunt, 2001). Very often, high yield stability is associated with low levels of manifes tation, and vice versa (Tsenov et al., 2004; Atanasova et al., 2010).

Table 5 presents the analysis of variance, where the strength of influence of genotype, environment and their interaction factors on the occurrence of the studied indices were evaluated.

The data from the analysis determined a leading influence of environment conditions on all three studied indicators, with Ŋ values ranging from 60.4 (1000 grains weight) to 68.6% (grain yield). The second most influential factor was genotype for the test weight (61.2%) and 1000 grain weight (60.4%) traits, while the interaction of genotype x environment conditions factors had a minor influence on the occurrence of the grain yield trait, with a value of Ŋ=9.9%. The influence of the sources of variation genotype, environment and their interaction was signifficant at α=0.001, the only exception being observed in grain yield where the influence of year was mathematically assured at α=0.01 level of confidence.

Table 5. Analysis of variance (ANOVA) for grain yield from common winter wheat

Indicator	Sources of variation	SS	df	MS	F exp.	F tab.	Ŋ,%	Sig.
Grain yield	Genotype - factor A	141294.0	10	14129.4	6.6	3.3	8.1	***
	Environment - factor B	1197354.4	4	299338.6	140.9	5.0	68.6	***
	Interaction - AxB	172311.4	40	4307.8	2.0	1.8	9.9	**
	Error	233750.0	110	2125.0			13.4	
	Total	1744709.8	164				100.0	
Test weight	Genotype - factor A	428.4	10	42.8	2243.9	3.3	31.2	***
	Environment - factor B	840.1	4	210.0	11001.3	5.0	61.2	***
	Interaction - AxB	101.7	40	2.5	133.2	2.1	7.4	***
	Error	2.1	110	0.0			0.2	
	Total	1372.3	164				100.0	
1000 grains weight	Genotype - factor A	1355.6	10	135.6	418.4	3.3	30.3	***
	Environment - factor B	2699.0	4	674.7	2082.5	5.0	60.4	***
	Interaction - AxB	378.7	40	9.5	29.2	2.1	8.5	***
	Error	35.6	110	0.3			0.8	
	Total	4469.0	164				100.0	

SS - sum of squares; gf - degrees of freedom; MS - variance; F exp. - F experimental; F tab. - F tabular; ŋ - force of influence of the factor (%);** - significant at $\alpha = 0.01$ *** - significant at $\alpha = 0.001$

A very important condition for determining the stability and adaptability of genotypes with respect to the trait yield is the presence of a proven interaction between the studied genotypes and the conditions of the environment in which they are grown (Uhr, 2015; Ivanov et al., 2018). Based on the signifficant influence of growing conditions on the manifestation of the studied traits in the analysis of variance gives us the basis to evaluate the studied genotypes also by their stability of the studied traits under different climatic conditions. The calculated variance stability σi^2 and Si^2 by Shukla, the Wricke's ecovalence W_i^2 and the Kang's stability criterion YSi are presented in Tables 6, 7 and 8. Varieties showing lower values for the parameters σi^2, Si^2, Wi are judged to be more stable because they interact less with the environmental conditions.

Negative values of the indicators σi^2 and Si^2 are assumed to be 0. At high values of the parameters - σi^2, Si^2, W_i^2 genotypes are considered as unstable. The results obtained for the stability of yield in the criteria σi^2, Si^2, W_i^2 (Table 6) show that the highest stability in the indicator of grain yield possess the varieties Nadita and Ginra. These genotypes interact less with environmental conditions and their yield is at a relatively constant level. The varieties Gizda and .Fermer are characterised as not stable in terms of yield, with large differences from year to year in the values obtained for the trait.

A comprehensive assessment of the integrity of genotypes is given by the Kang criterion (YSi). It is based on a simultaneous evaluation of the values of realized grain yield and its stability over the different climatic years. According to this criterion, genotypes are ranked in descending order, with those with the lowest values being the most economically valuable. In our study, Boryana, Ginra and Nadita can be likened as such varieties combining high and stable yield over the years.

Table 6. Stability parameters for the grain yield of common winter wheat in terms of years

№	Variety	GY	σ^2_i	s^2_i	W_i^2	YSi
1	Sadovo 1 st.	582.3	1512.7	598.5	5472.8	16
2	Pobeda	547.0	2502.3	842.4	8711.8	20
3	Murgavets	602.7	814.8	325.1	3188.8	11
4	Boryana	630.0	602.0	354.3	2492.5	6
5	Geya	625.0	921.3	478.1	3537.6	9
6	Fermer	569.1	3511.1	1268.3	12013.1	21
7	Gizda	632.5	3078.9	1215.7	10598.6	12
8	Nikibo	589.6	1264.4	631.0	4660.3	14
9	Ginra	608.0	-4.1	65.3	508.7	7
10	Nadita	604.8	-59.9	40.8	326.3	7
11	Sashets	652.2	1655.4	218.0	5940.0	9

GY- grain yield (da); σ^2_i - Shukla's stability variance; s^2_i - deviation from redression; W_i^2 - Wricke's ecovalence; YSi -Kang's criterion

The calculated parameters of phenotypic stability in test weight (Table 7) show that the varieties Murgavets and Geya1 are characterized by the highest stability of the indicator according to the criteria σ^2_i and W_i^2, and according to the stability variant s^2_i variety Sashets ranks first, followed by Murgavets. As unstable and high fluctuations in test weight values we can liken Boryana, Sadovo 1 and Ginra. The varieties distinguished by high test weight values and good stability according to Kang's criterion (YSi) are the genotypes Pobeda, Nadita and Sashets.

Table 7. Stability parameters for the test weight of common winter wheat in terms of years

№	Variety	TW, $\bar{x}$	σ^2_i	s^2_i	W_i^2	YSi
1	Sadovo 1 st,	74.14	1.524	0.530	5.30	15
2	Pobeda	75.60	0.646	0.194	2.42	7
3	Murgavets	73.46	0.033	0.032	0.42	10
4	Boryana	74.10	3.102	1.008	10.46	18
5	Geya	69.28	0.239	0.137	1.09	13
6	Fermer	73.76	0.270	0.132	1.19	12
7	Gizda	74.78	0.667	0.351	2.49	10
8	Nikibo	72.03	0.663	0.062	2.48	17
9	Ginra	74.54	1.308	0.638	4.59	12
10	Nadita	74.12	0.247	0.093	1.12	9
11	Sashets	74.19	0.620	0.028	2.34	9

TW- test weight (kg/hl); σ^2_i - Shukla's stability variance; s^2_i - deviation from redression; W_i^2 - Wricke's ecovalence; YSi - Kang's criterion

The results obtained for 1000-grain weight (Table 8) show that high stability over the study period was found in the cultivars Gizda, Pobeda, and Nikibo, while Sashets and Sadovo 1, characterized by the highest values of the stability variants σ^2_i, s^2_i, and W_i^2, can be indicated as not stable. Boryana and Nikibo appear to be the most valuable according to Kang's criterion (YSi), combining high trait values and good stability across climatic years.

Table 8. Stability parameters for the 1000-grain weight of common winter wheat in terms of years

№	Variety	1000 GW, $\bar{x}$	σ^2_i	s^2_i	W_i^2	YSi
1	Sadovo 1 st.	41.90	5.942	2.876	20.59	15
2	Pobeda	39.28	1.375	0.795	5.65	11
3	Murgavets	41.44	2.708	0.914	10.01	12
4	Boryana	42.02	1.963	1.052	7.57	9
5	Geya	44.24	5.328	0.674	18.58	10
6	Fermer	39.87	1.575	0.804	6.30	12
7	Gizda	33.20	1.060	0.442	4.62	12
8	Nikibo	43.02	2.931	0.083	10.74	9
9	Ginra	40.69	1.428	0.692	5.82	10
10	Nadita	37.88	4.234	1.760	15.01	18
11	Sashets	42.18	6.171	2.350	21.34	14

1000 GW- 1000 grain weight (g); σ^2_i - Shukla's stability variance; s^2_i - deviation from redression; W_i^2 - Wricke's ecovalence; YSi - Kang's criterion

CONCLUSIONS

In the conditions of the Pazardzhik region:

- The highest average grain yield was realized by the Sashets variety;
- The maximum value of the trait test weight was recorded in variety Pobeda and the best result in the 1000 grains weight showed variety Geya;
- The leading influence on the phenotypic manifestation of the studied traits had the growing conditions.

The following genotypes can be singled out as the most valuable from the breeding point of view, distinguished by a good combination of high and stable results under different climatic conditions:

- Ginra: high and stable value of the trait grain yield;
- Sashets: high and stable value of the trait test weight;
- Nikibo: high and stable value of the trait 1000 grains weight.

The obtained data can be used in the selection and improvement work in the creation of new varieties of winter wheat, distinguished by quality stability and high values of the traits yield, test weight and 1000 grains weight.

REFERENCES

Akcura, M, Kaya, Y. (2008). Nonparametric stability methods for interpreting genotype by environment interaction of bread wheat genotypes (*Triticum aestivum* L.). *Genet. Mol. Biol.,* 31, 906–913.

Atanasova, D., Tsenov, N., Stoeva, I., Todorov, I. (2010). Performance of Bulgarian winter wheat varieties for main end-use quality parameters under different environments. *Bulg. J. Agric. Sci.*, *16*(1), 22–29.

Bern, C., Brumm, T. (2009). Grain weight fraud. Iowa State University-University Extension. PMR 1005.

Bhatta, M., Bhattarai, S., Rai, M., Sharma, P., Kumar, A. (2022). Impact of Genotype × Environment Interaction on the Stability of Wheat Yield: Insights from Multi-Location Trials. *Crop Science, 62*(4), 1097–1111.

Bilgin, O., Guzman, C., Baser, I. (2016). Evaluation of grain yield and quality traits of bread wheat genotypes cultivated in Northwest Turkey. *Crop Sci.* 56, 73–84.

Christov, N., Mladenova, N., Djuric, V., Kondic-Spika, A., Marjanovic-Jeromela, A., Simic, D. (2010). Genotype by environment interactions in wheat quality breeding programs in southeast Europe. *Euphytica* 174, 315–324.

Dimova, D. Marinkov, E. (1999) Experimental Work and Biometrics. *Academic Publishing House of the Agricultural University*, Plovdiv, 127-166.

Farrell, A. D., Deryng, D., Neufeldt, H. (2023). Modelling adaptation and transformative adaptation in cropping systems: Recent advances and future directions. *Current Opinion in Environmental Sustainability*, 61, 101265.

Gauch, H. G. (2020). A simple protocol for AMMI analysis of yield trials. *Agronomy Journal, 112*(1). 186–192.

Georgieva, V., Kazandjiev, V., Bozhanova, V., Mihova, G., Ivanova, D., Todorovska, E., Uhr, Z., Ilchovska, M., Sotirov, D., Malasheva, P. (2022). Climatic Changes A Challenge for the Bulgarian Farmers. *Agriculture,* 12(12), 2090.

Gooding, M. J. (2023). Wheat. In ICC Handbook of 21st Century Cereal Science and Technology. *Elsevier: Hoboken, NJ, USA*, 121–130.

Gooding, M. J., Shewry, P. R. (2022). Wheat: Environment, food and health. *John Wiley & Sons*.

Gu, C. J., Mu, X. M., Gao, P., Sun, W., Zhao, G. (2017). Characteristics of temporal variation in precipitation and temperature in the Loess Plateau from 1961 to 2014. *J. Arid Land Resour. Environ*, 31, 136–143.

Hilmarsson, H. S., Rio, S., Sánchez, J. I. Y. (2021). Genotype by environment interaction analysis of agronomic spring barley traits in Iceland using AMMI, factorial regression model and linear mixed model. *Agronomy*, *11*(3), 499.

Ivanov, G. (2019). Quality assessment of common winter wheat varieties grown under organic and conventional farming conditions. *New Knowledge*, 62-68.

Ivanov, G., Uhr, Z., Delchev, G. (2018). Estimation of yield and stability of varieties of common winter wheat grown under organic and conventional agriculture. *New Knowledge Journal of Science*, *7*(2*),* 265–272 (Bg).

Jiang, T., Wang, B., Xu, X., Cao, Y., Li Liu, D., He, L., He, J. (2022). Identifying sources of uncertainty in wheat production projections with consideration of crop climatic suitability under future climate. *Agricultural and Forest Meteorology*, 319, 108933.

Kang, M. (1993). Simultaneous selection for yield and stability in crop performance trials: Consequences for growers. *Agronomy Journal*, 85, 754-757.

Kang, M. S., Magari, R. (1995). STABLE: A BASIC program for calculating stability and yield-stability statistics. *Agronomy Journal*, *87*(2), 276–277.

Kaya, Y., Akcura, M. (2014). Effects of genotype and environment on grain yield and quality traits in bread wheat (*T. aestivum* L.). *Food Science and Technology*, 34, 386–393.

Kazandjiev, V., Georgieva, V., Ivanov, M., Mihova, G., Uhr, Z. (2023). Evaluation of the productivity of different varieties of winter wheat in the conditions of the future climate until 2030-2050. *Agriculture and Food*, *11*(1), 187–194.

Lobell, D. B., Hammer, G. L., McLean, G., Davies, D. N., Martin, E. J., Basso, B., Franke, J., O`Leary, D. (2018). The critical role of extreme heat for maize and wheat production in the United States. *Nature Climate Change, 8*(7), 599–604.

Malakouti, S. M. (2023). Utilizing time series data from 1961 to 2019 recorded around the world and machine learning to create a Global Temperature Change Prediction Model. *Case Studies in Chemical and Environmental Engineering*, 7, 100312.

Mohammadi, R., Aghaee, M., Haghparast, R., Pourdad, S., Rostaii, M., Ansari, Y., Abdolahi, A., Amri, A. 2009. Association among non-parametric measures of phenotypic stability in four annual crops. *Middle Eastern and Russian Journal of Plant Science and Biotechnology* 3, 20–24.

Nazarenko, M., Mykolenko, S. Okhmat, P. (2020). Variation in grain productivity and quality of modern winter wheat varieties in northern Ukrainian Steppe. *Ukrainian Journal of Ecology*, *10*(4), 102–108.

Nazarenko, M., Mykolenko, S., Okhmat, P. (2020). Variation in grain productivity and quality of modern winter wheat varieties in northern Ukrainian Steppe. *Ukrainian Journal of Ecology*, *10*(4), 102–108.

Nehe, A., Akin, B., Sanal, T., Evlice, A. K., Ünsal, R., Dinçer, N., Morgounov, A. (2019). Genotype x environment interaction and genetic gain for grain yield and grain quality traits in Turkish spring wheat released between 1964 and 2010. *PLoS One*, *14*(7), e0219432.

Oleksiak, T., Spyroglou, I., Pacoń, D., Matysik, P., Pernisová, M., Rybka, K. (2022). Effect of drought on wheat production in Poland between 1961 and 2019. *Crop Science*, *62*(2), 728–743.

Pepo, P., Kovačević, V. (2011). Regional analysis of winter wheat yields under different ecological conditions in Hungary and Croatia. *Acta Agronomica Hungarica*, *59*(1), 23–33.

Sharma, S., Gupta, P., Mishra, R., Kumar, S., Yadav, S., Meena, S. (2023). Genotypic and Environmental Effects on Wheat Yield Components: A Comparative

Study. *Theoretical and Applied Genetics, 136*(4), 1089–1103.
Shukla, G. K. (1972). Some statistical aspects of partitioning genotype-environmental components of variability. *Heredity*, *29*, 237–245.
Singh, R. K., Shukla, R., Kumar, A., Yadav, R. (2019). The Effect of Genotype × Environment Interaction on Wheat Yield: A Comprehensive Review. *Agricultural Systems,* 169, 51–63.
Taneva, K., Dragov, R., Petrova, I., Bojanova, V. (2014). Investigation of quality parameters in durum wheat breeding lines. *Scientific Papers*, *Volume 3*, 81–91.
Tsenov, N., Atanasova, D., Stoeva, I., Tsenova, E. (2015). Effects of drought on grain productivity and quality in winter bread wheat. *Bulg. J. Agric. Sci.*, 21, 592–598.
Tsenov, N., Kostov, K., Gubatov, T., Peeva, V. (2004). Study on the genotype x environment interaction in winter wheat varieties. I. Grain quality. *Field Crops Studies*, *1*(1), 20–29 (Bg).
Uhr, Z. (2015). Rating yield and stability of prospective lines winter common wheat. *New Knowledge Journal of Science*, *4*(4), 42–46 (Bg).
Wang, D., Li, Y., Zhang, B., Jiang, T., Wu, S., Wu, W., Feng, H. (2025). Explore the evolution of winter wheat production and its response to climate change under varying precipitation years in the Loess Plateau of China. *Agricultural Water Management*, 309, 109335.
World Bank, (2019). The Changing Nature of Work; A World Bank Group Flagship Report; World Bank: Washington, DC, USA, 151p.
Wricke, G. (1962). Uber eine methode zur erfassung der okologischen streubreite in feldversucen. *z. Pflanzenzuchtung*, 47, 92–96.
Yan, W., Hunt, L. A. (2001). Interpretation of genotype× environment interaction for winter wheat yield in Ontario. *Crop Science, 41*(1), 19–25.
Yan, W., Tinker, N. A. (2019). Biplot analysis of multi-environment trial data: Principles and applications. *Canadian Journal of Plant Science*, *99*(6), 895–909.
Yang, Y., Zhang, L., Zhao, J., Liu, X., Li, X., & Zhang, J. (2020). Assessment of Genotype × Environment Interaction for Wheat Grain Yield using GGE Biplot Analysis. *Euphytica, 216*(2). 34.
Yaşar, M., Ekinci, R., Sezgin, M. (2020). Investigation of change of yield and yield components in sesame (*Sesamum indicum* L.) according to years and locations. *Yuzuncu Yıl University Journal of Agricultural Sciences*, *30*(4), 852–857.
Zhang, W., & Zhou, T. (2020). Increasing impacts from extreme precipitation on population over China with global warming. *Science Bulletin*, *65*(3), 243–252.