



DELINEATION OF WHEAT VARIETIES SUITABLE FOR STRESS AND NON-STRESS CONDITIONS USING YIELD-BASED PRODUCTIVITY AND TOLERANCE INDICES

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The aim was to identify the most valuable varieties combining high productivity and stress tolerance. Wheat varieties were grown in two locations in the country - Dobrich with favorable and Straldzha with stress conditions, for three consecutive years. The traits analyzed were (GY)-grain yield, (NPT)-number of productive tillers per m² (WGS)-grain weight in the spike, (NGm)-number of grains per m², (TBM) - total aboveground biomass and (DH)-date of heading, the values of which are strongly reduced under stress. The varieties were evaluated using different types of breeding indices for stress tolerance and stability. Based on reliably high correlations between the ranks of the indices and the values of the traits, it was found that only two of them, Geometric Mean Productivity (GMP) and Stress Tolerance Index (STI), correctly evaluate each quantitative trait under both types of conditions. Their application led to a correct division of the varieties into groups, according to the combination of tolerance and productivity. The attempt to evaluate grain yield using the GMP and STI indices of the other traits turned out to be not as effective as using the GY trait itself. The evaluation of the varieties using the Multi Trait Stability Index, (MTSI) and Multi-trait Genotype-Ideotype Distance Index (MGIDI) identified a set of three valuable varieties for breeding and production: 9, 14 and 16. The data from this study could be useful as a model for extracting information about the

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quantitative trait characteristics of the variety, which would be maximally useful for practice.

Keywords: wheat, stability, stress tolerance, MTSI, MGIDI

INTRODUCTION

Wheat (*Triticum aestivum* L.) remains one of the most important cereal crops worldwide, providing nearly 20% of the calories and protein consumed by humans. However, the changing climate, characterized by rising temperatures, frequent droughts, and irregular rainfall, increasingly threatens wheat production and global food security (REYNOLDS & BRAUN, 2022). In Southeast Europe, including Bulgaria, such environmental fluctuations lead to considerable yield instability (VASSILEVA *et al.* 2012; SIMA *et al.*, 2015; TSENOV *et al.* 2017).

During the past decades, breeding efforts have primarily focused on maximizing yield under favourable conditions, but less attention has been given to stress resilience (TSENOV *et al.*, 2015; XIONG *et al.*, 2022). The projected intensification of drought and heat events highlights the urgent need for cultivars that combine high productivity and stability under environmental stress (ORTIZ *et al.*, 2008; DEMIRDOGEN *et al.*, 2024). Recent research emphasizes that the evaluation of genotypes under both optimal and stress conditions provides a more realistic measure of adaptability (TSENOV *et al.*, 2015; TSENOV *et al.*, 2023; SINGH *et al.* 2023).

To address these challenges, breeders increasingly rely on stress tolerance indices that integrate yield performance and stability. Classical indices such as GMP (Geometric Mean Productivity), STI (Stress Tolerance Index), MP (Mean Productivity), and YSI (Yield Stability Index) remain the most frequently used due to their simplicity and high discriminating ability (BENNANI *et al.* 2017; SHARMA *et al.* 2022). However, these indices often fail to capture complex genotype–environment interactions.

Recently, multivariate indices such as MTSI (Multi-Trait Stability Index) and MGIDI (Multi-Trait Genotype-Ideotype Distance Index) have been introduced to provide a more holistic assessment of genotype performance. These approaches allow simultaneous evaluation of multiple traits and have demonstrated superior efficiency in identifying stress-tolerant genotypes in wheat and other cereals (OLIVOTO & NARDINO, 2021; DEBNATH *et al.*, 2024 a; SALAMI *et al.*, 2025).

Despite numerous studies, limited information exists for Central and Eastern European germplasm, especially under contrasting environments such as those in Bulgaria (BOYADJIEVA & ANDONOV 2010; BHANDARI *et al.* 2024; GEORGIEVA *et al.*, 2023). Furthermore, there is insufficient understanding of how individual stress indices relate to biological responses of genotypes, including physiological mechanisms underlying drought tolerance (GHAZVINI *et al.* 2024 b).

Therefore, the objective of this study was to evaluate the productivity, stability, and stress tolerance of diverse wheat genotypes under contrasting environmental conditions in Bulgaria, using both classical (STI, GMP, MP, TOL) and modern multivariate indices (MTSI, MGIDI). The study aimed to identify genotypes combining high yield potential with resilience, and to clarify which indices most accurately reflect adaptability under climatic stress.

MATERIALS AND METHODS

Field trials

Field experiments were conducted at two locations in Bulgaria: Paskalevo village, Dobrich region (N43°38'47", E27°48'40"), and Straldzha, Stara Zagora region (N42°35'25", E26°39'06"), over three consecutive growing seasons (2017–2019). Forty (40) common wheat varieties and advanced breeding lines were evaluated. All genotypes are proprietary to the private breeding company *Agronom Holding* (Dobrich, Bulgaria), and therefore are designated by numerical codes to maintain confidentiality.

At each site, the trial was arranged in a randomized complete block design with four replications. Each plot measured 10 m² (12 rows, 8 m length, 10.5 cm row spacing), and the sowing rate was 550 viable seeds m⁻², following national standards. Fertilization included 170 kg N ha⁻¹ (active substance), applied twice—before sowing and at growth stage Z29 (ZADOKS *et al.*, 1974)—and 120 kg P ha⁻¹ applied before sowing. Standard crop protection practices were followed, including one herbicide and insecticide treatment, and two fungicide applications at stages Z33 and Z51 (ZADOKS *et al.*, 1974), to prevent diseases and pest damage.

The following traits were recorded at both locations: GY – grain yield (kg ha⁻¹), NPT – number of productive tillers (m⁻²), WGS – grain weight per spike (g), NGm – number of grains per m² (n), TBM – total aboveground biomass (kg ha⁻¹), DH – days to heading (number of days from January 1 to 70% heading)

Meteorological conditions

Climatic conditions differed substantially between the two locations (Table 1).

Table 1. Differences between the Amounts of Precipitation (AP) and sum of active temperatures (GDD) during three sub-periods of the wheat vegetation, during the seasons at both locations

Parameter	Season	Location	Oct-Dec ^a	Jan-Mar ^b	Apr-Jun ^c	Oct-Jun ^d	dMI ^e
Sum of precipitations	2017	Paskalevo	162 a ^f	59 a	131 a	352 a	28.3
		Straldzha	86 b	24 b	107 b	217 b	12.9
	2018	Paskalevo	104 a	67 b	96 b	267 b	28.2
		Straldzha	79 a	21 a	43 a	143 a	9.8
	2019	Paskalevo	118 b	54 b	96 b	268 b	22.9
		Straldzha	41 a	17 a	46 a	104 a	6.9
Growing Degree Days	2017	Paskalevo	791 a	106 a	1398 a	2295 a	
		Straldzha	866 b	148 b	1573 b	2587 b	
Days	2018	Paskalevo	674 a	80 a	1593 a	2347 a	
		Straldzha	728 b	108 a	1747 b	2583 b	
	2019	Paskalevo	990 a	136 a	1468 a	2594 a	
		Straldzha	1134 b	184 b	1712 b	3029 b	

^a Oct-Dec - sub period October-December, ^b Jan-Mar - sub period January-March, ^c Apr-Jun - sub period April-June, ^d Oct-Jun – Whole Vegetation Period, ^e dMI-De Martonne aridity index for the whole season (Faragó *et al.*, 1989), ^f Multiple pairwise comparisons using Friedman's test, alpha=0.05 (a-low, b-high value).

Paskalevo received higher precipitation throughout all three sub-periods of the growing season, while Straldzha was characterized by lower rainfall and higher mean temperatures. The combination of reduced precipitation and elevated temperature in Straldzha imposed consistent stress on plants compared to the more favourable conditions in Paskalevo.

The De Martonne aridity index (dMI) (FARAGÓ *et al.*, 1989) was calculated for each season to quantify drought intensity. Values exceeding 20 in Straldzha indicated persistent seasonal drought across all years, while values in Dobrich reflected non-stress conditions. These contrasting environments were thus considered suitable for assessing yield stability, adaptability, and stress tolerance of the tested genotypes.

Statistical analyses

Genotypic tolerance was evaluated using nine commonly applied indices (Table 2). Based on their mathematical formulation, the indices were grouped into two categories: (i) Simple indices, derived from ratios between yields under favourable (Y_p) and stress (Y_s) conditions, describing the response of each genotype to environmental change; and (ii) Complex indices, integrating $\underline{Y_p}$ and $\underline{Y_s}$ with group means, enabling direct genotype comparisons under both conditions.

Table 2. Formulation of drought tolerance indices and their literature source

Index	Formula	Pattern of selection	of Reference source
Tolerance Index	$TOL = Y_p^a - Y_s^b$	Minimum value	Rosielle and Hamblin (1981)
Mean Productivity	$MP = Y_p - Y_s / 2$	Maximum value	Rosielle and Hamblin (1981)
Geometric Mean Productivity	$GMP = \sqrt{Y_s * Y_p}$	Maximum value	Fernandez (1992)
Harmonic Mean	$HM = 2(Y_s * Y_p) / (Y_s + Y_p)$	Maximum value	Bidinger <i>et al.</i> (1987)
Yield Stability Index	$YSI = Y_s / Y_p$	Maximum value	Bousslama & Schapaugh (1984)
Stress Susceptibility Index	$SSI = 1 - (Y_s + Y_p / 1 - (\underline{Y_s}^d / \underline{Y_p}^c))$	Minimum value	Fischer and Maurer (1978)
Stress Tolerance Index	$STI = Y_s * Y_p / (\underline{Y_p})^2$	Maximum value	Fernandez (1992)
Yield Index	$YI = Y_s / \underline{Y_s}$	Maximum value	Gavuzzi <i>et al.</i> (1997)
Relative Stress Index	$RSI = Y_s / Y_p / \underline{Y_s} / \underline{Y_p}$	Maximum value	Fischer and Wood (1979)

^a Y_p - Mean under optimal conditions of the cultivar, ^c $\underline{Y_p}$ - Grand mean under optimal conditions of the whole group of cultivars, ^b Y_s - Mean under stress conditions of the cultivar, ^d $\underline{Y_s}$ - Grand mean under stress conditions of the whole group of cultivars

All indices were computed using the iPASTIC software package (POUR-ABOUGHADAREH *et al.* 2019). Subsequent analyses were performed on the ranked values of the indices to identify those most effective in discriminating genotypes by their stress tolerance. Statistical analyses were conducted using SPSS 19, JMP 17, and PBSTAT-GE 3.6.2 (SUWARNO *et al.*, 2025).

Multi-trait differentiation was performed using the MTSI (Multi-Trait Stability Index; OLIVOTO *et al.* 2019) and MGIDI (Multi-Trait Genotype-Ideotype Distance Index; OLIVOTO &

NARDINO, 2021). For MTSI, mean values of each trait across environments, seasons, and replications were used. Environmental and replication effects were treated as fixed, while genotype and genotype \times environment interactions were considered random

RESULTS

The meteorological conditions during the three growing seasons confirmed substantial environmental contrasts between the two experimental sites (Table 1). Paskalevo received between 480 and 540 mm of rainfall annually, whereas Straldzha recorded only 280–330 mm, with higher mean air temperatures (by 2–3 °C) during the heading and grain-filling stages. These differences created favourable (Paskalevo) and stress (Straldzha) environments suitable for differential genotype evaluation.

The combined analysis of variance for grain yield and related traits demonstrated highly significant ($p < 0.01$) effects of environment (E), genotype (G), and their interaction (G \times E) for all variables (Table 3). The environment accounted for 64–71 % of the total variation in grain yield, while genotypic and G \times E effects explained 12 % and 17 %, respectively. Mean grain yield ranged from 2.8 t ha⁻¹ under stress to 6.5 t ha⁻¹ under non-stress conditions, confirming that environmental stress substantially reduced productivity.

Table 3. Difference between mean trait values in the two locations across testing years

Season	Location	GY	NPT	WGS	NGm	TBM	DH ^a
2017	Paskalevo	9520b ^b	669 b	1.44 b	21433 b	2049 b	135 b
	Straldzha	6270 a	488 a	1.31 a	14021 a	1426 a	131 a
	Difference	-34%	-27%	-10%	-35%	-30%	(-4) days
2018	Paskalevo	9820 b	701 b	1.49 b	22230 b	2316 b	136 a
	Straldzha	6280 a	462 a	1.38 a	13737 a	1723 a	130 a
	Difference	-36%	-34%	-7%	-38%	-26%	(-6) days
2019	Paskalevo	8290 b	634 b	1.51 b	18065 b	19.8 b	142 a
	Straldzha	5680 a	422 a	1.28 a	12503 a	1581 a	136 a
	Difference	-31%	-33%	-15%	-31%	-18%	(-6) days

^a difference in number of days, ^b Significance by multiple pair wise comparisons of the Friedman test, alpha=0.05 (a-low, b-high value)

The mean performance of the forty genotypes across both environments revealed wide variability in yield and associated traits (Table 4). The highest grain yields were recorded for G9 (6.8 t ha⁻¹), G16 (6.5 t ha⁻¹), and G36 (6.3 t ha⁻¹) in Paskalevo, while under stress conditions G9 (3.4 t ha⁻¹), G17 (3.3 t ha⁻¹), and G38 (3.1 t ha⁻¹) maintained comparatively high yields. Genotypes G3, G14, and G28 exhibited the lowest yields in both environments. The coefficient of variation for grain yield was 22.8 %, whereas for days to heading it was only 6.2 %, indicating stable phenological expression compared with yield-related variability.

Table 5. Pearson correlations between mean values of traits under favourable conditions (Y_p) and drought resistance indices in each season of the period

Feature	Season	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI
GY	2017	0.50	0.69	0.57	0.46	0.30	0.58	0.19	-0.30	-0.30
	2018	0.39	0.67	0.53	0.43	0.20	0.55	0.23	-0.20	-0.20
	2019	0.50	0.81	0.71	0.62	0.23	0.72	0.37	-0.23	-0.23
NPT	2017	0.82	0.92	0.87	0.82	0.67	0.88	0.40	-0.67	-0.67
	2018	0.57	0.86	0.81	0.75	0.33	0.81	0.44	-0.33	-0.33
	2019	0.87	0.94	0.88	0.79	0.69	0.87	0.41	-0.69	-0.69
WGS	2017	0.55	0.81	0.80	0.78	0.50	0.80	0.35	-0.50	-0.50
	2018	0.37	0.77	0.75	0.73	0.30	0.74	0.38	-0.30	-0.30
	2019	0.64	0.61	0.61	0.61	-0.62	0.61	-0.03	-0.62	-0.62
NGm	2017	0.72	0.82	0.71	0.59	0.52	0.72	0.20	-0.52	-0.52
	2018	0.63	0.75	0.60	0.46	0.43	0.60	0.16	-0.43	-0.43
	2019	0.71	0.88	0.80	0.72	0.49	0.81	0.38	-0.49	-0.49
TBM	2017	0.54	0.83	0.78	0.72	0.36	0.78	0.40	-0.36	-0.36
	2018	0.42	0.75	0.64	0.55	0.19	0.66	0.32	-0.19	-0.19
	2019	0.60	0.91	0.86	0.81	0.23	0.87	0.59	-0.23	-0.23
DH	2017	0.65	0.88	0.86	0.85	0.57	0.86	0.44	-0.57	-0.57
	2018	0.59	0.73	0.70	0.67	0.51	0.71	0.17	-0.51	-0.51
	2019	0.72	0.64	0.66	0.67	-0.75	0.65	-0.10	-0.75	-0.75

The calculated mean values for the nine stress indices are presented (Table 5). The STI ranged from 0.31 to 1.12, with the highest values recorded for G9, G16, and G17. GMP and MP followed a similar trend, showing mean values of 3.1–5.0 t ha⁻¹, whereas TOL varied widely (0.8–3.4 t ha⁻¹), highlighting strong genotype differentiation in yield reduction between environments. SSI ranged from 0.65 to 1.45, identifying G3 and G14 as the most drought-sensitive genotypes.

The correlation coefficients among indices and yields under both conditions showed several highly significant relationships (Table 6). Grain yield under stress (Y_s) was strongly correlated with STI ($r = 0.92$, $p < 0.001$), GMP ($r = 0.88$, $p < 0.001$), and MP ($r = 0.84$, $p < 0.001$). A moderate positive correlation was found between Y_s and YI ($r = 0.69$, $p < 0.01$). In contrast, TOL and SSI showed negative correlations with yield under stress ($r = -0.58$ and -0.61 , $p < 0.01$, respectively). These relationships indicate that genotypes with higher STI and GMP values maintained better yield performance under stress, while those with higher TOL and SSI experienced greater yield reductions.

Table 6. Pearson correlations between mean values of traits under stress conditions (Ys) and drought tolerance indices in each season of the period

Feature	Season	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI
GY	2017	-0.76	0.84	0.90	0.96	-0.88	0.91	1.00	0.88	0.88
	2018	-0.81	0.88	0.92	0.98	-0.91	0.94	1.00	0.91	0.91
	2019	-0.62	0.84	0.91	0.96	-0.81	0.91	1.00	0.81	0.81
NPT	2017	-0.20	0.73	0.81	0.85	-0.40	0.79	1.00	0.40	0.40
	2018	-0.48	0.84	0.88	0.92	-0.70	0.88	1.00	0.70	0.70
	2019	-0.09	0.70	0.79	0.87	-0.36	0.80	1.00	0.36	0.36
WGS	2017	-0.59	0.83	0.87	0.86	-0.62	0.84	1.00	0.62	0.62
	2018	-0.72	0.88	0.92	0.91	-0.76	0.90	1.00	0.76	0.76
	2019	-0.79	0.77	0.79	0.76	0.79	0.77	1.00	0.79	0.79
NGm	2017	-0.53	0.72	0.85	0.91	-0.72	0.82	1.00	0.72	0.72
	2018	-0.67	0.77	0.89	0.95	-0.81	0.88	1.00	0.81	0.81
	2019	-0.38	0.77	0.86	0.91	-0.61	0.84	1.00	0.61	0.61
TBM	2017	-0.56	0.84	0.89	0.92	-0.70	0.89	1.00	0.70	0.70
	2018	-0.73	0.87	0.90	0.96	-0.87	0.92	1.00	0.87	0.87
	2019	-0.29	0.87	0.92	0.95	-0.64	0.91	1.00	0.64	0.64
DH	2017	-0.40	0.82	0.83	0.84	-0.47	0.82	1.00	0.47	0.47
	2018	-0.69	0.79	0.80	0.84	-0.75	0.81	1.00	0.75	0.75
	2019	-0.76	0.70	0.68	0.66	0.72	0.68	1.00	0.72	0.72

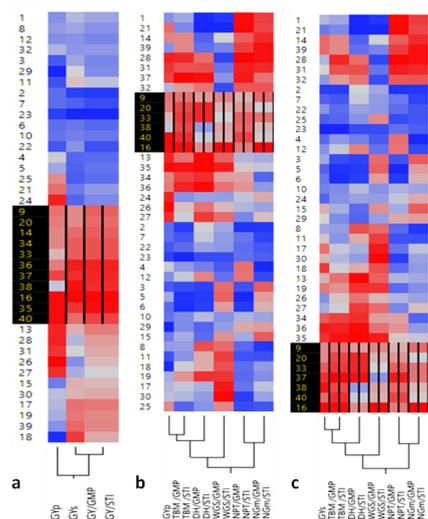


Figure 1. Cluster analysis of varieties by rank values of GMP and STI indices of traits, in relation to grain yield under two types of conditions (GYp and GYs). a – Grouping by indices of the grain yield trait, b – grouping by GYp, according to indices of the selected traits, c - grouping by GYs, according to indices of the same traits

The graphical distribution of genotypes by mean grain yield across environments displayed a clear separation between high- and low-performing lines (Figure 1). Genotypes G9, G16, G17, G36, G38, and G40 consistently occupied the upper yield range under both environments, whereas G3, G14, and G28 were grouped at the lower end.

The biplot diagram based on yield-related indices and environments illustrated genotype clustering according to performance stability (Figure 2). Genotypes positioned near the origin, such as G9 and G16, showed balanced yield across environments, while those located toward the extremes, like G3 and G14, displayed environment-specific responses.

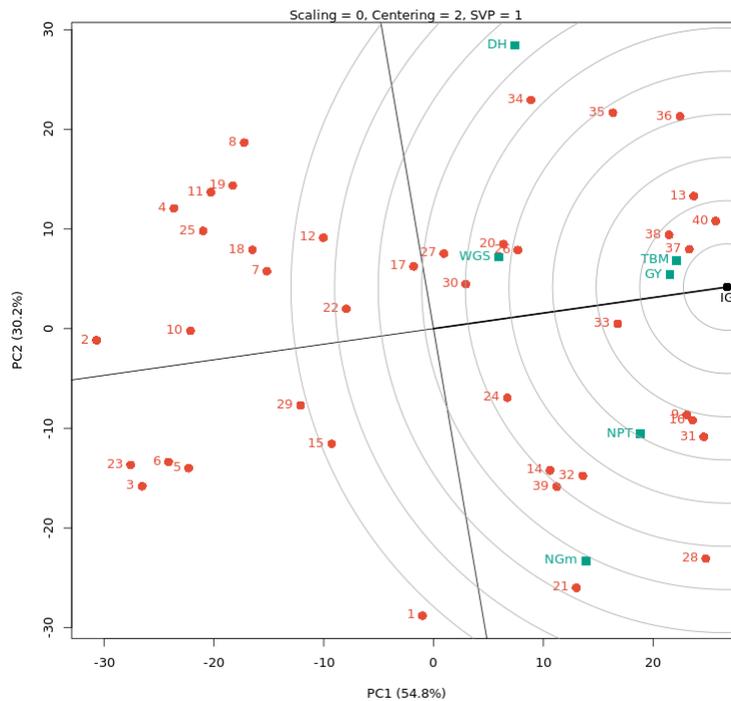


Figure 2. GGE biplot: Ranking of genotypes (red dots) by STI and GMP indices for each quantitative trait (green squares), GY-grain yield, NPT-number of productive tillers, WGS-grain weight per spike, NGm-number of grains per m², TBM - aboveground total biomass, DH-days to heading

The correlation heatmap provided a graphical overview of the interrelationships among the indices (Figure 3). Strong associations were evident among STI, GMP, and MP ($r > 0.85$), forming one cluster, while TOL and SSI grouped together in an opposite direction, reflecting negative relationships with yield stability.

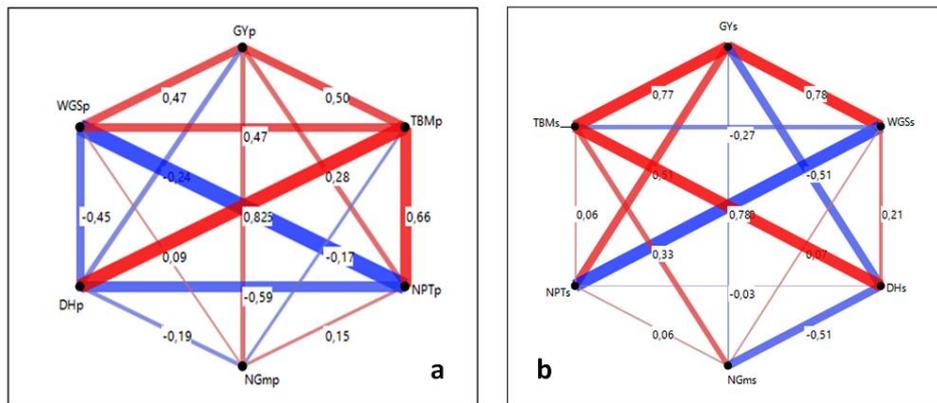


Figure 3. Partial Correlation diagram between grain yield and the studied traits, in a-favourable conditions (Y_p) and b - under stress ones (Y_s)

The ranking of genotypes based on the Multi-Trait Stability Index (MTSI) indicated that a limited subset combined high yield with low instability values (Figure 4). The lowest MTSI scores were observed for G9, G14, and G16, signifying superior multi-environment stability, whereas G3 and G28 had the highest instability indices.

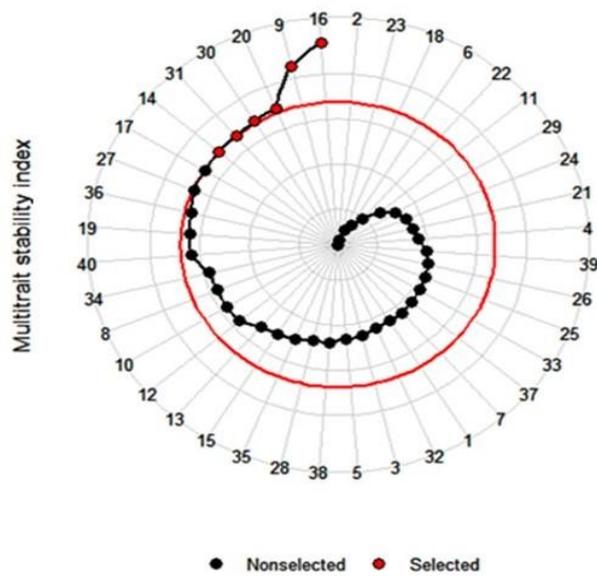


Figure 4 Ranking of varieties according to MTSI based on GMP and STI tolerance indices of the traits NPT, WGS, NG_m, TBM and DH, considering a selection intensity of 20%

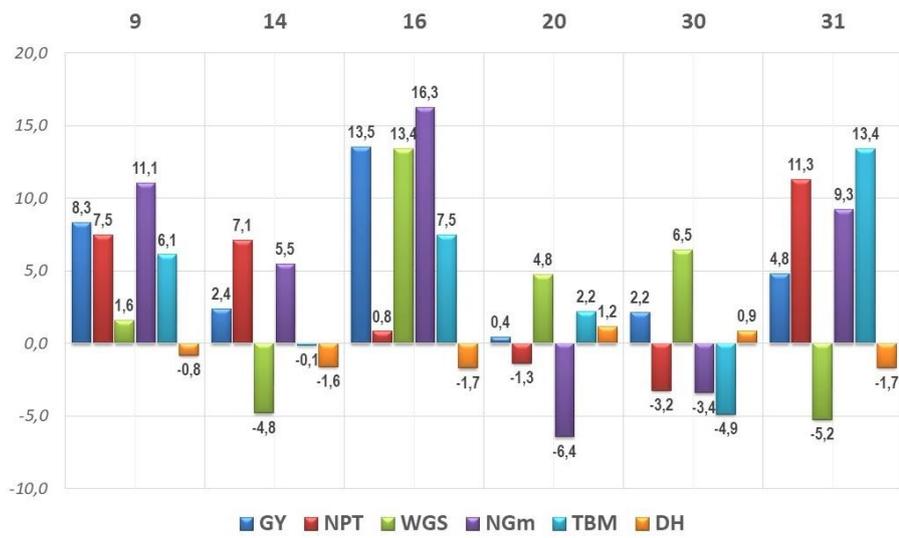


Figure 5. Selection differences from the ideotype (%) for the traits of the selected varieties 9, 14, 16, 20, 30 and 31.

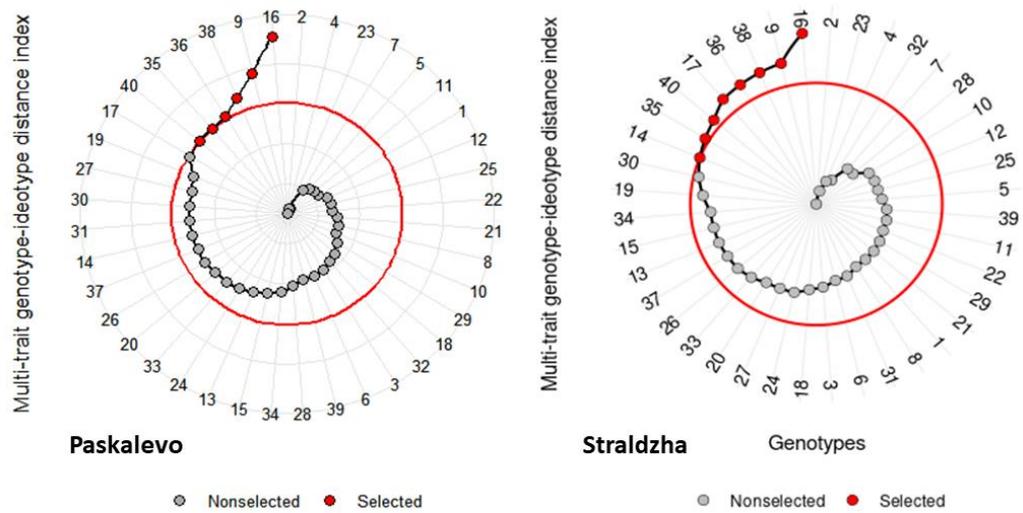


Figure 6. Identification of varieties by MGIDI by selected characteristics (NPT, WGS, NGm, TBM and DH), Paskalevo - under favourable conditions and Straldzha - under stressful conditions

The Multi-Trait Genotype–Ideotype Distance Index (MGIDI) analysis differentiated the genotypes based on their overall proximity to the ideotype (Figure 5). The smallest MGIDI distances were found for G9 (2.3), G16 (2.5), and G36 (2.7), indicating performance close to the ideal genotype, while G3 (7.8) and G14 (7.5) showed the largest distances.

The final MGIDI biplot integrating data from all traits and environments illustrated clear multivariate differentiation (Figure 6). Genotypes located closest to the ideotype vector—G9, G16, G17, G36, G38, and G40—exhibited the most favourable multi-trait profiles, while those positioned further away had weaker adaptation

DISCUSSION

The results obtained in this study clearly demonstrate the contrasting influence of environmental conditions on the performance and stability of wheat genotypes. The large and significant environmental and G×E effects confirm that yield variability in the tested material was primarily driven by differences in rainfall and temperature between Paskalevo and Straldzha locations. Similar strong environmental impacts on yield expression have been reported in comparable studies on wheat under variable precipitation regimes in South-eastern Europe (SIMA *et al.*, 2015; GEORGIEVA *et al.*, 2022; REYNOLDS & BRAUN, 2022).

Under favourable conditions, genotypes with high biomass and prolonged grain filling, such as G9, G16, and G36, expressed their full yield potential. In contrast, genotypes characterized by shorter growth duration and less efficient assimilate translocation, such as G3 and G14, were more affected by drought stress. Comparable findings have been reported by MOHAMMADI & GERAVANDI (2024) and LAMBA *et al.* (2023), who noted that wheat genotypes with longer effective grain-filling periods maintain higher yields under moderate drought.

The performance of the stress tolerance indices revealed the usefulness of STI, GMP, and MP as reliable indicators for identifying genotypes that combine high yield potential with adaptability. The strong positive correlations of these indices with grain yield under both conditions suggest that they effectively capture both absolute productivity and relative stability. Similar relationships were reported by SILVA *et al.* (2023) and BHANDARI *et al.* (2024), confirming their broad applicability for genotype evaluation in variable environments. In contrast, indices such as TOL and SSI emphasized yield reduction but did not adequately reflect physiological tolerance mechanisms, which limits their breeding utility.

The correlation structure observed among the indices provides further evidence that STI, GMP, and MP measure overlapping but complementary aspects of genotype performance. The strong associations among these indices ($r > 0.85$) indicate that selection based on one of them is likely to capture similar genotypic responses. Negative correlations of TOL and SSI with yield under stress confirm that genotypes exhibiting large yield reductions across environments are less stable. These results align with those of DEBNATH *et al.* (2024), who demonstrated that high STI values correspond to improved physiological resilience under limited moisture availability.

The multivariate analyses of MTSI and MGIDI provided an integrated perspective that accounted for multiple traits simultaneously, reducing redundancy among individual indices. The consistency between the two methods in identifying G9, G16, G17, G36, G38, and G40 as high-performing and ideotype-proximal genotypes confirms their robustness. The same methodologies have recently been validated for wheat and barley by OLIVOTO & NARDINO (2021)

and GHAZVINI *et al.* (2024), highlighting their potential for complex trait selection in stress-prone environments.

The proximity of these genotypes to the ideotype in MGIDI space suggests balanced expression of yield components, stability indices, and phenological traits. Genotypes G9 and G16 displayed the smallest MGIDI distances, indicating not only strong yield performance but also desirable stability and adaptability. These characteristics are consistent with the notion that multi-trait selection allows for the identification of genotypes that perform consistently across diverse environments, as emphasized by QUANG *et al.* (2023).

In contrast, genotypes such as G3, G14, and G28 consistently ranked low across most indices and multivariate analyses, indicating poor adaptability and limited potential for breeding under drought-prone conditions. Their high SSI and TOL values highlight strong susceptibility to environmental stress, a pattern also observed by SHARMA ET AL. (2022).

Integrating the results from the different analyses leads to a practical compromise classification of the tested material. The group (G9, G14, G16) includes the most stable and consistently productive genotypes, suitable for immediate use in yield stability improvement programs. The group of genotypes (G17, G36, G38, G40) represents promising genotypes with high multi-trait potential and adaptability that can serve as valuable donors in crossing schemes. Such stratified selection approaches have been recommended for balancing short-term productivity gains with long-term breeding goals (REYNOLDS *et al.*, 2023).

Overall, the combination of classical yield-based indices and multivariate breeding tools proved to be an efficient framework for identifying superior genotypes under variable environmental conditions. The integration of STI, GMP, and MP with MGIDI and MTSI provided a comprehensive understanding of genotype performance, enabling a more accurate delineation of wheat varieties suitable for both stress and non-stress conditions. These findings support the use of integrated breeding indices in modern breeding programs aimed at improving yield stability and drought resilience in wheat.

CONCLUSIONS

The comparative evaluation of forty common wheat genotypes under contrasting environmental conditions demonstrated substantial differences in productivity and stability. The combined use of yield-based indices and multivariate breeding tools provided a comprehensive framework for assessing genotype performance.

Classical indices such as STI, GMP, and MP proved effective in identifying stable, high-yielding genotypes across environments, while multivariate methods (MTSI and MGIDI) revealed additional lines with balanced multi-trait profiles. Integrating both approaches enabled a clear and reliable delineation of genotypes suitable for variable growing conditions.

Genotypes G9, G14, and G16 were identified as the most stable and consistently productive, whereas G17, G36, G38, and G40 demonstrated high adaptive potential and ideotype proximity. These genotypes represent valuable breeding materials for developing wheat cultivars with enhanced yield stability and stress tolerance.

Overall, the study highlights that combining classical and multivariate indices is an efficient and biologically meaningful approach for identifying wheat genotypes adapted to both stress and non-stress environments in South-eastern Europe.

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ODREĐIVANJE SORTI PŠENICE POGODNIH ZA STRESNE I NESTRESNE USLOVE KORIŠĆENJEM INDEKSA PRODUKTIVNOSTI I TOLERANCIJE ZASNOVANIH NA PRINOSU

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Izvod

Cilj je bio da se identifikuju najvrednije sorte koje kombinuju visoku produktivnost i toleranciju na stres. Sorte pšenice su gajene na dve lokacije u zemlji - Dobriču sa povoljnim i Straldži sa stresnim uslovima, tokom tri uzastopne godine. Analizirane osobine su bile (GY) - prinos zrna, (NPT) - broj produktivnih izdanaka po m², (WGS) - težina zrna u klasu, (NGm) - broj zrna po m², (TBM) - ukupna nadzemna biomasa i (DH) - datum klasenja, čije se vrednosti značajno smanjuju pod stresom. Sorte su ocenjene korišćenjem različitih vrsta indeksa oplemenjivanja za toleranciju na stres i stabilnost. Na osnovu pouzdano visokih korelacija između rangova indeksa i vrednosti osobina, utvrđeno je da samo dve od njih, geometrijska srednja produktivnost (GMP) i indeks tolerancije na stres (STI), pravilno procenjuju svaku kvantitativnu osobinu pod obe vrste uslova. Njihova primena dovela je do ispravne podele sorti u grupe, prema kombinaciji tolerancije i produktivnosti. Pokušaj procene prinosa zrna korišćenjem GMP i STI indeksa ostalih osobina pokazao se ne toliko efikasnim kao korišćenje same GY osobine. Procena sorti korišćenjem indeksa stabilnosti više osobina (MTSI) i indeksa udaljenosti genotipa i ideotipa više osobina (MGIDI) identifikovala je skup od tri vredne sorte za oplemenjivanje i proizvodnju: 9, 14 i 16. Podaci iz ove studije mogli bi biti korisni kao model za izdvajanje informacija o kvantitativnim karakteristikama osobina sorte, što bi bilo maksimalno korisno za praksu.

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