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BREAD WHEAT FROM STRESS TO PRODUCTIVITY IN PURSUIT OF FOOD SECURITY IN RAPID CLIMATE CHANGE

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Abstract: The sample of 596 plants, in total, of bread wheat varieties Pobeda, Sara, Renesansa, and Pesma were tested for abiotic stress tolerance in eight environments, out of which six were under soil or/and atmospheric stress. Plant adaptive plasticity was followed by the variation of three phenotypic markers: grain weight/spike, spike length, and grain number per spike. A desirable genetic variation was recognized and singled out within the existing gene pool, to enhancing stress tolerance in wheat in order to face the challenges and contribute to food security in rapid climate changes.

Keywords: wheat, stress, tolerance, spike traits, food security

Introduction

Climate changes and global warming that have been speeding up in the last 65 years influence various aspects of human life, food production and security included (Abbas et al., 2022). Great efforts are put to meet these challenges, especially in classic and molecular plant breeding. A part of these efforts are directed in mitigation of stressful effects of degraded and naturally low productive soil, particularly in enhancing adaptive plasticity of wheat, as one of the staple food (Bhoite et al., 2023; Johanson et al., 2023). Genetics at the Faculty of Agriculture, University of Novi Sad, has been engaged, for more than twenty years, in research on behavior and adaptive plasticity of wheat in stressful conditions. The results are scientific knowledge, disseminated results, and training of young researchers (Petrović et al., 2003; Petrović et al., 2023).

The aim of this study is to get an insight into the adaptive plasticity of a complex sample of four bread wheat varieties exposed to a different kind and intensity of abiotic stress. To single out usable genetic variability within the existing genetic gene pool for the wheat tolerance increment to solonetz soil type and atmospherically caused stress.

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Materials and methods

A population of four wheat (*Triticum aestivum* L. subsp. *aestivum*) varieties, Pobeda, Sara, Renesansa and Pesma, from the wheat breeding programme of the Institute of Field and Vegetable Crops in Novi Sad (IFVCNS), was grown in four seasons at two localities. One locality was at the experimental field of the Faculty of Agriculture, UNS at the village of Kumane (K), exact Google map location 45°31'19.3"N 20°11'40.6"E, on the solonetz soil type (SN) of unfavorable high sodium and clay content in the Bt horizon (Belić et al, 2012). The other was, 35.32 km straight line distance to the SW from K, at the IFVCNS experimental fields in Rimski Šančevi (RS), 45°19'21.9"N 19°50'22.2"E, on the fertile chernozem soil (CH). Four seasons were chosen out of twenty years long multi genotype and environmental trial (MGET). The season 2004/05 was characterized by abundant precipitations, water excess (WE), and soil saturation. The season 2011/12 was a period of long-lasting drought, and temperature extremes (DTE). The season 2015/16 was very favourable (VF) with the wheat yield 20% higher than in previous ten years. The season 2019/20 was a normal, average season (NA) with wheat yield within multiyear average. That made eight environments (E_n). The total wheat sample consisted of 596 wheat plants. In E1, of combined stress sources (SN+WE) n=60 individual plants of four wheat varieties were tested; E2 (CH+WE) n = 60; E3 (SN+DTE) n=60; E4 (CH+DTE); E5 (SN+VF) n=120; E6 was the first non-stressful season (CH+VF) n=120; E7 (SN+NA) n=58, and E8 was the second non-stressful season (CH+NA) n=58. The phenotypic markers for plant discriminatory behaviour across the environments were SL - spike length (cm), GNS - grain number/spike, and GWS - grain weight/spike (g). Their values were standardized by z-scoring to common scale. The mean (μ) was substracted from observed values (x), and divided by the standard deviation [$z = (x-\mu)/\sigma$]. That way variables with the larger scale are prevented to dominate the analysis, and the contribution of variables measured in different units or with different variances is brought to more comparable level. The multiple discriminant analysis (MDA), and canonical discriminant analysis (CDA), was used. Since dependent variable (y), the stress absence (0), or presence (1) as input gave a binary outcome, the linear probability model (LPM) was utilized (Hair et al., 2010; Gomila, 2021).

Results and discussion

The effect of different stressful, and non-stressful environments on phenotypic variation of GWS, SL, and GNS, as discriminative phenotypic markers of choice revealed that solonetz soil type, of unfavourable physical and chemical properties, was of the primary stress source in the MGET. The atmospheric stress modulated the strength of that stress. The primary stress on chernozem soil type was atmospherically induced, where favourable soil type has alleviated the deleterious effects of water excess, but the drought and temperature extremes have taken the toll. The strongest stress, according to GWS and GNS averages, was on the SN+NA. The combination SN+WE had more stressful effect than SN+DTE due to unfavourable solonetz physical properties causing water lodging. Very favorable meteorological conditions in K had the stress effect like a water excess at the same locality, probably due to complex of abiotic and biotic influences. The depression of GWS and SL means in a meteorologically VF season was denoted in chernozem, too. Nevertheless, it should be kept in mind that the traits of individual plants were measured, meaning that the focus of the study was individual genotype behavior that could deviate from population reaction to environmental variation. The canopy thinning opened the vegetation space for the remaining plants to try to compensate the losses, as well as to develop resistance mechanisms. Hence, the losses were greater in the yield per unit area. Standardized mean values provide a closer insight into the environmental variation effects on phenotypic variability of studied spike traits. The SL was the least affected by stresses. Its reduction was notable in K, except in E3. For the GWS and GNS K locality was stressful in all the seasons, varying in intensity depending on the atmospheric conditions. In RS atmospheric stress left its toll on spike yield, and GNS in E4, where drought and temperature extremes hit the MGET (Table 1).

Table 1. Four seasons at two localities i.e. six stress and two non-stress environments, four wheat varieties, and three traits, GWS - grain weight/spike (g), SL - spike length (cm), and GNS - grain number/spike made the MGET

Soil type	Solonetz (Kumane)				Chernozem (Rimski Šančevi)			
Season Trait	Water excess	Drought/ Temp. Ex.	Very favour.	Average season	Water excess	Drought/ T.E.	Very favour.	Average season
Seasonal mean values								
GWS	1.29	1.52	1.23	1.07	2.07	1.64	2.23	2.90
SL	7.37	8.63	7.63	7.59	10.25	9.37	9.07	9.34
GNS	35.48	38.82	30.85	27.90	44.60	33.31	49.15	56.60
Seasonal standardized mean values								
GWS	-0.6477	-0.3234	-0.7246	-0.9532	0.4298	-0.1630	0.7795	1.5683
SL	-0.8144	0.0245	-0.6374	-0.6648	1.0959	0.5100	0.3114	0.4952
GNS	-0.3413	-0.0685	-0.7208	-0.9626	0.4051	-0.5195	0.7775	1.3875

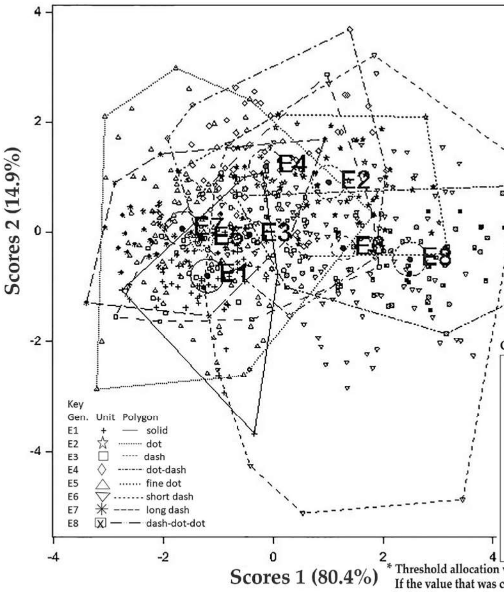
The LPM gave a first insight into eventual higher stress tolerance genetic variability existence within four tested wheat varieties. In a total sample of 596 plants in eight environments, the number of stressed plants was $n_0 = 418$, while in non-stress environments were $n_1 = 178$ plants. According to basic regression statistics, the overall correlation between GWS, SL, and GNS as stress/non-stress predictors and stress/non-stress outcome, brought out by Multiple R was 0.688, while coefficient of determination was $R^2 = 0.473$, indicating that about 50% of phenotypic variation across environments could be explained by joint variation of predictors in study. Though, residual SS was slightly higher than regression SS, the overall significance of the regression still stood, indicated that one or more predictors significantly influenced stress/non-stress plant's adaptive discrimination. Coefficients of LPM indicate that all three phenotypic markers significantly discriminated individual plant reaction to stress (Table 2).

Table 2. Linear probability model as a special case of multiple linear regression

Regression statistics		ANOVA					
			df	SS	MS	F.	F-sig.
Multiple R	0.687640758	Regression	3	59.03006	19.67669	177.007	6.598E-82
R Square	0.472849811	Residual	592	65.80886	0.111164		
Observations	596	Total	595	124.8389			

Coefficients of LPM					
	Coefficients		Standard Error	t Stat	P-value
Intercept	0.298657718	β_0	0.013657091	21.86832555	3.73573E-78
GWS (x_1)	0.261780485	β_1	0.030794126	8.500987584	1.53227E-16
SL (x_2)	-0.04922463	β_2	0.015560996	-3.16333406	0.001639652
GNS (x_3)	0.080482673	β_3	0.030191543	2.66573566	0.007891744

The average discriminant score ($\bar{d}$) as the mean value of individual LP $\hat{Y} = \beta_0+\beta_1x_1+ \beta_2x_2+ \beta_3x_3$) for stress ($\bar{d}_0 = 0.1574$), as well as, non-stress ($\bar{d}_1 = 0.6303$) environments and the number of unsatisfactory (stress) $n_0 = 418$, and satisfactory (no stress) $n_1 = 1$ binary Y, gave a cutoff between stress and non-stress environments based on LPM [$c = (n_0\,\bar{d}_0 + n_1\,\bar{d}_1)/(n_0+n_1) = 0.2987$]. A binary predictor outcome was established in respect to the c. The misclassification check was established comparing the binary input and the binary outcome, giving 79.9% concordance of binary classification based on soil and atmospheric conditions and binary classification based on phenotypic variability i.e. the discriminative power of GWS, SL, and GNS. That has left 20.1% of misclassified phenotypic variability worthy of further analysis in quest for higher stress tolerance variation. Mahalanobis distances (D2) were used to quantify the separation between observations and/or environmental means. The primary discrimination source was soil type on the first discriminative function. The secondary canonical variates were meteorological conditions. It was less discriminatory in K, than in RS, followed by D^2 that ranged in K from 0.157 (E5/E7) to 2.120 (E3/E7), while in RS D2 varied broader from 1.743 (E2/E6) to 9.753 (E4/E8). Threshold allocation value (Tallocate), determined the belonging of each individual genotype to an appropriate environment. The accompanying allocation table shows counts for that threshold allocations, observed in canonical space. Two behavioural patterns were observed. One is narrower adaptation, where individual plants adaptive reaction is limited to the stress presented in their environment. The other is broader adaptive reaction, which indicate that those plants could adapt to different kind of stress and/or different stress levels. In that second adaptive plasticity pattern, genotypes of particular interests are those who are coming from stressful, but are allocated to non-stressful environments, according to calculated threshold allocation values. This is an indication, based on discriminant analysis of the spike yield, SL, and GNS that enhanced tolerance to abiotic stress studied in this MGET could be found within an existing wheat inter and intra varietal variation (Graph 1).



Mahalanobis (D^2) quantifies intergroup distances

	E1	E2	E3	E4	E5	E6	E7	E8
E1	0.000							
E2	7.829	0.000						
E3	1.232	3.019	0.000					
E4	5.487	2.133	2.537	0.000				
E5	0.690	6.909	1.379	3.122	0.000			
E6	6.421	1.743	3.297	4.345	6.730	0.000		
E7	1.157	8.337	2.120	3.646	0.157	8.776	0.000	
E8	14.114	4.947	9.695	9.753	14.577	1.685	17.563	0.000

Discriminant scores for the environmental means

	1	2	3
E1	-1.1970	-0.7964	0.2547
E2	1.0108	0.9047	0.5006
E3	-0.4356	-0.0550	0.5756
E4	-0.1313	1.1964	-0.3619
E5	-1.3026	-0.1184	-0.2138
E6	1.2753	-0.2947	0.0166
E7	-1.6573	0.0587	-0.2082
E8	2.4927	-0.4969	-0.3862

Counts for allocation of 596 genotypes over eight environments

		Environments								
	Counts	E1	E2	E3	E4	E5	E6	E7	E8	Total
Tallocate*	E1	42	.	12	.	29	6	6	.	95
	E2	.	31	5	7	.	19	1	.	63
	E3	6	3	21	9	14	14	7	2	76
	E4	3	16	3	30	9	6	4	.	71
	E5	8	.	9	5	21	1	8	.	52
	E6	.	3	6	5	3	40	.	12	69
	E7	1	1	4	4	44	.	32	.	86
	E8	.	6	.	.	.	34	.	44	84
	Total	60	60	60	60	120	120	58	58	596

* Threshold allocation value Tallocate = $(\mu i + \mu j)/2$, where μi and μj are means of two environments; If the value that was calculated based on traits data i.e. discriminant score is greater than the threshold allocation value, than the genotype is assigned to the Ei, otherwise it is assigned to the Ej.

Graph 1. Canonical discriminant analysis of wheat four varieties population behaviour under six stress and two non-stress environments

Conclusion

A complex wheat varietal sample of 596 plants, subjected to six stressful and two non-stressful environments. GWS, SL, and GNS, were of discriminant value in DA. Potential higher tolerance to solonetz soil and atmospherically caused stresses were spotted within the existing gene pool. Further study would be required for deeper insight. The stress tolerant genotypes within the existing genetic variability could be of immediate use, as well as, for creating novel improved genetic variation in pursuit of food security in climate changes.

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