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Evaluation of the stability and adaptability of yield in triticale varieties using non-parametric methods

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Abstract

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In this study, 9 non-parametric stability methods were used to evaluate the environment interaction on grain yield of 8 triticale varieties. The genotypes were evaluated for grain yield in the region of Sadovo for 5 years. A combined analysis of variance, non-parametric stability statistics and rank correlations among them were determined. Significant differences were detected between genotypes and their EGIs. Different non-parametric stability statistics were used to determine stability of the studied genotypes. The level of association among the statistics was assessed using Spearman's rank correlation. Rank-correlation coefficients between yield and some non-parametric stability statistics were highly significant. Genotypes mean yield was significantly correlated to the non-parametric stability statistics $NP^{(4)}$ ($r = 0.833^{*}$), $NP^{(3)}$ ($r = 0.762^{*}$) and $S^{(3)}$ ($r = 0.738^{*}$). In conclusion, based on most non-parametric stability statistics, the genotypes Indiana and Orbital were found to be the most stable and high yielding. These genotypes can be used for the improvement of adaptation and high yielding in triticale breeding programs.

Keywords: triticale; genotype x environment interaction; nonparametric stability measure

Introduction

Triticale (×*Triticosecale Wittmack*) is a man-made cereal formed by crossing wheat with rye. It possesses the genomes of the genus *Triticum* and *Secale* ssp., and thus the advantageous properties of wheat grain with the features of rye, such as resistance to abiotic and biotic stresses (Ukalska & Kociuba, 2013). Triticale seems to be an interesting alternative to other cereals, particularly bread wheat, in environments where growing conditions are unfavorable or in lowinput systems (Erekul & Kohn, 2006).

The development of cultivars, which can be adapted to a wide range of diversified environments (widely adapted), is the final objective of plant breeders in a crop improvement program. Cultivars showing wide adaptation have to be stable for yield in dynamic sense across a range of environments to exhibit small variation of Genotype by Environment (GE) interaction effects and also their mean performance (yield potential) has to be relatively high. Then, the major goal of plant breeding programs is to improve wide adaptation of cultivars through increasing both their yield potential and stability (Segherloo et al., 2008).

There are two major approaches for studying GE interactions, namely parametric and nonparametric. The parametric stability estimates have good properties under certain statistical assumptions, like normal distribution of errors and interaction effects, but they may not perform well if these assumptions are violated (Verma et al., 2017). Therefore, the parametric methods are not practical because of outliers. In such circumstances, nonparametric measures for stability based on ranks provide a viable alternative to existing parametric measures based on absolute data (Khalili & Pour-Aboughadareh, 2016). The nonparametric methods have some advantages over the parametric stability methods (Mortazavian & Azizinia, 2014). Firstly, these methods reduce the bias caused by outliers and no assumptions are needed about the distribution of the observed values and secondly, these methods are easy to use and interpret and the additions or deletions of one or few genotypes don't cause much variation of results. Many nonparametric approaches have been established by different researchers to explain and infer the responses of genotypes to the environmental variation (Fox et al., 1990; Huehn, 1990; Khalili & Pour-Aboughadareh, 2016; Nassar & Huehn, 1987; Thennarasu, 1995). Several nonparametric statistical procedures have been proposed to study crossover and non-crossover G x E interactions. These methods have been developed in the field of medicine and would be applied to G x E interactions in multi-environmental trials in agricultural studies (Truberg & Huehn, 2000). Four nonparametric measures of phenotypic stability i.e., $Si^{(1)}$, $Si^{(2)}$, $Si^{(3)}$, and $Si^{(6)}$, were proposed to combine mean grain yield and genotypes stability (Huehn, 1990; Nassar & Huehn, 1987). In addition, four alternative nonparametric statistics, i.e., $NPi^{(1)}$, $NPi^{(2)}$, $NPi^{(3)}$, and $NPi^{(4)}$ were proposed which were based on ranks of adjusted mean of the genotypes as those whose position in relation to the others remained unaltered in the set of environments assessed (Thennarasu, 1995). However, most of these procedures fail to distinguish between significant crossover and non-crossover (usual) interaction (Bortz et al., 1990). These methods for the test of G x E interaction provide a useful alternative to parametric methods such as the ANOVA currently used that is based on original data value. Therefore, the nonparametric phenotypic stability analysis is the key assess criteria for the G x E interaction evaluation in crops. The objectives of this study were to (1) to analyse genotype by environment interaction on grain yield of 8 triticale varieties using nonparametric methods (2) to identify genotypes that have high yield and stable performance across 5 years in the region of Sadovo, and (3) to study the relationships among the non-parametric stability methods.

Material and Methods

This study was carried with 8 triticale genotypes from introduction in the experimental field of IPGR Sadovo.The studied genotypes were selected from triticale introduction program of IPGR-Sadovo. The experimental layout was a randomized complete block design with three replications with a plot size of 10 m^2. The seeding rate was about 550 seeds m^2. Fertilizer application was 40 kg N ha, 40 kg P_2O_5 and 40 kg K_2O at planting and 70 kg N ha at the beginning of stem elongation stage. Harvesting was done in 1 m x 10 m (10 m^2) by experimental combine. Yield (kg ha^{-1}) was obtained by converting the grain yields obtain from plots to hectares.

Results and Discussion

Genotype × environment interaction analysis

The results of the analysis of variance of the yield from 8 triticale genotypes are presented in Table 1. Strongest influence on yield have the conditions of the year which explained 66.94% of the total (E + G + EGI) variation, whereas G and EGI accounted for 9.88% and 18.10%, respectively (Table 1).

Table 1. Analysis of variance for grain yield from 8 triticale genotypes in the region of Sadovo

Source of Variation	df	MS	ŋ
Environment (E)	4	108707.500***	66.94
Genotype (G)	7	9165.714***	9.88
E x G Interaction	28	4196.071***	18.10
Error	40	825.000	5.08
Total	80		100.00

*** – Significant at $P \leq 0.001$

Stability analysis

The results from 9 different non-parametric stability statistics and genotype mean yields are presented in Table 2. The first four non-parametric measures of phenotypic stability – $Si^{(1)}$, $Si^{(2)}$, $Si^{(3)}$ and $Si^{(6)}$ of Nassar & Huehn (1987) found the most stable varieties – Falko, Orbital and Indiana.

Results of Thennarasu's (1995) nonparametric stability statistics NPi $^{(1)}$,NPi $^{(2)}$,NPi $^{(3)}$, and NPi $^{(4)}$, which are calculated from ranks of adjusted yield means are shown in Table 2 and the ranks of genotypes according to these parameters are given in Table 3. Using these parameters, genotypes with minimum low values are considered more stable. According to all methods genotypes Falko, Indiana and Orbital were considered stable in comparison to the other genotypes since these genotypes had lower values (Tables 2 and 3).

Kang's (1988) rank-sum uses both yield and Shukla's (1972) stability variance; in which genotypes with a low rank-sum are regarded as the most desirable. According to the rank-sum statistic, Falko followed by Indiana, Olympus, and Orbital had the lowest values and were stable genotypes with high yield, whereas genotypes Amur, and Calao, which had the highest values, were undesirable (Tables 2 and 3).

Relationship between mean yield and stability statistics

Correlation coefficients between mean yield and all of the non-parametric stability statistics are presented in Table 4. Mean yield was statistically significant ($\alpha < 0.05$) and positively correlated with rank-sum and $NP^{(4)}$, $NP^{(3)}$ and $S^{(3)}$ parameters, respectively.

Table 2. Mean yields (Y) and nonparametric stability measures for 8 triticale genotypes in the region of Sadovo

Genotype	Y	$S^{(1)a}$	$S^{(2)}$	$S^{(3)}$	$S^{(6)}$	$NP^{(1)b}$	$NP^{(2)}$	$NP^{(3)}$	$NP^{(4)}$	KR^{c}
Kolirit	5470	2.4	3.8	4.22	2.11	1.8	0.48	0.51	0.67	11
Amur	5010	3	8.7	12.43	3.71	2.4	2.60	0.97	1.07	16
Olympus	5640	2.6	4.7	3.92	1.92	2.4	0.37	0.47	0.54	7
Orbital	5560	1.4	1.3	1.18	1.00	2	0.32	0.44	0.32	7
Vizerunok	5220	2.4	4.8	8.00	3.50	2.2	1.20	1.11	1.00	13
Calao	5930	2	2.7	1.74	1.10	2.2	0.46	0.44	0.32	8
Indiana	5540	1.4	1.5	1.50	1.00	1	0.20	0.34	0.35	7
Falko	5850	1	0.8	0.43	0.49	1.2	0.30	0.18	0.14	3

[a]Si, Huehn's (1979) nonparametric stability parameters
[b]NP, Thennarasu's (1995) nonparametric stability parameters
[c]KR, Kang's (1988) stability parameters

Table 3. Ranks of 8 triticale genotypes using 9 different non-parametric methods

Genotype	Y	$S^{(1)a}$	$S^{(2)}$	$S^{(3)}$	$S^{(6)}$	$NP^{(1)b}$	$NP^{(2)}$	$NP^{(3)}$	$NP^{(4)}$	KR^{c}
Kolorit	6	5	5	6	6	3	6	6	6	6
Amur	8	8	8	8	8	7	8	7	8	8
Olympus	3	7	6	5	5	7	4	5	5	2
Orbital	4	2	2	2	2	4	3	4	2	2
Vizerunok	7	5	7	7	7	5	7	8	7	7
Calao	1	4	4	4	4	5	5	3	3	5
Indiana	5	2	3	3	2	1	1	2	4	2
Falko	2	1	1	1	1	2	2	1	1	1

[a]Si, Huehn's (1979) nonparametric stability parameters
[b]NP, Thennarasu's (1995) nonparametric stability parameters
[c]KR, Kang's (1988) stability parameters

Table 4. Correlations between yield and 9 different non-parametric methods of 8 triticale genotypes in the region of Sadovo

	Y	$S^{(1)}$	$S^{(2)}$	$S^{(3)}$	$S^{(6)}$	$NP^{(1)}$	$NP^{(2)}$	$NP^{(3)}$	$NP^{(4)}$	KR
Y	1	.491	.667	.738*	.695	.187	.595	.762*	.833*	.681
$S^{(1)}$		1	.936**	.889**	.901**	.851**	.795*	.772*	.842**	.675
$S^{(2)}$			1	.976**	.968**	.746*	.857**	.881**	.952**	.811*
$S^{(3)}$				1	.991**	.640	.905**	.905**	.976**	.898**
$S^{(6)}$					1	.695	.945**	.923**	.945**	.903**
$NP^{(1)}$						1	.693	.640	.533	.478
$NP^{(2)}$							1	.881**	.810*	.941**
$NP^{(3)}$								1	.881**	.811*
$NP^{(4)}$									1	.833*
KR										1

[a]Si, Huehn's (1979) nonparametric stability parameters
[b]NP, Thennarasu's (1995) nonparametric stability parameters
[c]KR, Kang's (1988) stability parameters
* sufficient evidence for reliability α = 0.05
** sufficient evidence for reliability α = 0.01

In this study, cluster analysis separated 8 triticale varieties into three clusters (Figure 1). Accordingly, the cluster III comprised the high yielding varieties Orbital, Falko and Indiana that had relatively low values of non-parametric statistics (sum ranks of stability parameters ranged from 11 to 23) and were identified as more stable genotypes (Tables 1 and 2).These varieties can be used for the improvement of adaptation and high yielding in triticale breeding programs.

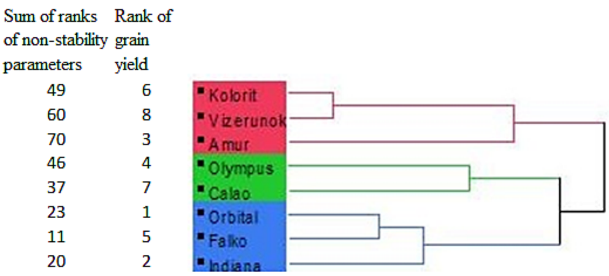

Fig. 1. Dendrogram showing hierarchical classification of 8 triticale genotypes based on ranks of mean yields and non-parametric statistics

Conclusions

Strongest influence on yield have the conditions of the year which explained 66.94% of the total (E + G + EGI) variation, whereas G and EGI accounted for 9.88% and 18.10%, respectively.

$NP^{(4)}$, $NP^{(3)}$ and $S^{(3)}$ parameters would be as the best parameters for selecting superior genotypes and they have a significant and positive correlation with mean yield.

Genotype Indiana and Orbital can be recommended as the most stable genotypes with regard to both stability and yield. They were the most stable genotype based on 9 non-parametric stability statistics and had the first and second highest grain yield among the eight triticale genotypes studied. These genotypes can be used for the improvement of adaptation and high yielding in triticale breeding programs.

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