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Analysis of Grain Yield Stability of Triticale (×*Triticosecale wittmack*) Based on the Some Parametric and Non-Parametric Index under Semi-arid Conditions

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ABSTRACT

Field experiment was conducted during the three consecutive cropping seasons (2017–2018, 2018–2019 and 2019–2020) at the experimental field of ITGC, Setif, Algeria to study the selection of adapted and stable genotypes of triticale based on the use of some parametric and non-parametric index. The program STABILITYSOFT was used to calculate the parametric and non-parametric index. The graphic distribution of the genotypes tested based on the relationship between the mean grain yield and regression coefficient (bi), proved that the suitable genotypes for the tested conditions are G2, and G3. The association between Wricke'secovalence (Wi^2), the coefficient of variance (CVi), the mean variance component (θ_i) and the Stability variance (σ^2_i) indices with the grain yield proved that the best genotypes for growing under these conditions were G2 and G3.In addition, the selection based on the non-parametric index showed that the genotypes G1, G2 and G3 were the most stables. The combination selection based on highest grain yield and the parametric indices proved that the genotypes G2 and G3 are the more stable and more adapted under semi-arid conditions. The results of spearman's rank correlation and PCA analysis for grouping the different parametric stability statistics studied showed that stability indices could be classified into four groups. Moreover, and based on the static and dynamic concepts, the parametric indices bi and CVi are related to the static concept, while the other indices were associated with dynamic stability concept. Overall, the results of this study confirmed that the parametric and non-parametric methods were the suitable tools to identify the most stable triticale genotypes at various environmental conditions.

KEYWORDS: Genotypes, grain yield, non-parametric, parametric, selection, stability, triticale

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1. INTRODUCTION

Triticale *(×Triticosecale wittmack*) is the first successful man-made cereal that was derived from inter-specific crossing between wheat and rye in 1875 (Dumbrava et al., 2014). 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 and Kociuba, 2013). Nowadays, triticale is concerned as a commercial crop with vast potential for human and animal nutrition (Glamoclija et al., 2018). Compared to wheat, on better dry matter and grain yield, triticale is considered as a feed source for cattle (Ghodsi, 2009). In general, triticale is more tolerant to the unfavourable conditions of the environments (Motzo et al., 2015, Randhawa et al., 2015, Mendez-Espinosa et al., 2019).According to many contemporary scholars, triticale must have the best properties of both parents, the quality of wheat for marketing and with rye resistance to adapt to difficult soil conditions, drought tolerance, cold tolerance and disease and low food demand (Dumbrava et al., 2014).One of the most basic positive characteristics of triticale is high productive potential. This isdue to the composition of the yield components inherited from the wheat and rye (Estrada-Campuzano et al, 2012, Ivanova and Tsenov, 2014, Stoyanov and Baychev, 2015, Ramazani et al., 2016).Plant breeders are interested in the selection of varieties that have good performance in a range of environments. An important objective of plant breeding for areas with limited resources for agricultural inputs is to select genotypes with higher average yield and best stability in various environments. A genotype is considered to be more adaptive and stable if it has a high mean grain yield but a low degree of fluctuation in its yield when grown over diverse environments. However, genotype by environment (G×E) interactions frequently interferes with the identification of widely adapted genotypes (Ceccarelli, 1994).Many researchers have adopted various stability parameters to evaluate the adaptation and stability of triticale (Ismail and Al-fahdi, 2012, Kaya and Ozer, 2014, Ramazani et al., 2016). Several models for the statistical measurement of stability have been proposed, each one reflecting different aspects of stability and no single method can adequately explain the performance of the genotype in different environments. The first and most common approach is parametric, which relies on distributional assumptions about genotypic, environmental and G×E interaction effects. The second major approach is the non-parametric or analytical clustering approach, which relates environments and phenotypes relative to biotic and abiotic environmental factors without making specific modelling assumptions. Several parametric methods including univariate and multivariate ones have been developed to assess the stability and adaptability of genotypes. The parametric approach continent many indices such as the regression coefficient (bi; Finlay and Wilkinson, 1963), variance of deviations from the regression (S^2_{di}; Eberhart and Russell, 1966), Wricke's ecovalence stability index (Wi^2; Wricke, 1962), Shukla's stability variance (σ_i^2; Shukla, 1972), environmental coefficient of variance (CVi; Francis and Kannenberg, 1978), mean variance component (θ_i; Plaisted and Peterson, 1959). The second group of analytical methods includes non-parametric methods such as Nassar and Huehn's statistics ($S^{(1)}$, $S^{(2)}$; Nassar and Huehn, 1987), Huehn's equation ($S^{(3)}$ and $S^{(6)}$; Huehn, 1990), Thennarasu's statistics ($NP^{(i)}$; Thennarasu, 1995). The aim of this study is to evaluate the performance of some genotypes of triticale based on some parametric and non-parametric methods.

2. MATERIALS AND METHODS

2.1. Plant material and field conditions

Field experiment was conducted during the three consecutive cropping seasons (2017–2018, 2018–2019 and 2019–2020) at the experimental field of ITGC, Setif, Algeria (5°20'E, 36°8'N, 958 m above mean sea level). The statistical design employed was based on a completely randomized block design (CRBD) with three replications. 7 genotypes of triticale were used in this study. The seeds were sown using an experimental drill in 1.2 ×5 m^2 plots consisting of 6 rows with a 20 cm row space and the seeding rate was about 300 seeds per m^2. The pedigree and the origin of the genotypes tested during this study are given in Table 1.

2.2. Statistical analysis

2.2.1. Parametric measures

The regression coefficient (bi) is the response of the genotype to the environmental index that is derived from the average performance of all genotypes in each environment (Finlay and Wilkinson, 1963). If bi does not significantly differ from 1, then the genotype is adapted to all environments. In addition to the regression coefficient, variance of deviations from the regression (S^2di) has been suggested as one of the most-used parameters for the selection of stable genotypes. Genotypes with an S^2di == 0 would be most stable, while an $S^2di > 0$ would indicate lower stability across all environments. Hence, genotypes with lower values are the most desirable (Eberhart and Russell, 1966). Wricke (1962) proposed the concept of ecovalence as the contribution of each genotype to the GEI sum of squares. The ecovalence (Wi) of the i^{th} genotype is its interaction with the environments, squared and summed across environments. Thus, genotypes with low values have smaller deviations from the mean across environments and are more stable. Shukla (1972) suggested the stability variance of genotype *i* as its variance across environments after the

Table 1: Code, pedigrees and origin of genotypes evaluated in this study

Code	Variety/Pedigree	Origin
G1	LIRON_2/5/DISB5/3/SPHD/PVN//YOGUI_6/4/KER_3/6/BULL_10/MANATI_1/7/RHINO_3/BULL_1-1/8/BAT*2/BCN//CAAL/3/ERIZO_7/BAGAL_2//FARAS_1	CIMMYT
G2	POLLMER_2.2.1*2//FARAS/CMH84.4414/6/BAT*2/BCN//CAAL/3/ERIZO_7/BAGAL_2//FARAS_1/5/DAHBI_6/3/ARDI_1/TOPO 1419//ERIZO_9/4/FAHAD_8-1*2//HARE_263/CIVET	CIMMYT
G3	BAT*2/BCN//CAAL/3/ERIZO_7/BAGAL_2//FARAS_1/8/GAUR_2/HARE_3//JLO 97/CIVET/5/DIS B5/3/SPHD/PVN//YOGUI_6/4/KER_3/6/150.83//2*TESMO_1/MUSX 603/7/GAUR_2/HARE_3//JLO 97/CIVET	CIMMYT
G4	RONDO/BANT_5//ANOAS_2/3/RHINO_3/BULL_1-1/4/BAT*2/BCN//CAAL/3/ERIZO_7/BAGAL_2//FARAS_1	CIMMYT
G5	NILEX/3/BULL_10/MANATI_1//FARAS/CMH84.4414/6/HX87-244/HX87-255/5/PRESTO//2*TESMO_1/MUSX 603/4/ARDI_1/TOPO 1419//ERIZO_9/3/SUSI_2	CIMMYT
G6	OUED EDHEB	Algeria
G7	JOUANILLO	Algeria

main effects of environmental means have been removed. According to this test, genotypes with minimum values are intended to be more stable. Plaisted and Peterson (1959) proposed the variance component of genotype environment interactions for interactions between each of the possible pairs of genotypes and considered the average of the estimate for all combinations with a common genotype to be a measure of stability. Accordingly, the genotypes which show lower value for the θ_i are considered more stable. Finally, the coefficient of variation is suggested by Francis and Kannenberg (1978) as a stability statistic through the combination of the coefficient of variation, mean yield, and environmental variance. Genotypes with low CVi, low environmental variance (EV), and high mean yield are considered to be the most desirable.

2.2.2. Non-parametric measures

Huhn (1990) and Nassar and Huhn (1987) suggested four non-parametric statistics. We use during this study three parameters: (1) $S^{(1)}$, the mean of the absolute rank differences of a genotype over all tested environments, (2) $S^{(3)}$,the sum of the absolute deviations for each genotype relative to the mean of ranks, and (3) $S^{(6)}$, the sum of squares of rank for each genotype relative to the mean of ranks. The lowest value for each of these statistics reveals high stability for a certain genotype. In addition, four NP (1–4) statistics are a set of alternative non-parametric stability statistics defined by Thennarasu (1995). The parameters used in this article are ($NP^{1)}$, $NP^{(2)}$ and $NP^{(4)}$). These parameters are based on the ranks of adjusted means of the genotypes in each environment. Low values of these statistics reflect high stability.

2.2.3. Stability software

The data were analysed by the using of new online software (STABILITYSOFT) to calculate parametric and non parametric stability statistics for crop traits developed by Pour-Aboughadareh et al. (2019).

3. RESULTS AND DISCUSSION

3.1. Parametric measures

The mean grain yield and the stability parameters for seven genotypes tested in this study were calculated and the results are presented in Table 2.

The values of regression coefficient (bi) varied from 1.291 for the genotype G5 to 0.664 for the local landrace Jouanillo, this variation in regression coefficients indicates that genotypes had different responses to environmental changes. According to the definition described by Pour-Aboughadareh et al. (2019) genotypes with a regression coefficient equal to zero (bi < 1) are very suitable to low yield environments, but the contrary for the genotypes with high values (bi > 1). The local landrace Jouanillo is very suitable to growing under the poor condition or just under rainfall conditions. In addition, the graphical distribution (Figure 1) between the regression coefficient and the mean grain yield of tested genotypes demonstrated that the adapted and stable genotypes with high mean grain yield under these conditions are G2, and G3.

The genotypes G1, G4, G5 and the local landrace Oued Edheb (G6) are greater specificity of adaptability to high-yielding environments (Irrigated conditions). According to Megahed et al. (2018) genotypes with regression coefficient greater than unity would be adapted to more favorable environments. The values of deviation from regression (S^2_{di}) classified the genotype G2 as the most desirable genotypes, with mean grain yield (5625) higher than the general mean

Table 2: Parametric, non-parametric stability index and mean grain yield (kg ha^{-1}) for the triticale genotypes used in the study

Genotype	b_i	S^2d_i	W_i^2	σ^2_i	CVi	θ_i	Grain Yield
G1	1,291	4,339	84,727	50,918	41,267	49,882	5682,2
G2	0,715	0,070	52,447	28,323	22,794	40,468	5625,4
G3	0,975	4,940	34,974	16,091	33,477	35,371	5363,8
G4	1,202	0,151	27,380	10,776	42,229	33,156	5103,1
G5	1,064	9,037	65,901	37,740	41,271	44,392	4814,8
G6	1,086	7,162	54,964	30,085	41,899	41,202	4814,8
G7	0,664	15,839	183,021	119,72	29,082	78,552	4827,8
Mean	0,999	5,934	71,916	41,950	36,002	46,146	5173,4
Maximum	1,291	15,839	183,021	119,72	42,229	78,552	5682,2
Minimum	0,664	0,070	27,380	10,776	22,794	33,156	4814,8
Correlation with GY	0,115^{ns}	-0.651^{ns}	-0.300^{ns}	-0.300^{ns}	-0.327^{ns}	-0.300^{ns}	-
	Non-Parametric index						Mean
	$S^{(1)}$	$S^{(3)}$	$S^{(6)}$	$NP^{(2)}$	$NP^{(3)}$	$NP^{(4)}$	Grain yield
G1	2	0,875	0,625	0,238	0,385	0,375	5682,2
G2	2,666	1,882	0,941	0,285	0,285	0,470	5625,4
G3	2,666	2	1,076	0,277	0,277	0,615	5363,8
G4	2	1,5	1	0,333	0,408	0,5	5103,1
G5	2	2	1,333	1	0,831	0,666	4814,8
G6	2,666	3,25	1,75	0,666	0,770	1	4814,8
G7	3,333	4,666	2	0,666	0,831	1,111	4827,8
Mean	2.475	2,310	1,246	0,495	0,541	0,676	5173,4
Maximum	3,333	4,666	2	1	0,831	1,111	5682,2
Minimum	2	0,875	0,625	0,238	0,277	0,375	4814,8
Correlation with GY	-0,242^{ns}	-0,678^{ns}	-0,848*	-0,841*	-0,882**	-0,796*	-

bi: Regression coefficient, S^2d_i:Deviation from regression, W_i^2:Wricke'secovalence index, σ^2_i : Shukla's stability variance, CVi: Environmental coefficient of variance, θ_i : Mean variance component, $S^{(1)}$, $S^{(3)}$ and $S^{(6)}$: Nassar and Huhn's non-parametric statistics, $NP^{(2)}$, $NP^{(3)}$ and $NP^{(4)}$: Thennarasu's non-parametric statistics.

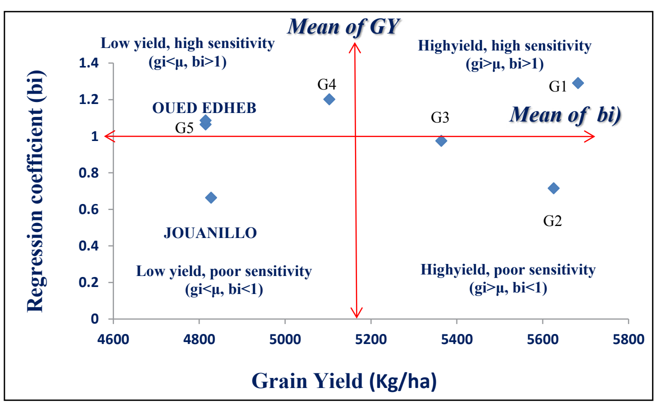

Figure 1: The relationship between the regression coefficients and mean grain yield (kg ha^{-1}) for triticale genotypes tested

of grain yield (5173). The combination between the S^2_{di} and the mean grain yield of tested genotypes proved that the genotypes G1, G2 and G3 have lowest values of S^2_{di} and highest mean grain yield (> average grain yield). Eberhart and Russell (1996) emphasized that the genotypes with high mean yield, a regression coefficient equal to the unity (bi == 1) and small deviations from regression (S^2di == 0) are considered stable. The genotype G2 also have regression coefficient close to unity (0.715) and small deviation from regression (0.07) and its average yield is higher than the general mean yield, was wider adaptive. The selection based on the graphical distribution between the Wricke's ecovalence stability index (Wi^2) on the one hand and the Stability variance (σ^2_i) on the other hand with the mean grain yield of tested genotypes (Figure 2) demonstrate that the adapted and stable genotypes with high mean grain yield under these conditions are G2 and G3. The genotype Jouanillo showed high values of equivalence and the stability

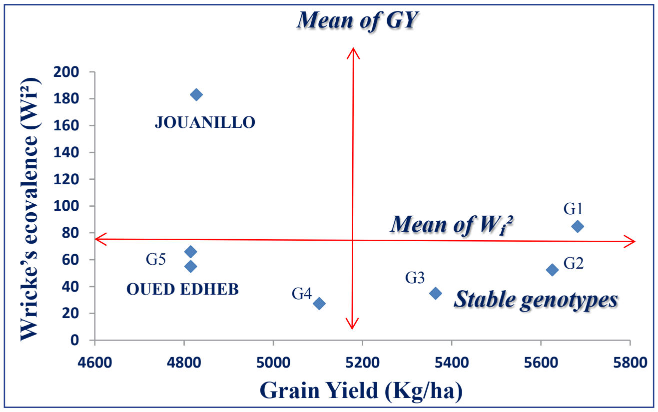

Figure 2: The relationship between the Wricke's ecovalence stability index (Wi^2) and mean grain yield (kg ha^{-1}) for triticale genotypes tested

variance, and is therefore classified as an unstable genotype with a low average grain yield (4827).

The lowest values of W_i^2 and σ^2_i are registered in the genotype G4, but its grain yield (5103) is slightly lower than the general mean of grain yield (5173).

Based on the environmental coefficient of variance (CVi), the G2 considered as the most desirable and stable genotype with height average grain yield and lowest value of CVi. In contrary, the genotype Jouanillo was considered undesirable because, although it had a small CVi, its mean grain yield (4827) was lower than the average grain yield (5173).

Plaisted and Peterson (1959) suggested using mean variance component (θ_i) as a parametric stability parameter. The genotypes with the smallest θ_i values are considered more stable. The genotypes G2, G3, G4, G5 and Oued Edheb had lower θ_i and were stable (Table 2), conversely, G1, and Jouanillo were instable due to higher values from θ_i. According to the graphical distribution (Figure 3) between the coefficient of variance (CVi) on the one hand and the mean variance component (θ_i) on the other hand with mean grain yield, the genotypes G2 and G3 show lowest values of CVi and θ_i with the highest mean grain yield 5625 and 5363, respectively are considered more stable.

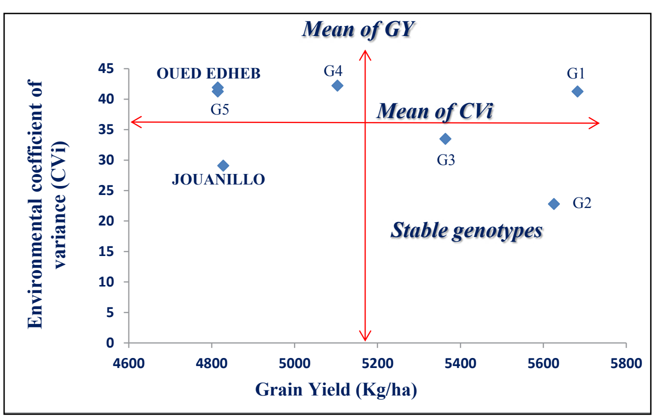

Figure 3: The relationship between the environmental coefficient of variance (CVi) and mean grain yield (kg ha^{-1}) for triticale genotypes tested

Many studies confirmed the efficiency of using like these parametric index to select adapted and stable triticale genotypes (Dogan et al., 2010, Kaya and Ozer, 2014, Ramzaani et al., 2016), barley genotypes (Guendouz and Bendada, 2022, Verma et al., 2019) and stable durum wheat genotypes (Guendouz and Hafsi, 2017).

3.2. Non-parametric measures

The nonparametric measure proposed by Huhn (1990) and Nassar and Huhn (1987) is based on the ranks of cultivars across environments and it gives equal weight to each environment. Accordingly, $Si^{(1)}$, $Si^{(3)}$ and $Si^{(6)}$ of the evaluated genotypes (Table 1) revealed that G1 is the most stable genotype with the lowest value over all genotypes and the highest mean grain yield (5682). Hover, Jouinillo and Oued Edheb had the highest values of $Si^{(1)}$, $Si^{(3)}$ and $Si^{(6)}$, therefore, they were classified as unstable genotypes. In addition, the graphical distribution (Figure 4) between the Nassar and Huhn's non-parametric index $Si^{(3)}$, $Si^{(6)}$ and the mean grain yield of tested genotypes showed that the adapted and stable genotypes with high mean grain yield under these conditions are G1, G2 and G3. Our results are in according with the research of Khalili and Pour-Aboughadareh (2016), which proved that the indices of Nassar and Huhn's are very suitable to select stable and adapted barley genotypes.

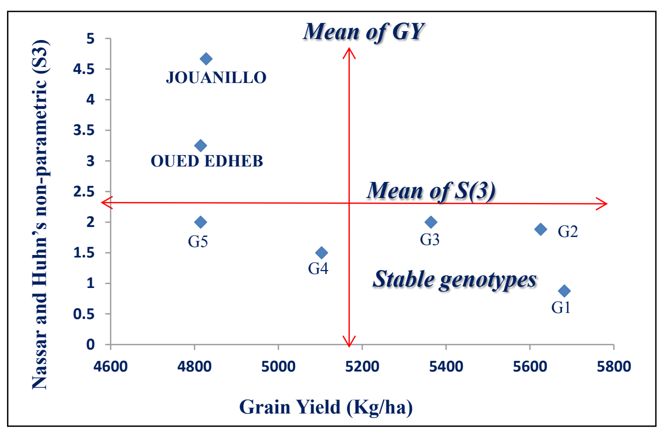

Figure 4: The relationship between the Nassar and Huhn's non-parametric index ($Si^{(3)}$) and mean grain yield (kg ha^{-1}) for triticale genotypes tested

The results illustrated in the Table 2, showed that the genotype G1 have the lowest values for the Thennarasu's non-parametric statistics ($NP^{(2)}$ and $NP^{(4)}$) with highest grain yield over all genotypes tested, while the lowest value of $NP^{(3)}$ was recorded in G3. In addition, the graphical classification based on the distribution (Figure 5) between

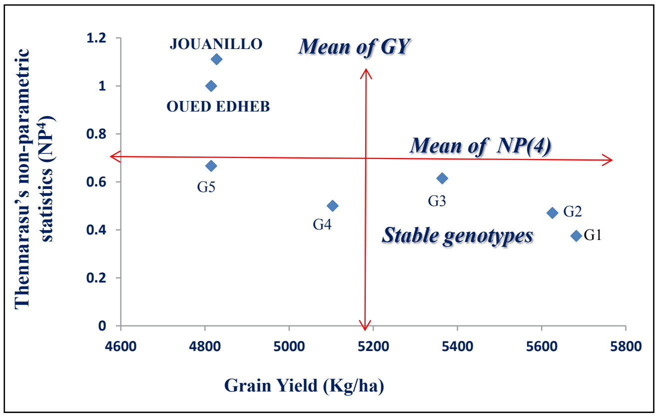

Figure 5: The relationship between the Thennarasu's non-parametric index (NP^4) and mean grain yield (kg ha^{-1}) for triticale genotypes tested

the Thennarasu's non-parametric index and the mean grain yield of tested genotypes showed that the adapted and stable genotypes are G1, G2 and G3.

Many researchers suggested that the used non-parametric measures cited below in the selection of stable and adapted soybean genotypes (El- Hashash et al., 2019), durum wheat (Guendouz and Hafsi, 2017, Hannachi et al., 2019) are very suitable under arid and semi-arid conditions.

3.3. Association among stability parameters and grain yield

The results of Spearman's coefficient of rank correlations between mean grain yield and the different parametric and non-parametric stability indices used in this study are presented in Table 2. The mean grain yield correlated significantly and negatively with the majority of non-parametric indices tested ($S^{(6)}$, $NP^{(2)}$, $NP^{(3)}$ and $NP^{(4)}$) and no significant correlations with the $S^{(1)}$ and $S^{(3)}$. Similar results were mentioned by El-Hashash et al. 2019 in Soybean and Khalili and Pour-Aboughadareh, 2016 in barley. Thus, selection of stable genotypes based on these stability parameters may not enable triticale breeders to identify genotypes that are both high-yielding and stable. A study of durum wheat genotypes using the same stability parameters (Kilic et al., 2010) also identified below-average-yielding genotypes as the most stable and the highest-yielding genotypes as more unstable. In addition, no significant correlations are registered between the mean grain yield and the parametric indices (Table 2).

As illustrated in the Table 3, significant and positive correlation registered between $S^{(3)}$ and $S^{(6)}$ (r == 0.958^{***}) and among $S^{(6)}$ and $NP^{(3)}$, $NP^{(4)}$ (r == 0.82^{*}, r == 0.988^{***}), respectively. $NP^{(2)}$ was positively correlated with $NP^{(3)}$ (r == 0.917^{**}). Kilic (2012) reported that this significant positive correlation between these stability parameters suggests that these parameters would play similar roles to select adapted and stable genotypes. Deviation from the regression (S^2d_i) was positively correlated with $S^{(3)}$ (r == 0.803^{*}), $S^{(6)}$ (r == 0.801^{*}), $NP^{(3)}$ (r=0.806^{*}), $NP^{(4)}$ (r= 0.815*). In addtion, the S^2d_i is correlated significaltly and positively with: W_i^2, σ^2_i, θ_i (r=0.838^{*}, r=0.838^{*}, r=0.838^{*}, respectively). Ecovalence (Wi^2), stability variance (σi^2), stability parameters of θ_i were highly correlated with each other (r == 1.00^{***}), which indicated that one of these three parameters would be sufficient to select stable and suitable triticale genotypes in a breeding programs.

3.4. Classification based on principal component analysis (PCA)

Principal component (PC) analysis based on the rank correlation matrix was performed and presented in Figure 6.

The results proved that the first two principal components (PCA1 and PCA2) of the rank correlation represented respectively 62.26% and 22.35% of the variation, making a

Table 3: Spearman's rank correlation coefficients among parametric and non parametric stability indices used in this study

	$S^{(1)}$	$S^{(3)}$	$S^{(6)}$	$NP^{(2)}$	$NP^{(3)}$	$NP^{(4)}$	b_i	S^2d_i	W_i^2	σ^2_i	CVi	θ_i
$S^{(1)}$	1											
$S^{(3)}$	0,860	1										
$S^{(6)}$	0,701	0,958	1									
$NP^{(2)}$	0,065	0,489	0,671	1								
$NP^{(3)}$	0,248	0,684	0,820	0,917	1							
$NP^{(4)}$	0,734	0,960	0,988	0,599	0,785	1						
b_i	-0,838	-0,665	-0,505	-0,130	-0,143	-0,464	1					
S^2d_i	0,570	0,803	0,801	0,661	0,806	0,815	-0,382	1				
W_i^2	0,625	0,718	0,591	0,321	0,558	0,608	-0,512	0,838	1			
σ^2_i	0,625	0,718	0,591	0,321	0,558	0,608	-0,512	0,838	1,000	1		
CVi	-0,676	-0,318	-0,095	0,258	0,274	-0,075	0,898	-0,037	-0,312	-0,312	1	
θ_i	0,625	0,718	0,591	0,321	0,558	0,608	-0,512	0,838	1,000	1,000	-0,312	1

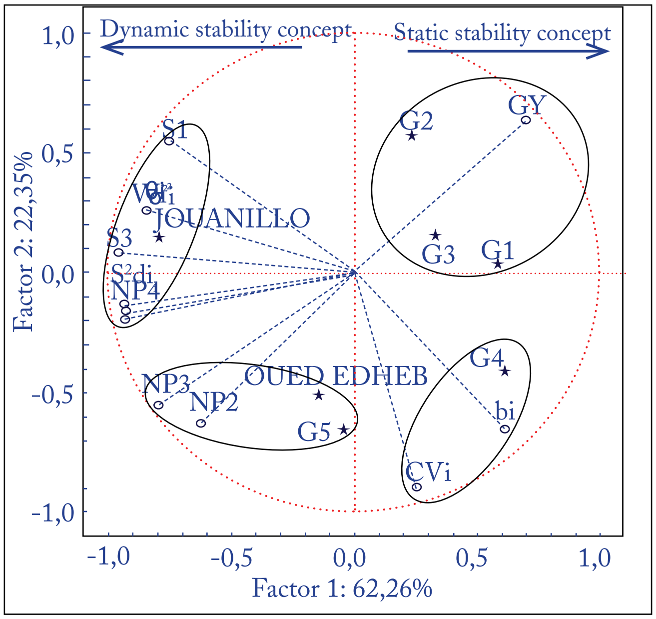

Figure 6: Biplot of IPC1 (F1) and IPC2 (F2) of the rank correlation matrix of the stability parameters with grain yield and triticale genotypes tested

total of 84.61% of the original variance among the stability parameters. Kaya and Ozer (2014) were reported as these results in triticale. On the basis of the distribution of the different stability indices measured and the genotypes tested during this study on the two axes, four groups (Figure 6) can be defined as follows:

Group 1: consisted of 03 genotypes (G1, G2 and G3), which have high values of grain yield.

Group 2: composed of G4, characterized by high values of bi and CVi, which indicate that this genotype is unstable.

Group 3: consisted of 02 genotypes (G1, and Oued Edheb), which are characterized by high values of $NP^{(2)}$ and $NP^{(4)}$. Based on this result, the genotypes cited above are considered undesirable.

Group 4: composed by the local landrace (Jouanillo), which have high values of ($NP^{(1)}$, $S^{(1)}$, $S^{(3)}$, $S^{(6)}$, S^2d_i, W_i^2, σ^2_i and θ_i). According to these results and on the basis of these parameters, jouanillo is considered unstable.

The static and dynamic yield stability concepts describe the differential response of genotypes to variable environments (Becker and Leon, 1988, Becker et al., 2001). The high yield performance of released genotypes is one of the most important targets of breeders, therefore, they prefer a dynamic concept of stability because this concept of stability means that a genotype would show high response to high levels of agronomic inputs such as fertilizer or better environmental conditions. Based on the PC analysis the parametric indices bi and CVi are associated with static stability, while the rest of the indices are associated with dynamic stability. In addition, the principal component analysis classified the genotypes G1, G2 and G3 in static stability group with highest grain yield. Whereas, Jouinillo, Oued Edheb and G5 are in the dynamic stability group but their grain yield is lower than the general average.

4. CONCLUSION

The graphical distributions between the parametric indices (bi), (W_i^2), (σi^2), (CVi), (θ_i) and the mean grain yield proved that G2 and G3 were the adapted and stable genotypes with high yield. The genotypes G1, G2 and G3 were found the most stable genotypes based on the non-parametric indices. The mixed selection based on the highest grain yield and the parametric indices also proved the G2 and G3 as more stable and adaptable.

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