International Journal of Bio-resource and Stress Management   https://pphouse.org/ijbsm.php

Crossref

IJBSM February 2022, 13(2):172-178   Print ISSN 0976-3988   Online ISSN 0976-4038   Article AR2469

Research Article   Natural Resource Management

DOI: HTTPS://DOI.ORG/10.23910/1.2022.2469

Stability Analysis for the Grain Yield of Some Barley (*Hordeum vulgare* L.) Genotypes Growing under Semi-arid Conditions

A. Guendouz[1] and H. Bendada[2]

[1]National Institute of the Agronomic Research of Algeria, Setif unit (19000), Algeria
[2]Dept.of Agricultural Sciences, Faculty of Science and Technology, Relizane University, Relizane (48000), Algeria

Corresponding guendouz.ali@gmail.com

0000-0002-9081-6497

ABSTRACT

The Field experiment was conducted during 03 cropping season from 2017 to 2020 and sowing at the same period in December at the experimental field of ITGC, Setif, Algeria. The aims of this study were the selection of adapted and stable genotypes based on the use of parametric and non-parametric index. To calculate the parametric and non-parametric index we used the program STABILITYSOFT. 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 were the advanced line G2, Fouarra and G12. The values of deviation from regression (S^2_{di}) classified the genotype the advanced line G6 as the most desirable genotypes. The association between Wricke's ecovalence (Wi^2) indice and the grain yield proved that the best genotypes for growing under these conditions are G13, G10, G6 and Fouarra. In addition, the non-parametric index confirmed the results which registered by the selection based on the parametric index. Thus, the genotypes Fouarra and the advanced line G6 are the most stable genotypes. The combination selection based on highest grain yield and the parametric indices proved that the genotypes G6, Fouarra and G2 were the more stable and adapted genotypes under semi-arid conditions. The Principal component (PC) analysis classified the genotype Fouarra and G2 in dynamic stability group with highest grain yield. Overall, the results of this study confirmed that the parametric and Non-parametric methods were the suitable tools to identify the most stable barley genotypes at various environmental conditions. In addition, the best adapted and stable genotypes during this study were Fouarra and G6.

KEYWORDS: Algeria, barley, non-parametric, parametric, stability

Citation* (VANCOUVER)*: Guendouz and Bendada, Stability Analysis for the Grain Yield of Some Barley (*Hordeum vulgare* L.) Genotypes Growing under Semi-arid Conditions. *International Journal of Bio-resource and Stress Management,* 2022; 13(2), 172-178. HTTPS://DOI.ORG/10.23910/1.2022.2469.

Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

Conflict of interests: The authors have declared that no conflict of interest exists.

RECEIVED on 28th June 2021   RECEIVED in revised form on 20th December 2021   ACCEPTED in final form on 18th February 2022   PUBLISHED on 28th February 2022

1. INTRODUCTION

Among the cereals, barley is the firstborn domesticated food-cereal across the globe (Bendada et al., 2021); is one of a few crops grown successfully in semi-arid areas, where rainfall varies significantly with year. Algeria with its topographical and bioclimatic characteristics which make it possible to show a diversity of landscapes and cropping systems, cereal growing is the predominant speculation of agriculture. It extends over an annual area of about 3.6 million hectares compared to the useful agricultural area (UAA) (MADR, 2012). Yield stability is an important criterion for the development of cultivars intended for environments with variable rainfall. Many methods of stability analysis are proposed in the literature such as parametric and non-parametric stability indices (Benmahammad et al., 2010; Rose et al., 2008). Barley (Hordeum vulgare L.) is predominant to be the most drought tolerant of the small grain cereal crops (barley, durum wheat and bread wheat) and is a major crop in Middle East and North Africa countries, because it is the predominant crop lower 300 mm of annual rainfall. In Mediterranean areas barley is primarily grown as animal feed and both grain and straw yields are used (Fatma et al.,2018). Drought stress decreases grain yield of barley genotypes through negative influence on yield components i.e. No. of plants/unit area, No. of spikes and grains per plant or unit area and 1000-grain weight, which are determined at different stages of plant development (Haddadin, 2015; Al-Ajlouni et al., 2016). The importance of G × E interactions in national cultivar evaluation and breeding programs have been demonstrated in almost all major crops, including wheat genotypes (Frih et al., 2021). Multi Environment Trials are important in plant breeding and agronomy for studying yield stability and predicting yield performance of genotypes across environments. Genotype x environment interactions (GEI) complicates the identification of superior genotypes (Sankar et al., 2021) but their interpretation can be facilitated by the use of several statistical modelling methods. GEI occurs when the genotypes respond differently across environments, and it is considered one of the main factors limiting progress in breeding and, hence, in agricultural production. The first and most common approach is parametric, which relies on distributional assumptions about genotypic, environmental and GxE 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 varieties. 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^2; Shukla, 1972), environmental coefficient of variance (CVi; Francis and Kannenberg, 1978) and the yield stability index (YSi; Kang, 1991). The second group of analytical methods includes non-parametric methods such as Nassar and Huhn's statistics ($S^{(1)}$, $S^{(2)}$; Nassar and Huhn, 1987), Huhn's equation ($S^{(3)}$ and $S^{(6)}$; Huhn, 1990), Thennarasu's statistics ($NP^{(i)}$; Thennarasu, 1995). Non-parametric statistics are a feasible alternative to parametric statistics because their performance is based on ranked data (Nassar and Huhn, 1987) and no assumptions are needed about the distribution and homogeneity of the variance of the errors. Because each method has its own merits and weaknesses, most breeding programs now incorporate both parametric and non-parametric methods for the selection of stable genotypes. The aim of this study is to select adapted and stable barley genotypes based on the some parametric and non-parametric methods.

2. MATERIALS AND METHODS

2.1. Plant material and field conditions

Field experiment was conducted during the 2017-2020 cropping seasons 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 complete randomized block design (CRBD) with three replications. Sixteen Barley (*Hordeum vulgare* L.) genotypes were used in this study. The seeds were sown using an experimental drill in 1.2 m×2.5 m plots consisting of 6 rows with a 20 cm row space and the seeding rate is about 250 seeds per m^2.

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^2_{di}) has been suggested as one of the most-used parameters for the selection of stable genotypes. Genotypes with an $S^2_{di}=0$ would be most stable, while an $S^2_{di}>0$ 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. 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 two parameters: (1) $S^{(1)}$, the mean of the absolute rank differences of a genotype over all tested environments; (2) $S^{(6)}$, 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). We use just tow parameters ($NP^{(2)}$ 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. The data were analyzed by the using of the online software (STABILITYSOFT) developed by Pour-Aboughadareh et al. (2019).

3. RESULTS AND DISCUSSION

3.1. Parametric measures

The Table 1, showed that the values of regression coefficient (bi) varied from 1.685 for the advanced line G5 (2 row spike type) to 0.172 for the local landrace Saida 183 (6 row spike type). This variation in regression coefficients indicates that genotypes had different responses to environmental changes. Based on the definition described by Pour-Aboughadareh et al. (2019) the genotypes with low values (b_i<1) are very suitable to low-yielding environments, but the contrary for the genotypes with high values (b_i>1). The local landrace Saida 183 and Tichedrette are very suitable to growing under the poor condition or just under rainfall conditions.

Table 1: Parametric, non-parametric stability index and mean grain yield (q ha^{-1}) for the barley genotypes tested under semi-arid conditions

Genotype	Parametric index				Non-Parametric index				Mean
	b_i	S^2d_i	W_i^2	CVi	$S^{(1)}$	$S^{(6)}$	$NP^{(2)}$	$NP^{(4)}$	Grain yield
G1	1.551	2.756	53.049	28.296	10.667	1.182	0.379	0.727	42.320
G2	0.931	4.292	30.577	17.484	3.333	0.286	0.125	0.159	45.473
G3	1.276	0.160	9.586	23.627	6.667	0.842	0.463	0.526	40.393
G4	0.663	0.000	12.666	12.411	8.667	1.176	0.481	0.765	39.807
G5	1.685	0.228	53.750	29.418	8.000	0.936	0.362	0.511	42.813
G6	1.273	0.243	9.967	19.096	0.667	0.054	0.227	0.027	49.927
G7	0.829	0.467	6.533	15.975	6.667	0.865	0.392	0.541	39.500
G8	1.298	0.029	10.110	24.271	7.333	1.097	0.604	0.710	39.913
G9	0.932	0.062	0.939	16.952	2.000	0.217	0.157	0.130	41.110
G10	1.124	1.232	10.343	19.476	2.667	0.230	0.152	0.131	44.350
G11	0.865	0.072	2.541	16.294	2.000	0.270	0.262	0.162	39.690
G12	0.555	1.731	34.107	11.055	7.333	0.714	0.174	0.393	43.577
G13	1.159	0.517	6.417	20.511	2.667	0.255	0.083	0.145	42.630
G14 (Fouarra)	0.746	2.487	24.597	12.658	2.000	0.141	0.053	0.085	49.737
G15 (Saida 183)	0.172	0.047	76.498	3.850	9.333	2.737	1.178	1.474	35.023
G16 (Tichedrette)	0.334	3.208	71.793	10.454	12.667	2.313	0.623	1.188	39.930
Mean	0.962	1.096	25.842	17.614	5.792	0.832	0.357	0.480	42.262
Max	1.685	4.292	76.498	29.418	12.667	2.737	1.178	1.474	49.927
Min	0.172	0.000	0.939	3.850	0.667	0.054	0.053	0.027	35.023
Correlation with grain yield	0.342^{ns}	0.377^{ns}	-0.25^{ns}	0.227^{ns}	-0.584*	-0.702**	-0.743***	-0.73**	-

b_i: Regression coefficient, S^2d_i: Deviation from regression, W_i^2: Wricke's ecovalence index, CVi: Environmental coefficient of variance, $S^{(1)}$ and $S^{(6)}$: Nassar and Huhn's non-parametric statistics, $NP^{(2)}$ and $NP^{(4)}$: Thennarasu's non-parametric statistics

In addition, the graphical distribution (Figure 1) between the regression coefficient and the mean grain yield of tested genotypes proved that the adapted and stable genotypes with high mean grain yield under these conditions are G2, Fouarra and G12. The advanced line G1, G3, G5, G6, G10 and G13 are greater specificity of adaptability to high-yielding environments (Irrigated conditions). According to

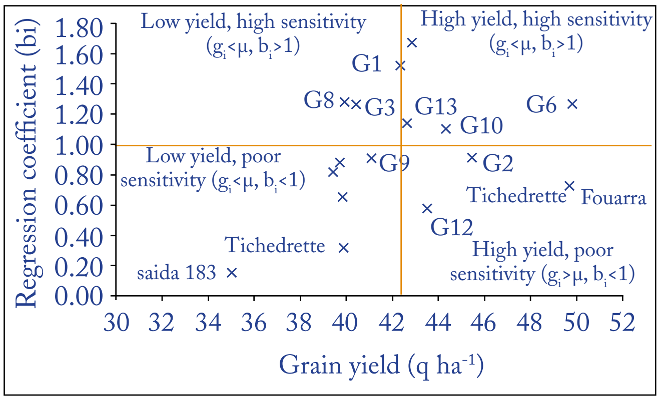

Figure 1: The relationship between the regression coefficients and mean grain yield (q ha^{-1}) for Barley genotypes tested

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 G4 (2 row spike type) as the most desirable genotypes, but with mean grain yield (39.8) lowest than the general mean of grain yield (42.26). The combination between the S^2_{di} and the mean grain yield of tested genotypes proved that the advanced line G5, G6 and G13 have lowest values of S^2_{di} and highest mean grain yield (>general mean of grain yield). Genotypes with high mean yield, a regression coefficient equal to the unity (bi = 1) and small deviations from regression (S^2_{di}=0) are considered stable (Eberhart and Russell, 1966). The graphical distribution (Figure 2) between the Wricke's ecovalence stability index (W_i^2) and the mean grain yield of tested genotypes proved that the adapted and stable genotypes with high mean grain yield under these conditions are G13, G6, G10 and Fouarra. The genotype Saida 183 displayed high ecovalence and is classified as unstable genotype with lowest mean grain yield (35.02). The lowest value of W_i^2 is registered by G9, this one have bi equal to the unity (0.932), lowest values of S^2d_i (0.062) and mean grain yield equal 41.11 (General mean of GY=42.26). In contrary, based on the environmental coefficient of variance (CVi) the genotype Saida183 is very stable, but with lowest mean grain yield (35.02). Many studies confirmed the efficiency of using like these parametric index to select adapted and stable barley genotypes (Ramla et al., 2016; Verma et al., 2019) and stable durum wheat genotypes (Guendouz and Hafsi, 2017).

3.2. Non-parametric measures

Accordingly, $Si^{(1)}$ and $Si^{(6)}$ of the tested genotypes (Table 1) showed that the advanced line G6 had the lowest values; therefore, this genotypes were regarded as the most stable genotypes according to $Si^{(1)}$ and $Si^{(6)}$ with highest grain yield 49.92 q ha^{-1}. In addition, the graphical distribution (Figure 3) between the Nassar and Huhn's non-parametric index ($Si^{(1)}$) and the mean grain yield of tested genotypes showed that the adapted and stable genotypes with high mean grain yield under these conditions are G6, Fouarra, G10, G13 and G2. In contrary, the advanced line G1 had the highest values of $Si^{(1)}$ and $Si^{(6)}$ and high mean grain yield (42.32) over general grain yield equal 42.26 q ha^{-1}. 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. Based on the non-parametric index developed by Thennarasu (1995), the advanced line G6 is the more stable genotype over all genotypes tested with lowest values for the both index tested (NP2 and NP4)

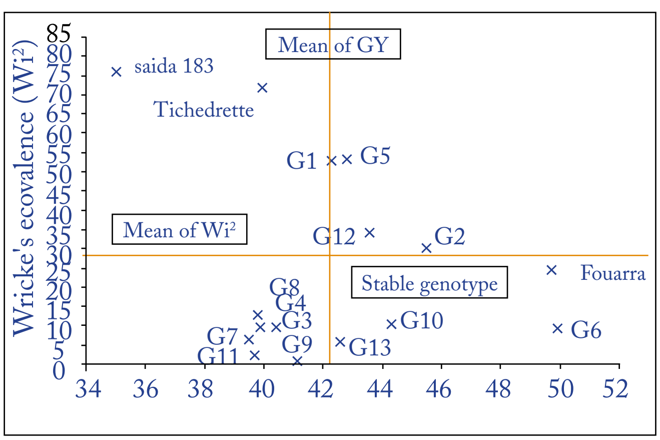

Figure 2: The relationship between the Wricke's ecovalence stability index (Wi^2) and mean grain yield (q ha^{-1}) for Barley genotypes tested

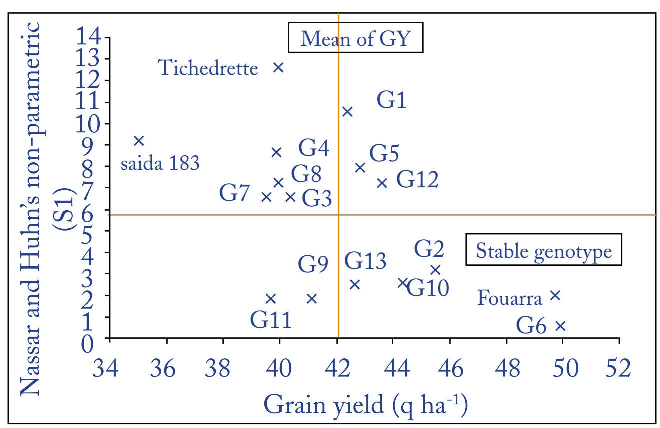

Figure 3: The relationship between the Nassar and Huhn's non-parametric index ($Si^{(1)}$) and mean grain yield (q ha^{-1}) for Barley genotypes tested

and highest mean grain yield (49.92 q ha^{-1}). In addition, the graphical classification based on the distribution (Figure 4) between the Thennarasu's non-parametric index and the mean grain yield of tested genotypes showed that the adapted and stable genotypes are G6, Fouarra, G10, G13, G2 and G12. Many researchers suggested that the used non-parametric measures cited below in the selection of stable durum wheat and barley genotypes (Guendouz and Hafsi, 2017; Hannachi et al., 2019; Khalili and Pour-Aboughadareh, 2016) are very suitable under arid and semi-arid conditions.

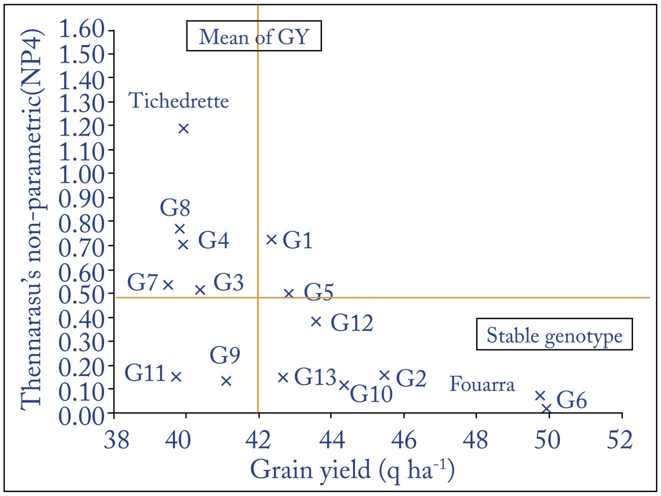

Figure 4: The relationship between the Thennarasu's non-parametric index (NP4) and mean grain yield (q ha^{-1}) for Barley genotypes tested

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 measures are shown in Table 1. The mean grain yield correlated significantly and negatively with all non-parametric indices tested. Many studies registered like this significant correlation in Barley (Khalili and Pour-Aboughadareh, 2016). Thus, selection of stable genotypes based on these stability parameters may not enable barley 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 1). As illustrated in the Table 1, significant correlation registered between the different parametric and non-parametric indices. Many studies revealed that $S^{(1)}$ and $S^{(6)}$ were positively and significantly correlated with each other and with $NP^{(2)}$ and $NP^{(4)}$ (Pour-Aboughadareh et al., 2019). During this study significant and positive correlation registered between $S^{(1)}$ and $S^{(6)}$ ($r = 0.86^{***}$) and among $S^{(6)}$ and $NP^{(4)}$ ($r = 0.99^{***}$), 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. The Wricke's ecovalence stability index (W_i^2) registered positive and significant correlation with all non-parametric indices tested; these results indicate that these parameters plays similar roles in the selection of stable barley genotypes.

3.4. *Classification based on principal component analysis*

Principal component (PC) analysis based on the rank correlation matrix was performed and presented in Figure 5. The results proved that the first and second principal components of the rank correlation accounted for 57.16% and 18.76% of the variation, respectively, making a total of 75.92% of the original variance among the stability

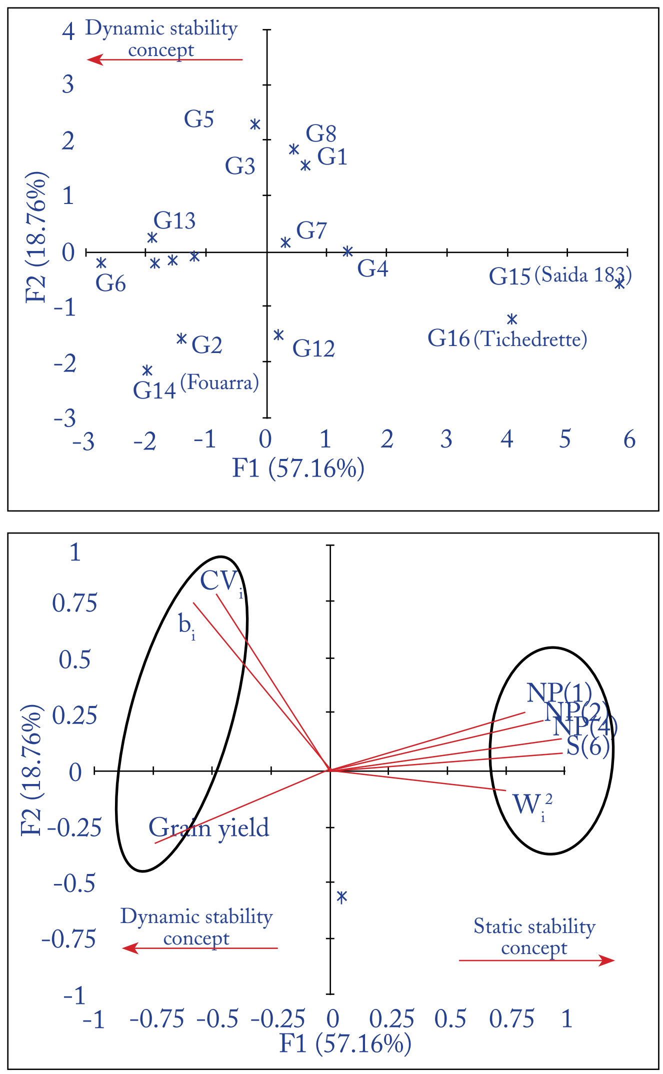

Figure 5: Biplot of IPC1 (F1) and IPC2 (F2) of the rank correlation matrix of the stability parameters with grain yield and Barley genotypes tested

parameters, many studies have been reported like these results in durum wheat (Kilic et al., 2010) and barley (Mut et al., 2010). The static and dynamic yield stability concepts describe the differential response of genotypes to variable environments (Becker and Leon, 1988). Based on the PC analysis the parametric indices bi and CVi are associated with dynamic stability but other indices are associated with static stability. In addition, the principal component analysis classified the genotypes Fouarra and G2 in dynamic stability group with highest grain yield. 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 different levels of inputs such as fertilizer, temperature and humidity.

4. CONCLUSION

The classification based on the mean grain yield describe that the genotypes G6, Fouarra and G2 had the highest grain yield. The selection of adapted and stable genotypes based on Parametric and Non-parametric indices of tested genotypes proved that the adapted and stable genotypes with high mean grain yield under these conditions are G2, G6, Fouarra, G10, G13, G2, G12 and G13. The Principal component analysis classified the genotype Fouarra and G2 in dynamic stability group with highest grain yield.

5. REFERENCES

Al-Ajlouni, Z.I., Al-Abdallat, A.M., AlGhzawi, A.A., Ayad, J.Y., Abu Elenein, J.M., Al-Quraan, N.A., Stephen Baenziger, P., 2016. Impact of pre-anthesis water deficit on yield and yield components in barley (*Hordeum vulgare* L.) plants grown under controlled conditions. Agronomy 6(33), 1-14.

Becker, H.C., Leon, J., 1988. Stability analysis in plant breeding. Plant Breeding 101, 1–23.

Bendada, H., Guendouz, A., Benniou, R., Louahdi, N., 2021. The effect of spike row type on the grain yield and grain filling parameters in barley (*Hordeum vulgare* L.) genotypes under semi-arid conditions. Agricultural Science Digest DOI: 10.18805/ag.D-311.

Benmahammed, A., Nouar, H., Haddad, L., Laala, Z., Oulmi, A., Bouzerzour, H. 2010. Analyse de la stabilite des performances de rendement du blé dur (*Triticum durum* Desf.) sous conditions semi-arides. Biotechnologien , Agronomie , Societe et Environnement 1(14), 177-186.

Eberhart, S.A.T., Russell, W.A.N., 1966. Stability parameters for comparing varieties. Crop Science 6, 36–40.

Fatma M.A.M., El-Khawaga, A.A., Ali, M.M.A., Hassan, A.I.A., 2018. Stability analysis of barley genotypes under different water stress levels.Zagazig Journal of Agricultural Research 45(5), 1521–1545.

Finlay, K.W., Wilkinson, G.N., 1963. Adaptation in a plant breeding programme. Australian Journal of Agricultural Research 14, 742–754.

Francis, T.R., Kannenberg, L.W., 1978. Yield stability studies in short-season maize: I. A descriptive method for grouping genotypes. Canadian Journal of Plant Science 58, 1029–1034.

Frih, B., Oulmi, A., Guendouz, A., 2021. Study of the drought tolerance of certain of durum wheat (*Triticum durum* Desf.) genotypes growing under semi-arid conditions in Algeria. International Journal of Bio-resource and Stress Management 12(2), 137–141.

Guendouz, A., Hafsi, M., 2017. Comparison of parametric and non-parametric methods for selecting stable and adapted durum wheat cultivars under semi-arid conditions. Jordan Journal of Agricultural Sciences 13(3), 655–662.

Haddadin, M.F., 2015. Assessment of drought tolerant barley varieties under water stress. International Journal of Agriculture and Forestry 5(2), 131–137.

Hannachi, A., Fellahi, Z.E.A., Bouzerzour, H., 2019. Analyse de l'adaptabilité et la stabilité de quelques variétés de blé dur (*Triticum durum* Desf.) aux conditions sud mediterraneennes. Revue Agriculture 10(2), 56–67.

Huhn, M., 1990. Non-parametric measures of phenotypic stability. Part 1: Theory. Euphytica 47, 189–194.

Kang, M.S., 1991. Modified rank-sum method for selecting high yielding, stable crop genotypes. Cereal Research Communication 19, 361–364.

Khalili, M., Pour-Aboughadareh, A., 2016. Parametric and non-parametric measures for evaluation yield stability and adaptability in barley doubled haploid lines. Journal of Agricultural Science and Technology 18, 789-803.

Kilic, H., Mevlut, A., Husnu, A., 2010. Assessment of parametric and nonparametric methods for selecting stable and adapted durum wheat genotypes in multi-environments. Notulae Botanicae Horti Agrobotanici Cluj-Napoca 38, 271–279.

Kilic, H., 2012. Assessment of parametric and nonparametric methods for selecting stable and adapted spring bread wheat genotypes in multi-environment. Journal of Animal and Plant Sciences 22, 390–398.

MADR, Ministere de l'Agriculture et du Développement Rural, 2012. Statistiques agricoles, superficies et productions, Direction des Statistiques Agricoles et des Enquêtes Economiques, Série B. Avable on http://madrp.gov.dz/ . Accessed on December 15th , 2021.

Megahed, F.M.A., El-Khawaga, A.A, Ali, M.M.A., Hassan, A.I.A., 2018. Stability analysis of barley genotypes under different water stress levels. Zagazig Journal of Agricultural Research 45(5), 1521–1545.

Mut, Z., Gulumser, A., Sirat, A., 2010. Comparison of stability statistics for yield in barley (*Hordeum vulgare* L.). African Journal of Biotechnology 9, 1610–1618.

Nassar, R., Huhn, M., 1987. Studies on estimation of phenotypic stability: Tests of significance for non-parametric measures of phenotypic stability. Biometrics 43, 45–53.

Pour-Aboughadareh, A.M., Yousefian, H., Moradkhani, P., Poczai., Siddique, K.H.M., 2019. STABILITYSOFT: A new online program to calculate parametric and non-parametric stability statistics for crop traits. Applications in Plant Sciences 7(1), e1211.

Ramla, D., Yakhou, M.S., Bilek, N., Hamou, M., Hannachi, A., Aissat, A., Mekliche-Hanifi, L., 2016. Grain yield stability analysis of barley doubled haploid lines in algerian semi-arid zones. Asian Journal of Crop Science 8, 43–51.

Rose, L.W., Das, M.K., Taliaferro, C.M.A., 2008. Comparison of dry matter yield stability assessment methods for small numbers of genotypes of Bermuda grass. Euphytica, 164, 19–25.

Shukla, G.K., 1972. Some statistical aspects of partitioning genotype-environmental components of variability. Heredity 29, 237–245.

Sankar, S.M., Singh, S.P., Prakash, G., Satyavathi, C.T., Soumya, S.L., Yadav, Y., Sharma, L.D., Rao, A.R., Singh, N., Srivastava, R.K., 2021. Deciphering genotype-by-environment interaction for target environmental delineation and identification of stable resistant sources against foliar blast disease of pearl millet. Frontiers in Plant Science 12, 656158.

Thennarasu, K., 1995. On certain non-parametric procedures for studying genotype- environment interactions and yield stability. PhD thesis, PJ School, Indian Agricultural Research Institute, New Delhi, India.

Verma, A., Kumar, V., Kharab, A., Singh, G., 2019. Quantification of G×E interaction for feed barley genotypes by parametric and non-parametric measures. Bangladesh Journal of Botany 48(1), 33-42.

Wang, Y., Ren, X., Sun, D., Sun, G., 2015. Origin of worldwide cultivated barley revealed by NAM-1 gene and grain protein content. Frontiers in Plant Science 6, 803.

Wricke, G., 1962. Ubereine Methode zur Erfassung der okologischen Streubreite in Feldversuchen. Zeitschrift für Pflanzenzuchtung 47, 92–96.