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NONPARAMETRIC ANALYSIS OF GENOTYPE GRAIN YIELD PERFORMANCE OF BARLEY TRIALS BASED ON RANKS

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ABSTRACT

Plant breeding has been concerned with genotype by environment (GE) interaction and high yielding genotypes with stable performance are desirable while this target is difficult to achieve due to high environmental variations and unpredictable GE interaction. Stability of grain yield performance of 18 barley genotypes was evaluated at 5 locations for 3 years in the rainfed conditions and it was studied through 25 nonparametric stability methods. Four nonparametric tests indicated highly significant GE interaction due to differential performance of genotypes across fifteen environments. Regarding mean yield and six Hühn's statistics, genotype G12 (1946 kg ha^{-1}) was the most favorable genotype while based on the RN1, G4, G10 and G11 were the most stable genotypes. Genotypes G4, G8 and G10 were the most favorable genotypes according to rank-sum while genotypes G2, G13 and G18 were the most favorable genotypes based on nonparametric superiority. The relative interactivity index identified G4, G16 and G8 as the most stable genotypes while the genotypic classification identified G1, G2, G13 and G18 as the most stable genotypes. Clustering of the nonparametric stability methods indicated that there were two groups with different static and dynamic characteristics. In this study, five nonparametric stability methods as GC, FM, PA, RN2 and KR2 were associated with high grain yield and reflected the dynamic concept of stability, but the other twenty nonparametric stability methods were not positively correlated with yield and characterized a static concept of stability. Finally, genotypes genotype G13 (2114.13 kg ha^{-1}) and G18 (2062.69 kg ha^{-1}) were found to be the most favorable genotypes and are thus recommended for commercial release in semiarid areas of Iran.

Keywords: adaptation, dynamic stability, multi-environmental trials, static stability.

INTRODUCTION

The genotype by environment (GE) interaction as a differential genotypic response across environments reduces correlation between phenotypic and genotypic values, forcing breeders to test adaptation. Evaluation of GE interaction is also important to identify a proper breeding strategy for releasing cultivars with relatively high yield stability to target environments. According to Romagosa and Fox (1993), four statistical tools for assessing the stability of a set of genotypes are presented (i) variance partitioning; (ii) linear regression model; (iii) multivariate methods and (iv) nonparametric procedures. As a measurement of stability, the different parameters based on the GE interaction variance can be use and the greater the magnitude of such estimates for a genotype, the poorer its stability (Lin et al., 1986). The linear regression model is a concept model for stability analysis and the concept of a regression slope reflecting the behavior of genotype regarding the environmental conditions is appealing, but the juxtaposition of ecologically different environments with similar mean yields on the abscissa is a major problem (Crossa, 1990). Multivariate methods may be applied to explain relationships among genotypes and present most of the total variation in a few dimensions via graphic presentation (Sabaghnia, 2012).

All above parametric methods for estimating GE interactions and stability are

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used in breeding programs but the proper use of these methods needs some statistical assumptions, and their estimates can be influenced by outliers. Nonparametric procedures based on analysis of ranks, represents a return to the foundation of the GE problem and their advantages include: freedom from main assumptions like additivity of main effects, homogeneity of variances and linear response as well as insensitivity to errors (Huehn, 1990b). The percentage of adaptability (PA) is a statistic for the capacity of a genotype and selection of the most favorable genotypes with wide adaptation could be enhanced by paying attention to the environmental conditions under which the selection is made (St-Pierre et al., 1967). Several nonparametric statistics proposed by Huhn (1979) which use the idea of homeostasis as a measure of the stability and genotypes with similar rankings across environments are classified as stable. Langer et al. (1979) suggested two nonparametric stability measures as nonparametric range (RN1 and RN2) which are related to the ranges in productivity of genotypes as crude index of potential response.

Kang’s (1988) rank-sum is another nonparametric stability statistic where both yield and Shukla’s (1972) stability variance are used as selection criteria. Ketata et al. (1989) proposed ranking methods (Ketata’s ranks; KR1 and KR2) as consistency of performance through plotting the average rank across environments against the standard deviation of ranks for each genotype and as well as modified standard deviation of ranks. The stratified ranking of Fox et al. (1990), evaluates the proportion of environments where any genotype ranks in the top, middle or bottom third of the genotypes and a genotype usually found in the top third can be regarded well adapted.

Huehn (1990a) used corrected ranks by removing the genotype main effect to obtain independence from genotypic effects for some of his pervious statistics, and developed a new nonparametric statistic, S2, while we use the term S7 for discrimination from the previous S2. Piepho and Lotito (1992) defined Li statistic as the mean deviation of interaction GE effects and Ri statistic as the rank sum Li of ranks within environments whereas the smaller Li and Ri values, the more stable is a genotype in relation to the other tested genotypes.

Thennarasu (1995) suggested NP1, NP2, NP3 and NP4 nonparametric stability measures, based on ranks of adjusted mean values of genotypes. Kang and Magari (1996) introduced yield stability index (YSI) and the stability component in YSI is based on stability variance as Type 2 stability, meaning that it was a relative measure dependent on genotypes included in a particular test. Relative interactivity index (RII) as a nonparametric statistic for stability analysis was proposed by Harfouche (2000) which is adapted to assess GE interaction and interactivity based on rank comparisons in the paired trials. Thillainathan and Fernandez (2002) suggested genotypic classification (GC) to classify genotypes evaluated under multiple environments by classification of the environments into three classes, low, medium and high; and then grouping of genotypes into three groups, low, medium and high in each environmental class. Sabaghnia (2015) discussed two nonparametric statistics (NS1 and NS2) for yield stability analysis according to nonparametric dispersion indices, inter-quartile range and inter-decile range and nonparametric central tendency index as median. Stability statistics based on ranks need no statistical assumptions about the distribution of the values, are easy to use and interpret and compared with parametric methods, are less sensitive to errors of measurement (Sabaghnia and Janmohammadi, 2015). Also, addition and deletion of one or a few data is not as likely to cause great variation in the estimates as would be the case for parametric stability measures (Huehn, 1996). The objectives of this research were to (i) interpret ranks obtained by 18 barley genotypes over fifteen environments, (ii) assess how to vary rank measures, and (iii) determine promising genotypes with high yielding and stability.

MATERIAL AND METHODS

This research was carried out across fifteen environments, including five rain-fed locations undertaken in Gachsaran, Gonbad, Ilam, Lorestan and Mogan, during three growing seasons (2017-2019) while some characteristics of test locations are given in Table 1. Of 18 barley genotypes used, 16 were from the national barley improvement program, Iran, based on a joint project ICARDA (International Center for Agricultural Research in the Dry Areas) and two were standard check cultivars (Mahour and Khorram). In each environmental trial, experimental layout was a randomized complete block design with four replications and sowing was done by an experimental drill in 1.05 × 7.03 m plots, consisting of six rows with 17.5 cm left between the rows with seeding rate about 200 seeds m^{-2}. Harvesting was done from four center rows in 0.7 m × 5.5 m plots by experimental combine and grain yield (kg ha^{-1}) was obtained by converting the grain yields obtained from plots to hectares.

Table 1. Some geographical and climatic characteristics of locations

Location	Gachsaran	Gonbad	Ilam	Lorestan	Mogan
Altitude (m)	668	45	100	1125	975
Longitude	30°18′N	37°16′N	39°39′N	33°39′N	33°44′N
Latitude	50°59′E	55°12′E	47°88′E	48°28′E	46°36′E
Rainfall (mm) 2017	236.8	401.1	178.2	306.7	408.9
Rainfall (mm) 2018	176.8	341.4	250.1	488.4	496.4
Rainfall (mm) 2019	764.4	627.7	181.1	953	900.9

A SAS macro program (Akbarpour et al., 2016) was used for calculation of four nonparametric statistical procedures for nonparametric testing of genotype, environment and GE interaction according to Bredenkamp (1974), Hildebrand (1980), de Kroon and van Der Laan (1981), and Kubinger (1986). These nonparametric statistical tests have been described in detail by Huehn and Leon (1995) and Truberg and Hühn (2000). Also, this SAS macro program computes S1, S2, S3, S6 of Hühn (1979), RS of Kang (1988), Top, Mid and Low indices of Fox et al. (1990), and NP1, NP2, NP3 and NP4 of Thennarasu (1995). The percent adaptability (PA) statistic of St-Pierre et al. (1967), S4 and S5 of Hühn (1979), RN1 and RN2 of Langer et al. (1979), KR1 and KR2 of Ketata et al. (1989), S7 of Huehn (1990a), Li and Ri of Piepho and Lotito (1992), and NS1 and NS2 of Sabaghnia (2015) were calculated via spreadsheet program of Microsoft Excel software. Most of these nonparametric statistics tests have been described in detail by Sabaghnia (2016). The YSI of Kang and Magari (1996) was computed through a macro was SAS system (Cotes et al., 2002) and GC of Thillainathan and Fernandez (2002) was obtained from their suggested SAS codes. The RII nonparametric statistic of Harfouche (2000) was computed via the matrix completion algorithm was coded in Matlab version 9.4 (2018). Hierarchical cluster analysis was done using the rank correlation matrix to obtain an understanding of relationships among the nonparametric stability statistics and grain yields through Minitab version 17.0 (Minitab, 2014).

RESULTS AND DISCUSSION

Nonparametric tests based on chi-square statistic (χ^2) were conducted to determine the effects of environment (year × location combination), genotype, and their interactions, on grain yield of barley genotypes (Table 2). The genotype main effect was significant (P<0.01) in all nonparametric tests except test of Bredenkamp (1974) while the environment main effect was significant (P<0.01) in all nonparametric tests. The GE interaction effect was significant (P<0.01) in all nonparametric tests except test of Kubinger (1986), thus results of these tests indicated that both significant additive and crossover interactions were found in barley multi-environmental trials because the null hypothesis for Hildebrand (1980) and Kubinger (1986) tests is no additive GE interaction and for de Kroon and van der Laan (1981) is no crossover GE interaction. According to Truberg and Hühn (2000) and Sabaghnia et al. (2013), there were low differences between the nonparametric tests with parametric ANOVA and provide more specific information about the nature of GE interaction. The significance of GE interaction for barley grain yield is indicating the genotypes exhibited both crossover and additive types of GE interaction. Grain yield is the result of genotype, environment and GE interaction and such complexity is a result of diverse processes that occur during plant development. The large magnitude of GE interaction causes the more dissimilarity the genetic systems controlling the physiological processes conferring adaptation to different environments. However, the relative contributions of GE interaction for grain yield found in this study are similar to those found in other studies in rain-fed environments (Sabaghnia et al., 2014; Mohammadi et al., 2013).

Table 2. Nonparametric test statistics for a test of G, E and GE interaction effects

	Bredenkamp	Hildebrand	Kroon-Laan	Kubinger
Genotype (G)	21.75^{ns}	227.59^{**}	72.55^{**}	76.94^{**}
Environment (E)	850.23^{**}	805.03^{**}	1423.48^{**}	808.88^{**}
GE	6991.93^{**}	1077.12^{**}	383.38^{**}	220.63^{ns}

The tests are chi-square statistics based on Bredenkamp (1974), Hildebrand (1980), de Kroon and van der Laan (1981) and Kubinger (1986) methods.
** Significant χ^2 test at the 0.01 level.
^{ns} Nonsignificant χ^2 test at the 0.01 level.

The overall mean barley's grain yield ranged from 2159.43 kg ha^{-1} for G2 to 1742.50 kg ha^{-1} for G10 (Table 3). The most stable genotypes based on percent of adaptability (PA) of St-Pierre et al. (1967) were G1, G2, G3, G13 and G16 with relatively high and moderate yield performance while the most unstable genotypes were G7, G8, G14 and G17 (Table 3). The most stable genotypes based on the first two nonparametric stability statistics of Hühn (1979), S1 and S2, were G3, G12, G15 and G18 while according to S3 and S4 statistics, G3, G10 and G12 were the most stable genotypes (Table 3). The most stable genotypes based on S5 and S6 of Hühn (1979), were G3, G6, G10 and G12 with relatively low yield performance (Table 3). Regarding mean yield performance and all Hühn's (1979) statistics, it could be grasped that genotype G12 (1946 kg ha^{-1}) was the most favorable genotype. The most stable genotypes based on the RN1 nonparametric range of Langer et al. (1979), were G4, G10 and G11 while according to RN2, G2 and G18 were the most stable genotypes (Table 3). The identified genotypes based on RN1 had low or moderate yield performance while the selected genotypes according to RN2 statistic had high mean yield performance.

Table 3. Grain yield of barley (kg ha^{-1}) and the nonparametric stability statistics proposed by St-Pierre et al. (1967), Hühn (1979) and Langer et al. (1979)

	Yield	PA	S1	S2	S3	S4	S5	S6	RN1	RN2
G1	1976.18	66.67	6.21	28.70	40.21	4.92	4.44	7.37	14	8
G2	2159.43	66.67	6.93	35.89	66.90	5.14	4.05	10.25	17	1
G3	1890.77	73.33	4.82	17.46	19.23	3.85	3.20	4.14	14.5	3
G4	1939.30	60.00	6.08	27.89	29.97	4.59	3.96	5.65	13	11
G5	1997.77	46.67	6.00	26.98	37.21	4.65	3.98	6.84	15	8
G6	1843.95	60.00	6.78	33.67	24.05	4.25	3.12	4.15	16	6
G7	1948.98	53.33	5.73	23.78	43.97	5.15	4.44	7.37	16	6.5
G8	1877.53	53.33	6.08	27.41	30.54	4.90	4.48	5.69	15	7
G9	1970.42	60.00	6.02	25.95	36.50	4.70	4.07	6.74	16	3
G10	1742.50	60.00	6.53	31.35	14.84	3.70	3.21	3.47	11	11
G11	1866.73	60.00	6.32	29.26	28.18	4.55	4.00	5.45	13	3
G12	1946.02	60.00	4.97	18.69	21.79	3.72	3.03	4.77	14	3
G13	2114.13	66.67	6.30	30.74	46.47	4.19	3.38	8.94	15	5
G14	1965.57	53.33	7.30	39.27	60.15	5.90	5.24	9.08	17	3
G15	1897.27	60.00	5.49	23.17	29.39	4.79	4.07	5.21	16	4.5
G16	1945.15	66.67	6.40	29.40	45.18	5.34	4.84	7.66	16	7
G17	1916.38	53.33	7.05	36.60	58.10	5.64	4.72	8.63	17	13
G18	2062.69	60.00	5.60	22.86	46.00	4.27	3.65	9.24	14	1

Abbreviations are: PA, percent of adaptability (St-Pierre et al., 1967); S1, S2, S3, S4, S5 and S6, nonparametric statistics of Hühn (1979); RN1 and RN2, nonparametric range statistics of Langer et al. (1979).

According to RS (rank-sum) of Kang (1988), genotypes G4, G8 and G10 were the most favorable genotypes (Table 4), but their performance was not high, whereas we expected to select high yielding genotypes as the most stable in this method. Genotypes G12, G13 and G18 were the most stable through KR1 of Ketata's (1989) ranks measure plot while Genotypes G6, G11 and G17 were the most stable through KR2 of Ketata's (1989) ranks measure plot (Table 4). Although, KR1 measure could detect relatively high and moderate yielding genotypes as the stable but KR2 did not show such ability. Considering three Top, Mid and Low values of Fox et al. (1990) method (FM), genotypes G2, G13 and G18 were the most favorable genotypes from both stability and yield aspects (Table 4). In FM procedure, the Top value was related to the agronomic concept of yield stability (Flores et al., 1998; Sabaghnia et al., 2012) and our results are in a good agreement with this finding similar to the other researchers who used various nonparametric stability statistics in different crops. The most stable genotypes based on S7 of Huehn (1990a) were similar to S3, S4, S5 and S6 (G3, G10 and G12) and so like the other statistics of Hühn (1979) identified the low or moderate yield genotypes as the stable. The nonparametric statistics of Piepho and Lotito (1992), Li and Ri, detected G3 and G12 as the most stable and G14 and G17 as the most unstable genotypes (Table 4). According to Karimizadeh et al. (2012), S4, S5 and S7, have static concept of yield stability and usually detect low mean yielding genotypes as the most stable genotypes and it seems that the behavior of Li and Ri statistics is relativity similar to Hühn's (1979) statistics and reflect static concept of stability. In this concept, the best genotype tends to maintain a constant yield across different environments while from the other stability concept (dynamic); it implies that for a stable genotype a yield response that is parallel to be mean response (Annicchiarico 2002).

Table 4. Estimates of the nonparametric stability statistics introduced by Kang (1988), Ketata et al. (1989), Fox et al. (1990), Huehn (1990a) and Piepho and Lotito (1992)

	RS	KR1	KR2	Low	Mid	Top	S7	Li	Ri
G1	10	5.093647	2036.197	33.33	33.33	33.33	25.95	145.56	145
G2	7	5.324695	2229.087	13.33	26.67	60.00	28.35	180.56	153
G3	26	3.985987	1945.164	53.33	40.00	6.67	15.89	100.73	115
G4	28	4.748935	1996.469	53.33	26.67	20.00	22.55	160.30	142
G5	19	4.817626	2058.854	33.33	33.33	33.33	23.21	183.79	146
G6	24	4.399134	1897.013	40.00	53.33	6.67	19.35	160.53	160
G7	17	5.326707	2008.043	33.33	33.33	33.33	28.37	171.20	130
G8	31	5.073742	1931.221	53.33	33.33	13.33	25.74	150.39	142
G9	10	4.861902	2030.199	33.33	33.33	33.33	23.64	161.08	129
G10	28	3.833437	1789.31	80.00	20.00	0.00	14.70	179.16	153
G11	24	4.70562	1920.869	40.00	46.67	13.33	22.14	159.76	153
G12	22.5	3.852025	2004.458	26.67	60.00	13.33	14.84	96.59	102
G13	13	4.336995	2182.471	13.33	33.33	53.33	18.81	162.73	142
G14	25	6.102302	2025.597	33.33	26.67	40.00	37.24	228.27	175
G15	26.5	4.956237	1951.757	66.67	20.00	13.33	24.56	119.91	130
G16	13	5.527421	2003.63	53.33	13.33	33.33	30.55	171.95	148
G17	14	5.833401	1975.163	26.67	40.00	33.33	34.03	205.46	163
G18	4	4.415341	2128.95	13.33	26.67	60.00	19.50	143.68	137

Abbreviations are: RS, rank-sum of Kang (1988); KR1 and KR2, Ketata's (1989) ranks measures; Top, Mid and Low, statistics of stratified ranking method of Fox et al. (1990); S7, the new nonparametric statistic of Huehn (1990a); Li and Ri, nonparametric statistics of Piepho and Lotito (1992).

Regarding Table 5, genotypes G3, G12 and G18 were the most stable genotypes based on NP1, genotypes G3 and G15 were the most stable genotypes based on NP2, and genotypes G3, G10 and G15 were the most stable genotypes based on NP3 and NP4 of Thennarasu (1995). The nature of these statistics are similar to Hühn's (1979) statistics and indicated static concept of stability with introducing relatively low yielding genotypes as stable. According to YSI, yield stability index, of (Kang and Magari, 1996) which is modified rank-sum of Kang (1988), genotypes G3, G6 and G15 were the most favorable genotypes with low or moderate mean yield performance (Table 5). The relative interactivity index (RII) of (Harfouche, 2000), identified G4, G16 and G8 as the most stable genotypes. The genotypic classification (Thillainathan and Fernandez, 2002) or GC identified G1, G2, G13 and G18 as the most stable genotypes (Table 5) which were the high yielding genotypes. The first nonparametric statistic of Sabaghnia (2015), NS1, introduced genotypes G6, G10 and G12 as the most stable genotypes while the second nonparametric statistic (NS2) introduced genotypes G3, G4 and G10 as the most stable genotypes (Table 5).

Table 5. Nonparametric stability statistics of Thennarasu (1995), Kang and Magari (1996), Harfouche (2000), Thillainathan and Fernandez (2002) and Sabaghnia (2015)

	NP1	NP2	NP3	NP4	YSI	RII	GC	NS1	NS2
G1	4.60	0.66	0.57	0.69	8	8.27	MHM	1.29	1.91
G2	4.80	0.96	0.98	1.17	-4	7.93	MHH	1.40	3.16
G3	3.33	0.26	0.35	0.42	15	4.88	MLM	0.46	0.86
G4	4.20	0.32	0.48	0.58	9	4.46	MMM	0.54	0.95
G5	4.47	0.56	0.57	0.69	-1	5.64	MLH	1.00	1.80
G6	4.93	0.45	0.50	0.60	14	4.58	MML	0.45	1.18
G7	3.87	0.48	0.52	0.63	2	4.95	MMM	1.00	1.93
G8	4.27	0.30	0.43	0.51	12	4.06	MMM	0.57	1.03
G9	4.33	0.48	0.54	0.66	1	4.70	LMH	1.00	1.51
G10	4.47	0.30	0.39	0.47	11	4.63	MLL	0.40	0.73
G11	4.60	0.46	0.48	0.57	13	5.22	LMM	1.00	1.24
G12	3.27	0.30	0.44	0.52	11	5.50	MMM	0.36	1.05
G13	4.13	0.83	0.95	1.11	-3	4.82	HHH	1.20	2.52
G14	5.33	0.89	0.70	0.84	1	4.95	HML	1.83	2.63
G15	3.80	0.29	0.40	0.47	15	4.63	MMM	0.62	1.12
G16	4.40	0.37	0.55	0.68	4	6.33	MML	0.83	1.23
G17	5.20	0.58	0.71	0.86	6	7.99	MMM	1.33	1.82
G18	3.73	0.93	0.78	0.94	4	6.46	HMM	2.00	3.20

Abbreviations are: NP1, NP2, NP3 and NP4, nonparametric stability measures of Thennarasu (1995); YSI, yield stability index (Kang and Magari, 1996); RII, relative interactivity index (Harfouche, 2000); GC, genotypic classification (Thillainathan and Fernandez, 2002); NS1 and NS2, nonparametric statistics of Sabaghnia (2015).

Each one of the 25 nonparametric stability methods produced a unique genotype ranking (Table 6) and in order to discover the interrelationship among them, a cluster analysis was done. The denderogram plot of this cluster analysis (Figure 1) indicated that the 25 nonparametric stability methods divided into two main clusters: Cluster-A including grain yield and five nonparametric methods (GC, FM, PA, RN2 and KR2) and Cluster-B including remained 20 nonparametric methods. These clusters can be discussed by two main stability concepts (static versus dynamic) whereas most nonparametric benefits from static concept of stability because most of them use different variation indices, some of them are related with high yield performance and therefore define stability with dynamic concept. Traditionally, most researchers since Hühn (1979) have used the nonparametric statistics to characterize a genotype which indicates a relatively constant rank of yield across different environments with looking for genotype(s) with a minimal variation. This concept is in agreement with the homeostasis of quantitative genetics (Becker and Leon, 1988) while a genotype indicating a constant yield does not necessarily responses highly in better environments and so is not acceptable.

Table 6. Ranks of the 18 barley genotypes for grain yield and 25 different nonparametric stability statistics

	GY	PA	S1	S2	S3	S4	S5	S6	RN1	RN2	RS	KR1	KR2	FM	S7	Li	Ri	NP1	NP2	NP3	NP4	YSI	RII	GC	NS1	NS2
G1	5	3.5	10	10	11	13	13.5	11.5	5	14.5	15.5	12	16	7.5	13	5	10	13.5	14	12.5	12.5	9	18	3.5	14	13
G2	1	3.5	16	16	18	14	10	18	17	1.5	17	5	12	2.5	14	15	14	15	18	18	18	18	16	2	16	17
G3	14	1	1	1	2	3	3	2	7	5	5	6	10.5	16	3	2	2	2	1	1	1	1.5	8	15.5	4	2
G4	11	9.5	8.5	9	7	8	7	7	2.5	16.5	2.5	10.5	10.5	14.5	8	8	8	7	6	6.5	7	8	2	9	5	3
G5	4	18	6	7	10	9	8	10	9	14.5	10	4	14	7.5	9	16	11	11.5	12	12.5	12.5	16	13	9	10.5	11
G6	17	9.5	15	15	4	5	2	3	13	10	7.5	8	2.5	12	5	9	16	16	8	8	8	3	3	15.5	3	7
G7	8	15.5	5	5	12	15	13.5	11.5	13	11	11	14	6.5	7.5	15	12	4.5	5	10.5	9	9	13	9.5	9	10.5	14
G8	15	15.5	8.5	8	8	12	15	8	9	12.5	1	18	14	14.5	12	6	8	8	4	4	4	5	1	9	6	4
G9	6	9.5	7	6	9	10	11.5	9	13	5	15.5	8	17.5	7.5	10	10	3	9	10.5	10	10	14.5	6	9	10.5	10
G10	18	9.5	14	14	1	1	4	1	1	16.5	2.5	8	8.5	18	1	14	14	11.5	4	2	2.5	6.5	4.5	18	2	1
G11	16	9.5	12	11	5	7	9	6	2.5	5	7.5	10.5	2.5	11	7	7	14	13.5	9	6.5	6	4	11	15.5	10.5	9
G12	9	9.5	2	2	3	2	1	4	5	5	9	3	14	10	2	1	1	1	4	5	5	6.5	12	9	1	5
G13	2	3.5	11	13	15	4	5	15	9	9	13.5	1	5	1	4	11	8	6	15	17	17	17	7	1	13	15
G14	7	15.5	18	18	17	18	18	16	17	5	6	15	4	5	18	18	18	18	16	14	14	14.5	9.5	9	17	16
G15	13	9.5	3	4	6	11	11.5	5	13	8	4	17	17.5	17	11	3	4.5	4	2	3	2.5	1.5	4.5	9	7	6
G16	10	3.5	13	12	13	16	17	13	13	12.5	13.5	16	8.5	13	16	13	12	10	7	11	11	11.5	14	15.5	8	8
G17	12	15.5	17	17	16	17	16	14	17	18	12	13	1	4	17	17	17	17	13	15	15	10	17	9	15	12
G18	3	9.5	4	3	14	6	6	17	5	1.5	18	2	6.5	2.5	6	4	6	3	17	16	16	11.5	15	3.5	18	18

Abbreviations are: PA, percent of adaptability (St-Pierre et al., 1967); S1, S2, S3, S4, S5 and S6, nonparametric statistics of Hühn (1979); RN1 and RN2; nonparametric range statistics of Langer et al. (1979); RS, rank-sum of Kang (1988); KR1 and KR2, Ketata's (1989) ranks measures; FM, stratified ranking method of Fox et al. (1990); S7, the new nonparametric statistic of Huehn (1990a); Li and Ri, nonparametric statistics of Piepho and Lotito (1992); NP1, NP2, NP3 and NP4, nonparametric stability measures of Thennarasu (1995); YSI, yield stability index (Kang and Magari, 1996); RII, relative interactivity index (Harfouche, 2000); GC, genotypic classification (Thillainathan and Fernandez, 2002); NS1 and NS2, nonparametric statistics of Sabaghnia (2015).

Nowadays, most researchers prefer a dynamic concept of stability where for each environment the yield of a stable genotype corresponds to the expected magnitude and so, it is not needed that the response to changes should be equal for all genotypes. Most studies pointed out that the Hühn's (1979) statistics are associated with the static concept of stability (Flores et al., 1998; Karimizadeh et al., 2013; Sabaghnia et al., 2014) and some other authors noted that the nonparametric measures of stability, NPs of Thennarasu (1995) are similar in concept to GE interaction measures and characterize stability based on homeostasis (Mohammadi et al., 2013). In some papers, RS and FM are reported to have dynamic concept of stability but there is few information about the nature GS, Li, RII and etc. Also, in past investigations, only limited numbers of nonparametric methods were used and up to now such comprehensive investigation was not performed. We found GC, PA, RN2 and KR2 have dynamic concept of stability and showed most nonparametric methods have static concept of stability (Figure 1). Finally, it seems that most of the nonparametric stability statistics tend to identify static stability type as Huehn (1990b) emphasized his stability statistics could be useful for detection of static concept in multi-environment trials. The nonparametric stability statistics do not need any assumptions about the data distribution and they are easy to use and interpret and could contribute to supplementary information on the genotypes for ultimate recommendation. In conclusion, the nonparametric stability statistics seem to be useful alternatives to parametric statistics, although they do not supply more information about genotype adaptability.

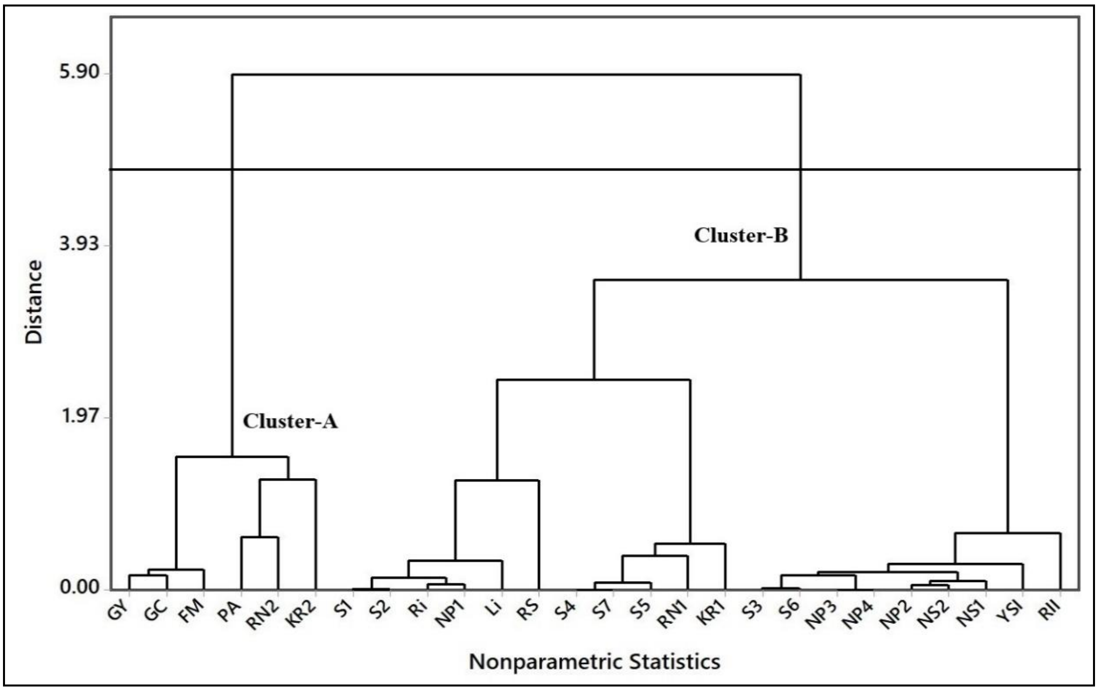

Figure 1. Denderogram plot of cluster analysis of 25 nonparametric stability statistics' ranks as well as grain yield rank, for 18 barley genotypes grown in 15 environments

Regarding the selection among the nonparametric stability statistics, we suggest that the static stability concept statistics (20 methods) should be used in any case in which a genotype shows unusual fluctuations among various test environments. Sabaghnia et al. (2006) suggested that S2 is useful than other the nonparametric statistics while Karimizadeh et al. (2013) suggested that NP1 and RS is easier to apply and interpret than other statistics. Mohammadi et al. (2013) suggested that S1 and S2 are easier to apply and interpret than other the nonparametric stability statistics while Sabaghnia et al. (2013) suggested that NP2 and NP3 are easier to apply and interpret. However, it seems that all of nonparametric stability statistics which benefits from static concept of stability are good candidates for stability analysis. Also, if a researcher wants to use the advantages of dynamic concept of stability, we recommend to use the other five nonparametric stability statistics as GC, FM, PA, RN2 and KR2.

Many statistical methods have been introduced to explore GE interaction but most of them fail to distinguish between significant crossover and additive interaction while the nonparametric tests can examine this phenomenon. Also, the GE interaction concepts for nonparametric classification via four nonparametric used tests are related to selection process in which breeders are interested (Huehn, 1996). According to Truberg and Hühn (2000), there were minor differences between parametric and nonparametric tests for additive interaction while the nonparametric tests for crossover interaction indicate a stronger differentiation and to be more sensitive for the detection of this interaction type than parametric methods. Thus, using nonparametric tests for examine of GE interaction is advised.

Although, the grain yield performance of tested genotypes ranged from 2159.43 kg ha^{-1} for G2 to 1742.50 kg ha^{-1} for G10 but the stability of high yielding genotypes was not high. In other word, due to mature of the most nonparametric methods, the moat stable genotypes ad moderate or low yield performance. Therefore, the mean ranks of genotypes based on 25 nonparametric methods plotted versus rank of grain yield and the most favorable genotypes were identified as G13 (2114.13 kg ha^{-1}) and G18 (2062.69 kg ha^{-1}) which had high mean yield and moderate stability (results are not shown).

CONCLUSIONS

The results from this study suggested that a significant GE interaction existed among 18 barley genotypes grown in 15 environments for grain yield. According to the most of nonparametric stability statistics and regarding high mean yield, genotype G13 (2114.13 kg ha^{-1}) and G18 (2062.69 kg ha^{-1}) were the most stable and favorable in all environments. The use of static concept-based nonparametric stability statistics as well as dynamic concept-based ones were recommended in stability analysis as an alternative strategy of parametric methods.

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