

Genotype × Environment Interaction and Stability Analysis of Seed Yield of Durum Wheat Genotypes in Dryland Conditions

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Abstract

The objective of this investigation was to evaluate seed yield of twenty durum wheat (*Triticum turgidum* spp. durum) genotypes. Evaluation of genotype × environment interaction and stability were also carried out at five diverse locations during the 2007-2009 growing seasons. Significant differences were found among the genotypes for seed yield on individual years and combined over years, in all locations. Genotype × environment interaction showed significance ($p > 0.001$) for seed yield. According to the coefficients of linear regression and deviations from the regression model, genotypes G2, G7 and G8 proved to be the most stable while based on α and λ parameters, genotypes G7, G12 and G13 were identified the most stable. Clustering genotypes based on all stability methods and mean yield divided them into four major classes, which Class II had relatively high stability and high mean yield performance. To compare relationships among stability statistics, hierarchical clustering procedure showed that the ten stability statistics and mean yield could be categorized into three major groups, which methods of Group C indicated dynamic concept of yield stability. The genotypic stability, stability variance, superiority index and desirability index provide information for reaching definitive conclusions. Also, the best recommended genotypes, according to the present investigation, were G2 (2697.18 kg ha⁻¹), G7 (2644.70 kg ha⁻¹), G8 (2580.16 kg ha⁻¹) and G10 (2637.43 kg ha⁻¹), which had high mean yield and were the most stable genotypes based on the above mentioned stability statistics.

Keywords: adaptation, clustering, desirability index, linear regression, superiority index

Introduction

The development of improved genotypes, which can be adapted to a wide range of environments, is one of the final goals of researchers in plant breeding program. The interplay between the effects of genotypes and environments is usually known as genotype × environment (GE) interaction (Moll and Stuber, 1974). The GE interaction is an important restricting factor in the estimation of variance components as well as in the efficiency of selection programs. The adaptability of a genotype over diverse environmental conditions is tested by the magnitude of its interaction with different locations and over several years (Baker, 1988). A genotype is considered to be more favorable one if it has a high mean yield but low amount of fluctuations in yielding ability when grown over diverse conditions. The GE interaction reduces the correlation between genotype and phenotype; and reduces the effectiveness of selection (Flores *et al.*, 1998). The presence of a GE interac-

tion for seed yield as a quantitative trait can decrease the usefulness of subsequent analysis, restrict the significance of inferences and seriously limit the feasibility of selecting favorable genotypes (Sabaghnia *et al.*, 2008).

Selection of stable genotypes, which perform consistently across environments, can reduce the magnitude of GE interaction. Durum wheat is cultivated in diverse conditions of Iran environments and so yield stability should be an important issue of recommended genotypes. Several statistical methods have been proposed to analyze GE interactions and yield stability. These methods can be divided in two major groups a univariate or multivariate stability parameters (Lin *et al.*, 1986), which most of these methods will be considered here. Joint linear regression (Finlay and Wilkinson, 1963) is the most popular procedure of univariate methods because of its simplicity of calculation and application. In this method, genotype means are regressed on an environmental index defined as the difference between the general mean and the mean of all

cultivars in each environment. However, Brandle and Mc Vetty (1987) showed that linear regression model is useful only if a large magnitude of the GE interaction variation is attributable to heterogeneity among regressions.

Eberhart and Russell (1966) further developed linear regression model and suggested the use of mean squares of deviations from regression as additional stability parameter when describing the performance of one genotype across a range of environments. Tai (1971) proposed a regression model, which uses two distinct statistics (α and λ) as the measures of stability that are similar to the regression coefficient and the deviation from conventional linear regression. These parameters are obtained by a continuation of the analysis of variance using the principle of structural relationships. Pinthus (1973) proposed the coefficient of determination (CD) for fulfillment of linear regression model for determining yield stability. Desirability index (DI), which combine both yield and regression coefficients, was proposed by Hernández *et al.* (1993).

The importance of yield stability in agriculture was recognized by Roemer (1917; in Becker, 1981), who used the variance across environments as a measure of yield stability. Francis and Kannenberg (1978) proposed the use of the coefficient of variation (CV) as a measure of genotype stability for removing scale effect. Shukla (1972) proposed a method as stability variance (SV) for measuring yield stability where a component of the GE interaction is assigned to each genotype. Kang and Miller (1984) has indicated that the SV can be a useful measure of genotype stability and Lin *et al.* (1986) have reported that SV may be useful if the data do not fit a linear regression model. Lin and Binns (1988) proposed the superiority index (PI) as the genotype general superiority and defined it as the distance mean square between the genotype's response and the maximum response over environments. Hanson's (1970) genotypic stability (GS) is according to linear regression analysis since it uses the minimum slope of common regression model from the Finlay and Wilkinson (1963) method.

The objectives of present investigation were to: (i) determine the magnitude of GE interaction for seed yield of durum wheat genotypes; (ii) determine seed yield of promising durum wheat genotypes and (iii) to identify genotypes that are widely stable and specifically adapted across test environments using different univariate stability statistics.

Materials and methods

Seed yield data for the twenty durum wheat genotypes were obtained from International Center for Agricultural Research in Dry Areas (ICARDA) or national durum wheat improvement program. The trials used in this investigation were grown during 2007, 2008 and 2009, at five locations representing different agroclimatic zones of Iran. Experiments were held at test locations: Gachsaran,

Gonbad, Khoramabad and Moghan for three years and for two years at Ilam location. Gachsaran, in southern Iran, is relatively arid and has silt loam soil. Gonabad in the north-east of Iran, are characterized by semi-arid conditions and have sandy loam soil. Moghan in the north-west of Iran is characterized by arid and semi-arid conditions with sandy loam soil and some supplemental irrigation water was applied during dry periods. Khoramabad and Ilam, in western Iran, have moderate rainfall and silt loam soil. The properties and the location of the experimental environments are given in Tab. 1. A randomized complete block design with four replications was used at each environment (year \times location). Seven-meter plots, consisting of six rows spaced 17.5 cm apart, were seeded by experimental seed drill. In all trials 50 kg N ha⁻¹ and 70 kg P₂O₅ ha⁻¹ were applied at planting. Appropriate pesticides were used to control insects, weeds and diseases. The center four rows were harvested to determine seed yield and then converted to kg/ha.

Analyses of variance were done for each trial of environments to plot residuals and identify outliers. Primary statistical analyses including Anderson-Darling normality test and Bartlett's test for homogeneity of variances were assessed. A combined analysis of variance was performed on the original dataset to partition out environment (E), genotype (G) and GE interactions. Genotype was regarded as fixed effect while environment was regarded as random effects. The main effect of E was tested against the replication within environment (R/E) as Error 1 and the main effect of G was tested against the GE interaction and the GE interaction was tested against (RG /E) as Error 2. The environmental variance (EV), coefficient of variation (CV) and stability variance (SV) which are recognized as the Type I stability concept by Lin *et al.* (1986); the common linear regression coefficient for a genotype (LR) and parameter α of Tai (1971) as indicators of Type II stability concept; and the mean squares of deviations from the common linear regression model (Eberhart and Russel, 1966) and parameter λ of Tai (1971) as indicators of Type II stability concept were calculated. Also, the superiority index (PI) measure and related MSGE (mean squares of GE interaction for each genotype) of Lin and Binns (1988),

Tab. 1. Geographical properties of test locations

| Location | Longitude Latitude | Altitude (m) | Soil Texture | Rainfall (mm) |
|------------|------------------------|-----------------|-----------------|------------------|
| Gachsaran | 50° 50' E 30° 20' N | 710 | Silty Clay Loam | 433.1 |
| Gonbad | 55° 12' E 37° 16' N | 45 | Silty Clay Loam | 367.5 |
| Khoramabad | 23° 26' E 48° 17' N | 1148 | Silt-Loam | 433.1 |
| Ilam | 46° 36' E 33° 47' N | 975 | Clay-Loam | 502.6 |
| Moghan | 48° 03' E 39° 01' N | 1100 | Sandy-Loam | 271.2 |

the genotypic stability (GS) of Hanson (1970) and desirability index (DI) of Hernandez *et al.* (1993) were computed. A comprehensive SAS-based program has become available, which calculates the most parametric stability statistics (Hussein *et al.*, 2000).

The stability statistics were compared using their ranks for each genotype via calculating Spearman's rank correlation (Steel and Torrie, 1980). To classifying similar genotypes and better reveal associations among stability statistics, the two-way data of ranks matrix, was analyzed further using a Ward's hierarchical clustering method and Pearson distance. All analyses were performed using the statistical package SPSS version 14.0 (SPSS Inc., 2004) and SAS release 9.1 (SAS, 2004).

Results

Combined analysis of variance was conducted to determine the effects of E, G and GE interaction on seed yield of durum wheat genotypes (Tab. 2). The main effect of environment was highly significant ($p < 0.01$), while the main effect of genotypes was only significant at 5% probability level. The GE interaction was highly significant ($p < 0.01$), which is indicating the studied genotypes exhibited complicated GE interaction. Seed yield is a quantitative trait, which its expression is the result of genotype, environmental factors and GE interaction. The large magnitude GE interaction, cause to the more dissimilar genetic systems, which controlling the physiological processes conferring yield stability to different environments (Cooper *et al.*, 2001). The relative contribution of GE interaction effects for seed yield found in this study are similar to those found in other studies in dryland environments (Bertero *et al.*, 2004; Sabaghnia *et al.*, 2006) and makes it difficult to select the most favorable genotypes in any plant breeding program (Kang, 1998). The grain yield of durum wheat genotypes varied from 154.5 kg/ha in genotype G16, grown at Moghan in 2007, to 6330.0 kg/ha at Gachsaran in genotype G15 grown in 2007. Maximum mean yields varied from 6330.0 kg/ha in G15 to 4529.3 kg/ha in G4, while minimum mean yield varied from 154.5 kg/ha in genotype G16 to 475.0 kg/ha in G6 (Tab. 3). Average yield was positively correlated with minimum mean yield but not with maximum. Yield amplitudes were very large, from 4093.0 kg/ha to 6002.5 kg/ha and were correlated with maximum yield, but not with minimum and average mean yield.

According to EV parameter (Tab. 4), genotypes G3, G5 and G20 were the most stable genotypes while genotypes G1, G11 and G15 were the most unstable genotypes. Also, genotypes G4, G7 and G19 were identified as the most stable genotypes based on environmental coefficient of variation (CV). Genotypes G7, G8 and G12 were the most stable genotypes according to stability variance parameter of Shukla (1972). Although, these mentioned stability statistics represent Type I stability concept and

Tab. 2. Combined analysis of variance of durum wheat performance trial yield data

| Source of Variation | DF | Mean Squares | % of G+E+GE |
|----------------------|-----|--------------|-------------|
| Environment (E) | 13 | 177747550.3* | 96.43 |
| Replication within E | 42 | 826660.4 | |
| Genotype (G) | 19 | 544937.2* | 0.43 |
| G × E | 247 | 304181.0* | 3.14 |
| R × G within E | 798 | 133065.7 | |

* and ** significant at the 0.01 and 0.05 probability level, respectively

Tab. 3. Average, maximum and minimum grain yields and yield amplitude in 20 durum wheat cultivars

| | Average | Minimum | Maximum | Amplitude |
|-----|---------|---------|---------|-----------|
| G1 | 2520.79 | 366.75 | 5158.50 | 4791.75 |
| G2 | 2697.18 | 456.00 | 5495.75 | 5039.75 |
| G3 | 2452.93 | 344.75 | 4860.25 | 4515.50 |
| G4 | 2635.18 | 436.25 | 4529.25 | 4093.00 |
| G5 | 2509.20 | 442.25 | 4913.00 | 4470.75 |
| G6 | 2528.38 | 475.00 | 5288.00 | 4813.00 |
| G7 | 2644.70 | 454.75 | 5179.75 | 4725.00 |
| G8 | 2580.16 | 206.25 | 4930.25 | 4724.00 |
| G9 | 2564.50 | 473.00 | 5236.50 | 4763.50 |
| G10 | 2637.43 | 330.50 | 5445.75 | 5115.25 |
| G11 | 2513.63 | 361.25 | 5463.00 | 5101.75 |
| G12 | 2493.38 | 306.75 | 4921.00 | 4614.25 |
| G13 | 2397.30 | 331.50 | 5040.50 | 4709.00 |
| G14 | 2562.68 | 391.25 | 5455.25 | 5064.00 |
| G15 | 2680.38 | 327.50 | 6330.00 | 6002.50 |
| G16 | 2376.07 | 154.50 | 5056.00 | 4901.50 |
| G17 | 2564.14 | 320.25 | 5127.25 | 4807.00 |
| G18 | 2641.20 | 400.75 | 4991.75 | 4591.00 |
| G19 | 2745.07 | 466.50 | 4777.00 | 4310.50 |
| G20 | 2470.54 | 299.00 | 4621.50 | 4322.50 |

usually introduce low mean yielding genotypes as the most stable genotypes but CV parameter could identify relatively high mean yielding genotypes (G7 and G19) as the most stable genotypes. Considering CV stability nature, which is known as static or biologic type of stability and high mean yield of G7 and G19, these genotypes were identified as the most favorable genotypes. The static concept of yield stability refers to a genotype's ability to perform consistently, ignoring high or low yield, across a wide range of environments. According to Becker and Léon (1988), most stability statistics relate to either of two contrasting concepts of stability: static (biologic) and dynamic (agronomic).

According to genotypic stability (GS) of Hanson (1970), genotypes G7, G8 and G20 were the most stable, while regarding both PI and MSGE parameters of Lin and Binns (1988), genotypes G2, G10 and G15 proved to be the most stable (Tab. 4). Like to CV parameter, stability statistics of Hanson (1970) and Lin and Binns (1988) have static stability concept, but most of the stable genotypes

Tab. 4. Stability parameters values for durum wheat performance trial yield data

| Durum genotype | EV | CV | SV | GV | PI | MSGE |
|----------------|-----------|-------|----------|-----------|----------|----------|
| G1 | 2264554.0 | 63.96 | 89557.9 | 1392710.8 | 239701.0 | 108145.8 |
| G2 | 2201710.6 | 58.94 | 44223.8 | 802247.9 | 97352.7 | 38688.9 |
| G3 | 1910453.1 | 60.37 | 76069.5 | 924084.7 | 285849.7 | 118519.0 |
| G4 | 1958354.8 | 56.90 | 116231.2 | 1440390.2 | 204468.1 | 123493.6 |
| G5 | 1903471.3 | 58.91 | 104692.3 | 1256134.7 | 263229.1 | 125868.1 |
| G6 | 2003212.6 | 59.98 | 109273.8 | 1397374.4 | 195727.7 | 67906.5 |
| G7 | 2065841.5 | 58.23 | 9744.4 | 276241.3 | 120304.5 | 42988.1 |
| G8 | 2147658.8 | 60.86 | 14435.2 | 403119.0 | 146407.3 | 42630.2 |
| G9 | 2172480.7 | 61.58 | 97299.9 | 1403756.1 | 208208.5 | 97424.1 |
| G10 | 2057670.4 | 58.27 | 52373.0 | 772716.8 | 111277.7 | 31175.5 |
| G11 | 2350560.4 | 65.35 | 81694.9 | 1374935.9 | 173286.5 | 38158.8 |
| G12 | 2104086.8 | 62.33 | 33405.2 | 589172.6 | 210426.9 | 64937.6 |
| G13 | 2060506.7 | 64.15 | 33405.6 | 551114.3 | 260482.7 | 60620.2 |
| G14 | 2166155.4 | 61.53 | 39589.1 | 716439.6 | 154736.8 | 43122.6 |
| G15 | 2782433.5 | 66.68 | 159397.0 | 2670105.2 | 86657.0 | 22300.8 |
| G16 | 2195846.9 | 66.82 | 56316.6 | 939990.6 | 264093.7 | 51052.3 |
| G17 | 2177079.3 | 61.65 | 47688.6 | 821667.6 | 148015.8 | 37068.9 |
| G18 | 2196289.2 | 60.12 | 46319.8 | 822275.6 | 156926.9 | 78275.1 |
| G19 | 1979528.2 | 54.91 | 165807.1 | 2044568.8 | 175524.6 | 131638.9 |
| G20 | 1906585.6 | 59.88 | 34744.3 | 432492.9 | 238622.6 | 80987.6 |

EV=environmental variance; CV=coefficient of variation; SV=stability variance; GV=genotypic variance; PI=priority index; MSGE=mean squares of GE interaction

based on these procedures such as genotypes G2, G7, G8, G10 and G15 indicated relatively high mean yield. The discussed static stability concept is analogous to the homeostasis in quantitative genetics, which a stable genotype tends to maintain keeping a constant yield across different environments (Dyke *et al.*, 1995). The static stability concept is similar to Type I stability, which is associated with relatively poor yield in environments high yielding for other genotypes (Lin *et al.*, 1986).

According to the coefficients of common linear regression slope (Finlay and Wilkinson, 1963), genotypes G1, G11 and G15 were the most stable (Tab. 5) while based on α parameter of Tai's (1971) regression model genotypes G3, G5 and G19 were the most stable ones. Lin *et al.* (1986) classified these parameters as Type II stability, which is corresponding to dynamic concept of stability. In this stability concept, the yield response of a stable genotype in each environment is always parallel to the mean response of the tested one. The measure of Type II stability or dynamic concept of stability depends on the specific set of tested genotypes, unlike the measure of static concept of stability (Lin *et al.*, 1986). In agreement to these reports, some of the most stable genotypes based on regression model such as G15 and G19 had high mean yield.

According to the mean squares of deviations from the common regression model (Eberhart and Russell, 1966) genotypes G7, G8 and G20 were the most stable (Tab. 5). Also, based on λ parameter of Tai's (1971) regression model, G8, G11, G12 and G20 were identified as the most stable genotypes. These statistics indicate Type II stability and have different nature to distinguish the GE interac-

tion and most stable genotypes (Lin *et al.*, 1986). However, the regression slopes and deviation from regression model must be considered simultaneously for identification of the most favorable genotypes. According to the coefficients of linear regression as well as mean squares of deviations from the regression model, genotypes G2, G7 and G8 were the most stable ones (Tab. 5), while based on α and λ parameters of Tai's (1971) regression model, genotypes G7, G12 and G13 were identified as the most stable. The most stable genotypes based on regression models, were not high yielding.

The amounts of coefficient of determination (CD) showed that genotypes G7, G8 and G20 fitted properly (Tab. 5). It is noticed that the CD of all studied genotypes were in a good manner, which indicates the adequate description of the total variation via regression models. The desirability index (DI) represents dynamic concept of yield stability through combining both mean yield and regression coefficient and showed that genotypes G2, G15 and G19 were the most stable ones (Tab. 5). The dynamic concept of yield stability is more acceptable to most plant breeders, who would prefer an agronomic concept of stability (Flores *et al.*, 1998). In the type of stability, there is no needed for the genotypic response to environmental conditions to be equal for all tested genotypes (Becker, 1981). Yield stability depends on yield components and other plant properties, such as tolerance to environmental stress factors (Sabaghnia *et al.*, 2008). Reductions in durum wheat yields in a dryland culture are chiefly observed after a pre-season drought, particularly if the season is also dry.

Tab. 5. Regression-based stability parameters for durum wheat performance trial yield data

| Durum genotype | α | λ | LR | ER | CD | DI |
|----------------|----------|-----------|-------|----------|-------|--------|
| G1 | 0.0621 | 3.293 | 1.028 | 96203.2 | 96.36 | 2674.5 |
| G2 | 0.0504 | 1.674 | 1.023 | 49276.2 | 98.08 | 2850.1 |
| G3 | -0.1190 | 2.398 | 0.946 | 76855.8 | 96.55 | 2594.3 |
| G4 | -0.1128 | 3.933 | 0.948 | 119748.4 | 94.76 | 2776.9 |
| G5 | -0.1363 | 3.281 | 0.938 | 104685.1 | 95.29 | 2649.3 |
| G6 | -0.0857 | 3.884 | 0.961 | 115161.3 | 95.07 | 2672.0 |
| G7 | -0.0051 | 0.502 | 0.998 | 14338.9 | 99.41 | 2793.8 |
| G8 | 0.0360 | 0.626 | 1.016 | 18619.4 | 99.26 | 2732.1 |
| G9 | 0.0097 | 3.723 | 1.004 | 106245.8 | 95.81 | 2714.6 |
| G10 | -0.0297 | 2.039 | 0.986 | 58669.9 | 97.56 | 2784.9 |
| G11 | 0.1114 | 2.673 | 1.051 | 83641.7 | 96.95 | 2670.7 |
| G12 | 0.0039 | 1.374 | 1.002 | 39184.8 | 98.40 | 2643.1 |
| G13 | -0.0192 | 1.360 | 0.991 | 39008.0 | 98.38 | 2545.5 |
| G14 | 0.0338 | 1.558 | 1.015 | 45110.7 | 98.21 | 2714.5 |
| G15 | 0.3031 | 2.465 | 1.139 | 125184.1 | 96.14 | 2850.6 |
| G16 | 0.0416 | 2.151 | 1.019 | 62376.4 | 97.57 | 2528.4 |
| G17 | 0.0357 | 1.851 | 1.016 | 53549.3 | 97.89 | 2716.1 |
| G18 | 0.0466 | 1.766 | 1.021 | 51661.0 | 97.98 | 2793.8 |
| G19 | -0.1252 | 5.644 | 0.943 | 170311.9 | 92.63 | 2886.0 |
| G20 | -0.1013 | 1.027 | 0.954 | 35419.8 | 98.41 | 2613.1 |

α and λ , parameters of Tai's (1971) regression model; LR=linear regression model slope; ER=mean squares of deviations from regression; CD=coefficient of determination of linear regression model; DI=desirability index of Hernández *et al.* (1993)

To reveal associations among studied genotypes, the two-way data of genotypes, across environments, was further analyzed using a clustering procedure. Ward's hierarchical clustering indicated that the twenty genotypes could be divided into four major classes (Fig. 1). Class I consist of genotypes G12, G13 and G20 with moderate

stability and low mean yield characteristics; Class II consist of genotypes G2, G7, G8, G10, G14, G17 and G18 with relatively high stability and high mean yield performance; Class III consist of genotypes G3, G4, G5, G6 and G19 with low stability and moderate mean yield characteristics; and Class IV consist of genotypes G1, G9, G11,

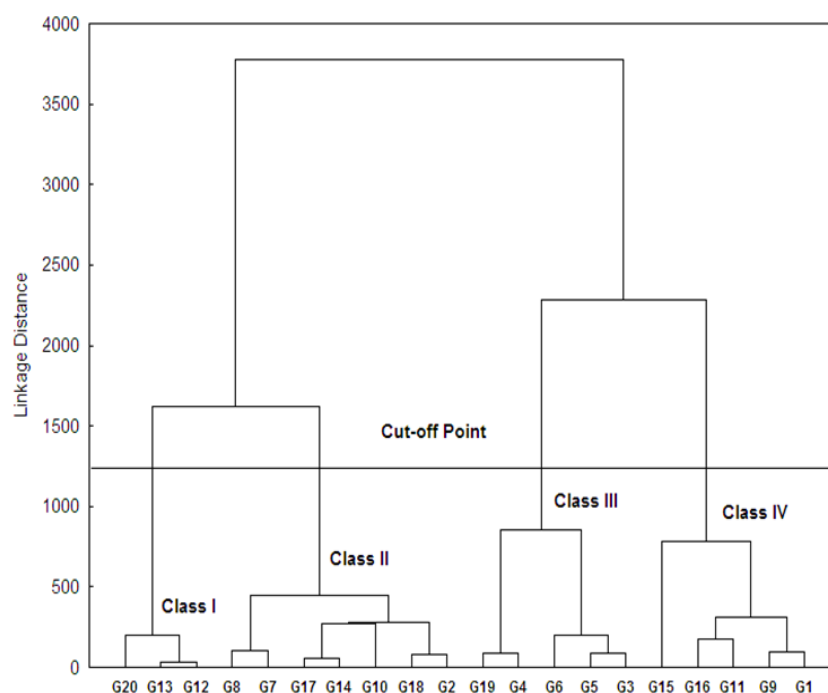


Fig. 1. Hierarchical cluster analysis of the 20 durum wheat genotypes based on Ward's method using a GE matrix of mean yields

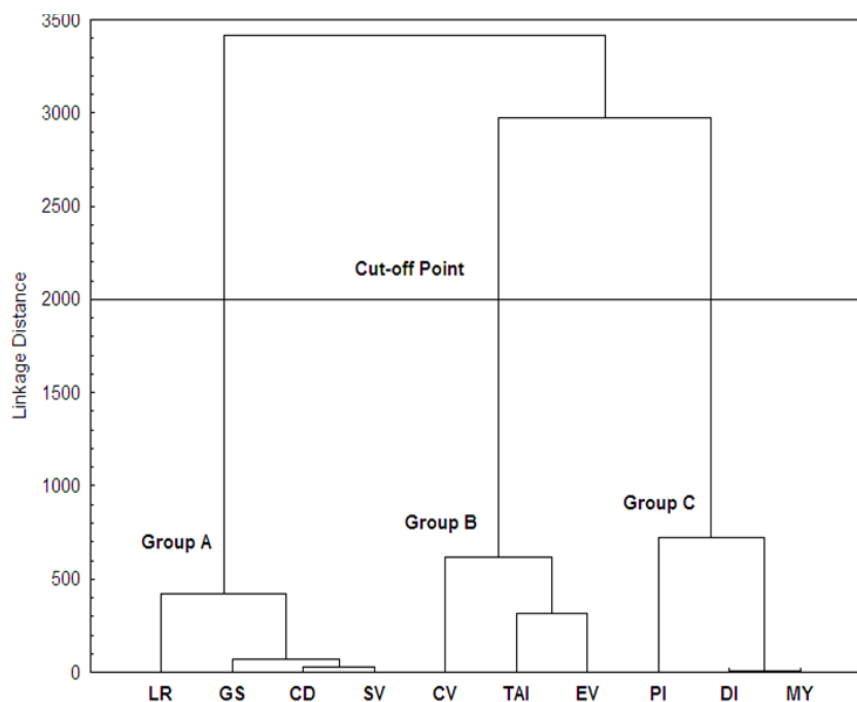


Fig. 2. Hierarchical cluster analysis of ranks of yield stability, estimated by 10 methods using yield data from 20 durum wheat genotypes grown in 14 environments

G15 and G16 with low stability and low mean yield performance. It seems that most of the favorable genotypes exist in Class II.

To compare relationships among different stability statistics, the two-way ranks of genotypes based on stability parameters, were illustrate using a dendrogram of Ward's hierarchical clustering procedure and showed that the ten stability statistics and mean yield (MY) could be categorized into three major groups (Fig. 2). Group A consist of LR, GS, CD and SV; Group B consist of CV, TAI and EV; while Group C consist of PI, DI and MY. The stability procedures of Groups A and B represent a static concept of stability, while the methods of Group C indicate a dynamic concept of yield stability.

Discussion

The influence of GE interaction resulted in variable performance of the studied genotypes in the different test environments. Most of the genotypes with low mean yield and some of the genotypes with high mean yield were less sensitive to environmental variation and are, therefore, more stable-yielding. On the other hand, the mentioned genotypes generally are reported to be illustrated static concept of stability. This phenomenon is perhaps the major factor that contributed to the high GE interaction in durum wheat, in the present investigation. Similarly, high contributions of complex and significant GE interaction have been detected in many regional trials (Flores *et al.*, 1998; Sabaghnia *et al.*, 2008). GE interaction is a consequence of different responses to environmental factors

(soil properties and climatic conditions) and biotic or abiotic stresses. Like on the other areas of the world (Janick, 1999), main limiting abiotic factors in Iran are high temperature, low relative air humidity during pollination period and drought stress.

Various statistical models, to measure yield stability of genotype performance across in multi-environment trials, are available. At present, one of the most widely used models is linear regression model and some of these stability statics are based on variance concept (environmental variance of GE interaction mean squares). However, yield stability is not necessarily a positive factor and it is desirable when associated with a high mean yield performance (Kang, 1998). In the present study, genotypes G2, G7, G8 and G10 were found to be most stable based on the most stability statistics and also had high mean yield or above average mean yield across environments and thus are recommended for commercial release as cultivars to contribute for enhanced durum wheat production in these environments.

The results of yield stability analyses are generally consistent with results found in various crops where EV, CV and SV represent the static concept of stability while DI and PI indicates dynamic concept of stability (Dehghani *et al.*, 2008; Mohebodini *et al.*, 2006). Also linear regression models of Finlay and Wilkinson (1963) and Tai (1971) indicated a static or biologic concept of stability and introduced relatively low or moderate mean yielding genotypes as the most favorable genotypes. Evaluation of these two concepts, it can be declared that the linear regression model is a widely used method, that those two

concepts are combined, because regression coefficients are in almost perfect correlation with the variances, and that mean squares of deviation from regression are highly correlated with the SV.

The GE interaction is an important source of total variation in seed yield of any crop. Among different stability parameters, analysis of variance is uninformative in the explanation of GE interactions. However, it seems that regression models are more useful for describing GE interactions (Annicchiarico, 2002; Yau, 1995), because the use of two stability parameters may be valuable for some purposes. Most of the univariate methods attempt to describe the GE interactions by one parameter and so had some deficiencies for explaining GE interaction patterns, while a comprehensive regression method uses three distinct parameters (regression coefficient, deviation from regression and coefficient of determination) for determining GE interaction (Dehghani *et al.*, 2008; Vargas, 1998). However, the multiplicative GE interaction component is far too complex to be summarized by one parameter.

Although, for a long time, most plant breeders used the static stability concept to characterize genotypes in multi-environmental trials but this type is not acceptable to most agronomist, who prefer an agronomic or dynamic concept of stability. It was found that some stable genotypes according to stability parameters, which benefit from static stability concept, such as CV, indicated high mean yield. These differences could be associated with the nature of the crop, environmental conditions or diverse genetic background obtained from different sources. There are many univariate parametric measures of yield stability that have been presented in the literature (Flores *et al.*, 1998; Lin *et al.*, 1986; 1998; Sabaghnia *et al.*, 2006). For making recommendations, it is essential to investigate the stability of studied genotypes based on different statistics and compare their results. It seems that it is not possible to advice a unique method for assessing GE interaction and yield stability.

Several of the univariate parametric stability statistics that have been employed in the present investigation quantified stability of genotypes with or with no respect to yield. However, both mean yield and stability should be considered simultaneously to exploit the useful effects of GE interaction and to make the selection of the favorable genotypes more precise and refined. Despite the fact that the different stability statistics are indicative of high, moderate, or low stability performance, the genotypic stability (GS) of Hanson (1970), stability variance (SV) of Shukla (1972), superiority index (PI) of Lin and Binns (1988), and desirability index (DI) of Hernández *et al.* (1993) provide information for reaching definitive conclusions. Therefore, these statistics are indispensable, as farmers would prefer to use a high-yielding genotype that performs consistently each year.

Conclusions

The best recommended genotypes according to the present investigation are: G2 (2697.18 kg ha⁻¹), G7 (2644.70 kg ha⁻¹), G8 (2580.16 kg ha⁻¹) and G10 (2637.43 kg ha⁻¹), which had high mean yield and were the most stable genotypes based on the above mentioned stability statistics. Selection of genotypes for yield stability is needed in most dry-land areas, where the environment is variable and unpredictable. Finally, the significant GE interactions suggest a breeding strategy of specifically adapted genotypes in homogeneously grouped environments.

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