

Path Analysis of Phenotypic Stability and Drought Tolerance in Bread Wheat (*Triticum aestivum* L.)

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ABSTRACT

In order to determine stable and drought-tolerant bread wheat genotypes and relative contribution of yield components in the genotype-environment (GE) interaction, field experiments were conducted with 14 genotypes for 3 consecutive years (2008-2011) under rainfed and irrigated conditions. Descriptive diagrams and combined analysis of variance indicated highly significant differences for GE interaction and high variability for yield and yield components indicating the possibility of selection for stable and drought-tolerant genotypes. AMMI-stability value (ASV) and yield stability index (YSI) discriminated genotype 10 as the most stable genotype with high grain yield (534.5 g). Path analysis revealed that the relative contribution of a genotypic component 1000-seed weight (TSW) in the phenotypic stability of grain yield was higher than that of number of spike per plant (SPP) and number of seed per spike (SPS). Environmental components of GE interaction exhibited that absolute value of r_1 (first environmental component) in all environments was higher than the second (r_2) and third (r_3) environmental components. In addition, variation of r_1 was more than r_2 and r_3 , and that of r_2 was higher than r_3 indicating that sensitivity of number of spike per m^2 (NS) and SPS to the environmental variation was higher than TSW. Therefore high grain yield and stability of genotype 10 was because of higher genotypic component V_3 (TSW) and lower environmental components r_3 (TSW). Path coefficient and cluster analysis of drought susceptibility index (DSI) discriminated genotypes Croos alborz, Ww33G.Vee"S".Mrn.3.Atilla.Tjn, Aazar-2, Sardari, Azd.HD2172..Kayson.Glenson.3.170-28.Ning8201, Ww33G.Vee"S".Mrn.3.Atilla.Tjn and T.AEST.SPRW"S"..CA8055.3.BACANORA88ICW92-0477 as drought tolerant with high grain yield for rainfed condition, while genotypes Shi#4414.Crow"S"..Fow-1 and CHAM-8.MAYON"S".CW93-0031-1AP-OL-OBR-2AP-1AP-OAP as drought sensitive and desirable for irrigated condition.

Keywords: AMMI stability value, drought susceptibility index, path coefficient over environment, yield stability index

INTRODUCTION

Wheat has an important place in nourishment of people all over the world. It is necessary to increase wheat production to remove nourishment needs of the excessive population. Borlaug and Dowsell (1997) estimated that global wheat production must increase by 40% until 2020 to meet the rising demand for wheat grain. It is apparent that the yield production of wheat is a joint contribution of both genes as well as environment. Wheat is the most important cereal crop in Iran, with a total area of 5.2 million hectares. Wheat is grown under irrigated and rainfed conditions. Rainfed wheat covers two-thirds of the total wheat area in Iran, but accounts for about one-third of the total wheat production (Mohammadi and Haghparsat 2011). The genotype-environment (GE) interaction reduces association between phenotypic and genotypic values and leads to bias in the estimates of gene effects and combining ability for various characters sensitive to environmental variations. The existence of GE interaction complicates the identification of superior genotypes for a range of environments and calls for the evaluation of genotypes in many environments to determine their true genetic potential (Yaghotipour and Farshadfar 2007; Atta and Shah 2009; Aghaee *et al.* 2010).

Various statistical methods [parametric (univariate and multivariate) and non-parametric] have been investigated and proposed to study the GE interactions (Lin *et al.* 1986; Becker and Léon 1988; Crossa 1990; Lin and Binns 1994; Mohammadi and Amri 2008; Mohammadi *et al.* 2009; Pourdard and Ghaffari 2009; Mohammadi *et al.* 2010b).

The main problem with stability statistics is that they do not provide an accurate picture of the complete response pattern (Hohls 1995). The reason is that a genotype's response to varying environments is multivariate (Lin *et al.* 1986) whereas the stability indices are usually univariate (Gauch 1988; Crossa 1990).

One of the multivariate techniques is the AMMI model. The AMMI model combines the analysis of variance for the genotype and environment main effects with principal component analysis of the GE interaction. The results can be plotted in a useful biplot that shows both main and interaction effects for both genotypes and environments (Zobel *et al.* 1988; Gauch and Zobel 1996). Purchase *et al.* (2000) developed the AMMI stability value (ASV) based on the AMMI model's IPCA1 and IPCA2 (interaction principal components axes 1 and 2, respectively) scores for each genotype. The ASV is comparable with the Shukla (1972), Wricke (1962) and Eberhart and Russell (1966) stability methods.

Path analysis is a form of multivariate analysis. The path analysis approach bears a resemblance to the principal component method as it also leads to the construction of a multiplicative model for the trait of primary interest. It is, in fact, a form of factor analysis. The γ parameters in the path model are independent factors postulated on the basis of the causal relationship between the concerned trait and its components (Darvishzadeh *et al.* 2011; Khazaie *et al.* 2011).

Grafius and Thomas (1971) proposed that environmental stresses that occur during the sequential development of yield components constitute the major ingredient of GE

interactions of yield. They expressed that expression of an economic trait of a crop plant is often the result of a series of physiological activities during growth. This type of trait is called a complex trait. A complex trait often has no direct linkage to the physiological activities that lead to its formation. It represents the final phenotypic expression of a complex developmental process during growth. Each of the physiological activities usually leads to the development of a component trait. Sometimes, a component trait is itself a complex trait that can be further broken down into components (Farshadfar 1990; Mohammadinejad and Rezaei 2007; Askarinia *et al.* 2008).

It is feasible to incorporate component traits that are easily measurable into a "working" developmental model for the investigation of the GE interaction. These components may themselves be complex traits but each represents a major milestone in the fundamental model. One typical example is the component traits of crop yield. The grain yield of wheat, for example, is formed due to three major phases of physiological activity. The first one is the initiation of stems, which involves germination of seeds and onset of tillers. This is followed by the ontogeny of "sink" organs, i.e., flowers in the heads on top of stems. Finally, fertilization followed by photosynthetic activity fills the kernels in the heads. Degrees of development of the three phases are measured by the three yield components: number of heads per plant (X), kernels per head (Y) and kernel weight (Z). Grain yield (W) is the multiplicative product of the components, i.e., $W = X \times Y \times Z$. The developmental relationship between W and X, Y and Z is sequential, i.e., $X \rightarrow Y \rightarrow Z \rightarrow W$. All physiological activity for the formation of W is channeled through X, Y or Z. W has no direct relationship to this activity. This sequential relationship between yield and yield components was developed into a working model for investigating of crop yield by Tai (1975), and has been shown to provide a powerful tool for studying GE interactions (Fagam *et al.* 2006; Hui *et al.* 2008; Das and Taliaferro 2009; Yasin and Singh 2010).

The objectives of the present investigation were (i) evaluation of phenotypic stability of bread wheat genotypes under rainfed and irrigated conditions (ii) determination of the contribution of yield components in the phenotypic stability and (iii) characterization of drought susceptibility index of yield and yield components.

MATERIALS AND METHODS

Plant genetic materials and experimental design

Fourteen genotypes of bread wheat (*Triticum aestivum* L.) listed in **Table 1** were received from the Dryland Agriculture Research Sub-Institute (Sararood Station). They were assessed using a randomized complete block design with three replications under both rainfed and irrigated [two supplementary irrigations: (i) 25 mm supplied at early flowering, and (ii) 25 mm at mid-anthesis stages] conditions during 2008–2011 growing seasons in the experimental field of the College of Agriculture, Razi University, Kermanshah, Iran (47° 20' N latitude, 34° 20' E longitude and 1351.6 m altitude). Climate in the region is classified as semi-arid with mean annual rainfall of 378 mm. Minimum and maximum temperature at the research station were -27 and 44°C, respectively. Each genotype was planted in 2-m rows and at 15 × 25 cm inter-plant and inter-row distances. Fertiliser application was 41 kg N ha⁻¹ and 46 kg P₂O₅ ha⁻¹ at planting. The soil of experimental field was clay loam with pH 7.1. The seeding rate was 400 seeds m⁻² for all plots. At the rainfed experiment, water stress was imposed after anthesis. Non-stressed plots were irrigated twice after anthesis, while stressed plots received no water. In each cropping season, two rainfed and irrigated trials were conducted. Environments 1, 3 and 5 represent rainfed conditions and 2, 4 and 6 represent irrigated conditions in 2008-2009, 2009-2010 and 2010-2011 cropping seasons, respectively.

The seeds were planted in early October and harvested in early July. At harvest time, yield potential (Y_p), stress yield (Y_s), number of spikes m⁻² (NS) (X), number of seed per spike (SPS)

Table 1 Pedigree of investigated genotypes.

Code	Pedigree/name
1	Croos alborz
2	Aazar-2
3	Sardari
4	Shi#4414.Crow"S"..Fow-1
5	Ww33G.Vee"S".Mrn.3.Atilla.Tjn
6	Shi#4414.Crow"S"..Vee"s:Nac
7	Ww33G.Vee"S".Mrn.4.HD2172.Bloudan..Azd.3..san.Ald"s"..Avd
8	Azd.HD2172..Kayson.Glenson.3.170-28.Ning8201
9	TEVEE S. KARAWAN S
10	Ww33G.Vee"S".Mrn.3.Atilla.Tjn
11	CHAM-8.MAYON"S'.CW93-0031-1AP-OL-OBR-2AP-1AP-OAP
12	T.AEST..SPRW"S"..CA8055.3.BACANORA88.CW92-0477-...
13	T.AEST..SPRW"S"..CA8055.3.BACANORA88ICW92-0477-...
14	AZD.HD2172..Ptoma.Cucurp88

(Y), 1000-seed weight (TSW) (Z) and grain yield (GY) were recorded from 2 rows of 2.5 m in length. The environments were considered as random factors, while genotypes as fixed factors.

Statistical analysis

The grain yield and yield components data were subjected to combined analysis of variance, mean comparison using Duncan's multiple range test (DMRT; Duncan 1955) and following biometrical analysis by statistical software SPSS ver. 16.0 (2007), MSTATC (Michigan State University 1991) and Microsoft Excel ver. 12 (2007).

1. AMMI stability value (ASV)

The AMMI stability value (ASV), as described by Purchase *et al.* (2000), was calculated as follows:

$$ASV = \sqrt{\left[\frac{IPCA1_{sum\ of\ square}}{IPCA2_{sum\ of\ square}} (IPCA1_{score}) \right]^2 + (IPCA2_{score})^2}$$

where SS_{IPCA1}/SS_{IPCA2} is the weight given to the IPCA1-value by dividing the IPCA1 sum of squares by the IPCA2 sum of squares. The larger the IPCA (interaction principal component analysis) score, either negative or positive, the more specifically adapted a genotype is to certain environments. Smaller ASV scores indicate a more stable genotype across environments.

2. Yield stability index (YSI)

A new approached known as YSI was calculated by the following formula:

$$YSI = RASV + RY$$

where RASV is the rank of AMMI stability value and RY is the rank of mean grain yield of genotypes (RY) across environments. YSI incorporate both mean yield and stability in a single criterion. Low value of this parameter shows desirable genotypes with high mean yield and stability (Farshadfar 2008).

3. Path analysis of GE interaction

If a group of m genotypes is tested over n environments, the yield of the *i*th genotype in the *j*th environment can be expressed as:

$$W_{ij} = \mu_{wi} + V_{1i}R_{1j} + V_{2i}R_{2j} + V_{3i}R_{3j} + e_{ij}$$

where $V_{gi} = V'_{gi}\sigma_{wi}$ for $g = 1, 2$ and 3 and σ_{wi}^2 is the variance of yields of the *i*th genotype.

The observed yield (W_{ij}) is composed by a mean genotypic effect (μ_{wi}), three multiplicative terms of the genotype-environment interaction effects formed by three genotypic components (V_{1i} , V_{2i} and V_{3i}), and three environmental components (R_{1j} , R_{2j} and R_{3j}), and an error deviate (e_{ij}). The three genotypic components each represents the efficiency of a genotype to utilize a stan-

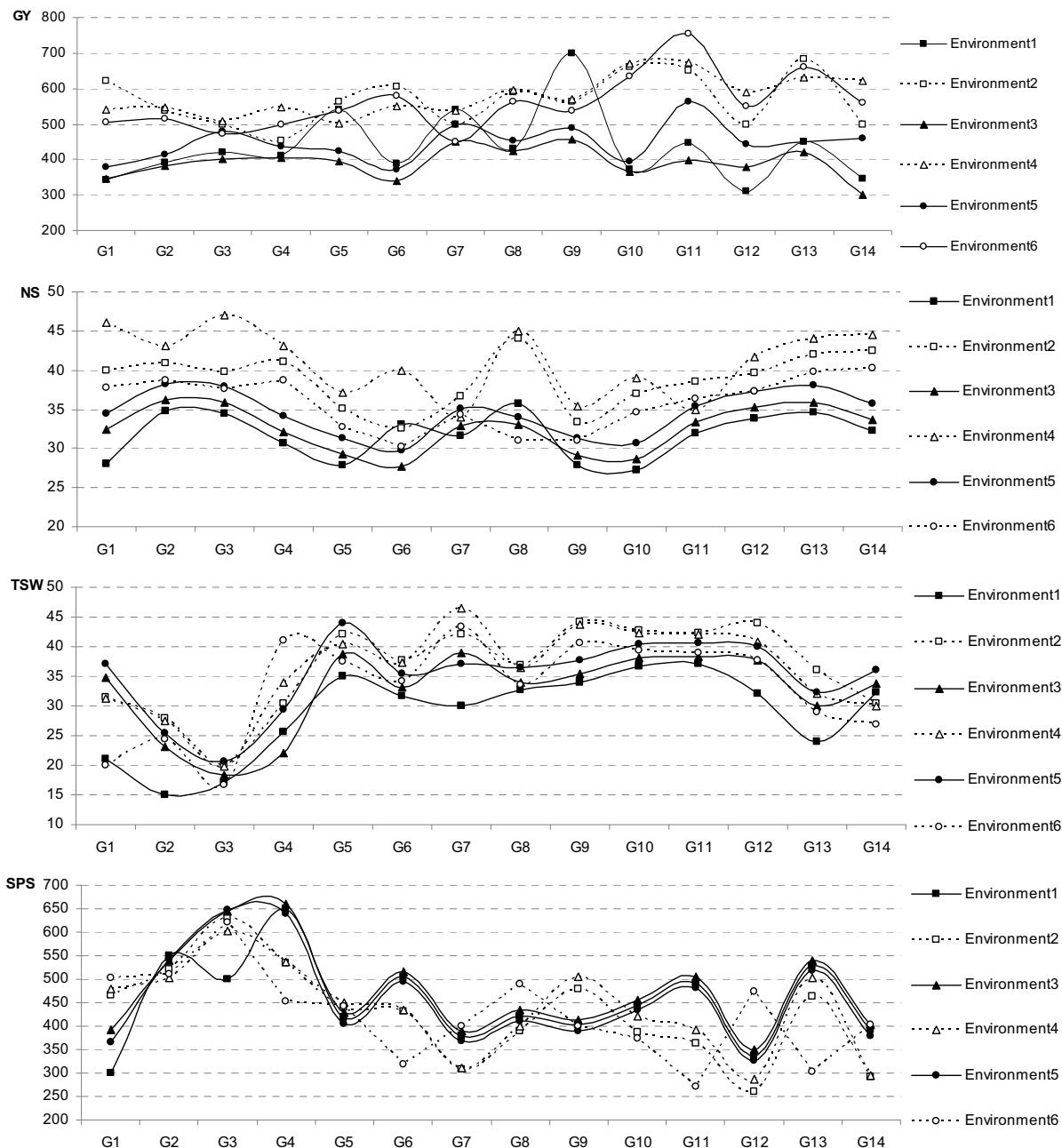


Fig. 1 Descriptive diagram of GE interaction for GY, NS, TSW and SPS. Environments 1, 3 and 5 represent rainfed conditions and environments 2, 4 and 6 represent irrigated conditions in 2008-2009, 2009-2010 and 2010-2011 cropping seasons, respectively.

dard deviation unit input in one of the three environmental components during the succeeding stages of plant development for the formation of final yield (Tai 1975, 1979; Tai *et al.* 1994).

4. Path analysis of drought susceptibility index (DSI_i)

Using the Tai *et al.* (1994) model, DSI_i was calculated for each genotype as:

$$DSI_i = c (V_{1i} (r_{11} - r_{13}) + V_{2i} (r_{21} - r_{23}) + V_{3i} (r_{31} - r_{33})) = DSI_{i1} + DSI_{i2} + DSI_{i3}$$

where $c = 1/(1 - DI) = \text{constant}$ for all cultivars,

$$DI = \text{drought intensity} = 1 - \left(\frac{\bar{Y}_s}{\bar{Y}_p} \right),$$

\bar{Y}_s and \bar{Y}_p are the mean of all cultivars under stress and non stress conditions, respectively and $DSI_{ik} = c (V_{1k} (r_{k1} - r_{k3}))$, $k = 1, 2$ and 3 . The three of DSI_{ik} in the index equation represent the components that contributed to drought susceptibility during successive stages of growth. V_{1i} and r_{ij} are genotypic and environmental components resulted from path coefficients analysis over environ-

ments. Mean of each genotype over rainfed and irrigated conditions was used for calculating DSI_i of each yield components for each variety.

RESULTS AND DISCUSSION

Descriptive diagrams

Descriptive diagram of yield and yield components indicated GE interaction and high variability for GY, NS, TSW and SPS over different environments and genotypes (Fig. 1). The variation for GY was low from genotype 1 to genotype 4 but high from genotype 5 to genotype 14. High GE interaction was found in environments 5 and 6 for GY.

The variation and GE interaction of NS (Fig. 1) was lower than GY. The GE interaction of NS for genotypes 3 and 8 was higher than other genotypes in different environments. Variation of genotypes for NS in environments 1, 2 and 4, was higher than other environments.

The variation and GE interaction of TSW (Fig. 1) was higher than GY and NS. This variation was very low for genotypes 3 and 8 over different environments, but high

Table 2 Combined analysis of variance analysis for yield and yield components.

Source	df	GY	TSW	SPS	NS
Replication	2	131197.6**	92.605*	15.98 ^{ns}	114517.1*
Environment (E)	5	521300.8**	524.45**	149.13**	28379.98**
Genotype (G)	13	60867.1**	176.41**	812.75**	160136.6**
GE	65	20097.37*	21.7**	38.42*	12006.35*
Error	166	6799.23	6.64	14.77	4295.45

*,** significant at 5% and 1% level of probability, respectively.

Table 3 Mean comparison of yield and yield components, AMMI stability values and yield stability indices of genotypes over rainfed and irrigated conditions.

Genotypes	GY	NS	SPS	TSW	ASVi	YSIi
1	460.0 ef	434.7 de	32.1 d	36.7 def	5.968	17
2	472.5 def	530.1 b	25.1 f	38.9 bc	8.228	18
3	457.7 ef	638.3 a	18.6 g	38.2 bcd	8.688	23
4	587.1 ab	601.4 a	28.3 e	37.2 cde	8.968	19
5	490.9 de	428.6 e	39.3 b	32.6 gh	8.168	14
6	491.7 de	475.2 cd	35.0 c	30.5 i	3.728	15
7	490.0 5de	349.3 e	42.7 a	35.1 f	4.538	14
8	518.2 cde	408.8 e	35.0 c	40.5 a	5.148	7
9	518.0 cde	435.9 de	39.7 b	31.6 hi	4.538	10
10	534.5 bcd	421.8 e	40.1 b	33.4 g	2.638	5
11	616.2 a	439.0 de	40.0 b	36.3 ef	6.068	8
12	424.6 fg	305.7 g	39.0 b	37.7 bcde	14.248	22
13	571.5 abc	502.3 bc	30.7 d	39.4 ab	6.998	11
14	396.0 g	349.4 e	31.1 d	38.7 bc	4.238	17

variation was found for genotypes 1, 2, 4 and 7. Variability of genotypes for TSW in environments 2 and 5 was lower than other environments.

Variability of SPS (**Fig. 1**) was lower than GY and TSW. The variation of SPS in different environments was very low for genotypes 2, 5 and 14, but very high in genotypes 1, 3, 4, 6, 11 and 13. Variation of genotypes for SPS in environments 1 and 6 was lower than other environments. Kozak (2010) suggested three plots namely regular performance plot (RPP), environment-centered performance plot (ECPP) and environment-standardized performance plot (ESPP) as a simplest method for analysis of both static and dynamic yield stability in a set genotypes evaluated in a range of environments. Kozak (2010) studied six soybean genotypes in eight environments and concluded that RPP in comparison to ECPP and ESPP is suitable for studying genotype stability in a static sense and provides more information about environments. ECPP was useful for presenting genotype stability in a dynamic sense and the information provided by ESPP was poor in the both static and dynamic senses.

Combined analysis of variance

Combined analysis of variance (**Table 2**) over locations (stress and non-stress) and years resulted in highly significant differences ($P < 0.01$) for genotypes, environments and GE interaction effects. The significant GE interactions suggest that grain yield and yield components of genotypes varied across irrigated and rainfed conditions. Significant differences for genotypes, environments and GE interaction indicated the effect of environments in the GE interaction, genetic variability among the entries and possibility of selection for stable genotypes and determination of the contribution of yield components in the stability of GY. Chandra *et al.* (1974) reported that GE interaction with location is more important than GE interaction with year. As the GE interaction was significant, therefore we can further proceed and estimate phenotypic stability (Farshadfar and Sutkla 2006; Osiru *et al.* 2009).

Mean comparisons

Mean performance (**Table 3**) of grain yield (GY) and yield components over 6 different irrigated and rainfed conditions ranged from 616.2 g for genotype 11 to 396 g for genotype 14. Maximum NS, SPS and TSW were attributed to genotypes 3, 7 and 8, while minimum NS, SPS and TSW were observed for genotypes 12, 3 and 6, respectively. 7 classes were obtained for GY. Genotypes 4, 11 and 13 were located in class 1(a) with no significance difference. Genotype 14 with minimum GY was located in class 7 (g) with genotype 12. Other genotypes were located in classes 2 to 6 and indicated high variability among genotypes for GY.

Mean comparison of yield components revealed 7 classes for NS and SPS, while 9 classes for TSW indicating high variability for yield components. Genotypes 3 and 4 showed maximum NS and were grouped as class 1(a) with no significance difference. Genotype 12 was grouped as class 7 with minimum NS. The rest of the genotypes were located in classes 2 to 6 indicating high variation among genotypes for NS. Genotype 7 exhibited maximum SPS and class 1(a) with significance difference with other genotypes. Other genotypes were located in classes 2 to 6 and a few of genotypes were located in especial classes indicating high genetic variation among genotypes for SPS. Genotypes 8 displayed maximum TSW and grouped as class 1(a) with genotype 13. Minimum TSW was observed for genotype 6 and grouped with genotype 9 in class 9 (i). Other genotypes were located in classes 2 to 8 and indicating high variation among genotypes for TSW.

AMMI stability value (ASV)

Purchase *et al.* (2000) developed the AMMI stability value (ASV) based on the AMMI model's IPCA1 and IPCA2 (Interaction Principal Components Axes 1 and 2, respectively) scores for each genotype. The ASV is the distance from the coordinate point to the origin in a two dimensional graph of IPCA1 scores against IPCA2 scores in the AMMI model. The ASV is comparable with the methods of Shukla (1972), Wricke (1962) and Eberhart-Russell (1963) stability methods. Smaller ASV score indicates a more stable genotype across environments. Because the IPCA1 score contributes more to the GE interaction sum of squares, a weighted value is needed. This weight is calculated for each genotype and each environment according to the relative contribution

Table 4 Mean, genotypic components of GE interaction and drought susceptibility index of genotypes over 6 rainfed and irrigated conditions.

Genotypes	Means	V ₁	V ₂	V ₃	DSI _i
1	460.08	-20.45	54.05	77.07	0.10
2	472.58	-17.08	45.13	64.35	0.08
3	457.78	-9.87	26.09	37.21	0.05
4	587.06	-37.20	98.32	140.20	0.41
5	490.96	-18.61	49.18	70.13	0.20
6	491.74	-30.46	80.48	114.77	0.33
7	490.05	-30.86	81.55	116.28	0.34
8	518.28	-18.36	48.52	69.19	0.20
9	518.06	-10.91	28.84	41.12	0.12
10	534.58	-34.51	91.19	130.03	0.38
11	616.28	-45.07	119.11	169.85	0.49
12	424.69	-24.05	63.56	90.64	0.26
13	571.50	-30.43	80.40	114.65	0.33
14	396.06	-22.32	58.99	84.12	0.24
Average	-	-25.01	66.10	94.26	0.25
Standard deviation = SD	-	0.18	0.01	0.12	0.13

of IPCA1 to IPCA2 to the interaction sum of squares. The ASV is already applied to identify genotypes in cereal crops (i.e., wheat, barely and durum wheat) in compared to other phenotypic stability parameters (Mohammadi *et al.* 2010b). The ASV could be used if selection is to be based primary on stability (Mohammadi *et al.* 2010b). In ASV method, a genotype with least ASV score is the most stable (Table 3), accordingly, genotypes 10 (ASV= 2.638) followed by 6 (ASV= 3.728) and 14 (ASV= 4.238) were the most stable.

Yield stability index (YSI)

Stability *per se* should however not be the only parameter for selection, because the most stable genotypes would not necessarily give the best yield performance (Mohammadi *et al.* 2009, 2010b), hence there is a need for approaches that incorporate both mean yield and stability in a single index, that is why Kang (1993) introduced three selection criteria for simultaneous selection of yield and stability entitled: rank – sum (RSM), modified rank – sum (MRSM) and the statistics yield – stability (YSi).

In this regard, as ASV takes into account both IPCA1 and IPCA2 that justify most of the variation in the GE interaction, therefore the rank of ASV and yield mean in such a way that the lowest ASV takes the rank one, while the highest yield mean takes the rank one and then the ranks are summed in a single simultaneous selection index of yield and yield stability named as: Yield stability index (YSI). The least YSI is considered as the most stable with high yield mean. It is applied to identify high yielding stable genotypes in cereal crops i.e., maize (Fan *et al.* 2007) and durum wheat (Mohammadi *et al.* 2010a). Based on the YSI (Table 3) the most stable genotype with high grain yield was genotype 10 followed by genotypes 8 and 11, respectively.

Contribution of yield components in the grain yield stability

Principal hypothesis in path analysis is explanation of variable group using covariance or correlation matrix of the fewer assumptive factors. Essential object of this analysis is the three environmental components (r_1 , r_2 and r_3) that explain the variance of genotype in different environments. Hypothesis of three common factors (r_1 , r_2 and r_3) and determination of path coefficients (V_1 , V_2 and V_3) were analyzed based on the date arrangement of growth yield component. In this analysis, there is no need to rotate the factors, because position of three factors with their path relations of yield and yield components are attended. Achievements of this method depend on the credibility of path relation and on this fact that three environmental components of the GE interaction are common among genotypes.

Path analysis over different environments (Fig. 2) indi-

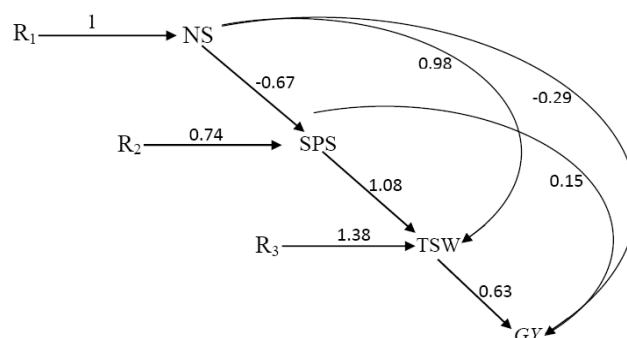


Fig. 2 Direct and indirect effects of yield components with grain yield in path analysis over environments. R1, R2 and R3 environmental components; NS: number of spikes/m²; SPS: seeds/spike; SPP: spikes/plant; TSW: 1000-seed weight; GY: grain yield.

Table 5 Environmental components of GE interaction.

Environmental sources	Environments					
	1	2	3	4	5	6
r_1	4	-24	-16	-8	-4	-16
r_2	4	-16	-4	-8	0	-12
r_3	0	16	0	8	0	-8

cated that direct effect of TSW (0.63) on GY was higher than NS (-0.29) and SPS (0.15), while indirect effects of NS and SPS on GY through TSW were higher than their direct effects. Therefore, the contribution of TSW in the variation of GY over different environments was higher than other yield components. In other words, instability of GY was caused by TSW in different environments. Askarinaia *et al.* (2008) in wheat and Mohammadinejad and Rezaei (2007) in oat and barley reported the same results.

Comparison of three genotypic components (V_1 , V_2 and V_3) for each genotype indicated that V_3 was much higher than V_2 and V_2 was higher than V_1 (Table 4). Therefore, yield formation was supported by following arrangement: formation of spike, formation of seed per spike and formation of 1000 seed weight. It is also concluded that genotypic component V_3 (TSW) more contribute to GE interaction of grain yield, i.e. relative contribution of thousand seed weight in the phenotypic stability of grain yield was higher than that of number of spike per plant (V_1) and number of seed per spike (V_2).

Environmental components of the GE interaction (Table 5) exhibited that absolute value of r_1 in all environments was higher than r_2 and r_3 . In addition, variation of r_1 was more than r_2 and r_3 and that of r_2 was higher than r_3 indicating that sensitivity of NS and SPS to the environmental variation was higher than TSW.

Table 6 Mean and DSI of yield components over six different rainfed and irrigated conditions.

Genotypes	Means	DSI of V_1	DSI of V_2	DSI of V_3
1	460.08	0.23	0.01	0.15
2	472.58	0.07	0.01	0.04
3	457.78	0.06	0.01	0.04
4	587.06	0.58	0.02	0.39
5	490.96	0.17	0.01	0.11
6	491.74	0.36	0.02	0.24
7	490.05	0.35	0.03	0.23
8	518.28	0.16	0.02	0.11
9	518.06	0.44	0.04	0.29
10	534.58	0.28	0.02	0.18
11	616.28	0.65	0.02	0.43
12	424.69	0.39	0.02	0.26
13	571.50	0.32	0.01	0.21
14	396.06	0.50	0.03	0.33

Therefore high grain yield and stability of genotypes 8, 10 and 11 are because of higher genotypic component V_3 (TSW) and lower environmental components r_3 (TSW). The same results were reported by Farshadfar (1999) in wheat substitution lines, Mohammadinejad and Rezaei (2007) in oat and barley and Askarinia *et al.* (2008) in wheat.

Path analysis of drought susceptibility index

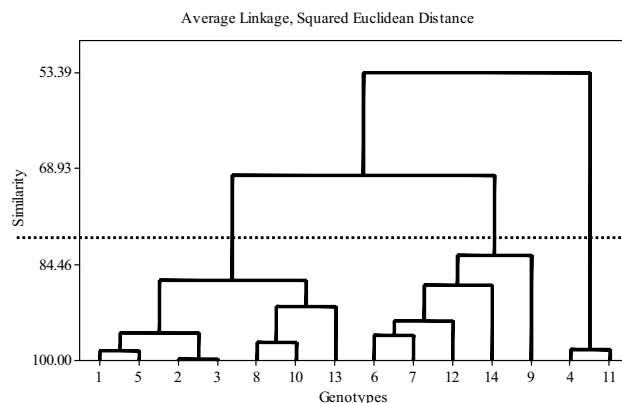
This procedure can identify cultivars for drought conditions and to select tolerant parental lines for breeding new varieties with improved to drought and rainfed environments. The drought susceptibility indices (DSI_i) of all genotypes are shown in the last column in **Table 4**. They were estimated from the mean of Y_s and Y_p over 6 different rainfed and irrigated conditions. The index ranged from 0.05 of genotype 3 (resistant genotype) to 0.49 of genotype 11 (susceptible genotype). The mean and standard deviation (SD) over all genotypes were DSI = 0.25 and SD = 0.13, respectively. Genotypes outside the range DSI \pm SD area included 4 (DSI = 0.41), 11 (DSI = 0.49), 1 (DSI = 0.10), 2 (0.08) and 3 (DSI= 0.05). The first two were susceptible genotypes whereas the latter three, particularly genotype 3, were resistant genotypes.

Cluster analysis

The three components (DSI₁, DSI₂ and DSI₃) and average grain yield (**Table 6**) were used in a cluster analysis (Khadadadi *et al.* 2011). Discriminant analysis of the clusters grouped the genotypes into three different classes. The first group included drought-resistant genotypes 1, 5, 2, 3, 8, 10 and 13 with high grain yield and desirable for rainfed conditions. The second group included semi-tolerant (semi-sensitive) genotypes 6, 7, 12, 14, and 9, while genotypes 4 and 11 formed the third group (drought sensitive) and recommended for irrigated condition (**Fig. 3**). Groups 1 and 3 are suggested for hybridization programs to produce recombinant inbred lines for QTL (quantitative trait loci) mapping or genetic analysis of drought tolerance indicators using diallel mating design or generation mean analysis.

CONCLUSIONS

It is common that researchers use grain yield for analysis of stability. As yield is a complex trait, therefore we have to find out which components contribute more to yield stability. The reason is that components are simple traits with higher heritability than complex trait and easier for improvement. There are three methods to discover relative contribution of components in the yield stability (log method, covariance method and path analysis method). As drought susceptibility index is also calculated based on the yield (complex trait) in the stress and nonstressed conditions, hence by linking the results of path analysis to the

**Fig. 3** Dendrogram resulting from cluster analysis of average grain yield and drought susceptibility indices of yield components over six rainfed and irrigated conditions.

formula of drought susceptibility index we can identify relative contribution of yield components in the drought susceptibility index and use that simple component for improvement of drought tolerance. Using the above mentioned logic 1000-seed weight indicated a more important role in the improvement of stability and less contribution in the drought susceptibility index.

ACKNOWLEDGEMENTS

The authors express their appreciations to the Iran National Science Foundation for providing financial support for this research project (code number = 88002345).

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