AMMI analysis application for explanation of ecotype by sowing date (E×SD) interaction in terms of seed yield in cumin (*Cuminum cyminum* L.) ecotypes

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Abstract
Different responses of plant genotypes to the change of environmental conditions have been the most important and challenging issue for plant breeders and agronomists for the selection of superior genotypes. Cumin is one of the most important medicinal and aromatic plants in Iran that are strongly affected by varying environmental conditions. This study was aimed to investigate E×SD interaction and also select stable and adaptable ecotypes of cumin in different sowing dates by AMMI analysis. For this purpose different cumin ecotypes were evaluated in five sowing dates in Kerman (a semiarid region in Iran). Accordingly, nine cumin ecotypes were evaluated in a RCBD with three replications in each sowing date during growing season of 2011-12. Seed yield were measured at the end of growing season in each sowing date and the collected data were analyzed using the AMMI model. The AMMI ANOVA showed a significant variation among sowing dates, ecotypes and G×SD interaction for seed yield. For this trait, 26.95% of the total sum of squares was attributable to ecotypes, 26.15% to sowing dates, and 46.9% to E×SD, indicating high genotypic variation to sowing dates. The first two IPCA explain 72.32% of the E×SD interaction effect (43.65% and 28.67% for IPCA1 and IPCA2, respectively). Rank correlations confirmed a relationship between ASV, AMMI1, and YSI and agreement between YSI and yield in ranking ecotypes. Based on the mentioned statistics, Isfahan and Khorasan-Jonoubi were identified as unstable ecotypes. Semnan ecotype with regard to the high yield-stability reaction in different sowing dates is recommended for cultivation in semiarid regions of Iran.

Key words: AMMI Model, Adaptability, Rank correlation, Yield stability.

Abbreviations
AMMI: additive main effect and multiplicative interaction; ANOVA: analysis of variance; ASV: AMMI stability value; E×SD: ecotype by sowing date interaction; IPCA: interaction principal component axes; RCBD: randomized complete block design; YSI: yield stability index.

INTRODUCTION

Cumin (*Cuminum cyminum* L.) is an annual herbaceous industrial and medicinal plant belonging to the *Apiaceae* family cultivated in arid and semiarid regions of Iran like Kerman (Kafi *et al.*, 2006). Cumin is one of the most important cultivable medicinal plants in Iran (Kafi *et al.*, 2006) and today it is the popular spices in the world after black pepper (Bettaieb *et al.*, 2012). Despite medicinal and aromatic benefits, cumin like many other crop plants, responds differently under varying environmental conditions, due to the genotype × environment interaction (GE). Recognizing the importance of genotype × environment interaction and understanding of stability in cumin variety, are important before recommendation for cultivation in wide areas (Kafi *et al.*, 2006). A variety of research conducted, pointed out that the seed yield in cumin are strongly varied when are not planting in proper time (Kamkar *et al.,* 2011; Rezvani Moghaddam *et al.,* 2014).

When a genotype is sown in different environmental conditions frequently, it shows a significant oscillation in yield performance in comparison to others. Sowing date is one of the most predictable variations of the environment that are determined by man and can therefore be fixed more or less at will, so this agronomic practice is known to be of central importance for agricultural productivity (Allard and Bradshaw, 1964; Laux *et al.*, 2010). The appropriate sowing date is very important to maximize the use of natural resources since it superposes the critical periods for yield and its components with the duration of the growth season where more environmental resources are available. In Interpretation of hybrid × sowing date interaction, de la Vega *et al*. (2001 and 2002) and Balalić *et al.* (2012) showed strong differences between sowing dates in terms of the oil yield, in sunflower that severely complicate selection for broad adaptation to normal and late sowing dates.

Crop performance depends largely on genotype (G), environment (E) and genotype by environment interaction (GE). Understanding the genotype responses in different environments is an important topic for plant breeders in crop breeding programs. GE is a routine occurrence in plant breeding programs that has been an important and challenging issue among plant breeders, geneticists and agronomists engaged in performance testing (Kang, 1998; Farshadfar *et al.*, 2011). GE usually causes significant changes in genotype ranks in diverse environments (Crossa, 1990) that makes difficult the evaluation and selection of superior genotypes (Simmonds, 1991; Ebdon and Gauch, 2002; Allard and Bradshaw, 1964). Genotypes that show the least GE interaction is deemed to be stable genotypes in responses to environmental fluctuations. A genotype showing a constant performance in all environments is known to have a wide adaptation capacity, while genotypes with high and poor yield potential in specific conditions / non-target conditions are known as genotypes with a specific adaptability (Barah *et al.,* 1981; Lin and Binns, 1991).

Many biometrical, univariate (Huehn, 1996; Finlay and Wilkinson, 1963; Eberhart and Russell, 1966; Shukla, 1972; Wrike, 1962) and multivariate (Gauch, 1992; Gauch and Zobel, 1988 and 1997) methods have been used to study GE interaction and stability in different crops (Lal, 2013; Lal, 2015; Fashadfar *et al.*, 2011; Zhang *et al.,* 2011; Ramburana *et al.,* 2011); between them, AMMI (Additive Main Effects and Multiplicative interactions) model was found a very powerful model for the multi-year trials (Lal, 2013; Lal, 2015; Fashadfar *et al.,* 2011). This method has been shown to be effective because it captures a large portion of the GEI sum of squares and separates main and interaction effects (Lal, 2013; Lal, 2015). AMMI clarifies the G×E interaction, summarizes patterns and relationships of genotypes and environments (Zobel *et al.*, 1988; Crossa *et al.*, 1990) and improves the accuracy of yield estimates (Farshadfar *et al.*, 2011). Gauch and Zobel (1997) corroborated the usefulness of AMMI analysis in breeding program decisions, like in the selection of environments or test site locations.

Zhang *et al.* (2011) in evaluating the environmental adaptability and stability of soybean germplasm using the AMMI model, stated that this model not only facilitated judging phenotypic stability of crop genotype but also G×E model can be intuitively depicted and analyzed based on biplot. This provides great convenience in crop breeding and production.

Fashadfar *et al.* (2011) mentioned that in comparison univariate statistics, non-parametric indices and Yield Stability Index (YSI) (based on AMMI stability value), the YSI were introduced as the most desirable indices for discriminating the most stable genotypes with high grain yield.

Adaptability and stability among different genotypes of Mucuna (*Mucuna pruriens* L.) for seed yield (Lal, 2015) and mint for menthol (Lal, 2013) were compared using AMMI model. In these studies the AMMI model were described to provide broader information and interpretations on stability very deeply in detail.

Despite the importance of the GE interaction and necessity of genotypic selection for high yield-stability in cumin plant, no study has been focused on this issue, therefore, this research was aimed to evaluate and identify genotypic reaction pattern to different sowing dates, selection and introduce superior ecotypes based on the stability in cumin germplasm using the AMMI model in Kerman, Iran.

MATERIALS AND METHODS

Plant materials, Site Description and Experime- ntal Design

A cumin germplasm collection consisted of Iranian provinces with the highest cumin production, including Semnan (4 ecotypes), Fars (4 ecotypes), Yazd (5 ecotypes), Golestan (4 ecptypes), Khorasan-Razavi (7 ecotypes), Khorasan-Shomali (4 ecotypes), Khorasan-Jonoubi (5 ecotypes), Isfahan (6 ecotypes) and Kerman (10 ecotypes) were evaluated during growing seasons of 2011-2012 in Agricultural Research field of Shahid Bahonar University of Kerman, Iran(more information about the studied ecotypes is given in Ghanbari and Khajoie Nejad (2014)). Ecotypes were sown in different sowing dates including 26th December (SD1), 10th January (SD2), 25th January (SD3), 9th February (SD4) and 24th February (SD5) to assess the adaptability test. The trial at each sowing date was laid out in a randomized complete block design (RCBD) with three replications. The experiment site located at 56º, 58' E, 30º, 15' N and 1754 meters elevation above sea level. Soil type was a Sandy-loam, with pH 7.4, EC 4.4 (dS/m), and mean annual precipitation of 150 mm. Figure 1 shows regional meteorological records of the study site (according to weather data of the Meteorological Laboratory of Kerman, Iran) also some information about plant growth conditions in each sowing date are presented in table 1.

Each ecotype was planted in 3 rows (2 m in length) with 0.4 m spacing between rows (2.4 m^2 plot area) and 5 cm spacing between plants (120 plants per plot density). Fertilizers were applied before sowing (based on soil analysis and nutrient requirement of cumin) at the recommended rates of 30 kg N (from urea source) and 85 kg P_2O_5 (from triple superphosphate source) per hectare, respectively for each sowing date. The first irrigation was done after sowing and then every 7 days before germination and monthly after emergence, alternately) and hand weeding was carried out for weeds control. At the maturity stage, 1 m^2 of each plot was harvested to measure seed yield per unit area.

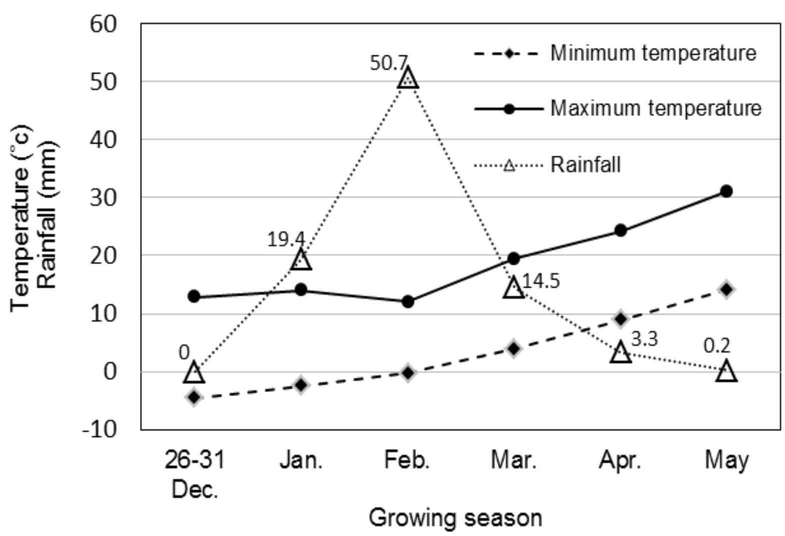

Figure 1. Regional meteorological records of study site during the growing season of 2011-2012 at Kerman, Iran

Table 1. Sowing, germination and harvesting dates, calculated GDD as well as mean of rainfall for each sowing dat-e

Sowing date	Germination date	Harvesting date	∑GDD	Rainfall (mm)
26^{th} Dec. 2011	7^{th} Feb. 2012	27^{th} May. 2012	1152.7	88.1
10^{th} Jan. 2012	14^{th} Feb. 2012	30^{th} May. 2012	1182.2	87.9
25^{th} Jan. 2012	23^{rd} Feb. 2012	2^{nd} June. 2012	1193.1	83.2
9^{th} Feb. 2012	2^{nd} Mar. 2012	4^{th} June. 2012	1202.4	56.3
24^{th} Feb. 2012	10^{th} Mar. 2012	7^{th} June. 2012	1230.8	33.5

Statistical Analysis

Combined analysis of variance (ANOVA) for seed yield data was conducted to determine the effects of sowing date (SD), ecotype (E), and E×SD interaction (Freeman and Dowker, 1973). Bartlett's test was also performed to assess the homogeneity of variances (Gomez and Gomez, 1984). The GE interaction was partitioned according to the AMMI model (Gauch and Zobel, 1997) and the biplot was used to further assess the AMMI results (Gabriel, 1971). Analyses were carried out with the SAS 9.1 statistical package (SAS Institute Inc., 2009).

AMMI stability value (ASV) was generated as described by Purchase *et al.* (2000) and was calculated for each ecotype and each sowing date considering the significance of the first three IPCA to identify more sustainable ecotypes, as follows:

(1) ASV=

$$\sqrt{\left[\frac{IPCA1\,SS}{IPCA2\,SS}(IPCA1_{score})\right]^2+\left[\frac{IPCA2\,SS}{IPCA3\,SS}(IPCA2_{score})\right]^2+[IPCA3_{score}]^2}$$

Where:

$IPCA1_{SS}$ and $IPCA2_{SS}$ are sum of squares of interaction principal component analysis one, two and three, respectively.

IPCA1, 2 and 3 $_{score}$ are scores of interaction principal component analysis one, two and three, respectively.

The yield stability index (YSI) statistic (Farshadfar *et al.*, 2011) was applied for selecting high-yielding and stable genotypes. YSI was calculated based on the rank of seed yield mean of ecotypes (RY) in sowing dates and rank of ASV (RASV) in a single criterion (YSI) as:

(2) YSI = RASV + RY

Ranks were assigned for mean yield and stability parameter, so that the ecotype with the highest yield and the lowest estimated value for each statistic given a rank of 1 (Farshadfar *et al.*, 2011; Roostaei *et al.*, 2014). For AMMI2, rank was assigned for the lowest distance to origin (calculated for each ecotype based on Pythagoras' theorem) received rank of 1. Spearman's rank correlation coefficients were calculated using SPSS Statistics ver. 17.0 among the ranks given by each statistic.

RESULTS AND DISCUSSION

Combined and AMMI ANOVA

Result of Bartlett's test (χ^2= 9.2, df 4, P>0.05) suggested that error variances were homogeneous. The combined and AMMI analysis of variance results are presented in Table 2. As seen, seed yield in cumin was significantly affected by sowing dates (SD), ecotypes (E) and ecotype by sowing date interaction (E×SD), which explained 26.15%, 26.95% and 46.9% of the total sum of squares respectively (Table 2). Most of the total SS was explained by the ecotype × sowing date interaction (E×SD), reflecting a much wider range of E×SD interaction than E and SD main effects.

The range of mean seed yield of ecotypes across sowing dates varied from 519.8 kg ha^{-1} (Fars ecotype) to 797.1 kg ha^{-1} (Kerman ecotype) as shown in Table 3. The sowing dates mean seed yield varied from 524.8 kg ha^{-1} at SD1 to 758.6 kg ha^{-1} at SD5 (data not shown). The seed yield data also indicate that E×SD data matrix ranged from 337.7 kg ha^{-1} (due to Yazd ecotype at SD1) to 1067 kg ha^{-1} (Kerman ecotype at SD5) (data not shown).

The IPCA1, IPCA2 and IPCA3 MS were highly significant (P<0.001) for seed yield (Table 2). The results showed that the first two principal component axes of the interaction (IPCA) explain 72.32% of the E×SD interaction effect (43.65 and 28.67 for IPCA1 and IPCA2 respectively) for seed yield of cumin (Table 2). In order to simultaneously visualizing both mean performance and stability (IPCA1) of ecotypes and sowing dates the AMMI1 biplot (Figure 2) was plotted on the basis of main effects (abscissa) and its IPC1 scores (ordinate).

AMMI1

The ecotypes with IPCA1 scores close to zero have a low contribution to the interaction, being considered stable and represented wide adaptation reaction whereas the larger scores on the ordinate depicted more specific adaptation to environments with the same IPCA1 sign (Ebdon and Gauch 2002; Crossa *et al.*, 1991). Therefore, Kerman and Khorasan-Shomali with the same sign and higher mean yields than mean were specifically adapted to SD2. On the contrary, Fars ecotypes with the high distance from the IPCA1 and low mean yield were specifically adapted to the poorer sowing date (SD1). Yazd ecotypes had the similar sign and seed yield mean to SD2 and SD3 and showed specific adaptability reaction to these sowing dates. Semnan ecotypes with the combination of high seed yield and stable performance across sowing dates (low contribution of the G×SD interaction) can be considered as the best ecotypes based on IPCA1 biplot (Figure 2).

Table 2. Analysis of variance and AMMI model for seed yield of cumin ecotypes grown in different sowing dates.

Source of variation	Df	Sum of squares	Mean square	Total SS (%)	G×SD SS (%)
Model	44	959262.97	21801.41**		
Sowing date (SD)	4	250838.8	62709.69**	26.15	
Block (SD)	10	27187.2	2718.72		
Ecotype (G)	8	258526.3	32315.79*	26.95	
G×SD interaction	32	449896.9	14059.28**	46.9	
IPCA1	11	196389	17853.54**		43.65
IPCA2	9	129001	14333.44**		28.67
IPCA3	7	118273.81	16896.26**		26.29
Residual	5	6234.97	1246.99ns		1.39
Error	80	238825.2	2985.3		
Total	134	1225275.37			

df: Degree of freedom; ns: non-significant; * Significant at $P < 0.05$; ** Significant at $P < 0.01$.

Table 3. Applied statistical methods and attributed rank of each cumin ecotypes across different sowing dates.

Ecotype	AMMI1		AMMI2		Yield		ASV		YSI	
	IPCA1	R	Distance	R	Mean	R	ASV	R	YSI	R
Semnan	0.107	1	0.491	1	652.4[abc]	3	1.016	1	4	1
Fars	0.726	6	0.736	3	519.8[c]	9	1.303	6	15	9
Yazd	-0.546	5	0.649	2	648.8[abc]	4	1.179	3	7	3
Golestan	0.520	4	0.741	4	641.5[abc]	5	1.186	4	9	4
Kh-Razavi	-0.325	2	0.946	5	591.9[bc]	8	1.088	2	10	5
Kh-Shomali	-0.947	9	0.974	6	729.9[ab]	2	1.477	9	11	6
Kh-Jonoubi	0.929	8	0.987	7	609.3[bc]	6	1.468	8	14	7.5
Isfahan	0.788	7	0.998	8	606.2[bc]	7	1.374	7	14	7.5
Kerman	-0.504	3	1.000	9	797.1[a]	1	1.215	5	6	2

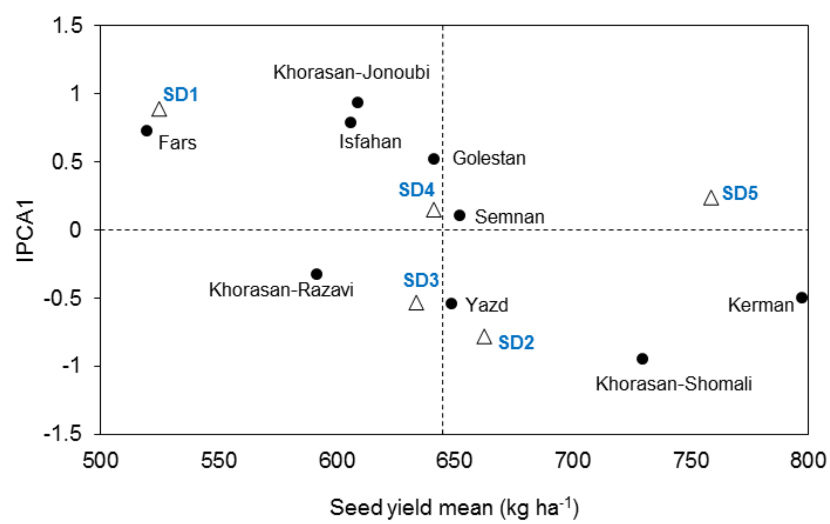

Figure 2. AMMI1 biplot of IPCA1 scores vs. seed yield mean of cumin ecotypes grown in different sowing dates. Cumin ecotypes and sowing dates (SD1-SD5) were characterized by (●) and (∆), respectively.

AMMI2

Figure 3 shows the AMMI2 biplot for seed yield, which accounted for 72.3% of the E×SD interaction. In the AMMI2 biplot points situated nearby to the origin with low scores for two IPCA1 and IPCA2 axes represent stable ecotypes and sowing dates. The interpretation of AMMI2 biplot for GE interaction is based on the magnitude and signs of the scores of the genotypes or environments for the interaction axes considered. The genotypes near the origin are not sensitive to environmental interaction and those distant from the origins are sensitive and have a large interaction (De Vita *et al.*, 2010).

The AMMI2 biplot (Figure 3) indicates that Semnan ecotypes were found to be closest to the origin. These ecotypes had the smallest scores, thus they had the smallest E×SD interaction effect and were non sensitive to change in sowing date and environmental interactive factors. Yazd ecotypes showed a specific E×SD interaction in IPCA2 scores that have a negative sign similar to SD3 and opposite to SD5. Golestan and Isfahan ecotypes showed a positive IPCA2 score with a specific E×SD interaction with SD5. Specific E×SD interactions were also observed for Kerman and Khorasan-Razavi ecotypes in their large positive and negative IPCA2 scores, respectively. In general Kerman, Isfahan, Khorasan-Jonoubi and Khorasan-Shomali ecotypes had the highest distance from the origin so these are sensitive to sowing date changes and have a large interaction based on AMMI2 biplot. Among them Isfahan, Khorasan-Jonoubi ecotypes with mean yields less than the overall mean and accordingly can be regarded as the most unstable ecotypes.

Among the sowing dates, SD3 and SD2 had the lowest distance to the origin which represent a more stable reaction than the others,The sowingdates were also correlated positively, and ecotypes showed similar reaction to them. SD3 was correlated with SD4 and negatively correlated with SD1 and SD5, while SD5 showed no significant correlation with SD1 as well as SD2. Therefore SD3 and SD4 produced similar discriminations among the ecotypes grown in these sowing dates.

AMMI Stability Value (ASV)

Since the AMMI model does not make provision for a quantitative stability measure, the AMMI stability value (ASV) is proposed by Purchase *et al.* (2000) to cope with this problem. In order to identify high yielding stable ecotypes ASV was plotted against the yield mean (Figure 4). In ASV method, a genotype with least ASV score is the most stable (Purchase *et al.*, 2000; Farshadfar *et al.*, 2011); on this basis, Semnan, Khorasan-Razavi, Yazd and Golestan ecotypes were the most stable ones where Semnan and Yazd ecotypes by considering the fact that their mean yield was more than the overall mean, were identified as yield stable ecotypes. Golestan ecotypes with a reaction close to the average performance were categorized as relatively stable ecotypes and Khorasan-Razavi ecotypes with low performance were considered poorly stable. The position of the environments within the biplot of the ASV indicate that Kerman ecotypes specifically adapted to SD5 (favorable environment), while Fars ecotypes seemed to be favored by SD1 (unfavorable environment). Khorasan-Shomali ecotypes performed better in SD2 while Yazd and Golestan ecotypes had the best performance in SD3 (Figure 4).

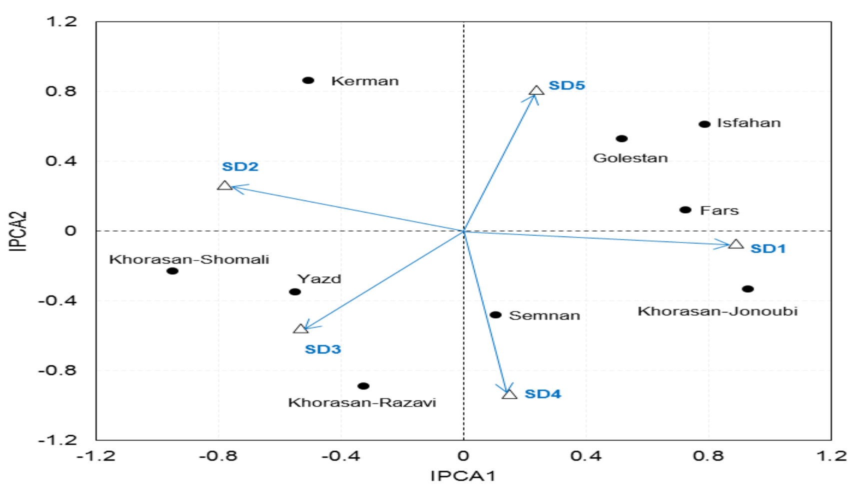

Figure 3. AMMI2 biplot of the first two axes of the AMMI model for seed yield data. Cumin ecotypes and sowing dates (SD1-SD5) were characterized by (●) and (Δ), respectively.

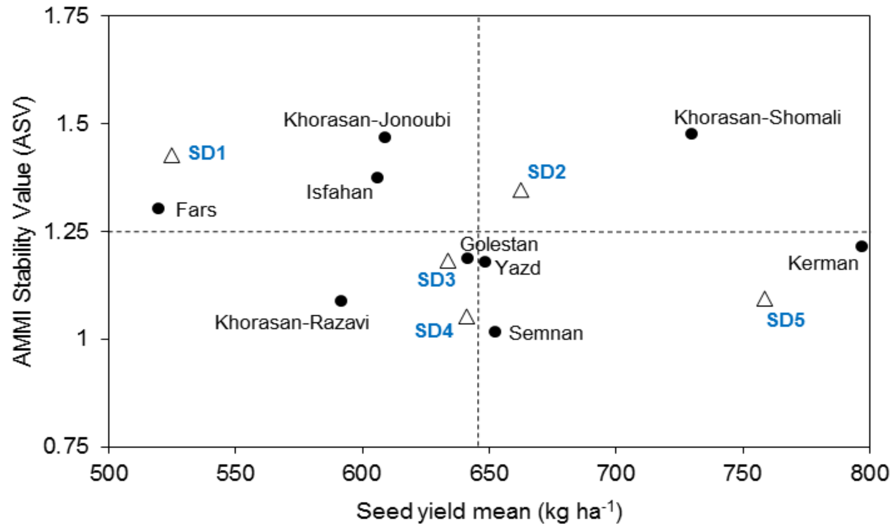

Figure 4. Scatter plot of ASV against seed yield mean of cumin ecotypes grown in different sowing dates. Cumin ecotypes and sowing dates (SD1-SD5) were characterized by (●) and (∆), respectively.

Yield Stability Index (YSI)

The rank of ASV and mean seed yield are incorporated in a single stability index namely yield stability index (YSI). YSI allows the simultaneous selection for yield and stability performance; on this basis genotypes with the least YSI represent stable genotypes with the high performance (Farshadfar *et al.*, 2011). YSI values indicated that Semnan ecotypes with YSI=4 were high-yielding and stable ones, in contrast Fars, Khorasan-Jonoubi and Isfahan with the highest values (15, 14 and 14 respectively) were identified as unstable ecotypes based on YSI (Table 3).

Spearman's Rank Correlation

The rank correlations of applied stability and yield-stability statistics for cumin ecotypes are given in Table 4. Comparison of the statistical methods based on the ranks showed that the AMMI1 and ASV statistical methods were highly correlated in identifying stable ecotypes (r = 0.93, P<0.01). These methods generally gave similar results in ranking of ecotypes. For example, the two top-ranked ecotypes were Semnen and Khorasan-Razavi; whereas Khorasan-shomali, Khorasan-Jonoubi and Isfahan based on the ranks of both AMMI1 and ASV statistics were characterized as unstable ecotypes.

The significant rank correlation (P<0.05) between the YSI and the AMMI1, yield and ASV (Table 4) suggests that the YSI was in agreement with the mentioned three statistics for stability rankings. Rank correlation coefficients of YSI with yield and ASV statistics indicating that YSI is better correlated to yield than ASV for ranking genotypes when integrate both yield and stability performance (Table 4). According to the YSI and yield performance Fars ecotypes with the lowest performance were recognized as unstable ecotypes while based on other statistics categorized as moderate stable ecotypes (Table 4). Stable ecotypes, according to yield ranks and yield-stability ranks (YSI) such as Kerman ecotype would be recommended for favorable sowing dates or environments. Ecotype effects were significantly different for seed yield in cumin, indicating significant variation in yield performance of the ecotypes. The seed yield is also highly influenced by ecotype × sowing date interaction indicating that the response patterns of the ecotypes to change in sowing date were significantly different and ecotypes are required to be tested in multi-location trials for sowing date in order to identify generally and specifically adapted ecotypes.

Selection of stable genotypes in different plants has been identified using AMMI model in Mucuna pruriens (L.) (Lal, 2015), cassava (Tumuhimbise *et al.*, 2014), mint (Lal, 2013), durum wheat (De Vita *et al.*, 2010), wheat (Roostaei *et al.*, 2014), sugarcane (Ramburan *et al.*, 2011), soybean (Zhang *et al.*, 2011) and bread wheat (Farshadfar *et al.*, 2011).

Recommendation of stable genotypes for regional land would be a suitable choice whereas in cases that farmers have the specific and high potential conditions

Table 4. Spearman's rank correlations among the different parameters over the ecotypes

Parameters	IPCA1	IPCA1 vs. IPCA2	Yield	ASV	YSI
IPCA1	1				
IPCA1 vs. IPCA2	0.383	1			
Yield	0.100	-0.133	1		
ASV	0.933**	0.617	0	1	
YSI	0.728*	0.276	0.711*	0.695*	1

* Significant at $P < 0.05$; ** Significant at $P < 0.01$.

for producing cumin in favorable environments, using specifically adapted genotypes (such as growing Kerman ecotype in SD5) to get high yield could be useful. In these cases, use of YSI, would be beneficial to introduce high yield-stability ecotypes (Farshadfar, 2008; Farshadfar *et al.,* 2011). Based on YSI, Semnan, Kerman and Yazd ecotypes can be proposed for these cases (Table 3).

Some of the statistics did not show any relationship with yield rank such as: IPCA1, IPCA1 vs. IPCA2 and ASV that can be noted that genotypes identified according to these statistics may not be as good as the responsive ones under favorable or unfavorable conditions.In other words, the mentioned statistics can be used to identify genotypes with the general stability across different environments. In accordance to AMMI2, Semnan ecotypes were found to be stable whereas Kerman, Isfahan and Khorasan-Jonoubi ecotypes were characterized as unstable. ASV takes into account the scores of all significant IPCAs that justify most of the variation in the GE interaction, therefore, selection will be more reliable based on the ASV (Farshadfar, 2008; Farshadfar *et al.,* 2011). ASV identified Semnan ecotype as stable and Khorasan-Shomali, Khorasan-Jonoubi and Isfahan as unstable (Table 3).

Semnan ecotypes were identified as high-yielding and stable ecotypes based on all methods and showed the least variation across sowing dates whilst Isfahan and Khorasan-Jonoubi with the highest ranks and mean yields less than the overall mean, accordingly can be regarded as the most unstable ecotypes (Table 3).

CONCLUSION

The observations of this study revealed that: (i) the seed yield is highly influenced by sowing dates (SD), ecotypes (E) and E×SD interaction in cumin. According to the obtained results change in sowing date caused different responses in ecotypes. (ii) Rank correlation analysis revealed the similarity between the statistics in ranking ecotypes for seed yield. Rank correlations were confirmed relationship between ASV, AMMI1, and YSI statistic for stability results, and agreement between YSI and yield is due to integrating yield with stability. (iii) The final conclusion is based on all of the mentioned statistics; Isfahan and Khorasan-Jonoubi were identified as unstable ecotypes while Semnan ecotypes showed the high adaptability and stability in different sowing dates. Therefore, these ecotypes are recommended for cumin growing areas in semiarid region of Iran.

REFERENCES

Allard R. W., and Bradshaw, A. D. (1964). Implications of Genotype-Environmental Interactions in Applied Plant Breeding. *Crop Science,* 4: 503-508.

Balalić I., Zorić M., Branković G., Terzić S., and Crnobarac J. (2012). Interpretation of hybrid× sowing date interaction for oil content and oil yield in sunflower. *Field Crops Research,* 137: 70-77.

Barah B. C., Binswanger H. P., Rana B. S., and Rao G. P. (1981). The use of risk aversion in plant breeding; concept and application. *Euphytica,* 30: 451-458.

Bettaieb R. I., Jabri-Karoui I., Hamrouni-Sellami I., Bourgou S., Limam F., and Marzouk B. (2012). Effect of drought on the biochemical composition and antioxidant activities of cumin (*Cuminum cyminum* L.) seeds. *Industrial Crops and Products,* 36: 238-245.

Crossa J. (1990). *Statistical analyses of multilocation trials.* Advances in Agronomy, 44. pp. 55-85.

Crossa J., Fox P. N., Pfeiffer W. H., Rajaram S., and Gauch H. G. (1991). Ammi adjustment for statistical-analysis of an International wheat yield trial. *Theoretical and Applied Genetics,* 81: 27-37.

Crossa J., Gauch H. G., and Zobel R. W. (1990). Additive main effect and multiplicative interaction analysis of two international maize cultivar trials. *Crop Science,* 30: 493-500 de la Vega A. J., Chapman S. C., and Hall A. J. (2001). Genotype by environment interaction and indirect selection for yield in sunflower. I. Two-mode pattern analysis of oil and biomass yield across environments in Argentina. *Field Crops Research,* 72: 17-38.

de la Vega A. J., Hall A. J., and Kroonenberg P. M. (2002). Investigating the physiological bases of predictable and unpredictable genotype by environment interactions using three-model pattern analysis. *Field Crops Research,* 78: 165-183.

De Vita P., Mastrangelo A. M., Matteu L., Mazzucotelli E., Virzì N., Palumbo M., Lo Storto M., Rizza F., and Cattivelli L. (2010). Genetic improvement effects on yield stability in durum wheat genotypes grown in Italy. *Field Crops Research,* 119: 68–77.

Ebdon J. S. and Gauch H. G. (2002). Additive main effect and multiplicative interaction analysis of national turfgrass performance trials: I. Interpretation of genotype×environment interaction. *Crop Science,* 42: 489-496.

Eberhart S. A. and Russell W.A. (1966). Stability parameters for comparing varieties. *Crop Science,* 6: 36-40.

Farshadfar E. (2008). Incorporation of AMMI stability value and grain yield in a single non-parametric index (GSI) in bread wheat. *Pakistan Journal of Biological Sciences,* 11(14): 1791-1796.

Farshadfar E., Mahamodi N., Yaghotipoor, A. (2011) AMMI stability value and simultaneous estimation of yield and yield stability in bread wheat (*Triticum aestivum* L.). *Australian Journal of Crop Science,* 5 (13): 1837–1844.

Finlay K. W., and Wilkinson G. N. (1963). The analysis of adaptation in a plant breeding program. *Australian Journal of Agriculture Research,* 14: 742-754.

Freeman G. H., and Dowker B. D. (1973). Statistical methods for the analysis of genotype-environments. *Heredity,* 33:339–354.

Gabriel K. R. (1971). The biplot-graphical display of matrices with applications to principal components analysis. *Biometrika,* 58: 453-467.

Gauch H.G. (1992). *Statistical Analysis of Regional Yield Trials: AMMI Analysis of Factorial Designs*. Elsevier Science Publishers, Amsterdam, The Netherlands.

Gauch H. G., and Zobel R. W. (1997). Identifying mega-environments and targeting genotypes. *Crop Science,* 37: 311–326.

Gauch H. G., and Zobel R. W. (1988). Predictive and postdictive success of statistical analysis of yield trials. *Theoretical and Applied Genetics,* 76: 1-10.

Ghanbari J., and Khajoie Nejad G. R. (2014). Evaluation of yield and agronomic traits of cumin (*Cuminum cyminum* L.) ecotypes in different sowing dates at Kerman region. *Journal of Agroecology,* 6(1): 142-151.

Gomez K. A., and Gomez A. A. (1984). *Statistical procedures for agricultural research.* (2nd ed.). Wiley, New York.

Kafi M., Rashed Mohassel M. H., Koocheki A., Nassiri M. (2006). *Cumin (Cuminum Cyminum): Production and Processing*. Science Publishers,U.S., Enfield, New Hampshire.

Kamkar B., Koocheki A., Nassiri Mahallati M., Teixeira da Silva J. A., Rezvani Moghaddam, P., and Kafi M. (2011). Fungal diseases and inappropriate sowing dates, the most important reducing factors in cumin fields of Iran, a case study in Khorasan provinces. *Crop Protection*, 30: 208-215.

Kang M. S. (1993). Simultaneous selection for yield and stability in crop performance trials: consequences for growers. *Agronomy Journal,* 85: 754–757.

Kang M. S. (1998). Using genotype-by-environment interaction for crop cultivar development, *Advances in Agronomy,* 62: 199-252.

Lal R. K. (2013). Adaptability patterns and stable cultivar selection in menthol mint (*Mentha arvensis* L.). *Industrial Crops and Products,* 50: 176-181.

Lal R. K. (2015). Genotype selection for agronomical trait - seed yield in kewachh (Mucuna pruriens L.). *Industrial Crops and Products,* 65: 62-70.

Laux P., Jackel G., Munang Tingem R., and Kunstmann H. (2010). Impact of climate change on agricultural productivity under rainfed conditions in Cameroon. A method to improve attainable crop yields by planting date adaptations. *Agricultural and Forest Meteorology,* 150: 1258-1271.

Purchase J. L., Hatting H., and Vandeventer C. S. (2000). Genotype × environment interaction of winter wheat (*Triticum aestivum* L.) in South Africa: Π. Stability analysis of yield performance. *South African Journal of Plant and Soil,* 17: 101-107

Ramburan S., Zhou M., and Labuschagne M. (2011). Interpretation of genotype × environment interactions of sugarcane: Identifying significant environmental factors. *Field Crops Research,* 124: 392-399.

Rezvani Moghaddam P., Moradi R., and Mansoori H. (2014). Influence of planting date, intercropping and plant growth promoting rhizobacteria on cumin (*Cuminum cyminum* L.) with particular respect to disease infestation in Iran. *Journal of Applied Research on Medicinal and Aromatic Plants,* 1: 134-143.

Roostaei M., Mohammadi R., and Amri A. (2014). Rank correlation among different statistical models in ranking of winter wheat genotypes. *The crop journal,* 2: 154-163.

SAS Institute Inc. (2009). SAS/STAT® 9.2. Users Guide, second ed. SAS Institute Inc., Cary, NC.

Simmonds N. W. (1991). Selection for local adaptation in a plant breeding program. *Theoretical and Applied Genetics,* 82: 363-367.

Tumuhimbise R., Melis R., Shanahan P., and Kawuki. R. (2014). Genotype × environment interaction effects on early fresh storage root yield and related traits in cassava. *The crop Journal,* 2: 329-337.

Zhang X. L., Chun Y. Y., Ran X.U., Wei-Guo L., Yong Q., Li-Feng Z., Ru-Zhen C., and Li-Juan Q. (2011). Analysis of Adaptability of Soybean Mini Core Collection in Huang-Huai Rivers Region in China. *Acta Agronomica Sinica,* 37(3): 443-451.

Zobel R. W., Wright M. J. and Gauch H. G. (1988) Statistical analysis of a yield trial. *Agronomy Journal,* 80: 388-393.