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STABILITY AND ADAPTABILITY ANALYSIS IN SUGAR BEET VARIETIES FOR SUGAR CONTENT USING GGE-BIPLOT AND AMMI METHODS

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Abstract

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The genotype and environment interaction effects is important for plant breeding and release of new cultivars. The aim of this study was to evaluate the stability and compatibility of cultivars for sugar content and estimation of the genotype × environment effects in sugar beet cultivars under different climates using GGE biplot and AMMI methods. In order to study the interaction of genotype with environment, nine sugar beet cultivars in a randomized complete block design with four replications was evaluated in 6 regions in 2016. In based on the results of AMMI analysis, the effect of environment, genotype and interaction between theirs was significant at 1% probability level. In this method, the first main component of the interaction was significant and alone explained 67.87% of the total variation. The AMMI1 graph showed that ARAS 101 and JAAM genotypes had high stability and AMMI2 graph showed that the JAAM genotype is the most stable genotype. The GGE biplot graph explains 90.57% of total variations. The graph of sugar content against stability for genotypes, showed that (I13 * A37.1) * SH-1-HSF.5 genotype is the best genotype for stability. The biplot graphical technique divided the tested areas into three mega-environments and identified for each of the mega-environments different genotypes as stable genotypes. ARAS 101 genotype in the first mega-environment, BR1 genotype in the second, and (I13 * A37.1) * S1.88239, (I13 * KWS) * 302-HSF.20, 7233 genotypes in the third mega-environment had a high compatibility. The results of this study confirmed that the sugar content in sugar beet genotypes was largely influenced by environmental factors.

Key words: AMMI model; GGE biplot; mega-environment; stability; sugar beet

Introduction

The sugar beet (*Beta vulgaris* L.) is one of the most important sources of sugar production in the world specially Iran. In this plant, the amount of root sugar production depends on several factors, among factors, year and place of production play an important role in sugar production (Rahimiyan and Asadi, 1999). Due to the financial benefits of the sugar industry, some social benefits and the possibility of using its in the production of ethanol fuel, which has received considerable attention in recent years, cultivation of sugar beet continues to grow in many countries (Erdal et al., 2007). Stability refers to constant production (Stable performance) in different places and years (Fernandez, 1991). In breeding programs, genotypes should be evaluated in different environmental conditions, in other words, in different years and places, so that the information obtained from the estimation of the compatibility and stability of genotypes performance is a reliable criterion in recommending genotypes and provides the efficiency of selection and realization of cultivars (Ebdon and Gauch, 2002; Lin et al., 1986). The existence of interaction between genotype and environment decreases

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the efficiency of breeding methods and reduces the extent of cultivation of modified genotypes, thus forcing researchers to breed different genotypes for different locations (Becker and Leon, 1988; Crossa et al., 1990). Awareness of the nature of the interactions of the genotype and the environment helps the breeder to better evaluation the genotypes and select the superior genotypes for creating the high yield and stability (Lin et al., 1986; Gauch and Zobel, 1996; Cornelius and Crossa, 1999; Roy, 2000).

The biplot method is a very useful tool for visual evaluating the genotypes and interpreting the response pattern of the cultivars, environments and their interaction. Biplot is a graphical representation and simultaneous presentation of two variables. This method was first proposed by Gabriel (Gabriel, 1971) and its suitable graphical method was introduced for the analysis of large volumes of data by other researchers (Gauch, 2006; Shorter et al., 1991). The effects of genotype (G) and the interaction between genotype and environment (G × E), which together represent them as GGE, are important factors in selection of cultivars.

The additive main effect and multiplicative interaction model (AMMI) is an effective method for eliminating error and revealing the appropriate data pattern (Yan and Hunt, 2002). The reason for the widespread use of this method is why this model justifies a large part of the sum of squares of the interaction and separates the main effects from interactions effects (Ebdon and Gauch, 2002). Also, this approach is very useful in designing long-term corrective programs for specific adaptation and appropriation environment selection (Gauch and Zobel, 1996). Different researchers from different methods of stability analysis reported that AMMI is a reliable way to analyze the adaptive response, stability of cultivars and assign cultivars to different environments or locations (Gower and Hand, 1996; Crossa et al., 2001).

Tarakanovas and Ruzgas introduced the AMMI method as an effective method for studying the interaction of genotype and environment then reported that the results of the graphical method can select suitable cultivars under appropriate environments or specific environmental conditions (Tarakanovas and Ruzgas, 2006). In an experiment on ten genotypes of durum wheat in Spain for two years, several statistical methods used to study of the interaction between genotype and environment and according to results the regression method in comparison with AMMI has less performance for interpretation of the genotype and environment interactions (Rarrabti et al., 2003).

Shojaei and his colleagues evaluated the ten cultivars of canola in four regions using the GGE biplot method and they were identified the maga-environments and ranked the cultivars base on stability, general adaptability and specific adaptability (Shojaei et al., 2013).

During an experiment was doing on the eight of sugare beet monogerm varieties in 11 important cultivation area , Univers cv. and Hybrid 276 cv. were better than others (Ebrahimian et al., 2001). To study the interaction of the genotype per environment and stability analysis, an experiment was conducted on eight cultivars of sugar beet; different statistical methods were used to evaluate some traits include root yield, impure sugar yield, pure sugar yield, etc. Finally, IC cv. was compared with anothers, so that cultivars introduced as a completely stable variety in base of three traits of root yield, impure sugar yield and pure sugar yield (Keshavarz et al., 2001).

Moradi and colleagues in evaluating the genotype and environment interaction of the sugar beet monogerm cultivars using AMMI method, showed that about the grain yield, two first interaction components explain more than 99% of the data variance and in this study, Zarghan cultivar showed the highest general adaptability and Lattitia variety showed the least its (Moradi et al., 2012).

Huffman et al., studying nine sugar beet genotypes in 52 different environments over the past two years in Europe showed that the effect of environment, genotype and their interaction were 80%, 5%, and 3% of total variance, respectively (Hoffmann et al., 2009).

The aim of this study was to identify the stable cultivars, selection of cultivars with appropriate sugar percent and estimation of genotype- environment interaction in sugar beet cultivars in different climates using GGE biplot and AMMI methods.

Materials and Methods

In order to investigate the compatibility and stability of sugar beet cultivars, 9 sugar beet cultivars and hybrids were studied in six regions including Isfahan, Karaj, Kermanshah, Khoy, Mashhad and Moghan during crop season in 2016. Depending on the area, sowing operation was carried out in April and harvest operation counducted in November. The names of the used cultivars in experiment are presented in Table 1.

Sugar beet genotypes were evaluated in each environment in a randomized complete block design with four replications for measuring of the sugar content. Each plot includethree rows (8 meter long) and inter distance equal to 50 centimeter. The land preparation stages included deep plowing (In the fall of the previous year), surface plowing, disc, leveling operations and creating rows of cultivars. In the harvesting step, in order to remove the marginal effects, the first and the end of each row were set aside by 1 meter. Weeding was handled

Table 1
Sugar beet varieties and hybrids with their codes that studied in experiment

Row	Variety	Code
1	1571	G1
2	(I13*KWS)*302-HSF.20	G2
3	(I13*A37.1)*SH-1-HSF.5	G3
4	(I13*A37.1)*S1.88239	G4
5	7233	G5
6	IC	G6
7	BR1	G7
8	JAAM	G8
9	ARAS 101	G9

mechanically. Irrigation and harvesting procedures were performed according to the usual methods of each area. Analysis of variance was done by SAS software and graphical study of interaction between genotype and environment were conducted with base Yan and Hunt (2001) using GGE biplot software (Yan, 2001; Yan and Kang, 2003). Minitab software was used to draw AMMI1 and AMMI2 charts.

Results and Discussion

Bartlett's test was used to test the homogeneity of variance of experimental errors. Combined analysis of variance of root content percent showed that genotype, environment and their interaction, mean square was significant at 1% probability level. This indicates the diversity of genotypes in different environments. Significance of genotype and environment interaction based on AMMI stability method indicated that genotypes have different sugar content in different environments (Table 2). The effect of genotype, 1.47 percent of total sum of squares and environmental effects, accounts about 84.10 percent of total sum of squares, while the interaction of genotype with environment was 4.58 percent of total sum of squares. Gobatov et al., in a study on winter wheat, reported that the genotype had the lowest amount whereas location had the highest amount of total variance (Gubatov et al., 2017).

Table 2
Analysis of variance base AMMI model for sugar content in 9 sugar beet cultivars.

S. O. V.	df	SS	MS	SS%
Environment	5	2284.55	456.91**	84.10
Genotype	8	40.04	5.01**	1.47
Env × Gen	40	124.58	3.11**	4.58
IPCA1	12	84.56	7.04**	67.87
IPCA2	10	26.45	2.64ns	21.23
Noise	18	13.56	0.75	10.87
Error	159	261.09	1.64	
Coefficient of variation (%)		8.67		

**, ns: Significant at 1% probability level and not significant, respectively

In order to decompose the genotype × environment effect using AMMI model, the principal component analysis was performed on the remaining matrix, which the main component of the first interaction effect was significant ($p<0.01$). The first main component (IPCA1) explained 67.87% of the interaction sum of squares. The significance of the interaction component demonstrates the complex nature of the trait and indicate that this trait change in different environments. The second main interaction component was not significant and it was explain 21.23% of the interaction variance (Table 2).

To further examine the percentage of sugar and instability, the figures of the AMMI1 were plotted (Figure 1). In this figure, the vertical line in the middle of the graph represents the total average sugar percentage. The genotypes and locations in right hand of this line have sugar content above the average. According to this explanation, G9, G3, G8 and G7 genotypes, were placed in the right side of the perpendicular line in the middle of the biplot, have the highest sugar content percentage, respectively. According to this chart, G1 had the lowest sugar content. Also, among the locations, Kermanshah, Isfahan and Mashhad, had the highest average sugar percentage. Karaj had the lowest sugar content.

The horizontal axis in the middle of the graph indicates that there is no interaction (IPCA=0). The genotypes in the

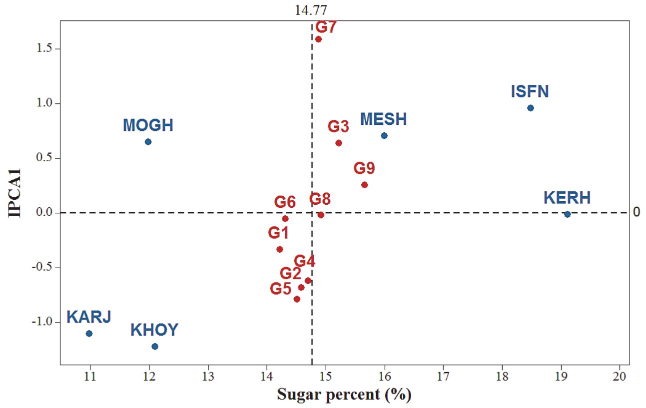

Fig. 1. AMMI1 biplot (Sugar percent vs. IPCA1 scores) for the genotypes across environments
Genotypes are labeled with G letter and number. Environmental codes are: ISFN (Isfahan), KRJ (Karaj), KERH (Kermanshah), KHOY (Khoy), MESH (Mashhad), MOGH (Moghan)

center of the graph with zero interaction were more stable. Therefore, the genotypes G8, G6, G9 and G1 have a low interaction effect, however, G9 and G8 with a mean sugar percenthigher than the total mean are known as desirable stability genotypes in compare to the rest of the cultivars. The genotype G7, which has the greatest distance from the source, has the highest diversity and the lowest stability (Figure 1).

The biplot chart of the first and second principal components of genotype × environment interaction for genotypes and environments (AMMI2) is presented in Fig. 2. Genotypes and environments are determined based on the values of the first and second main components of interaction of the genotype with the environment. The genotypes with the first and second main components of the interaction are close to the origin of the coordinates (close to zero) have the least interaction. This graph (the main component of the first and second interaction) in total explained more than 90% of the variation of the genotype and the environment interaction. In the separation of genotypes and places, the contribution of the first and second main interaction components was 67.87% and 21.23%, respectively.

In this chart, genotypes that near to a location are specific adaptibility to environment, and genotypes that are located near the components' axes have a general adaptability. Therefore G9 and G3 genotypes with Moghan and Mashhad, G7 genotype with Isfahan, G5, G1 and G6 genotypes with Kermanshah and Khoy and Karaj with G8 and G4 genotypes have specific adaptability. The G8 genotype has a high degree of general adaptability because it is close to the origin of the coordinates (Figure 2).

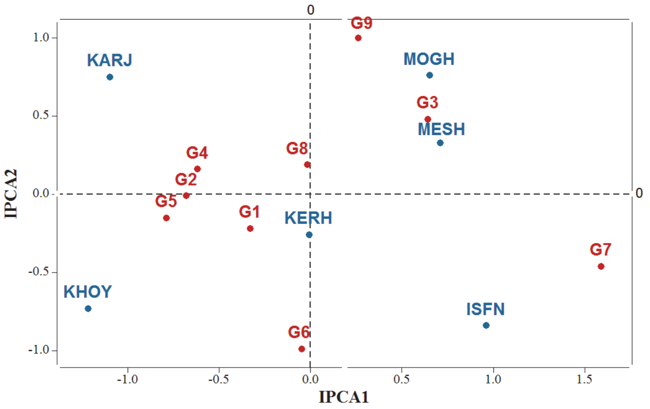

Fig. 2. AMMI2 biplot (IPCA1 vs. IPCA2 scores) for the genotypes across environments

Genotypes are labeled with G letter and number. Environment codes are: ISFN (Isfahan), KRJ (Karaj), KERH (Kermanshah), KHOY (Khoy), MESH (Mashhad), MOGH (Moghan)

The GGE biplot graph explained 90.57% of the total variation (PC1=60.34%, PC2=30.23). In other words, the sum of these two components could explain 90.57% of the changes in the sugar percentage, which indicates the reliability of the results of the biplot graph. The ranking of the cultivars based on the mean sugar percentage and the stability of the genotypes is shown in Figure 3. Ranking of genotypes were G9, G3, G8, G7, G4, G2, G5, G1 and G6, respectively. The G7 genotype due to the distance from the middle axis was the most unstable genotype is consistent with the results of the AMMI1 and AMMI2 graphs. The genotype G9 has the highest sugar content and has a consistent stability that matches the results of the AMMI1 graph but does not match to the results of the AMMI2 graph. Such differences are common and observed in studies by other researchers (Gubatov et al., 2017; Agyeman et al., 2015). The G8 genotype in the middle of the graph has mean sugar content, but has a high stability (Figure 3).

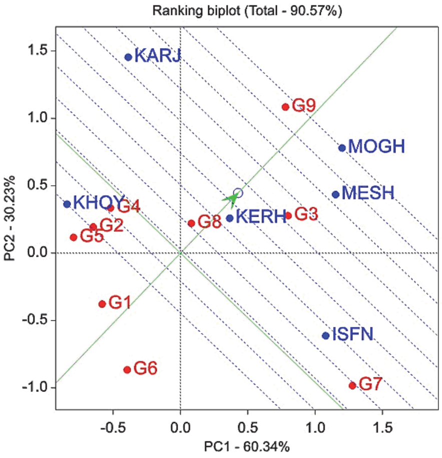

Fig. 3. Ranking biplot base mean and stability for genotypes

Genotypes are labeled with G letter and number. Environmental codes are: ISFN (Isfahan), KRJ (Karaj), KERH (Kermanshah), KHOY (Khoy), MESH (Mashhad), MOGH (Moghan)

According to Figure 4, genotypes G9 in Karaj, Moghan, Mashhad and Kermanshah, G7 genotype in Isfahan region, G4, G2 and G5 genotypes in Khoy had the highest specific adaptability and the highest sugar content. G1 and G6 genotypes produced low sugar content anywhere (Figure 4).

Figure 5 is used to grouping the environments and determines the mega-environments. This chart divides the studied areas into three mega-environments. Karaj, Kermanshah, Moghan and Mashhad, as the first mega-environment, Isfahan was recognized as the second mega-environment and

Khoy as the third mega-environment. In the first mega-environment, the G9, G3 and G8 were the best cultivars. In the second mega-environment, G7 was the best cultivar and in the third mega-environment G2, G4 and G5 were the best genotypes (Figure 5).

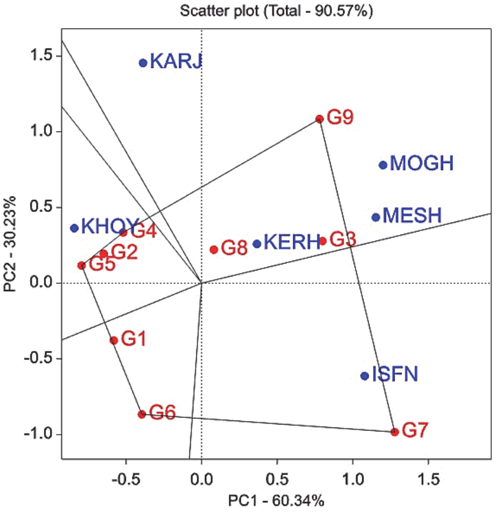

Fig. 4. Polygon view for genotype-by-environment interaction interpretation

Genotypes are labeled with G letter and number. Environmental codes are: ISFN (Isfahan), KRJ (Karaj), KERH (Kermanshah), KHOY (Khoy), MESH (Mashhad), MOGH (Moghan).

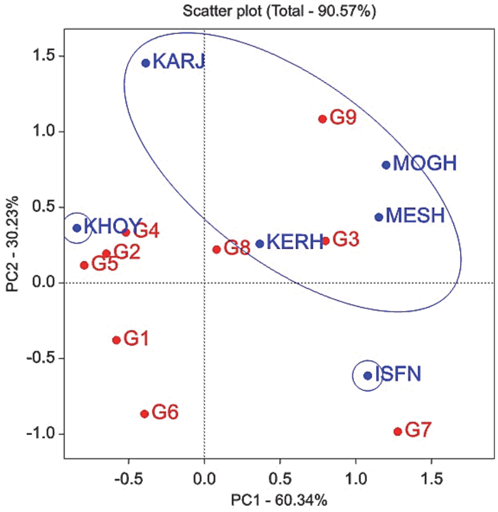

Fig. 5. Biplot figure for identification of mega-environments between locations

Genotypes are labeled with G letter and number. Environmental codes are: ISFN (Isfahan), KRJ (Karaj), KERH (Kermanshah), KHOY (Khoy), MESH (Mashhad), MOGH (Moghan)

Correlations and relationships between environments are shown in Figure 6. The smaller angle between the environment vectors, indicate the greater correlation between those environments. There was a high correlation between Kermanshah, Moghan and Mashhad locations. Correlation between Karaj and Mashhad is near zero, which indicates the dissimilarity of these two environments for climate conditions in relation to the sugar percentage, In other words, genotypes in these two location have an independent response. In Karaj and Isfahan, Moghan and Khoy, Kermanshah and Khoy, Mashhad and Khoy and Isfahan with Khoy were negative correlated, so genotypes have a different process in these environments (Figure 6).

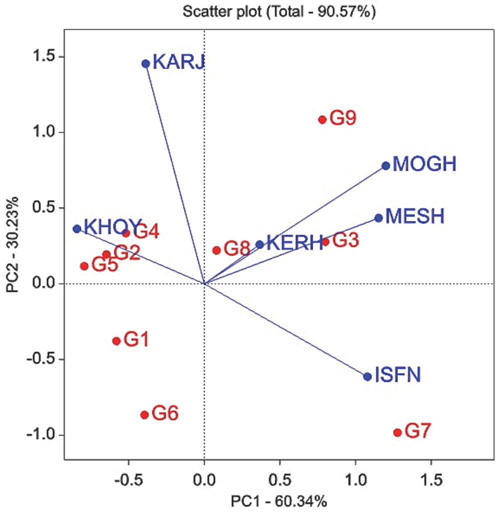

Fig. 6. Biplot figure for determination relationship between environments

Genotypes are labeled with G letter and number. Environmental codes are: ISFN (Isfahan), KRJ (Karaj), KERH (Kermanshah), KHOY (Khoy), MESH (Mashhad), MOGH (Moghan).

Conclusion

Due to the geographic diversity of Iran, such studies could be useful for optimum use of resources and maximum production. The significance of the environmental effects and the interaction between the genotype with environment indicates that the introduction of similar cultivars is not correct for all environments and it is necessary to introduce the appropriate cultivar for each environment. Also distribution of cultivars in this biplot graph confirms.

The biplot and AMMI diagrams explain a high variance percentage (90.79 and 89.1%, respectively), which indicates the reliability of the results. For stability and adaptability of the cultivars, there was a good match between the results of these two methods. These two methods illustrated well the behavior of cultivars in different environments and provided valuable information about the planting of appropriate cultivars in each region. Planting the adequate cultivar in each area avoids waste of resources and increases production. Ranking and grouping of cultivars and regions makes it possible to in subsequent studies for some cultivars and areas has been shown the same reaction reduce the size of the experiment. This order can reduce costs and increase the accuracy of the test.

Three mega-environments were detected in this experiment. The first mega-environments comprise Moghan, Kermanshah, Karaj and Mashhad. In this mega-environment, the genotypes G3, G8 and G9 shown the best response. The second mega-environment includes Isfahan, where the genotype G7 known as the best genotype. Finally, the third mega-environment was Khoy that G2, G3 and G5 genotypes had the highest sugar percentage.

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