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Stability and Compatibility of some Iranian Eggplant (*Solanum melongena* L.) Lines using AMMI Method

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ABSTRACT

Eggplant has high variation in the world and there are many landraces of the eggplant in Iran. In the previous studies, five landraces of Minab's eggplant have been collected from the main production regions with the aim to select the pure lines, consequently 15 superior genotypes were selected from these landraces and their stability and compatibility were analyzed. In the present study, 15 eggplant genotypes together with two superior mother landraces were studied for the two successive years in the three regions of Iran including Minab, Karaj, and Jiroft. Based on the results of the means comparison of yield in the studied lines in each region from average of two years, GHE12 line in Minab region, SA13 line in Jiroft region, and AM4, SA15, and SA5 lines in Karaj region had acceptable yield than the other studied lines. According to the results of general compatibility and stability analysis, the three genotypes of Y7, AM7 and SA15 were recognized as the most stable genotypes with having the least interaction; therefore, they categorized as the first ranking of stability. According to the results of special compatibility and stability analysis, AM7, Y7 and GHE12 lines for Minab region; AM5 and SA5 lines for Jiroft region and SA5 and AM4 lines for the Karaj region can be recommended.

Introduction[*]

Eggplant (*Solanum melongena* L., Solanaceae family) is one of the crops that its cultivation economically requires a high cost and therefore the measures should be taken to incresae yield of this crop (Ranil et al., 2017). The eggplant yield, especially marketable yield, is low in the internal landraces because the internal landraces don't have uniform fruits and the main of the produced yield lost as wastage. There is sizeable genetic diversity in eggplant in Iran. In the south regions of Iran, the eggplant is produced by seed preparation from landraces

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but the mother plants are selected without especial accuracy, so that the obtained crop from these landraces doesn't have desirable status in respect of marketability and they can not compete with the top cultivars of the foreign companies. Cultivation of the top cultivars of the foreign companies has been a simple method to enhance the yield for many years, but their seed price is high and sometimes not available. Therefore, planning and performing for breeding research on Iranian eggplant landraces is so necessary and inevitable.

According to the reports of International Breeding Plant Genetic Resources (1985), varietal collections of eggplant landraces were collected from Nepal, Syria, Sudan, Spain, Zaire and Muris island and it seems some countries such as Pakistan, Iran and iraq are among this geographical chain and existence of varietal landraces in the mentioned countries is probable. Landraces of self-pollinated plants are mixture of pure lines, which they are considered valuable germplasms and contain resistance genes against biotic and abiotic stresses (Vojdani, 1993).

Eggplants are species of economic importance mainly in Asian and African countries and widely cultivated in America and Europe. Professional growers consider the necessity of introducing new varieties, particularly hybrids, breeding for very high quality production, in different climatic zones (Sekara et al., 2007; Plazas et al., 2013). Individual selection is used to isolate the desirable lines from the landraces of the self-pollinated vegetables and this method is one of the most effective procedures to using the presence germplasms. Desirable lines and varieties of tomato were introduced with the use of this method (Kalloo, 1988). Individual selection method has been used in the self-pollinated vegetables in USA (Androus, 1963). Ram (2006), recommended the individual selection method to achieve the pure lines in the collected eggplant landraces from farmers fields.

Negi et al. (2000), assessed the genetic diversity among 40 eggplant genotypes using 21 traits and they found the high genetic variation in the some characteristics such as the number of fruit per plant, the yield of fruit in the plant, and the amount of the fruit set; and many of the characteristics showed high heritability (more than 70%). Mohanty (1999), examined 25 eggplant genotypes in terms of the yield, the average of fruit weight, and the number of fruit per plant. He found that phenotypic coefficient of variation (PCV) was higher than genotypic coefficient of variation (GCV) in the all traits. The number of fruits and their weight increased by simple mass selection. Prohens et al. (2007), assessed the phenolic content and sensitivity to browning in an eggplant collection and they observed proper variation to improve alimentary quality and reduction of browning. They reported that may select new varieties with more phenolic content and the moderate degrees of browning by using the present variation in the available eggplants.

Bagheri et al. (2012), in the selection of the pure line from the Iranian landraces of eggplant in the north of Iran, evaluated 36 selective lines from the five Iranian landraces and finally selected the five lines to perform compatibility and stability trials. Kumar et al. (2016), evaluated the different hybrid combinations of eggplant in respect of the fruit yield and reported that the assessed hybrids can be used for commercial utilization. Plazas et al. (2013), selected the eggplant genotypes based on the amount of Chlorogenic acid (an important antioxidant resource).

Generally, the eggplant landraces are valuable germplasms for production especial hybrids with the ability of proper compatibility with the environmental conditions. According to Roudriguez-Buiui et al. (2008) the eggplant hybrids derived from the native parent genotypes can be compete with the commercial hybrids in the respect of yield and lead to increase diversity in the fruit type. Oluoch and Chadha (2007) checked the 41 selective eggplant lines in Tanzania in the respect of yield and yield components.

Generally, considerable genetic variability occurs in the landraces of eggplant. These landraces preserved the specific number of important properties in the genetic improvement of eggplant. The landraces may be illustrate the resistance or tolerance to the some biotic stresses. Bagheri et al. (2016), selected 22 superior lines using the stability analysis via AMMI method in the assessment the selective lines from the Iranian eggplant landraces for the future breeding programmes in terms of the yield and qualitative parameters. Yazdi-Samadi et al. (1998), reported that in the experiments to introduce the agricultural varieties, to evaluate compatibility and stability of the desirable genotypes, it is often necessary the genotypes must be evaluated in several regions for several years and the obtained results must be analyzed by combined analysis. Ehdaei (1995), divided the compatibility into two categories: private and general; and stated that if a genotype performs well in one location but is not desirable in another locations, it has the private compatibility and if a genotype has been moderate performance in the most environments but in neither of the environments does it have high performance, it has the general compatibility.

The crop sustainability assessment methods are grouped into 4 categories including variance analysis, regression methods, nonparametric methods and multivariate methods. However, the multivariate methods provide more comprehensive information on the interaction and environmental variability (Crossa, 1990). Among these methods, the AMMI method is important for the studying genotype and environment interactions because this model breaks down the interaction with a powerful statistical method. Gauch and Zobel (1997), used the AMMI method to take advantage of both the cumulative (variance analysis) and the multiplicative (principal components) models. The AMMI model is a combination of the analysis of variance and the principal component analysis. In this model, the main effects of genotypes and environment are estimated using ordinary variance analysis (main additive effects) and then the interaction between the genotype and environment are analyzed using the principal analysis components (multiplicative Interactions). This method can be used to reduce the number of replicates and thus save the cost of the use more replications (Farshadfar, 1998). The AMMI model improves the accuracy of the crop yield evaluation and the selection of higher-yield genotypes and it is more effective in the identifying highly stable and high-yield genotypes in the multiple environmental trials compared to the other sustainability methods (Gauch, 1992).

Due to the high percentage of self-pollination in the eggplant, it is possible to achieve the varieties with a uniform product and the optimal yield by performing a pure line selection breeding method. Collection and breeding program of Minab's eggplant landraces started in 2013-2014 and five landraces after collection from different regions of Minab, were subjected in a three-year project to select pure line. After the end of the third year, the top 15 lines were selected from the mentioned landraces (Hasanzadeh Khankahdani, 2016). By reaching this stage, it was necessary to evaluate the compatibility and stability of these lines in order to select and introduce the best superior lines for the susceptible regions as well as the specific superior lines for the specific regions. For this purpose, for the two consecutive years, in the three regions of Minab, Karaj and Jiroft, 15 genotypes of the round eggplant selected from the five local Minab landraces, along with the two superior local mother masses (in total 17 genotypes) in the different regions and years for the compatibility and stability were studied.

Materials and Methods

This study was conducted in the three regions with the characteristics listed in Table 1 in the two consecutive years 2016-2017 and 2017-2018.

Table 1. Geografical and ecological properties of the three studied regions

Region (Province)	Latitude	Longitude	Altitude (m)	Minimum temperature (°C)	Maximum temperature (°C)
Minab (Hormozgan)	27° 06´ 23´´	57° 05´ 34´´	31	24.2	34.0
Jiroft (Kerman)	28° 32´ 60´´	57° 51´ 51´´	633	12.3	33.6
Karaj (Alborz)	35° 47´ 29´´	50° 56´ 42´´	1281	8.7	21.1

The seeds of 15 round eggplant genotypes selected from Minab landraces were planted along with two local mother masses (Y and AM) in the nursery in Minab in the mid-July, Karaj in the March and Jiroft in the mid-December. The lists of the studied genotypes are presented in Tables 2 and 3 and Figure 1.

Table 2. The studied eggplant genotypes and native mother masses

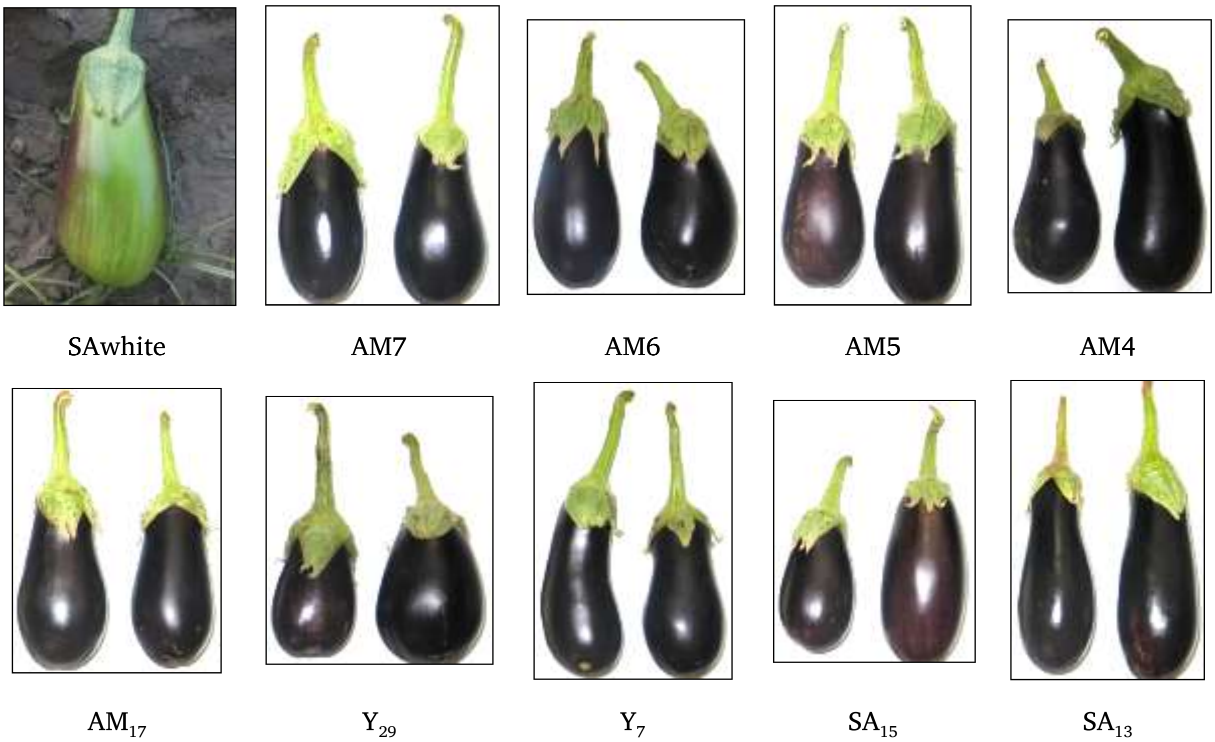
Code	Genotype	Description
1	Y	Mother mass- Tiroor region 2 (Yazdani field)
2	AM	Mother mass- Domshahr region (Abbasi Musa field)
4	SAwhite	Selective single plant in the second year with variegated fruit from SA mother mass
5	AM_7	Selective genotype from AM mother mass [Domshahr region (Abbasi Musa field)]
6	AM_6	Selective genotype from AM mother mass [Domshahr region (Abbasi Musa field)]
7	AM_5	Selective genotype from AM mother mass [Domshahr region (Abbasi Musa field)]
8	AM_4	Selective genotype from AM mother mass [Domshahr region (Abbasi Musa field)]
9	AM_{17}	Selective genotype from AM mother mass [Domshahr region (Abbasi Musa field)]
10	Y_{29}	Selective genotype from Y mother mass [Tiroor 2 region (Yazdani field)]
12	Y_7	Selective genotype from Y mother mass [Tiroor 2 region (Yazdani field)]
13	SA_{15}	Selective genotype from SA mother mass [Tiroor 1 region (Salari Ali field)]
14	SA_{13}	Selective genotype from SA mother mass [Tiroor 1 region (Salari Ali field)]
15	SA_5	Selective genotype from SA mother mass [Tiroor 1 region (Salari Ali field)]
16	SA_{20}	Selective genotype from SA mother mass [Tiroor 1 region (Salari Ali field)]
17	GHE_{26}	Selective genotype from GHE mother mass [Gowarban region (Ghasemi Ebrahim field)]
18	GHE_{25}	Selective genotype from GHE mother mass [Gowarban region (Ghasemi Ebrahim field)]
19	GHE_{12}	Selective genotype from GHE mother mass [Gowarban region (Ghasemi Ebrahim field)]

It should be noted that in the compatibility and stability tests, the evaluation of the selected lines is based on the amount of the yield. In our previous (Hassanzadeh Khankahdani., 2016) the quantitative and qualitative traits of the fruit and other characteristics of each line were examined and the top lines were selected. A summary of morphological features is provided in Table 3.

Table 3. Morphological properties of the studied eggplant genotypes and native mother masses

Row	Characteristics	Status
1	Plant growth habit	Erect in all genotypes
2	Stem anthocyanin	None in all genotypes
3	Thorny calyx	None in AM_4, SA_{13} and SA_{20} genotypes
4	Calyx anthocyanin	Only in AM_6, AM_4, AM_{17}, SA_{20}, GHE_{26} and GHE_{25} genotypes
5	Below calyx anthocyanin	None in Y, SAwhite and SA_{15} genotypes
6	Fruit peel color in ripening stage	dark purple in all genotypes, Streaked in SAwhite
7	General fruit shape	Pear-shaped in all genotypes
8	Pulp fruit color	Whitey in all genotypes

The necessary cares was taken in the nursery such as irrigation, fertilization, weed control, and pests (including birds and grasshopper). The main field preparation was done based on the custom of each area including plowing (late of August in Minab, May in Karaj and early January in Jiroft) and double discs perpendicular. Then it was created the furrows with 0.3 m width and 1.5 m distance apart from each other using furrower. The length of each planting line was 7.5 m in each plot and the blocks intervals were 3 m. At the bottom of the furrows, an irrigation strip with 30 cm drop intervals was installed.



SA_5 SA_{20} GHE_{26} GHE_{25} GHE_{12}

The transplants were planted in the randomized complete block design with the three replications on either side of the furrow as alternate. The transplanting to the main field was done in the Minab region in the late August, in the Karaj region in mid-May, and in the Jiroft region in late January, so that 26 transplants from each genotype in each plot and a total of 78 transplants were planted. During the project, the harvest was recorded in each plot according to the appropriate time of marketing. The first date of harvest time in Minab region was in late November, in Karaj region in late July and in Jiroft region in late April and the harvest continued in Minab region until mid-April, in Karaj region in late September and in Jiroft region in early July.

Statistical Analysis

The Kolmogorov-Smirnov and Shapiro-Wilk tests were utilized using SPSS 20.0 software to evaluate the normality of the recorded data (Park, 2006). After making sure the data were normal, combined analysis of variance was performed using SAS 9.1 software, and the means were compared by PLSD ($p < 0.05$). To evaluate the compatibility of the lines to different regions, AMMI stability analysis was performed and the superior genotypes were selected.

Results

Analysis of variance

According to the results of the combined analysis of variance in relation to the yield of the studied genotypes, it was no observed significant difference between two years (F value = 0.08^{ns}). There was a signifiant difference among the three regions (F value = 43.8^{**}). Furthermore, a significant interaction was observed between year and region (F value = 5.29^{*}), which showed the difference in the results from the regions in the two years of the experiment. It was observed a significant difference among the eggplant genotypes (F value = 4.96^{**}). Moreover, there was a significant interaction between the region and eggplant genotypes (F value = 3.20^{**}), which showed the difference between the eggplant genotypes in the studied regions (Table 4).

Table 4. The combined analysis of variance for the yield data of the 17 advanced eggplant genotypes in the three regions including Minab, Karaj and Jiroft during the two successive years

Source of variation (S.V)	Degree of freedom (D.F)	Mean of Square (M.S)
Year (Y)	1	6.6^{ns}
Region (R)	2	3474.5^{**}
Year × Region (YR)	2	419.6^{*}
Error	12	79.3
Eggplant Genotype (G)	16	138.7^{**}
Year × Genotype (YG)	16	17.3^{ns}

Source of variation (S.V)	Degree of freedom (D.F)	Mean of Square (M.S)
Region × Genotype (RG)	32	89.4^{**}
Year × Region × Genotype (YRG)	32	23.9^{ns}
Error	192	27.9
Total	305	C.V% = 24.6

^{ns}Not significant, *Significant at $p<0.05$, **Significant at $p<0.01$.

The mean comparison of the yield in each region for the two years

In the assessment of the yield during two years of the experiment in the three regions, in the first year the yield in Minab region was significantly higher than in the other two regions and no significant difference was observed between Jiroft and Karaj regions. In the second year, the yield was highest in Minab region and the lowest in Jiroft region and there was a significant difference among the three regions. Except for the Karaj region, where the yield was significantly higher in the second year than in the first year, there was no significant difference between the two years of the experiment in the Minab and Jiroft regions (Fig. 2).

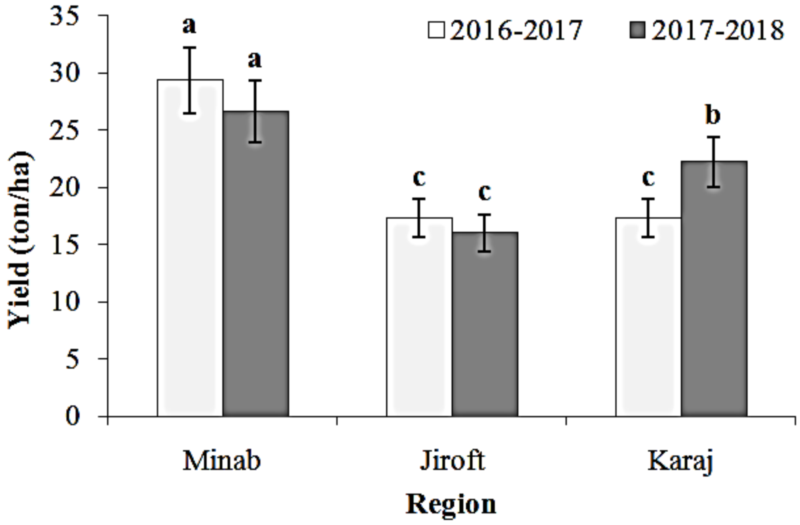


Fig. 2. The yield of eggplant as influenced by the interaction of year and region

The mean comparison of the genotype's yield in each region

Based on the results of the mean comparison of the yield in the studied genotypes in the three regions, the differences between genotypes in each region had no similar trend (Table 5). In Minab region, during the two years of the experiment, Y mother mass with average of 42.36 ton/ha produced the highest yield, followed by GHE_{12} genotype with 36.51 ton/ha and no significant difference was observed among them. The SA_{13}, SA_{20}, Y_7 and AM_7 genotypes were in the second statistical class with 33.07, 32.93, 31.85, and 31.08 ton/ha, respectively. In this respect, AM_6, Y_{29}, GHE_{26}, GHE_{25},SA_5, SAwhite and AM_{17} genotypes produced the lowest yield with 21.25, 22.76, 22.89, 23.14, 23.17, 23.73 and 24.41 ton/ha, respectively. Both Y_7 and Y_{29} genotypes had significantly lower yield than their parent (Y). However, the genotypes derived from AM genotype did not have a significant difference with their parents. In genotypes derived from GHE mother mass, the yield in GHE_{12} genotype was significantly higher than the other two genotypes (GHE_{25}

and GHE_{26}). Among the genotypes derived from SA mother mass, the highest yield was obtained from SA_{13} genotype (33.07 ton/ha) and the lowest yield from SA_5 genotype (23.17 ton/ha). In this regard, a significant difference was observed between SA_{13} genotype with SA_5 and SA_{15} genotypes (Table 5).

In Jiroft region, during the two years of the experiment, Y mother mass with average of 22.11 ton/ha produced the highest yield, followed by SA_{13} genotype with 20.60 ton/ha and no significant difference was observed between them. In this region, the difference among many of the genotypes was not significant. The lowest yield was observed in the genotypes of SA_{15}, Y_{29} and GHE_{26} and AM mother mass with 13.38, 14.02, 14.10 and 14.11 ton/ha, respectively. Similar to the Minab region, in Jiroft region also both Y_7 and Y_{29} genotypes had significantly lower yield than their parent (Y). However, the yield of genotypes derived from AM mother mass were non-significantly higher than their parents. In genotypes derived from GHE mother mass, the yield in GHE_{12} genotype was higher than the other two genotypes (GHE_{25} and GHE_{26}) but there was no significant difference among the three genotypes. Among the genotypes derived from SA mother mass, the highest yield was obtained from SA_{13} genotype (20.60 ton/ha) and the lowest yield from SA_{15} genotype (13.38 ton/ha). In this regard, only significant difference was observed between SA_{13} and SA_{15} genotypes (Table 5).

Table 5. Comparison among the yield of the eggplant genotypes in three regions of Minab, Jiroft and karaj, Iran

Region Eggplant genotypes	Minab	Jiroft	Karaj	F value	P value
Y	42.36^{aA}	22.11^{aB}	17.47^{cdeB}	37.6	< 0.0001
AM	26.44^{deA}	14.11^{cB}	21.02^{bcdA}	8.21	0.0004
SAwhite	23.73^{eA}	17.14^{abcB}	19.98^{bcdeAB}	2.35	0.0442
AM_7	31.08^{bcdA}	16.56^{abcB}	17.25^{cdeB}	14.41	< 0.0001
AM_6	21.25^{eA}	15.10^{bcB}	15.88^{deAB}	2.41	0.0428
AM_5	26.70^{deA}	19.39^{abcB}	14.87^{eB}	7.65	0.0006
AM_4	26.18^{deA}	18.78^{abcB}	28.08^{aA}	5.19	0.0064
AM_{17}	24.41^{eA}	14.61^{bcB}	21.13^{bcdA}	5.35	0.0055
Y_{29}	22.76^{eA}	14.02^{cB}	16.65^{deB}	4.31	0.0147
Y_7	31.85^{bcdA}	16.06^{bcB}	20.07^{bcdeB}	14.5	< 0.0001
SA_{15}	26.99^{cdeA}	13.38^{cB}	24.02^{abA}	11.0	< 0.0001
SA_{13}	33.07^{bA}	20.60^{abB}	21.00^{bcdB}	10.8	< 0.0001
SA_5	23.17^{eA}	18.96^{abcA}	24.05^{abA}	1.59	0.2064
SA_{20}	32.93^{bcA}	15.79^{bcC}	22.93^{abcB}	15.9	< 0.0001
GHE_{26}	22.89^{eA}	14.10^{cB}	15.60^{deB}	4.75	0.0097
GHE_{25}	23.14^{eA}	15.69^{bcB}	18.47^{bcdeAB}	3.04	0.0401
GHE_{12}	36.51^{abA}	17.10^{abcB}	17.40^{cdeB}	26.6	< 0.0001
F value	7.23	2.37	2.76	-	-
P value	< 0.0001	0.0442	0.0005	-	-

Means having same small letters in each column (for comparing genotypes in each region) and the means having same capital in each row (for comparing regions in each genotype) are not significantly different according to PLSD ($p < 0.05$).

In Karaj region, during the two years of the experiment, AM_4 genotype with average of 28.08 ton/ha produced the highest yield, followed by SA_5, SA_{15} and SA_{20} genotypes with

24.05, 24.02 and 22.93 ton/ha, respectively, and no significant difference was observed among them. The lowest yield was observed in the genotypes of AM_5, GHE_{26}, AM_6 and Y_{29} with 14.87, 15.60, 15.88 and 16.65 ton/ha, respectively. In this region both Y_7 and Y_{29} genotypes had no significant difference with their parent (Y). In the genotypes derived from AM mother mass only the yield of AM_4 genotype was significantly higher than its parents. In genotypes derived from GHE mother mass, the yield in GHE_{25} genotype was higher than the other two genotypes (GHE_{12} and GHE_{26}) but there was no significant difference among the three genotypes. Among the genotypes derived from SA mother mass, the highest yield was obtained from SA_5 genotype (24.05 ton/ha) and the lowest yield from SAwhite genotype (19.98 ton/ha) but it was no observed significant difference between these genotypes (Table 5).

Comparing the mean yield of each eggplant genotype in the three studied regions indicated that the yield of SA_5 genotype in Karaj, Minab and Jiroft were 24.05, 23.17 and 18.96 ton/ha, respectively and were not significantly different. In the AM_4 genotype, average yield in the Karaj and Minab regions were 28.08 and 26.18 ton/ha, respectively and there was no significant difference between these two genotypes, but the yield of this genotype in both mentioned regions was significantly higher than that of Jiroft region (18.78 ton/ha). In the other genotypes and two mothe mass, the average yield in the Minab region was higher than the other two regions. In SA_{20} genotype, there was a significant difference between average yield of three regions (Table 5).

Stability analysis by AMMI method

According to the biplot diagram (Fig. 3), the yield against the first component ($AMMI_1$ model), genotype 7 (AM_5), and then the three genotypes 12 (Y_7), 5 (AM_7) and 13 (SA_{15}) with having the lowest interaction, the most stable genotypes were identified, so they were ranked first in term of stability. However, genotype 7 (AM_5) was lower in yields (20.317 ton/ha) than overall mean (21.267 ton/ha), but the next three genotypes [12 (Y_7), 5 (AM_7) and 13 (SA_{15})] were higher in yield than total average (22.659, 21.629 and 21.462 ton/ha, respectively). Therefore, Y_7, AM_7 and SA_{15} genotypes have high selectivity. Genotypes 1 (Y), 8 (AM_4) and 19 (GHE_{12}) exhibited the least stability with the highest level of interaction (Fig. 3). The highest average yield was in Minab region (27.967 ton/ha) and the lowest average yield was in Jiroft region (16.676 ton/ha).

In this model, genotypes that are closer to the AMMI biplot center have less genotype-environment interaction and are more generally stable, so would be recommended for most regions. In contrast, far-centered genotypes have private stability (Gucci and Zubel, 1997). Therefore, genotype 7 (AM_5) and then three genotypes including 12 (Y_7), 5 (AM_7) and 13 (SA_{15}) are considered as stable genotypes and the latter three genotypes (Y_7, AM_7, and SA_{15}) with the suitable yield are introduced and these genotypes are recommended for all tested regions.

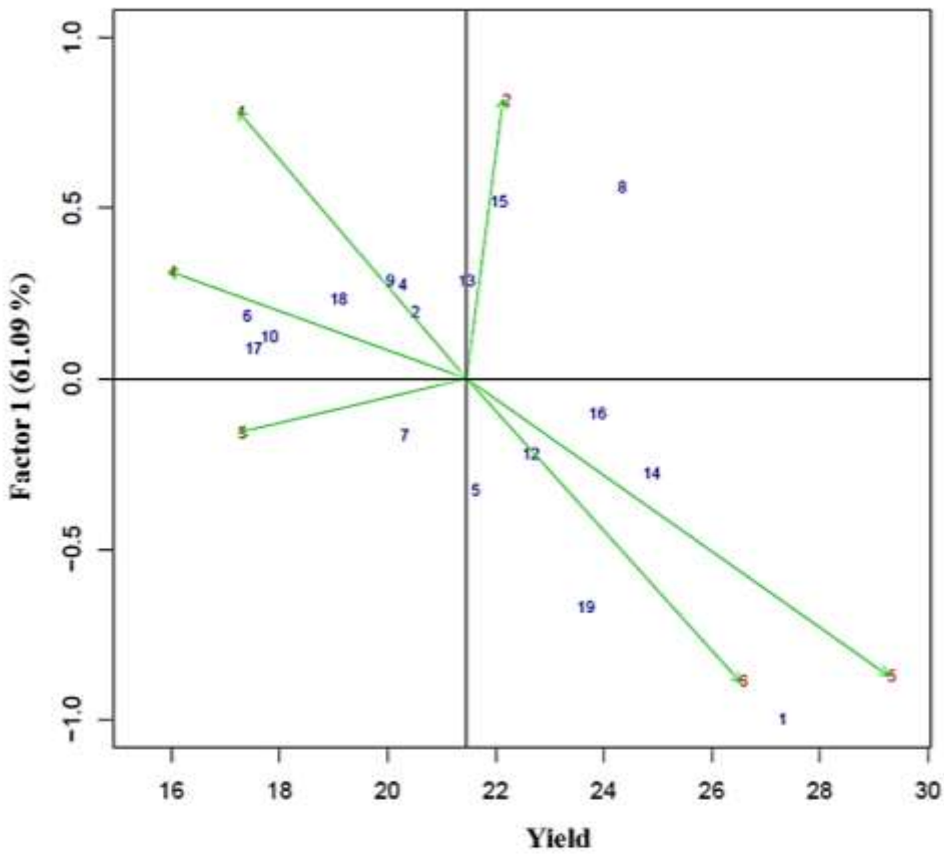


Fig. 3. Two-faced graph showing the mean of the eggplant genotypes yield, environments and their main components (AMMI1 model) during two years. [(Red numbers 1, 2: the first and second years in Karaj region; 3, 4: the first and second years in Jiroft region; 5, 6: the first and second years in Minab region); (Blue numbers: Eggplant genotypes code according to Table 2)].

In order to investigate the private compatibility of the genotypes with the studied regions, the AMMI2 model was used, which was generated by plotting the first two principal components (Factor 1 & Factor 2). In this biplot, genotypes 15 (SA_5) and 8 (AM_4) in Karaj region, genotype 7 (AM_5) and 15 (SA_5) in Jiroft region, and genotypes 5, 12, and 19 (AM_7, Y_7 and GHE_{12}, respectively) in Minab region were identified as the superior genotypes for each region. In other words, these genotypes showed the best response in each studied regions and were highly compatible with these regions (Fig. 4). Based on the results of the AMMI test and also according to the yield per genotype in each region, generally, genotypes 15 (SA_5) and 8 (AM_4) for Karaj region, genotypes 7 (AM_5) and 15 (SA_5) for Jiroft region and genotypes 5, 12 and 19 (AM_7, Y_7, and GHE_{12}, respectively) for Minab region are recommended.

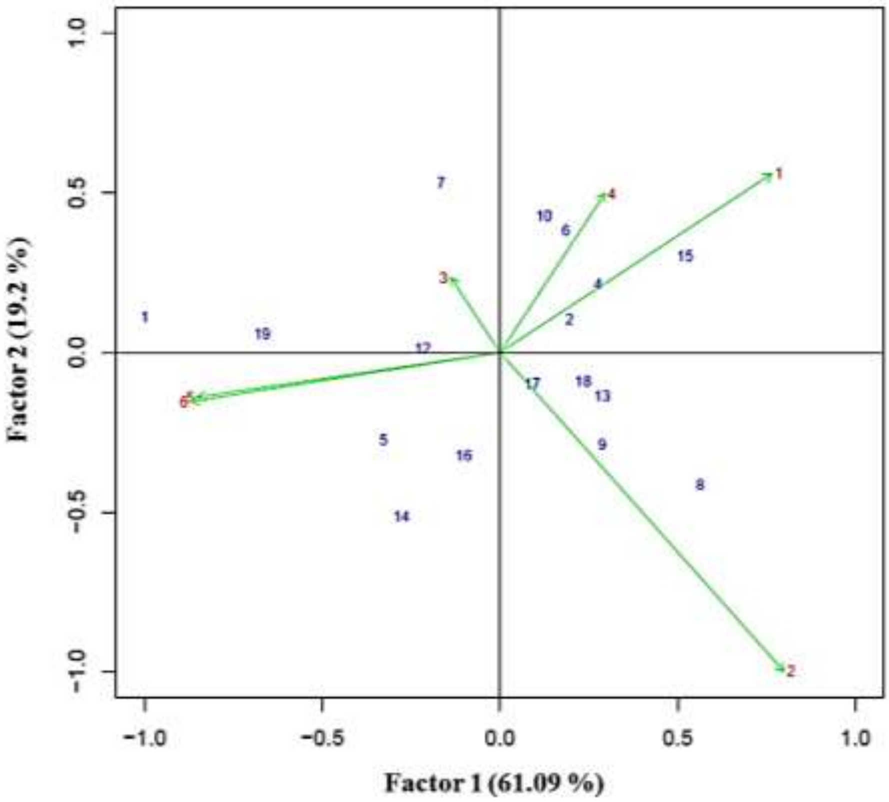


Fig. 4. Two-faced graph based on the AMMI2 model. [(Red numbers 1, 2: the first and second years in Karaj region; 3, 4: the first and second years in Jiroft region; 5, 6: the first and second years in Minab region); (Blue numbers: Eggplant genotypes code according to Table 2)].

Discussion

Since the crop cultivars show different responses under different environmental conditions and therefore it is inferred that there are usually interactions between genotype and environment, therefore, for the controlling these environmental effects, the compatibility testing of the genotypes should be performed during many years in the different places (Hashemi et al., 2018). For analyzing the regional yield comparison experimental data, the statistical methods such as GGE biplot, AMMI and principal components analysis (PCA) are used to determine the stability and compatibility of the genotypes based on the analysis of singular value decomposition (SVD) (Gauch, 2006). For example, GGE biplot and AMMI model has been used in the recent years as a powerful analytical tool for the studying genotype-environment interactions (Yan and Kang, 2003). The AMMI method is an efficient method with the graphical interpretation capability based on one and two main components and the ability to be interpreted by its parameters (Shadpour et al., 2010). In a study of the interaction between genotype and environment in corn hybrids, Albert (2004) compared the different methods of the stability analysis, but finally introduced the AMMI model as the most suitable method for the assessment of stability.

Based on the results of our study, GHE_{12} genotype in Minab region, SA_{13} genotype in Jiroft region and AM_4, SA_{15} and SA_5 genotypes in Karaj region had the acceptable yield compared to other genotypes. However, based on the compatibility and stability analysis, AM_7, Y_7 and GHE_{12} genotypes for Minab region, AM_5 and SA_5 genotypes for Jiroft region, and SA_5 and AM_4 genotypes for Karaj region are recommended. Therefore, based on the results of two tests, GHE_{12} and Y_7 genotypes in Minab region, AM_5 and SA_5 genotypes in Jiroft region, and SA_5 and AM_4 genotypes in Karaj region are introduced as the promising genotypes.

In this direction, Bagheri et al. (2016), using the results of AMMI stability assay, selected 22 long eggplant genotypes in a three-year experiment for the breeding programs. Also, Keshavarz (2018), determined the general stability of 12 long pepper genotypes and their private stability for the different regions of the Iran using GGE Biplot and AMMI analysis. The AMMI stability analysis has been used in the recent years by many researchers for the various crops that these include the crops such as Soybean (Soltan Mohamadi et al., 2017), tobacco (Sadeghi and Samizadeh, 2011), durum wheat (Sadeghzadeh et al., 2018), bread wheat (Bigonah-Hamlabadi et al., 2012; cotton (Damavandi-Kamali et al., 2011) and barley (Koocheki et al., 2012; Ansari Maleki et al., 2009), in which using AMMI method, the stability and compatibility of these genotypes were determined generally and privately with respect to the amount of production yield. Evaluation of vegetables landraces in different parts of the world is one of the most important measures to identify and preserve rich genetic resources. Crop landraces have been used widely in breeding work and are always thought to harbor valuable traits lost among cultivated varieties and the exploitation of such traits increases research findings and knowledge of the genetic variability which facilitates breeding for wider geographic adaptability (Hanson et al., 2007). Tembe et al. (2018) assessed the African tomato landraces based on morphological and horticultural traits and found that the variation observed among tomato landraces provides a potential source of genetic diversity for tomato crop improvement. Gholizadegan and Seifi (2020) tested different molecular markers for screening some Iranian muskmelon landraces for resistance against *Fusarium* wilt disease and they reported that Eyvankey and Mashhadi landraces can be used by muskmelon breeders to enhance resistance to *Fusarium* wilt in muskmelon. Shoorideh et al. (2016) in assessing the potential of Iranian Chicory genotypes for industrial application found that the first step to enrich the genetic basis of root chicory for industrial chicory breeding program is to find biannual chicory genotypes which are resistant to bolting since all inulin fractions were affected adversely by this important characteristic. Other studies evaluated the vegetables landraces to achieve the superior genetic resources, such as eggplant accessions (Gramazio et al., 2019, Taher et al., 2017), tomato (Manzano et al., 2015; Sousaraei et al., 2021) and lettuce (Missio et al., 2018).

Conclusion

Based on the results of the general compatibility, the three genotypes including Y_7, AM_7 and SA_{15} were identified as the most stable genotypes with the least amount of the interaction, so they had the first rank of the stability and high selectivity. Y, AM_4 and GHE_{12} genotypes showed the lowest stability with the highest interaction. In general, according to the results of the private stability, GHE_{12} and Y_7 genotypes in Minab region, AM_5 and SA_5 genotypes in Jiroft region and SA_5 and AM_4 genotypes in Karaj region are introduced as the promising genotypes. Accordingly, the promising genotypes can be evaluated in the research-extension experiments under the field conditions for the cultivar selection.

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Conflict of interest

The authors indicate no conflict of interest for this work.

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