



Assessment of marketable tuber yield stability of genotypes from breeding populations using AMMI and GGE bi-plot stability models in three region of Ardebil, Hamadan and Karaj in Iran

Mojtaba Ghasemi Fahim ¹, Seyed Kamal Kazemitabar ^{2*}, Davoud Hassanpanah ³, Ghafar Kiani ²

¹ Ph.D. student of Biometrical Genetic, Department of Plant Breeding and Biotechnology, Sari Agricultural Sciences and Natural Resources University (SANRU), Sari, IRAN

² Associated Professor. Department of Plant Breeding and Biotechnology, Sari Agricultural Sciences and Natural Resources University (SANRU), Sari, IRAN

³ Horticulture Crops Research Department, Ardabil Agricultural and Natural Resources Research Center, AREEO, Ardabil, IRAN

*Corresponding author: sdklkr@gmail.com

Abstract

In order to evaluate the stability of potato tuber marketable using AMMI and GGE bi-plot models a randomized complete block design was conducted with three replications in two years (2017-18) and three regions: Ardabil, Karaj and Hamadan. The results of combined analysis of variance showed that for the simple effects of region, year × genotype, the effect of location × year was significant at 1% probability level. Considering the significant effect of year-to-year interactions on genotype of consumer tuberculosis sustainability criteria using type 1 and 4 of stability determined. Based on parameters with the concept of stability dynamics, hybrids 6 and 12-Kaiser were selected as stable genotypes and hybrids 4 and 10 as unstable genotypes. Since the interaction between year and clones was significant, AMMI method was used to select stable genotypes. The results of AMMI analysis showed that E1 environment (Ardabil) genotypes 1, 4 and 8 as high yielding and stable, genotypes 3, 6, 12 and 13 as stable and low-yield, genotypes No. 2 and 5 as unstable and high-yielding, and genotypes, 7, 10 and 11 were identified as unstable and low product. The results of GGE Bi-plot method showed that the decomposition into first and second principal components was 52.44 and 21.86% explained the percentage change that indicates the relative validity of the GGE change Bi-plot. Based on the Biplot results of cultivars 1, 2, 4, 5 and 8 with mean values of 34.65, 32.42, 32.37 34.4 and 36.91 ton / ha had the highest marketable tuber yield, respectively. Genotypes 4 were the closest cultivar to the ideal genotype that had the highest marketable tuber yield and stability due to being close to the mean environment. Cultures No. 1, 2, 5 and 8 as desirable genotypes. In this experiment, GGE Bi-plot and AMMI models were identified as a suitable method for simultaneous selection of marketable and stable tuber yield and were able to select genotype 4 as a stable cultivar with high marketable tuber yield.

Keywords: potato, consumer tuber yield, AMMI analysis, GGE bi-plot

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INTRODUCTION

Potato (*Solanum tuberosum* L.) is an annual plant and autotetraploid is the fifth largest agricultural product in the world and plays an important role as a staple food in Mediterranean countries and being one of the most widely distributed crops in the world and produced in 132 countries worldwide (FAOSTAT, 2017., Addis et al., 2017). Different methods have been proposed for genotype-environment interaction analysis. Lin and Bins (1988) divided sustainability methods into two univariate groups (parametric and nonparametric) and multivariate.

They named variance and environmental coefficient of sustainability methods as Type I, Paulstead and Peterson, Rick, Shukla, and Finley and Wilkinson as Type II and Eberhart and Russell as Type III. They believed that it was unlikely to find a figure that would produce more product under both optimum and adverse conditions. They stated that there is no need to

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Table 1. The evaluated hybrids and the three control genotypes evaluated

Row	Parents	Hybrid code	Row	Parents	Hybrid code
1	Savalan ♀ × Kaiser ♂	75-16	8	Kaiser ♀ × Satina ♂	75-56
2	Savalan ♀ × Kaiser ♂	9-5	9	Kaiser ♀ × Satina ♂	75-12
3	Satina ♀ × Kaiser ♂	75-15	10	Savalan ♀ × Kaiser ♂	75-14
4	Savalan ♀ × Kaiser ♂	27699	11	Kaiser	-
5	Satina ♀ × Kaiser ♂	75-13	12	savalan	-
6	Satina ♀ × Kaiser ♂	27515	13	Satina	-
7	Kaiser ♀ × Savalan ♂	75-23			

Table 2. Climatic Conditions and Geographical position of studied locations

Location	Latitude	Longitude	Altitude (m)	Temperature (°C)			Precipitation (mm)	Relative Humidity (%)
				Average	Minimum	Maximum		
Ardabil	48°18'E	38°15'N	1351	9.9	4.10	15.80	277	68
Hamedan	48°32'E	34°48'N	1550	11.35	9.93	18.77	384	53
Karaj	51°00'E	35°48'N	1312	14.40	8	20.80	247	53

Source: Ardebil Province Meteorological Organization

determine the stability of varieties in different locations because spatial variability can be estimated. For this purpose, Lin and Binns (1988) computed a two-year stable of genotypes at each location, calculating the variance between years in each location. Lin and Bins (1989) later reported that Type II and III parameters are not heritable. While type I and IV are heritable and increase the probability of high yielding stable cultivars. They divided the sustainability study methods into two groups (univariate (parametric and nonparametric) and multivariate. This method has been used by various researchers to select stable genotypes (Crossa et al., 1990; Kaya et al., 2002; Tarakanovas and Ruzgas, 2006; Hasanpanah, 2014; Hasanpanah et al., 2016). The GGE bi-plot model was introduced by Yan Yan, 2001). Given the advantages of this method, the use of this model for genotype × environment interaction analysis has been suggested (Yan and Kang, 2003). In yield tests, when the interaction effect is significant, the genotype should not be selected solely on the basis of the main effects of the genotype or the genotype×environment interaction, and is selected on the basis of the sum of genotype and (G + GE) (Yan and Kang, 2003). Graphic representation of (G×E) interactions helps the breeder to easily evaluate genotype stability. This method makes it easy to examine the relationships between environments and identify target environments in breeding programs (Mohammadi et al., 2013). One of the new methods for studying (G×E) is GGE Bi-plot method in which genotype-environment and (G×E) are separated and sustainable cultivars were selected based on both effects (Pourdad and Jamshid Moghaddam, 2013; Arzehgar et al., 2019). Therefore, the GGE Bi-plot method is a suitable tool for grouping of different environments and determining stable and adapted genotypes to different environmental conditions. This method has been used to identify high-yielding and stable genotypes by a number of researchers (Hon et al. 1995; Yan and Tinker, 2005; Bhan et al., 2005; 2011; Mohammadi et al., 2014; Hasanpanah et al., 2016). The

purpose of this study was to determine the ideal genotypes and to recommend the best genotype in terms of stability and yield of most marketable tubers using AMMI, GGE Bi-plot models, factor analysis and consumption characteristics.

MATERIALS AND METHODS

10 hybrids from crosses of Satina, Kaiser and Savalan cultivars and their parents with a total of 13 genotypes (Table 1) were examined for three years in three locations of Adibil, Karaj and Hamadan according to RCBD design with three replications. The climatic conditions and geographical location of the study areas are presented in Table 2. The dimensions of each plot were 5 m in two rows with a distance of 75 cm and a distance of two plants 25 cm. Agronomic care was provided for all treatments. Consumer tuber yield was evaluated by composite analysis and the mean of years and locations evaluated and determined using univariate stability, CV% and variance of Lin and Binz to select stable and susceptible cultivars.

Analysis of variance was performed and the mean of treatments were compared using LSD at 5% probability level. By using SAS 9.1 software to determine the effects of year, location, genotype and interaction of genotype × year, genotype × location and triple effect of location × year × genotype on tuber yield. AMMI and GGE Bi-plot models were used to select stable and high yielding genotypes using GenStat 12 statistical software. The AMMI model was calculated as follows (Zobel et al., 1988):

$$Y_{ijk} = \mu + g_i + e_j + \sum_{n=1}^N \delta_n \zeta_{in} \eta_{jn} + \theta_{ij} + \varepsilon_{ijk}$$

Yijk the yield of genotype I in j environment and k repetition, μ total mean, g_i main effect of genotype i (mean genotype difference of mean total genotypes), e_j main effect of environment j (mean environment difference j of total environments), δ_n is the singular value of the nth element of the principal component

residue in the model that is equal to the root square of the characteristic of the same principal component, N is the number of major interaction elements in the model of AMMI that is equal to the following formula.

$$N \leq (\min (g-1), (e-1))$$

ζ_{in} in characteristic vector for the *i*th genotype of the *n*th main component of the interaction (I.P.C) η_{jn} in the characteristic vector for the *i*th environment of the *n*th main component of the interaction (I.P.C). θ_{ij} residual value (noise) ε_{ijk} error.

In the variance analysis of the AMMI model, the degree of freedom of the principal component of the interaction *k*th is obtained from the following relation in which *g* is the number of genotypes, *e* the number of environments, and the number of principal components (Zobel et al., 1988):

$$(g-1) + (e-1) - (2k-1) \leq g+e-1-2k$$

The following relationship was used to study the parameter of AMMI stability value (Purchase et al., 2000):

$$ASV_i = \sqrt{\left[\frac{SS_{IPCA1}}{SS_{IPCA2}} (IPCA_1 \text{ score}) \right]^2 + (IPCA_2 \text{ score})^2}$$

SS IPCA2 and SS IPCA1 the sum of squares of the principal components of the first and second interaction, IPCA1 and IPCA2, are the values of the first and second principal components of interaction for each genotypes. Dividing the phenotypic variance into its components includes $P = G + GE + E$, which includes *P* phenotypic variance, *G* genotypic variance, *G* × *E* variance of genotype interaction in environment and *E* environmental variance. If instead of the variance components we use the effects of the above factors which have the main measured data unit:

$$\hat{y}_{ij} = \mu + \alpha_i + \beta_j + \phi_{ij}$$

$$\hat{y}_{ij} - \mu - \beta_j = \alpha_i + \phi_{ij}$$

\hat{y}_{ij} :Expected yield of the *i*th genotype in the *j*th environment μ :total mean observation

α_i :The main effect of the genotype *i*th β_j :the main effect of *j*th environment ϕ_{ij} :Interaction of *i*th genotype and *j*th environment

Instead of *G* and *GE*, the formula for the GGE bypass is found in the formula and the GGE is divided into two multiplicative groups as follows:

$$\hat{y}_{ij} - \mu - \beta_j = g_i e_{1j} + g_i e_{2j} + \phi_{ij} + \varepsilon_{ij}$$

g_i and e_{1j} : Primary scores of genotype *i* and environment *j*, respectively

g_i and e_{2j} : secondary scores of genotype *i* and environment *j* th ε_{ij} : residual value

That is not justified by the primary and secondary effects. In fact, the GGE biplot method is obtained by plotting g_i versus g_i and e_{1j} versus e_{2j} in a distribution graph. The most common way to apply the above

Table 3. Composite variance analysis of potato marketable tuber yield

S.O.V	df	Mean of Square
Location	2	1923.075**
Year	1	565.258**
Location× Year	2	305.75**
Error type 1	12	154.85
Genotype	12	257.666**
Location× Gen	24	47.293
Gen× Year	12	47.887
Gen× Year ×Location	24	34.271
Error type 2	144	50.122
Coefficient of variation (%)		23.37
Average marketable tuber yield		30.39

*, ** Significant at $p \leq 0.05$ and 0.01 , respectively

equation is to use a single stagnant root (SVD), in which case the equation becomes:

$$\hat{y}_{ij} - \mu - \beta_j = \lambda_1 \xi_{i1} \eta_{1j} + \lambda_2 \xi_{i2} \eta_{2j} + \varepsilon_{ij}$$

λ_1 : Singular values of the first principal component

λ_2 : Singular values of the second principal component

ξ_{i1} : Genotype *i* vector for PC1

ξ_{i2} : genotype-specific vector *i* for PC2 η_{1j} : genotype-specific vector *j*th for pc1 η_{2j} : genotype-specific vector *j*th for PC2

The GGE Biplot model is based on two stochastic roots (SVD) of two components (Yan and Kang, 2003). Factor analysis was performed using principal components method and factor rotation using Verimax method. For the preparation of factor coefficients matrix, the number of factors whose eigenvalue was greater than one was selected. In each main factor, factor coefficients greater than 0.5 were considered as significant (Lawley and Maxwell, 1963). Minitab 16 software was used for factor analysis.

RESULT AND DISCUSSION

Combined analysis of variance showed that there was a statistically significant difference at 1% probability level for simple effects of location, year, and genotype. Hassanpanah and Hassanabadi (2011) reported that significant differences were observed between cultivar type and their interactions in terms of marketable tuber yield. Moghadaszadeh and colleagues (1979) find the main effect of genotype was significant for all traits, year-to-location interaction, and genotype × year interaction for tuber yield. Interaction effects of genotype in region were also significant for all traits. Considering the significance of year-to-year interactions at the region of sustainability measures of marketable tuber yield using Ramer's environmental variance (Romer, 1947), Francis and Kannenberg's environmental change coefficient (Francis and Kannenberg, 1978) (sustainability Type I) and the Inner Spatial Variation of Type IV stability were determined (Lin and Binns, 1988) (Table 3).

Type I and IV stability parameters Environmental variance of Rommer (Rommer, 1947)

In order to evaluate genotypes in terms of type I stability parameters, the environmental variance of

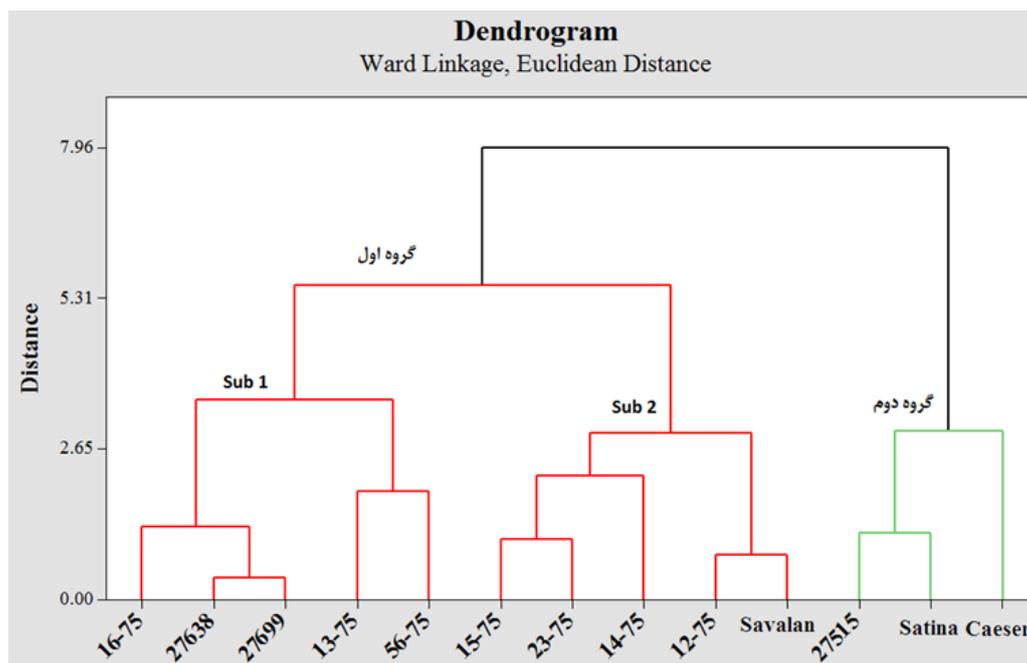


Fig. 1. Cluster analysis of 13 potato genotypes based on marketable tuber yield and nonparametric stability statistics

Table 4. Classical Stability Statistics of Type I and IV Potato Genotypes Studied in Two Years and Three Different Locations (Ardabil, Hamadan and Karaj)

Number	Genotype	marketable tuber yield (Ton/ha)	Type I stability		Type IV Stability
			Environmental variance of Rommer si ²	Environmental change coefficient of Francis and Conenberg (cv %)	Inner Variance of Lin and Bines
1	75-16	34.65	79.9	2.31	19.89
2	27638	32.42	83.4	2.57	25.53
3	75-15	29.62	48	1.62	19.4
4	27699	32.37	78.6	2.43	27.67
5	75-13	34.4	70.2	2.04	9.63
6	27515	29.42	37.6	1.28	7.39
7	75-23	28.74	60.6	2.11	14.74
8	75-56	36.91	47.6	1.29	18.42
9	75-12	28.4	61.3	2.16	2.94
10	75-14	26.69	69.2	2.59	27.28
11	Savalan	27.36	67.8	2.48	7.33
12	Caeser	26.89	11.1	0.41	23.97
13	Satina	27.26	23.2	0.85	3.55

Roemer was calculated for all genotypes (Table 4). According to this statistic, the clone(27515)genotype had the lowest environmental variance for Kaiser and Satina. Therefore, with the least yield variations among studied environments, the most stable genotypes were in terms of biological viability. Clone 2 (27638) also had the highest environmental variance and maximum yield fluctuations. Cultivar Number 8 (56-75) with lower environmental variance and higher than average yield was identified as the most stable cultivar.

Coefficient of Environmental Change of Francis and Kannenberg

Clones 3, 6, 8, 12 and 13 were the least and the most stable, and clone No. 10 (14-75) had the highest and the most unstable genotypes, respectively. In grade 2, they were introduced as desirable stable genotypes. Number 8 (56-75) was placed in Francis Kannenberg graph with the high average yield and low coefficient of variation

(first zone). The results of the two parameters of environmental variance stability and genotypic diversity coefficient are almost similar.

As Lin and Binns, 1986 and Acura et al. (2005) reported, the similarity of the statistical results within a given group is expected. Akcura et al. (2005) and Hun et al. (1995) used two methods of variance and coefficient of variation for achieving sustainable cultivars. The type I parameter is heritable, which is more appropriate for selecting varieties, but the most stable, yet most productive, variety cannot always be obtained (Lin and Binns, 1991).

Inner Variance of Lin and Binns

Lin and Binns (1991) believed that the location was fixed and the stations under study were similar locations and that the variable was a random factor for the year. Clones NO. 6, 9, 11, and 13 had the least intra-annual variance and most stable, and clone 10 (14-75) had the highest and most unstable genotypes, respectively.

Table 5. Analysis of variance of AMMI model for marketable tuber yield in different environments

S.O.V.	df	Sum of square	Mean of square	F	F prob
total	77	*	*	*	*
treatment	38	*	*	*	*
genotype	12	827.6	69	4.31	0.00024
environment	2	3752.2	1876.1	*	*
Genotype interaction in the environment	24	679.6	28.3	1.77	0.049
IPCA1	13	478.9	36.8	2.3	0.02
IPCA2	11	200.7	18.2	1.14	0.35
Residual (noise)	0	0.0	*	*	*
Merged error	39	623.4	16	*	*

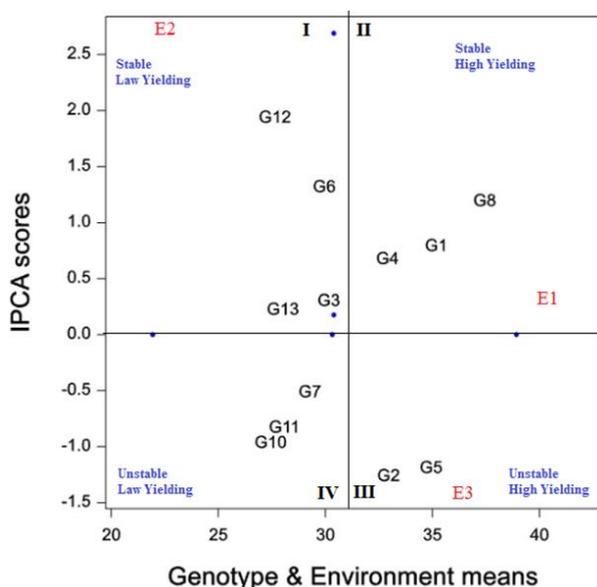


Fig. 2. Grouping of cultivars in terms of yield of AMMI-marketable tubers

Based on the results and on the basis of parameters having dynamic stability concept, hybrids No. 6 and 12 (27515 and Kaiser) with marketable tuber yield of 29.42 and 26.89 ton / ha as stable genotypes and hybrids No.

4, respectively. And 10 (27699 and 14-75) were identified as unstable genotypes with marketable tuber yield of 32.37 and 26.69 ton / ha, respectively.

Based on the results and on the basis of parameters having dynamic stability concept, hybrids No. 6 and 12 (27515 and Kaiser) with marketable tuber yield of 29.42 and 26.89 ton / ha as stable genotypes and hybrids No. 4, respectively.

AMMI model

Significance of genotype effect in environment with respect to analysis of variance of marketable tuber yield based on AMMI stability method (Table 5) indicates that genotypes showed different performance in different environments.

E1 (Ardabil) environment and genotypes 1, 4 and 8 as high yielding and stable genotypes 3, 6, 12 and 13, 27515, Kaiser and Satina) as stable and low-yielding (Fig. 2).

GGE Bi-plot model evaluation

The results of the GGE Bi-plot method showed that the first and second principal component analysis explained 61.46% and 30.97% of the variance, respectively, which indicates the relative validity of the GGE variation plot (Fig. 3). Examination of the polygon

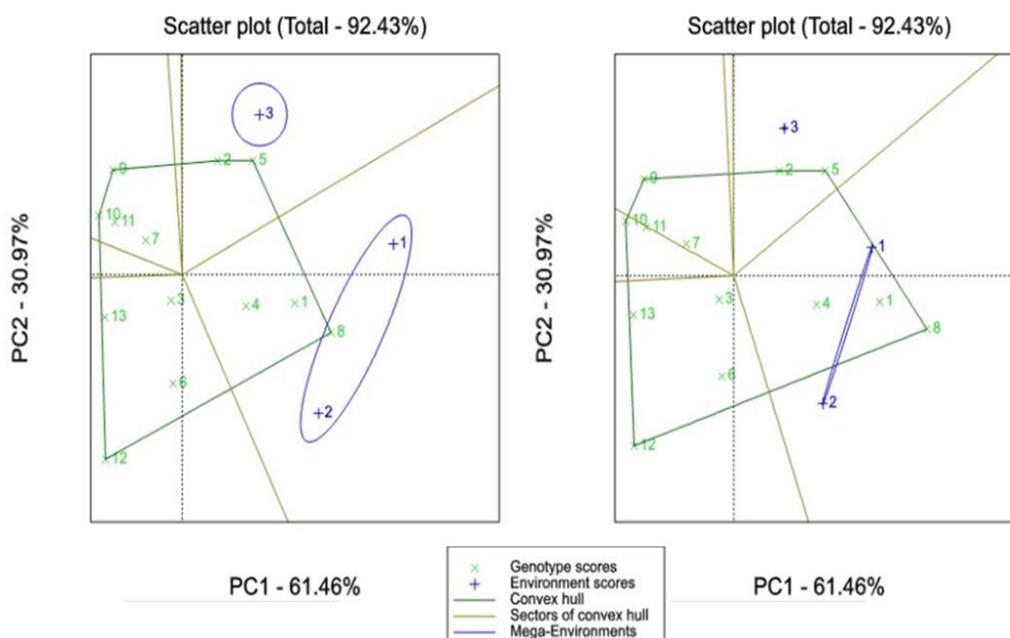


Fig. 3. Polygon GGE bi- plot to determine the superior cultivars in the evaluated years

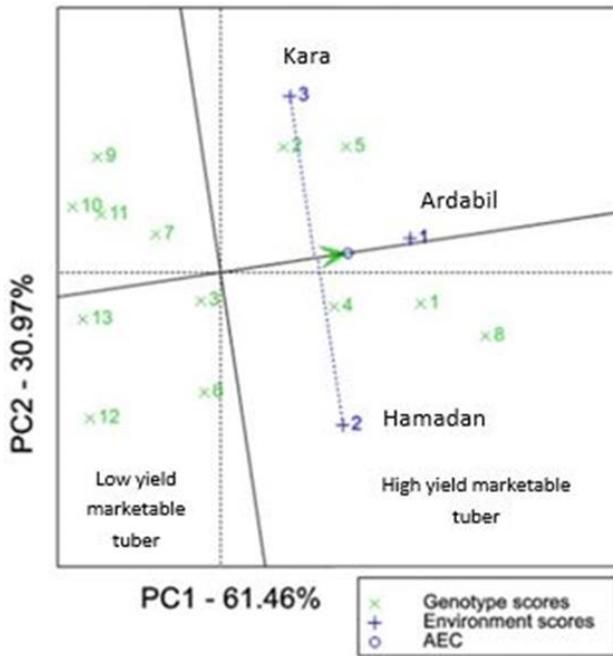


Fig. 4. Average biplot environment for simultaneous selection of marketable tuber yield and cultivar stability

chart to determine the top varieties in different years showed that the numbers 5, 8, 9 and 12 are in the polygon vertices. These cultivars are the best or the weakest clone for tuber yield in some or all environments (Yan and Kang, 2003). Adjacent genotypes are polygons that facilitate comparison (Yan, 2003). The

environments were in two parts of this polygon respectively in the first part of Karaj environment and in the second part of Ardebil and Hamedan environments (**Fig. 3**). An interesting feature of the GGE Bi-plot is that the polygon vertex genotypes of each segment perform better than other segments in all environments (Yan, 2003, Najaf Zadeh and A. Ehsanpour, 2012).

In **Fig. 4**, the numbers 1, 2, 4, 5 and 8 were averaged 34.65, 32.42, respectively. 32.37, 34.4 and 36.91 t / ha had the highest marketable tuber yield. Cultivars 2, 5 and 8 have higher tuber yield and low stability, cultivars 1 and 4 have high tuber yield and stability Higher, cultivars 6, 9 and 12 have low tuber yield and lower stability (greater than the distance from the ATC line) and cultivars Nos. 3, 7, 10, 11 and 13 had lower tuber function and greater stability (distance less than the ATC line).

An ideal genotype is the highest-yielding and sustainability in all environments and be centrally located in a concentric circles (Yan, 2001). Although such an ideal genotype may not actually exist, it can be used as a reference for evaluating genotypes (Yan and Tinker, 2006). The cultivars Nos. 1, 2, 5 and 8 were also close to the ideal genotype and were selected as desirable genotypes. Genotypes 3, 6, 7, 9, 10, 11, 12 and 13 as undesirable genotypes they were determined because they had the greatest distance to the ideal genotype (**Fig. 5**).

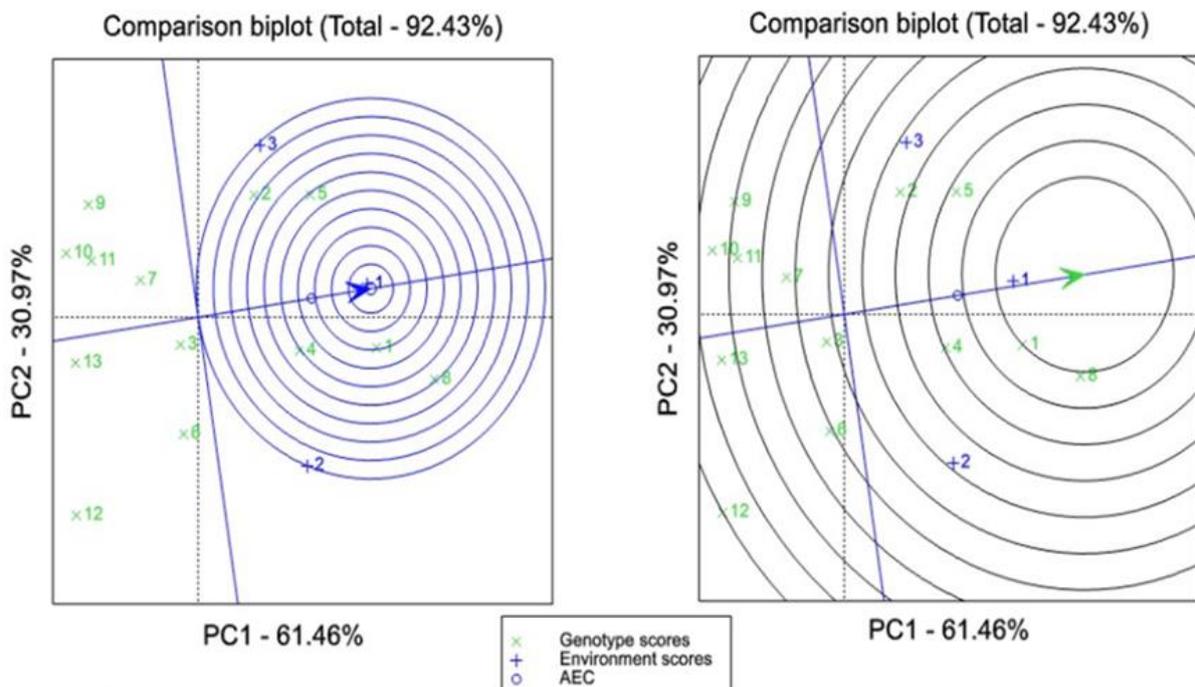


Fig. 5. Biplot Comparison of Cultivars with Ideal Genotype for Consumer Tuber marketable yield and Stability

Table 6. Yield and Principal Components 1 and 2

No.	Genotype	Marketable tuber yield Ton/ha	IPCA1	IPCA2
1	75-16	34.65	0.782	1.44
2	27638	32.42	-1.27	1.382
3	75-15	29.62	0.293	0.153
4	27699	32.37	0.666	1.377
5	75-13	34.4	-1.19	-0.09
6	27515	29.42	1.309	-0.045
7	75-23	28.74	-0.521	0.161
8	75-56	36.91	1.184	0.372
9	75-12	28.4	-1.575	-1.14
10	75-14	26.69	-0.973	0.111
11	Savalan	27.36	-0.837	0.184
12	Caeser	26.89	1.928	-1.71
13	Satina	27.26	0.214	-1.175

Table 7. Yield and main components of the first and second evaluated environments

number	environment	Yield tuber Ton/ha	IPCA1	IPCA2
1	Ardabil	38.92	0.175	2.58
2	Hamadan	21.93	2.689	-1.41
3	Karaj	30.32	-2.865	-1.167

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