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Identification of peach accessions stability and adaptability in non-balanced trials through years

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ABSTRACT

Identification of genotypes with acceptable yield and yield stability in different environments is an important issue in plant breeding. Genotype-by-environment interaction (GEI) can alter genotypes performances making the selection of superior material a tedious task for breeders. Consequently, it is necessary to assess the usefulness of different available methods and identify the most suitable for understanding GEI. The objectives of this work were to compare three methods to study genotype stability considering incomplete data sets: (i) Di Rienzo, Guzmán and Casanoves' test (DGC), (ii) relative yield (RY) and (iii) Piepho's method. In addition, AMMI (additive main effect and multiplicative interaction) analysis and eight AMMI stability measures SIPC, EV, ASV, Da, FP, B, FA and Za were computed to explore their advantages and disadvantages to select stable entries. The usefulness of the genotype selection index (GSI) and the rank-sum (RS) procedures to identify stable and high-yielding genotypes were evaluated and then compared with the superiority (P) and reliability indexes (I).The association between yield variation and climatic factors as frosts, chilling, heat, rainfall and the interactions among them were also analyzed. 29 peach entries were assessed in four to seven seasons in a completely randomized design with three replications. DGC and RY tests agreed on classifying Fireprince as a stable and high-yielding peach, RY classified 25 entries as stable, while Piepho's method did not separate the tested genotypes as DGC and RY did. The results of AMMI indicated that 25.06% of total variability was justified by genotypes, 9.76% by environments and 58.97% by GEI. The first five interaction principal components could explain 94.82% of GEI and showed the efficiency of AMMI model to study and understand GEI. The AMMI parameters showed no association with fruit yield, therefore, they could be useful to indicate stable entries but they would not be appropriate to select stable and high-yielding genotypes. The EV and Za indicated static stability while ASV, SIPC, Da, FA and FP pointed out the dynamic stability concept. The performance of the best entries selected by GSI, RS, P and I procedures were not different, therefore, any of them can be used to select superior peach genotypes. Rainfall during endodormancy, rainfall from floral bud endo- to ecodormancy - and heat accumulation during fruit development period showed significant correlation with yield variation across seasons.

1. Introduction

Mean yield of genotypes obtained through years or locations has been regularly used as crop performance and adaptation in different environments. The genotype-by-environment interaction (GEI) reduces the association between phenotypic and genotypic values and complicates superior genotype identification because accessions may have high yields in some environments and low yields in others (Cruz and Regazzi, 1997). The term stability is used to characterize a genotype that shows a relatively constant yield, independently of environmental conditions. This concept of stability is named biological or static (Becker, 1981). A genotype showing a consistent performance in all environments does not necessarily respond to improved growing conditions with increased yield. Plant breeders, therefore, prefer an agronomic or dynamic stability concept (Becker and Leon, 1988; Becker, 1981) by which genotypes are not required to respond equally to environmental fluctuations (Becker and Leon, 1988). These concepts represent different aspects

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of stability and do not always allow analyzing the problem as a whole.

Argentina is the ninth largest peach producer worldwide and the second in South America with 291 thousand tons (FAOSTAT, http://faostat3.fao.org/). In Argentina, the peach crop was recently expanded to regions as Córdoba, Misiones, Río Negro (middle and lower valley), Jujuy and Salta, whose microclimates allow obtaining fruits with specific organoleptic properties. The main peach-producing areas in Argentina are Mendoza, Rio Negro (high valley) and the northeastern of Buenos Aires province. San Pedro Agricultural Experimental Station of the National Institute of Agricultural Technology (INTA San Pedro) is located in this last region and has a wide peach and nectarine germplasm that is evaluated every season. Many of the peach varieties used in Argentina are initially selected in INTA San Pedro and final evaluation of genotypes is performed in each one of the geographic regions mentioned above. As peach varieties remain in production for many years, the selection of genotypes with high yield and stability through years would be critical for horticulturist, whose main concern is to avoid low production years and to prevent their incomes fall. Additionally, the production stability is also important to avoid disturbing the normal market supply.

Procedures based on analysis of the variance (ANOVA) are the most common approaches to study GEI and to determine genotype stability and adaptation (Huehn, 1996). Although there are well-recognized statistical and biological limitations in the regression approach (Crossa, 1990; Flores, 1993; Lin et al., 1986), it provides useful parameter estimates when the number of genotypes and environments are sufficiently large and when there are no extreme environments that bias regression slopes (Flores, 1993). ANOVA and regression methods are parametric and therefore, the assumption of normal data distribution and the homogeneity of variance are required. On the contrary, non-parametric stability measures are largely unaffected by data distribution. As these procedures are based on ranks and not on values, a genotype is considered stable if its ranking is relatively constant across environments (Huehn, 1979; Kang, 1988; Nassar and Huehn, 1987).

Most of these methods require the evaluation of genotypes in all environments. This condition is difficult to fulfill in practice since the germplasm evaluation is a dynamic process. Entries could be lost due to climatic factors, pest attack and continuous replacement of genotypes. If data sets are obtained from several locations, some genotypes may not be tested in all sites. Similarly, if yield tests are registered in different years, genotypes might not be tested yearly. Genotypes change from year to year as new genotypes become available and older ones become obsolete. Incomplete datasets require special analysis to consider all the information and minimize the chance of losing valuable genotypes. At the present time, several procedures that allow analyzing both yield and stability have been proposed. Some of them are easy to apply and can be used in non-balanced data sets. In the Fisher's protected LSD (least significant differences) test, the mean value of each varietal type in each environment is compared with the mean value of the highest yield varietal type in that environment using the LSD test of multiple comparisons (Steel and Torrie, 1980). Annicchiarico (1992) and Yau and Hamblin (1994) proposed the relative yield (RY) as a way to calculate stability parameters for stability evaluation, which eliminate the environment main effect. Piepho (1995) reported a procedure that can be considered in unbalanced data sets in which a value delta (δ) is used to compare the confidence intervals of each genotype to find differences between all entries and the best and to classify each genotype as adapted, non-adapted or unclassified.

The study of GEI in peach performed by Maulión et al. (2014a) has demonstrated that the crossover is predominant over non-crossover GEI. The crossover GEI is the main cause of erratic behavior of genotype performance among environments (Cruz and Regazzi, 1997). Therefore, more sophisticated statistical techniques should be considered to establish the real response of genotypes in different environments. The trend in modern times is toward multivariate methods that can provide further information on the real response of genotype to environments. The three main purposes of multivariate analysis are to eliminate the noise from the data pattern, to summarize the data, and to reveal the structure of the data (Purchase et al., 2000). Becker and Leon (1988) defined the aim of various multivariate classification methods as to assign genotypes into qualitatively homogeneous stability subsets. Within subsets, no significant GEI occurs, while differences among subsets are due to GEI. The most refined multivariate method is the additive main effect and multiplicative interaction widely known as the AMMI model (Crossa, 1990; Gauch, 1988; Zobel et al., 1988). The AMMI model is a powerful statistical method that incorporates both additive and multiplicative effects of a two-way data structure, and therefore, is the most useful technique to target genotypes and to select materials that are affected by crossover GEI (Baker, 1988). Although AMMI analysis is performed using balanced dataset, however, various methodologies have been proposed in order to solve this lack of balance caused by missing values. One of it was performed by Freeman (1975), who suggested imputing the missing values in an iterative way by minimizing the residual sum of squares and then doing the GEI analysis. Gauch and Zobel (1990) developed this approach, doing the imputation by using the expectation-maximization (EM) algorithm and incorporating the AMMI model, now known as the EM-AMMI approach. Arciniegas-Alarcon et al. (2010), Bergamo et al. (2008) and Yan (2013) described imputation systems that involve the singular value decomposition of a matrix, and therefore, they can be applied in any incomplete multi-environment experiments. AMMI model provides a visual inspection and interpretation of GEI and genotype stability constructing biplots (Zobel et al., 1988). The first biplot or AMMI1 provides a means of visualizing the stability and yield of each genotype plotting the first interaction principal component (IPCA1) scores against the average genotype performance. In the second biplot or AMMI2 the IPCA2 scores are plotted against their respective IPCA1 scores. Biplot formulation of interaction will be successful only when significant proportion of GEI is concentrated in the first or first and second IPCA axes. When the F test suggests retaining more than two axes, the biplot formulation of interaction fails (Raju, 2002) and the use of parameters derived from the AMMI model is recommended.

Stability and adaptability of fruit yield are two characters closely associated with weather conditions. Dormancy is an important evolutionary mechanism that allows species to survive adverse environmental conditions during winter, and favors the synchronization of vegetative bud break and flowering in the spring (Carl, 1996). Each genotype requires a specific amount of chill and heat to exit the bud dormancy (Richardson et al., 1975). If these requirements are not completed properly, an irregular flowering will be obtained and fruit production will be erratic over years. Genotypes whose thermal requirements do not match with particular location climate cannot be recommended for successful production.

The objectives of this work were (i) to compare three different methods to study the stability of fruit yield in peach considering incomplete data sets throughout years, (ii) to explore the utility of AMMI model to study GEI and test some stability measures derived from AMMI model to select stable and high-yielding peach genotypes, (iii) to evaluate the efficiency of single indexes in the selection of superior genotypes and (iv) to associate fruit yield fluctuation with environment variables.

2. Materials and methods

2.1. Plant material

Fruit yield data set was obtained from 29 peach accessions (Table 1) at the San Pedro Agricultural Experimental Station of the National Institute of Agricultural Technology (INTA San Pedro) located at 31°41′12″S and 60°47′32″W. The experiments were conducted over seven seasons: 2005-06 (Season Evaluation 1 (SE1)); 2006–07 (SE2); 2007–08 (SE3); 2008–09 (SE4); 2009-10 (SE5); 2010–11 (SE6) and 2011–12 (SE7) and each season was considered a different environment as all trials were carried out in different climatic scenarios. Since not all accessions had been evaluated in each season, a non-balanced trial among years was generated. Genotypes were arranged in a completely randomized design (CRD) with three replications, each of them consisted of three trees established at 5 × 4 m row spacing. Fruit yield was obtained for each replication by using a weighing machine (model Calel T2, Sgrilleti S.A., Argentina) and expressed in Kg/tree. The station has a temperate climate, with short and irregular winter, loamy-clay soil and a mean annual rainfall of 1066 mm. This area is representative of the major peach producing region of northeastern Buenos Aires province. Each year the orchard received standard commercial management recommended for the area; this included fungicide and insecticide sprays and pruning similar to the commercial orchards. Neither chemical means to break dormancy nor irrigation were used.

2.2. Statistical analysis

2.2.1. Stability methods for non-balanced trials

2.2.1.1. Di Rienzo, Guzmán and Casanoves' test *(DGC).* DGCís test is performed in a very similar way to LSD' Fisher. The mean fruit yield (FY) in each SE is compared with the average of the best-yielding accession in that environment according to Di Rienzo et al. (2002) test for multiple comparisons at 5% level of significance. As stated by this test the most stable genotype does not differ significantly from the best-yielding accession in most environments. Therefore, this method does not consider as stable those accessions that have yields significantly lower than the best-yielding entry and consequently these genotypes would be undesirable.

2.2.1.2. Method of relative yield (RY). In this method, the performance of each accession is expressed as the percentage of the average yield in that environment, which represent 100%. If genotypes have yields lower than the average of all genotypes in the same SE, a value less than 100% will be assigned, while those with yields higher than the average will be associated with values greater than 100%. The standard deviation of relative yields of each genotype across environments is used as a stability measure. The most stable accessions will be those with the smallest standard deviations. In addition, those genotypes with values higher than 100% might be considered as adapted to a particular environment (Yau and Hamblin, 1994).

2.2.1.3. Adaptability by multiple comparisons with the best (MCB). Proposed by Piepho (1995), this approach estimates the genotype adaptability based on a multiple comparison with the best genotype, which is a procedure suggested by Edwards and Hsu (1983). It involves a tolerance value δ chosen by the researcher, which is compared with a set of simultaneous confidence intervals for the difference between all genotypes and the best. δ corresponds to the smallest difference among accessions considered significant. Piepho (1995) suggested taking a value between 5 and 10% of the mean for all genotypes in a particular environment. According to this methodology, accessions can be classified as: (i) adapted, if their differences from the best are significantly smaller than δ (2) as non-adapted, if their differences from the best are significantly larger than δ and (3) as unclassified, if their differences from the best do not differ significantly from δ.

Since the methods mentioned above do not make any special weighting, they equally consider the contribution of each environment in the average calculation. That is to say they do not show bias for the best environments and therefore, can be used to analyze non-balanced data set.

The criterions used to consider an accession as stable are subjective and are established using different approaches. According to DGC' test, the accession is classified as stable if its performance is not significantly different from the best one in at least three SEs. In the RY method, the accession is considered stable if its standard deviation is lower than half of the highest estimates among the genotypes involved. Finally, δ values of 5, 10 and 15% are considered when the accession stability is evaluated by MCB procedure.

2.2.2. AMMI model and stability parameters

The NORM software v.2.3 (Schafer, 1999) was used to fill each missing data point through the multiple imputation procedure, balancing the incomplete data set. Then, AMMI model, which combines standard analysis of variance (ANOVA) with the principal component analysis (PC) (Zobel et al., 1988), was applied to investigate the GEI. The AMMI model is:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + \sum_{N} \lambda_n \gamma_{in} \delta_{jn} + \rho_{ij} + \varepsilon_{ijk}$$

where Y_{ijk} is the observed mean fruit yield of kth repetition of the ith genotype in the jth environment; μ is the grand mean; α_i is the genotype main effect; β_j is the environment main effect; λ_n is the eigenvalue of the interaction principal component analysis (IPCA); γ_{in}, and δ_{jn} are the genotype and the environment eigenvector values for n IPCA axis; N is the number of IPCA retained in the model; ρ_{ij} is the residual interaction and the ε_{ijk} is the random error term. Combined ANOVA was carried out to test the environment and genotype main effects as well as GEI. F test ratio value (Cornelius, 1993) to determine significant numbers of IPCA in AMMI model at 5% of significance ($P \leq 0.05$) was used.

Eight stability parameters derived from AMMI were considered (1) the sum of the absolute value of the IPCA scores (SIPC) retained in the AMMI model (Sneller et al., 1997) (2) the average of the square eigenvector values (EV) of each IPCA retained in the AMMI model (Zobel, 1994) (3) the AMMI's stability value (ASV) developed by Purchase et al. (2000) based in the IPCA1 and IPCA2 scores (4) the stability measure Da proposed by Annicchiarico (1997) (5) FP parameter was estimated considering only the first IPCA axis (6) B parameter was calculated using the first and second IPCA axes retained in the AMMI model; (7) FA parameter is a stability measure based on fitted AMMI model by retained N axes. These last three parameters were developed by Raju (2002). The last parameter (8) Za is the absolute value of the relative contribution IPCA to the interaction (Zali et al., 2012). The most stable genotypes across the tested environments show AMMI parameters near zero.

Two non-parametric procedures that incorporate both yield and yield stability were included. The genotype selection index (GSI) was calculated as the sum of the rank of mean yield of genotypes across environments and the rank of AMMI stability value (ASV) (Farshadfar, 2008). The rank sum (RS) was calculated for each genotype as the sum of the rank mean and the standard deviation of the rank (Farshadfar et al., 2011).

Selection efficiency of GSI and RS measures were compared with the superiority (P) (Lin and Binns, 1988) and reliability indexes (I) (Eskridge, 1990) since Maulión et al. (2014a) had previously showed the high efficiency of these last parameters in the selection of stable and high-yielding peach entries.

Table 1
Origin, thermal requirements to break floral bud dormancy and seasonally yield of 29 peach entries.

Accession	AN	Origin	CR	HR	FY(Kg/tree)							Grand
					SE1	SE2	SE3	SE4	SE5	SE6	SE7	Mean
81.315.009 P	1	ITA	988	5519	NE	NE	3.22	4.70	3.65	14.20	15.61	8.28
84.351.029 N	2	ITA	960	5394	NE	NE	8.30	21.76	1.73	14.72	16.29	12.56
86.395.095 N	3	ITA	961	5369	NE	NE	14.26	12.46	7.46	21.14	10.70	13.20
87.404.243 N	4	ITA	1032	4737	NE	NE	4.40	4.69	8.27	6.72	4.80	5.78
89.424.007 N	5	ITA	876	5263	NE	NE	2.51	2.02	3.11	7.91	4.80	4.07
89.429.003 N	6	ITA	988	2980	NE	NE	10.42	2.40	5.32	21.41	11.05	10.12
Caldessi 2010 N	7	ITA	694	7967	26.91	11.54	8.11	16.64	19.93	11.75	10.01	14.98
Cotogna del Berti P	8	ITA	699	9034	NE	NE	17.42	NE	3.65	12.91	8.17	10.54
Fireprince P	9	USA	863	7133	23.07	7.81	5.39	9.86	10.87	27.83	12.96	13.97
Flameprince P	10	USA	967	3742	10.47	10.50	20.09	6.71	6.82	10.75	23.43	12.68
Flavorcrest P	11	ITA	897	5058	14.20	11.90	15.22	2.51	17.45	16.82	13.90	13.14
Fred P	12	MEX	922	5550	1.87	NE	6.10	3.69	15.81	19.63	5.81	8.82
GaLa P	13	USA	858	5075	1.39	6.16	7.83	12.63	8.30	14.44	12.94	9.10
Goldprince P	14	USA	774	5609	2.56	6.21	6.85	6.79	16.18	15.87	11.76	9.46
Guglielmina P	15	ITA	1137	6136	3.25	NE	8.92	2.90	NE	14.45	19.16	9.74
Hermosillo P	16	USA	236	8385	13.99	NE	39.68	NE	23.95	31.03	4.26	22.58
LSCr P	17	MEX	755	6367	5.19	NE	1.54	5.61	13.48	14.01	6.50	7.72
María Anna N	18	ITA	1005	4489	NE	NE	1.50	1.90	3.35	9.35	14.53	6.13
María Aurelia N	19	ITA	976	5838	11.69	4.52	14.64	6.66	4.18	24.74	11.37	11.11
María Dorata N	20	ITA	933	5081	NE	NE	1.62	2.52	2.40	15.50	1.41	4.69
María Emilia N	21	ITA	706	7772	7.38	21.56	4.22	5.54	25.99	7.79	10.12	11.80
María Laura N	22	ITA	855	4745	1.54	4.97	6.56	10.15	NE	13.05	17.32	8.93
María Lucía N	23	ITA	1112	3964	NE	NE	7.21	1.85	7.74	17.45	14.98	9.85
Merrill Carnival P	24	USA	1048	3813	14.20	8.24	8.58	3.51	NE	10.30	4.20	8.17
Milenio INTA P	25	ARG	951	4569	6.40	NE	11.26	9.33	15.14	12.07	12.84	11.17
Sirio P	26	ITA	1088	7373	18.51	NE	1.48	NE	1.74	1.81	7.21	6.15
Starlite P	27	USA	659	6948	4.94	NE	15.47	3.08	15.72	15.62	15.65	11.75
Sunprince P	28	USA	923	6321	30.59	33.31	27.46	5.40	4.60	23.15	14.90	19.92
Vega N	29	ITA	1030	4171	15.21	3.45	14.92	14.49	2.46	18.18	13.87	11.80
CV%					22.31	20.68	14.62	29.98	31.97	18.56	15.84	
Average					11.23	10.85	10.18	6.92	9.59	15.33	11.40	10.54

AN: accession number, P: peach, N: nectarine; ITA: Italy, USA: United States of America; MEX: Mexico and ARG: Argentina; CR: chilling requirements; HR: heat requirements; FY: absolute mean fruit yield; SE1: season evaluation 2005/06; SE2: season evaluation 2006/07; SE3: season evaluation 2007/08; SE4: season evaluation 2008/09; SE5: season evaluation 2009/10; SE6: season evaluation 2010/11 and SE7: season evaluation 2011/12; NE: accession not evaluated.

Environmental variance $\left(S_x^2\right)$ (Roemer, 1917) and Wricke parameter (W) (Wricke, 1962) are two classical measures associated with static and dynamic stability, respectively, and were included to characterized AMMI statistics respect to those stability concepts. I and P are also associated with the dynamic concept stability and were used in the AMMI measures characterization.

Genotype ranks were assigned in an increasing order for all the stability parameters, but in a decreasing order for I and the mean fruit yield, and associations among stability measures were established by Spearman correlation (Steel and Torrie, 1980). Principal component analysis (PC) on Spearman correlation matrix was performed and static or dynamic stability was suggested to AMMI parameters according to the stability parameters, S_x^2, W, I or P, they were clustered with.

2.3. Climatic variables

Hourly air temperatures have been recorded at the meteorological station placed in the experimental field. Chill and heat accumulations were calculated for each SE and thermal requirements of each peach accessions were estimated as performed previously (Maulión et al., 2014b). Temperatures between 1st May and 28th February in each SE were extracted from the complete dataset. Then, chilling accumulations were estimated as 'positive chill units' (PCU) (Linsley-Noakes and Allan, 1994) during flower bud endodormancy (1st May to 31st July). On the other hand, heat accumulations were calculated as 'growing degree hours' (GDH) (Richardson et al., 1975) during flower bud ecodormancy, GDH_a, (1st August to 30th September) and fruit development period (FDP), GDH_b, (1st October to 28th February). Finally, rainfall was considered as follows: rainfall during endodormancy (R_a), rainfall from the beginning of endodormancy to the end of ecodormancy (R_b) and rainfall from the beginning of endodormancy to harvest season (R_c). Frosts number from ecodormancy to harvest date was also included.

These climatic variables were considered the main source of fruit production variation and therefore, their associations with yield were tested using Pearson correlation at 5% probability ($P \leq 0.05$) according to *t*-test. Before performing the correlation analysis the data was transformed using $\mathrm{Log_N}$. All statistical analysis were performed with Genes (Cruz, 2006) and InfoStat (Di Rienzo et al., 2013) programs.

3. Results

3.1. Stability methods for non-balanced trials

In the present work, performance and stability for fruit yield in peach accessions were evaluated using several methods. Table 1 shows the mean fruit yield (FY) and coefficient of variation (CV%) for each SE. Fruit yield variability among the accessions and SEs is evident since on average Sunprince peach had the highest yield at the SE1 and SE2, Hermosillo peach was the best one at the SE3 and SE6; the nectarines 84.351.029 and María Emilia at the SE4 and SE5, respectively, and the Flameprince peach at the SE7. Fruit yield fluctuation, both among accessions and SEs alters the genotype ranking which complicates the selection of genotypes. This observation agrees with previous report (Maulión et al., 2014a) who founded that the environment and crossover GEI were the main causes of the lack of genotype performance correlations among environments.

Table 2
Mean fruit yield and stability results obtained by DGC, relative yield (RY) and Piephoís methods.

Accession number	FY (Kg/tree)	DGC			RY method			Piepho method
		NSE	NSNDB	Classif	RY	SD	Classif	Classif
1	8.28	5	0	NS	67.09	37.66	S	NC
2	12.56	5	1	NS	134.39	112.71	NS	NC
3	13.20	5	0	NS	126.01	38.33	S	NC
4	5.78	5	0	NS	56.95	19.58	S	NC
5	4.07	5	0	NS	40.77	20.27	S	NC
6	10.12	5	0	NS	86.56	42.44	S	NC
7	14.98	7	1	NS	148.74	76.86	NS	NC
8	10.54	4	0	NS	90.62	56.79	S	NC
9	13.97	7	3	S	126.62	55.87	S	NC
10	12.68	7	0	NS	118.23	56.06	S	NC
11	13.14	7	0	NS	119.83	44.63	S	NC
12	8.82	6	0	NS	79.55	56.21	S	NC
13	9.10	7	0	NS	89.38	52.45	S	NC
14	9.46	7	0	NS	89.14	46.23	S	NC
15	9.74	5	0	NS	84.69	60.10	S	NC
16	22.58	5	3	S	201.81	132.89	NS	NC
17	7.72	6	0	NS	72.34	43.33	S	NC
18	6.13	5	0	NS	53.48	45.06	S	NC
19	11.11	7	0	NS	99.29	46.15	S	NC
20	4.69	5	0	NS	25.74	11.88	S	NC
21	11.80	7	1	NS	114.06	86.73	NS	NC
22	8.93	6	0	NS	85.07	55.48	S	NC
23	9.85	5	0	NS	85.34	41.20	S	NC
24	8.17	7	0	NS	73.86	31.00	S	NC
25	11.17	6	0	NS	109.04	36.35	S	NC
26	6.15	6	0	NS	54.63	65.15	S	NC
27	11.75	7	0	NS	107.78	53.07	S	NC
28	19.92	6	0	NS	180.15	102.92	NS	NC
29	11.80	5	0	NS	113.25	65.00	S	NC

FY: absolute mean fruit yield; DGC: Di Rienzo, Guzmán and Casanoves' test; NSE: number of season evaluated; NSNDB: number of seasons in which the accession did not differ from the best; Classif: classification; RY: average relative yield; SD: standard deviation; S: stable; NS: no stable and NC: no classified.

Stability and adaptability for fruit yield were analyzed by DGC' test, RY and Piepho methods and the results are given in Table 2. DGC and RY methods agreed in classifying the Fireprince peach accession as stable. Hermosillo peach was considered a stable genotype by DGC' test and its mean was higher than the general mean as Fireprinceís mean. However, it was classified as unstable according to RY because it had a high standard deviation (SD). No more stable accessions were detected by DGCís test according to our criterion. Since most accessions had low SD, they were classified as stables according to RY method, except for 84.351.029, Caldessi 2010 and María Emilia nectarines and Hermosillo and Sunprince peaches that were considered as non-stables genotypes. Twelve accessions had RY higher than 100% showing specific adaptability. All accessions were judged as unclassified for fruit yield according to Piephoís method.

3.2. *AMMI model and stability parameters*

The AMMI ANOVA for fruit yield of 29 peach accessions tested in seven environments showed that 25.06% of the total sum of squares (SS) was attributable to genotypic effects, 9.76% to environment effects, and 58.97% to GEI effects (Table 3). The large SS value attributable to genotypic effects indicated that there were differences among genotype mean yields. The lower proportion of the SS of environment effects indicated that the climatic scenario was different among years, but it influenced yield less than genotypic factor. However, since the GEI SS was near twice and six times higher than the genotypic and the environment effect SSs, respectively, it caused most of the yield variation across environments.

The application of AMMI model for partitioned of GEI revealed that the five first IPCA axes of AMMI were significant using the F-test and each one of these IPCA captured 34.23, 22.96, 20.36, 10.42 and 6.85% of GEI, respectively (Table 3). These IPCAs accounted for 94.82% of GEI while the remaining 5.18% corresponds to the residual or noise, which is not interpretable (Purchase, 1997).

IPCA scores of genotype and environments took positive and negative values (Tables 4 and 5). Scores with the same sign or near zero represent a non-crossover GEI or a proportionate genotype response (Mohammadi and Amri, 2008; Mohammadi et al., 2007). On the contrary, the fact that a genotype has large positive IPCA scores in some environments and large negative in others, indicates a disproportioned genotype response, which is the major source of variation for any crossover interaction (Mohammadi et al., 2007; Yan and Hunt, 2001).

The AMMI model reveled a complex GEI which could impede the visualization of genotypes in two-dimensional plot. Consequently, in this work, stability and GEI complexity for fruit yield were analyzed using eight stability parameters derived from AMMI analysis; mean fruit yield (FY); genotype selection index (GSI); rank-sum (RS); environmental variance $\left(S_x^2\right)$; Wricke parameter (W); superiority (P) and reliability indexes (I) (Tables 6 and 7).

In the ASV procedure, a genotype with the lowest ASV score is the most stable, accordingly, accession 10 (Flameprince) can be considered a desirable entry. In addition, this genotype showed an acceptable fruit yield (12.68 Kg/tree). The accessions 4, 5, 6 and 20 were also considered stable but showed a lower performance than Flameprince. The genotypes 1, 5, 20, 24 and 25 would be stable considering the EV values, while the entries 1, 5, 17, 18 and 25 would be stable considering the SIPC procedure. Annicchiarico (1997) stability measure (Da) showed the genotypes 5, 1, 23, 11 and 10 as promissory. From this set of accessions only Flameprince (10) and Flavorcrest (11) exhibited fruit yields higher than the general mean. The group of genotypes 4, 5, 6, 10, 20, and 1, 5, 11, 23, 25 would be introduced to germplasm considering the B and FA statistic stability, respectively, but only Flameprince (10) and Flavorcrest (11) exhibited fruit yields higher than the general mean. Flameprince was also selected among the entries 5, 10, 14, 19, and 24 as indi-

Table 3
Partition of the sum of squares and the mean of squares from the AMMI analysis of 29 peach genotypes fruit yield performance across seven seasons.

SOV	DF	SS	MS	FR-test	*P*	SSE%
Total	608	32331	53.2	–	–	
Treatments	202	30328	150.1	–	–	
Genotypes	28	8104	289.4	58.67	0.000	25.06
Environments	6	3156	526.1	94.22	0.000	9.76
GEI	168	19068	113.5	23.01	0.000	58.97
IPCA1	33	6527	197.8	40.10	0.000	34.23
IPCA2	31	4379	141.3	28.64	0.000	22.96
IPCA3	29	3884	133.9	27.15	0.000	20.36
IPCA4	27	1987	73.6	14.92	0.000	10.42
IPCA5	25	1307	52.3	10.60	0.000	6.85
Residuals	23	984	42.8	8.67	0.000	
Pooled Error	406	2003	4.9	–	–	
		R^2 = 91.0% CV = 21.26%				

SOV: Source of variation; DF: degrees of freedom; SS: sum of squares; MS: mean square; FR-test: Fisher ratio value test; *P*: probability value; SSE%: sum of square explained in percent; GEI: genotype-by-environment interaction; IPCA: interaction principal component axes; R^2: coefficient of determination; CV: coefficient of variation.

Table 4
Mean fruit yield, interaction principal component and eigenvectors of 29 peach genotypes.

Accession number	Mean yield (Kg/tree)	Interaction principal component					Eigenvectors for genotypes				
		IPCA1	IPCA2	IPCA3	IPCA4	IPCA5	γ_{i1}	γ_{i2}	γ_{i3}	γ_{i4}	γ_{i5}
1	9.26	0.502	−0.726	0.147	−0.506	−0.469	0.321	−0.589	0.126	−0.552	−0.650
2	10.74	1.780	0.214	1.360	−2.300	−0.788	0.982	0.173	1.170	−0.879	−2.990
3	10.89	0.392	0.661	1.590	0.203	−1.270	0.258	0.540	1.360	0.699	−1.780
4	7.02	0.274	0.305	−1.400	1.830	0.163	0.175	0.250	−1.200	0.155	0.340
5	5.52	0.026	0.347	90.382	90.331	1.460	0.017	0.284	−0.328	−0.218	0.049
6	8.53	−0.455	−0.133	1.520	0.534	0.206	−0.290	−0.109	1.300	0.850	0.680
7	14.98	1.330	0.375	−2.600	−1.010	−1.030	0.852	0.306	−2.230	−0.556	−0.850
8	11.63	0.775	2.540	−0.604	0.838	1.010	0.496	2.080	−0.518	0.067	0.106
9	13.97	0.999	0.852	−0.170	0.942	0.325	0.640	0.700	−0.146	2.270	1.400
10	12.68	−0.047	0.337	1.020	−0.798	−1.170	−0.030	0.277	0.880	−2.540	−1.090
11	13.14	−0.653	−0.290	−0.497	1.250	−0.374	−0.418	−0.238	−0.427	0.230	−1.760
12	8.15	−0.449	−1.450	0.303	−0.797	2.160	−0.287	−1.190	0.259	−1.990	0.230
13	9.10	0.483	−0.964	1.010	−0.101	0.414	0.310	−0.790	0.868	−0.370	2.030
14	9.46	−0.045	−1.670	0.259	−0.735	0.229	−0.029	−1.370	0.223	−0.590	0.280
15	10.13	−0.296	−1.280	0.720	−0.568	0.350	−0.189	−1.280	0.618	−1.110	1.400
16	22.41	−4.920	0.883	−0.385	0.508	−1.800	−3.150	0.720	−0.331	0.920	−1.410
17	7.47	0.167	-1.190	−0.525	0.157	0.034	0.105	−0.974	−0.450	1.040	0.450
18	6.20	0.902	−0.104	0.075	−0.195	0.512	0.580	−0.085	0.065	−0.880	1.560
19	11.11	0.065	0.986	1.520	−1.110	0.118	0.042	0.806	1.300	−1.390	0.520
20	4.31	0.184	0.696	−1.150	−0.340	−0.692	0.118	0.569	−0.987	−0.113	−0.580
21	11.80	−1.030	−2.330	−2.510	−1.680	−0.104	−0.659	−1.910	2.150	−0.810	−0.310
22	9.52	0.655	−1.660	0.772	0.133	0.112	0.419	−1.360	0.662	0.620	0.490
23	9.59	0.702	0.283	0.287	0.629	1.280	0.450	0.230	0.246	0.550	2.500
24	7.84	−0.104	0.997	−0.940	−0.140	0.244	−0.067	0.816	−0.806	−0.174	0.048
25	10.39	0.205	−1.020	0.043	0.197	−0.036	0.131	−0.839	0.037	0.216	−0.710
26	6.32	1.310	1.270	−1.740	0.769	−0.495	0.839	1.040	−1.490	1.230	−0.155
27	11.46	−0.806	−1.060	0.549	0.503	0.611	−0.516	−0.870	0.471	0.380	0.970
28	19.92	−2.830	1.790	0.624	0.060	0.076	−1.810	1.460	0.535	1.860	0.140
29	11.80	0.888	1.360	1.100	2.060	−1.080	0.569	1.110	0.944	0.128	−0.156
Eigenvalue							2.44	1.49	1.36	0.82	0.52

Table 5
Environmental means, variance, IPCA and ASVe scores.

SE	Mean yield (Kg/tree)	Interaction principal component					Eigenvectors for environments					ASVe
		IPCA1	IPCA2	IPCA3	IPCA4	IPCA5	δ_1	δ_2	δ_3	δ_4	δ_5	
SE1	11.03	2.434	3.660	3.016	0.685	−1.449	1.560	3.000	2.600	0.755	−2.010	4.499
SE2	9.31	3.713	0.126	1.786	−1.850	0.460	2.380	0.103	1.540	−2.048	0.638	3.991
SE3	10.23	3.026	2.111	1.902	−0.762	0.541	1.940	1.730	1.640	−0.842	0.749	3.869
SE4	6.99	3.245	0.183	0.418	−0.254	3.594	2.080	0.150	0.360	−0.280	4.985	3.479
SE5	9.66	0.671	4.172	2.564	1.390	−0.275	0.430	3.420	2.210	1.541	−0.382	4.230
SE6	15.09	0.718	0.156	2.830	3.470	−0.676	0.460	0.128	2.440	3.840	−0.938	0.776
SE7	11.38	2.465	1.696	2.216	−2.690	−2.194	1.580	1.390	1.910	2.971	3.041	3.133

SE: season evaluation; ASVe: AMMI stability value.

cated by FP measure, but these last accessions have low FY, except for María Aurelia nectarine (19). According to the Za parameter the accessions 1, 4, 5, 24 and 25 would be introduced as stable but neither of them had yield higher than the general mean. Among the genotypes classified as stable by the AMMI stability, María Aurelia nectarine (11.12 Kg/tree) and Flameprince (13.15 Kg/tree) and

Table 6
Mean fruit yield and statistic stability values of 29 peach accessions.

AN	FY	ASV	EV	SPIC	Da	FA	FP	B	Za	GSI	RS	I	P	W	S_x^2
1	9.26	0.94	0.24	2.64	1.19	1.43	0.61	1.57	21.99	28	22.78	78.35	243.77	206.41	56.63
2	10.74	1.88	2.41	7.28	2.88	9.61	5.74	5.82	53.71	37	24.65	82.44	241.48	1015.73	151.43
3	10.89	0.82	1.17	4.37	2.11	6.18	0.40	1.20	40.35	18	20.89	81.53	209.18	480.12	111.49
4	7.02	0.45	0.33	4.20	1.73	4.32	0.18	0.35	23.66	28	24.76	39.02	278.66	239.81	25.41
5	5.52	0.35	0.05	2.26	0.62	0.48	0.01	0.22	9.67	30	25.51	51.46	310.34	80.48	34.25
6	8.53	0.57	0.59	3.28	1.91	5.22	0.50	0.53	30.92	25	26.02	53.93	250.07	350.12	128.85
7	14.98	1.67	1.36	7.22	3.70	18.32	4.32	4.57	54.99	23	16.63	72.91	164.01	1060.65	134.95
8	11.63	2.71	0.97	6.50	3.40	11.81	1.46	13.47	45.25	35	24.17	67.07	199.27	997.48	166.30
9	13.97	1.49	1.60	3.89	1.89	3.59	2.43	3.79	43.77	22	17.06	136.35	173.91	726.16	190.38
10	12.68	0.34	1.70	3.20	1.27	2.32	0.02	0.21	34.95	7	19.17	78.25	173.35	669.58	119.98
11	13.14	0.85	0.71	3.35	1.2	1.67	1.04	1.19	25.32	12	15.82	114.95	155.25	254.45	76.38
12	8.15	1.55	1.11	5.10	1.94	3.82	0.50	4.42	38.18	41	28.22	27.45	268.99	542.86	137.81
13	9.10	1.13	1.14	3.50	1.83	4.05	0.57	2.30	37.87	34	23.37	38.13	246.60	393.84	65.52
14	9.46	1.67	0.47	3.24	2.06	4.31	0.03	5.21	26.58	39	23.73	46.61	240.59	359.50	81.83
15	10.13	1.33	1.05	3.63	2.13	4.91	0.21	4.76	41.06	31	20.30	52.08	222.73	407.62	101.69
16	22.41	6.07	2.68	10.97	7.78	60.53	59.07	60.51	88.67	30	21.92	68.66	55.06	3639.62	645.73
17	7.47	1.21	0.49	2.49	1.60	2.73	0.06	2.69	28.93	39	25.14	51.00	281.37	281.62	62.95
18	6.20	1.11	0.71	2.17	1.42	2.03	2.00	2.02	25.36	40	30.29	68.80	314.34	270.52	69.98
19	11.11	0.99	0.90	4.17	2.14	6.14	0.01	1.81	38.03	21	20.13	102.26	204.52	492.51	154.93
20	4.31	0.73	0.33	3.29	1.61	3.50	0.08	0.98	24.99	34	29.22	20.16	340.33	232.32	30.96
21	11.80	2.65	1.89	8.97	4.39	23.51	2.59	12.71	71.23	33	24.21	57.83	205.99	1518.49	215.91
22	9.52	1.83	0.62	4.15	2.44	6.37	1.04	6.17	40.62	40	23.91	40.15	249.62	476.95	86.06
23	9.59	0.90	1.37	3.27	1.19	1.49	1.20	1.35	28.64	24	25.11	120.73	242.18	310.55	110.91
24	7.84	1.00	0.27	2.78	1.64	3.31	0.03	1.87	23.35	34	24.20	46.22	252.69	214.32	41.58
25	10.39	1.05	0.25	1.82	1.29	1.67	0.10	2.05	18.65	26	18.42	66.69	215.05	230.70	34.54
26	6.32	2.04	1.11	6.68	3.27	12.75	4.12	7.19	57.11	51	28.95	27.15	316.52	859.62	107.36
27	11.46	1.45	0.46	4.09	1.92	3.89	1.59	3.68	34.12	26	20.44	65.38	187.40	364.06	92.39
28	19.92	3.89	1.83	7.44	4.97	25.03	19.50	25.42	74.74	30	16.22	130.86	85.45	1915.88	356.79
29	11.80	1.74	0.50	6.97	2.51	7.13	1.93	5.34	39.28	32	23.70	119.87	204.50	476.33	111.14

AN: accession number; FY: absolute mean fruit yield; ASV: AMMI stability value; EV: average of the square eigenvector values; SPIC: sums of the absolute value of the IPCA scores; Da: parameter of Annicchiarico (1997); FA: stability statistic based on the IPCA axes fixed in the AMMI model; FP: stability statistic based on the first IPCA axes of the first IPCA axes; B: stability statistic based on the first and second IPCA axes; Za: absolute value of the relative contribution IPCAs to the interaction; GSI: genotype selection index; RS: Rank-Sum; I: reliability index and P: parameters of Lin and Binns and W: Wricke parameter; S_x^2: environmental variance.

Table 7
Ranks of 29 peach genotypes using mean fruit yield and their stability measures.

AN	FY	ASV	EV	SIPC	Da	FA	FP	B	Za	GSI	RS	I	P	W	S_x^2
1	19	9	2	5	2	2	15	9	3	11	12	9	18	2	6
2	13	24	28	26	23	23	27	23	24	23	20	7	16	25	23
3	12	6	21	20	18	20	11	7	19	3	10	8	12	18	18
4	25	3	6	19	11	16	9	3	5	12	21	25	24	6	1
5	28	2	1	3	1	1	1	2	1	13	24	20	26	1	3
6	21	4	11	10	14	18	12	4	12	8	25	18	21	11	20
7	3	20	22	25	26	26	26	19	25	6	3	11	4	26	21
8	9	27	16	22	25	24	19	27	23	22	17	14	8	24	25
9	4	18	24	15	13	11	23	17	22	5	4	1	6	22	26
10	6	1	25	7	5	7	3	1	14	1	6	10	5	21	19
11	5	7	14	12	4	5	16	6	7	2	1	5	3	7	10
12	22	19	19	21	16	12	13	18	17	28	26	27	23	20	22
13	20	14	20	13	12	14	14	14	15	19	13	26	19	14	8
14	18	21	8	8	17	15	4	21	9	24	15	22	15	12	11
15	15	16	17	14	19	17	10	20	21	16	8	19	14	15	14
16	1	29	29	29	29	29	29	29	29	14	11	13	1	29	29
17	24	15	9	4	8	8	6	15	11	25	23	21	25	9	7
18	27	13	13	2	7	6	22	12	8	26	29	12	27	8	9
19	11	10	15	18	20	19	2	10	16	4	7	6	10	19	24
20	29	5	5	11	9	10	7	5	6	20	28	29	29	5	2
21	7	26	27	28	27	27	24	26	27	18	19	17	11	27	27
22	17	23	12	17	21	21	17	24	20	27	16	24	20	17	12
23	16	8	23	9	3	3	18	8	10	7	22	3	17	10	16
24	23	11	4	6	10	9	5	11	4	21	18	23	22	3	5
25	14	12	3	1	6	4	8	13	2	9	5	15	13	4	4
26	26	25	18	23	24	25	25	25	26	29	27	28	28	23	15
27	10	17	7	16	15	13	20	16	13	10	9	16	7	13	13
28	2	28	26	27	28	28	28	28	28	15	2	2	2	28	28
29	8	22	10	24	22	22	21	22	18	17	14	4	9	16	17

AN: accession number; FY: absolute mean fruit yield; ASV: AMMI stability value; EV: average of the square eigenvector values; SPIC: sums of the absolute value of the IPCA scores; Da: parameter of Annicchiarico (1997); FA: stability statistic based on the IPCA axes fixed in the AMMI model; FP: stability statistic based on the first IPCA axes of the first IPCA axes; B: stability statistic based on the first and second IPCA axes; Za: absolute value of the relative contribution IPCAs to the interaction; GSI: genotype selection index; RS: rank-sum; I: reliability index and P: parameters of Lin and Binns; W: Wricke parameter and S_x^2: environmental variance.

Flavorcrest peaches (13.14 Kg/tree) exhibited FY higher than the general mean.

To select high-yielding and stable genotypes, both stability and yield were unified in a single non parametric measure, GSI and RS. Considering the GSI procedure the most desirable accessions were 3, 9, 10, 11 and 19, while according to RS the genotypes 7, 9, 11, 25 and 28 had the best performances. Using I and P as selection criteria, genotypes 9, 11, 23, 28, 29, and 7, 10, 11, 16, 28 were respectively selected as high-yielding and stable. Accessions chosen by these four measures had FY closer or higher to the overall mean (10.54 Kg/tree). On the contrary, W and S_x^2, were associated with materials with low performance, only the genotype 25 showed an acceptable FY value (10.39 Kg/tree) (Table 6).

Associations among FY and AMMI stability parameters should be analyzed because some of them are appropriate to study only stability and others stability and yield. The Spearman's rank correlation was determined for each pair of stability statistics (Table 8) and was followed by principal component analysis (PC) to better understand the relationships among them. The AMMI stability values showed positive and high significant correlations among them ($P < 0.01$), except for the association between EV and B that shows lower significance ($P < 0.05$). The FY was associated in a highly negative manner with all AMMI parameters; consequently, these parameters could be used to select stable but not high-yielding genotypes. The single measures, GSI, RS, I and P showed positive and high significant correlations among them ($P < 0.01$) and with FY ($P < 0.01$). Therefore, only one of them could be used to select stable accessions with high performances. However, the magnitude of the correlations between RS, P and FY were the highest estimated, and consequently, RS and P would be the most suitable parameters to select the best peach accessions.

The first two PCs explained 93.60% (PC1 = 86.20% and PC2 = 7.40%) of the original variables variance. The relationships among different stability parameters are graphically displayed in the biplot of PC1 and PC2 (Fig. 1). In this scatterplot, the PC1 distinguished S_x^2, Za and EV (Group 1, Section A) and SIPC, FP, FA, Da, W, ASV and B (Group 2, Section B) from the single measures GSI (Section C), RS, I, P and FY (Group 3, Section C). The PC2 separated the parameters according stability concepts. The parameters S_x^2, EV and Za (Group 1, Section A) are related with static stability while those measures in Section B and C are associated dynamic stability concept.

3.3. Climatic variables

Influence of climatic conditions has been well established in peach performance. Therefore, climatic variables as rainfall, frosts number and thermal accumulation for each season were recorded (Table 9) and the association with fruit yield was analyzed by Pearson correlation. Rainfall during endo-dormancy (R_a), eco-dormancy (R_b) as well as heat accumulation during fruit development period (GDH_b) were significantly associated with fruit yield variation among season (Table 10).

4. Discussion

Generally, the GEI is the main cause of yield variation in crop (Giauffret et al., 2000) and this fact was also recently reported in peach (Citadin et al., 2014; Maulión et al., 2014a). Development and selection of high-yielding and stable peach cultivar scheme would be useful in Argentina, because peach fruit is used for domestic consumption and exported to neighboring and northern hemispheric countries where better market prices are obtained. Therefore, fruit yield should be constant because an unstable output interferes with marketing.

In this work, we evaluated three different methodologies that are useful to assess the performance of genotypes when the dataset is unbalanced. Since genotype stability is differently assigned by DGC' test and RY procedure, Fireprince peach was the only accession indicated as a stable by both methods. Similar results were reported by Cravero et al. (2010) and Giménez et al. (2001) assessing the stability of 10 globe artichoke and 64 soybean cultivars, respectively. Lúquez et al. (2002) evaluated 42 sunflower hybrids for oil content and grain yield in non-balanced trial and found 76 and 77% similarity between LSD and RY methods, considering oil content and grain yield respectively. DGC' test considers as stable those genotypes that do not differ significantly from the best entry in most environments evaluated. For this reason, genotypes with low fruit yield would not be classified as stable by this methodology, although they do not show significant performance variation. Stability obtained by DGC strongly depends on the number of environments evaluated. Our study includes results of entries evaluated for four to seven SEs, like those published by Giménez et al. (2001) and Cravero et al. (2010) and could be considered as a preliminary analysis. Piepho's method was applied considering δ values from 5 to 15% in order to relax the method requirement hoping that some entries were classified as adapted, nevertheless, all peach accessions were not classified. This means that no significant differences from the best were detected considering the δ values established. Giménez et al. (2001) studied soybean stability and Lúquez et al. (2002) sunflower stability using the relaxing Piepho's method and few genotypes were reported as adapted by these authors. This procedure did not discriminate the tested genotypes as DGC and RY did. Although average fruit yield were significantly different among peach accessions, the mean square errors that were used to calculate adaptability by this method, were not, thus no separation among genotypes were obtained.

The AMMI model is characterized by being able to make predictions for new sites and new years, thus contributing a real advance comparing with most statistical models (Gauch, 1988). The high significance of GEI for fruit yield and the large magnitude of genotype and environments main effects indicate that the entries studied exhibited complex GEI. In the present investigation, the GEI reached 59% of the total variance and five IPCAs were required to explain it. Similar results were obtained using AMMI models to analyze the GEI in multi-environment trials of different crop, such as quinoa (Bertero et al., 2004), durum wheat (Mohammadi et al., 2007; Sabaghnia et al., 2013), chickpea (Zali et al., 2012), soybean (Zobel et al., 1988) and yellow passion (de Oliveira et al., 2014). In this situation, the use of AMMI1 and AMMI2 to identify stable and high-yielding genotypes is limited, since the two first IPCAs axes explain only 56% of the total interaction variation. A portion of this yield variation could be explained considering the significant associations between fruit yield and climatic variables such as $GDH_{b,}$ R_a and $R_{b,}$ (Table 10). Although FN was the most variable climatic factor among years, it did not correlate with FY and therefore it would not explain yield variation. Rainfall during floral bud endodormancy (R_a) and from floral bud endo- to ecodormancy (R_b) took also variable values among years and the associations with FY found in this study were expected, since peach flower bud dormancy breakdown was reported to be highly sensitive to water supply (Erez and Couvillon, 1987). Heat accumulation during fruit development period (GDH_b) was the least variable climatic factor among years, however it correlated with FY and this association could be explained taking into account that GDH are necessary to promote fruit development (Lopez and Dejong, 2007).

Most of the genotypes that were considered as stable according to eight AMMI measures had moderate or low FY. In fact, all AMMI statistics showed negative correlation with fruit yield; therefore, any of these parameters could be used to select stable but not stable and high-yielding peach genotypes. Our finding agrees with previ-

Table 8
Spearman's coefficient of rank correlation for mean fruit yield and stabilities parameters.

	FY	ASV	SIPC	EV	Da	FP	B	FA	Za	GSI	RS	I	P	
ASV	−0.42*													
SIPC	−0.54**	0.67**												
EV	−0.61**	0.46**	0.65**											
Da	−0.48**	0.81**	0.88**	0.56**										
FP	−0.49**	0.69**	0.67**	0.60**	0.60**									
B	−0.41*	0.99**	0.66**	0.45*	0.82**	0.66**								
FA	−0.45**	0.72**	0.89**	0.56**	0.98**	0.58**	0.73**							
Za	−0.60**	0.77**	0.85**	0.82**	0.89**	0.70**	0.77**	0.86**						
GSI	0.51**	0.52**	0.09^{ns}	−0.11^{ns}	0.26^{ns}	0.11^{ns}	0.52**	0.20^{ns}	0.21^{ns}					
RS	0.80**	−0.10^{ns}	−0.17^{ns}	−0.25^{ns}	−0.16^{ns}	−0.12^{ns}	−0.11^{ns}	−0.13^{ns}	0.13^{ns}	0.64**				
I	0.69**	−0.06^{ns}	−0.16^{ns}	−0.40*	−0.05^{ns}	−0.38^{ns}	−0.04^{ns}	−0.03^{ns}	0.05^{ns}	0.61**	0.58**			
P	0.98**	−0.33^{ns}	−0.44*	−0.51**	−0.40*	−0.39^{ns}	−0.32^{ns}	−0.37^{ns}	−0.02^{ns}	0.57**	0.85**	0.69**		
S_x^2	−0.72**	0.59**	0.72**	0.82**	0.72**	0.59**	0.57**	0.67**	0.12^{ns}	−0.14^{ns}	−0.30^{ns}	−0.50**	−0.64**	
W	-0.66**	0.71**	0.83**	0.86**	0.85**	0.64**	0.70**	0.82**	0.28^{ns}	0.05^{ns}	−0.28^{ns}	−0.28^{ns}	−0.56**	0.90**

^{ns} non significant, * and ** significant at 5% and 1% probability, respectively.

FY: mean fruit yield; ASV: AMMI stability value; SPIC: sums of the absolute value of the IPCA scores; EV: average of the square eigenvector values; Da: parameter of Annicchiarico (1997); FP: stability statistic based on the first IPCA axes of the first IPCA axes; B: stability statistic based on the first and second IPCA axes; FA: stability statistic based on the IPCA axes fixed in the AMMI model; Za: absolute value of the relative contribution IPCAs to the interaction; GSI: genotype selection index; RS: Rank-Sum; I: reliability index and P: parameters of Lin and Binns; S_x^2: environmental variance and W: Wricke parameter.

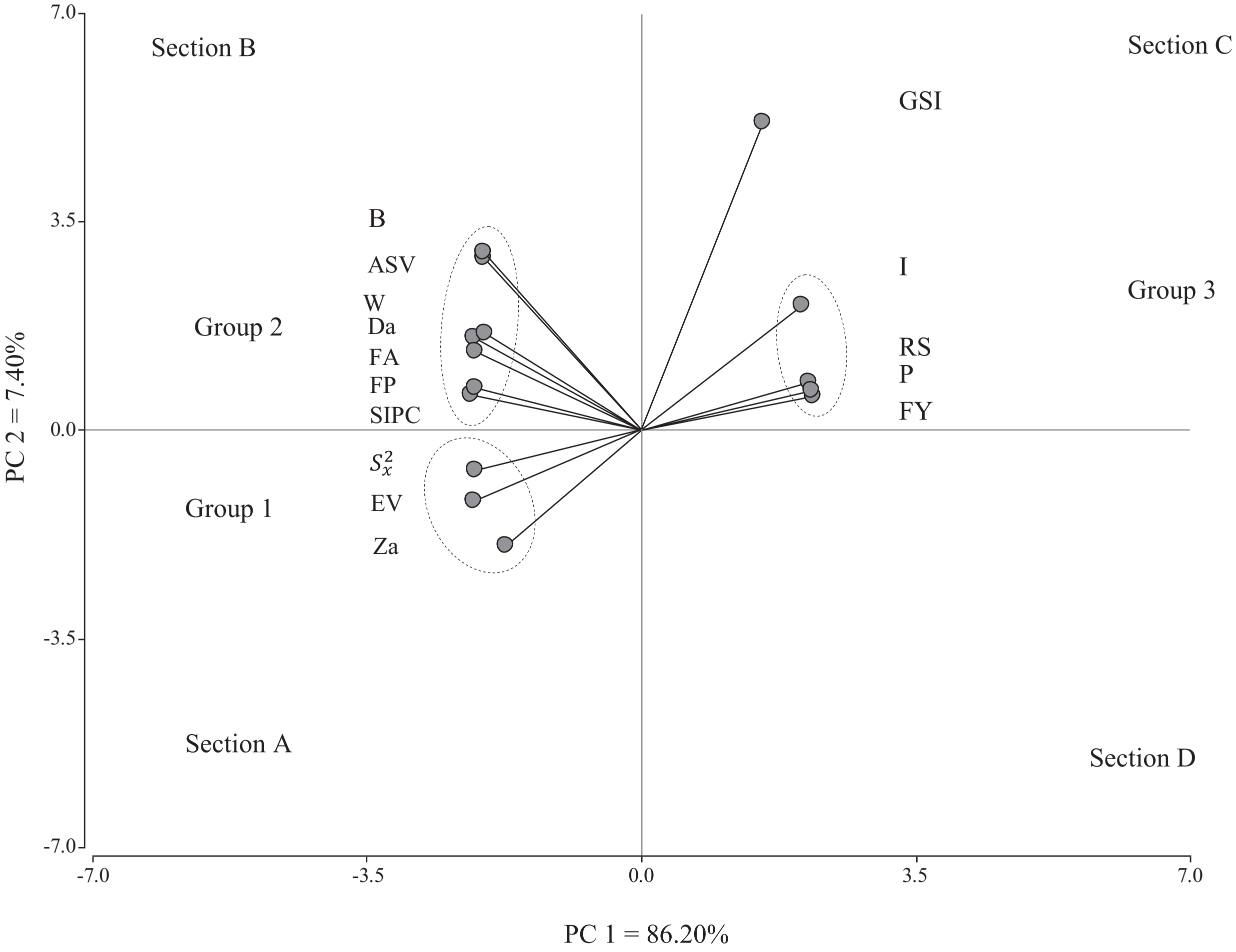

Fig. 1. Principal components analysis (PC1 and PC2) plot of rank values of stability parameters considering the performance of 29 peach accessions.

ous reports. Sabaghnia et al. (2013) assayed four AMMI measures in durum wheat and Dehghani et al. (2010) studied chickpea stability using seven AMMI parameters, in both works, AMMI analysis selected stable genotypes but they did not show the best performances. Also Mohammadi et al. (2007) obtained similar results in durum wheat considering ASV as selection criteria.

Stability should not be the only parameter for selection because the most stable genotypes would not necessary have the best yield performances. Hence, it is necessary to incorporate stability and yield in a single index. The average fruit yield of the genotypes selected by GSI measure was 12.40 Kg/tree, while the average of those selected by RS, I and P were 14.48 Kg/tree, 13.68 Kg/tree and 16.62 Kg/tree, respectively. These means are very similar and the

Table 9
Average fruit yield (Kg/tree) and climatic variables registered during each evaluated season.

SE	FY	PCU	GDHa	GDHb	Ra	Rb	Rc	FN
SE1	11.23	774.00	11783.10	56867.50	133.70	248.80	594.80	4
SE2	10.85	692.00	12146.55	58580.73	77.00	110.00	814.60	17
SE3	10.18	1222.00	11974.24	59046.71	48.70	180.60	641.20	4
SE4	6.92	792.50	12843.40	60704.20	26.00	70.40	542.90	7
SE5	9.59	927.50	12986.80	58980.60	127.40	246.90	1211.60	25
SE6	15.33	855.00	11694.50	57334.50	186.80	296.40	924.80	6
SE7	11.40	912.00	12630.40	59081.70	168.50	173.50	732.90	6

SE: Season evaluation; FY: Absolute mean fruit yield (Kg/tree); PCU: chilling accumulation during floral bud endodormancy expressed in Positive Chilling Unit; GDH: heat accumulation expressed in Growing Degree Hours during floral bud ecodormancy and fruit development period, GDH_a (1st August to 30th September) and GDH_b (1st October to 28th February), respectively; R_a: rainfall during floral bud endodormancy (mm) (1st May to 31st July); R_b: rainfall from floral bud endo- to ecodormancy (mm) (1st May to 30th September); R_c: rainfall from floral bud endodormancy to harvest date (mm) (1st May to 28th February) and FN: frosts number from 1st August to 28th February.

Table 10
Result of association analysis between fruit yield variation and climate variables obtained by Pearson correlation.

FY	PCU	GDH_a	GDH_b	R_a	R_b	R_c	FN	$GDH_a{}^*R_b$	$GDH_b{}^*R_c$	$R_a{}^*FN$	$R_b{}^*FN$
r	0.02	−0.70	−0.82	0.83	0.76	0.41	−0.18	0.73	0.35	0.45	0.32
P	0.9702	0.0797	0.0240	0.0215	0.0460	0.3674	0.7019	0.0627	0.4471	0.3081	0.4841

FY: Absolute mean fruit yield (Kg/tree); PCU: chilling accumulation during floral bud endodormancy expressed in Positive Chilling Unit; GDH: heat accumulation expressed in Growing Degree Hours during floral bud ecodormancy and fruit development period, GDH_a (1st August to 30th September) and GDH_b (1st October to 28th February), respectively; R_a: rainfall during floral bud endodormancy (mm) (1st May to 31st July); R_b: rainfall from floral bud endo- to ecodormancy (mm) (1st May to 30th September); R_c: rainfall from floral bud endodormancy to harvest date (mm) (1st May to 28th February); FN: frosts number from 1st August to 28th February; $GDH_a{}^*R_b$: the interaction between GDH_a and R_b; $GDH_b{}^*R_c$: the interaction between GDH_b and R_c; $R_a{}^*FN$: the interaction between R_a and FN; $R_b{}^*NF$: the interaction between R_b and FN; r: Pearson correlation coefficient; P-values lower than 0.05 indicate significant correlations between variables.

parameters correlate to each other in a highly positive way; therefore any of these four procedures could be used to select superior stable and high-yielding peach genotypes. Since these four procedures differ to each other, breeders may choose one of them according to their criteria and experimental conditions. GSI and RS usefulness were tested in bread wheat (Farshadfar et al., 2011) and rice (Bose et al., 2014), while P and I efficiencies were reported in peach (Maulión et al., 2014a) as well as in other crops (Acevedo et al., 2010; Flores et al., 1998; Gomez-Becerra et al., 2006; Ilker et al., 2008; Pena et al., 2012).

AMMI stability parameters, RS and GSI have been compared and their relationships with static or dynamic stability concepts have been suggested. Considering the graphical analysis, the PC1 did not separate the measures in agreement with the two stability concepts. Similar results were obtained in chickpea (Dehghani et al., 2010) and durum wheat (Sabaghnia et al., 2013). On the other hand, Sabaghnia et al. (2008) reported that the first PC separated the AMMI parameters into two groups consistent with the static and dynamic stability concepts. The AMMI model used in this research exhibited another complex interaction due to the crop nature, environment conditions and genetic backgrounds obtained from different sources. The second PC separated these two concepts of stability. The Za and EV are in section A with $< MML : MSUBSUP > Sx2 < /MML : MSUBSUP >$, which is a classical static stability parameter, and so it indicated static stability concept. The association between the EV parameter and the static stability concept was also reported by Dehghani et al. (2010) and Sabaghnia et al. (2013, 2008),). W measure, which is associated with dynamic stability, is located in section B and therefore, we considered that AMMI values in Group 2 would be related to that stability concept, although Dehghani et al. (2010) and Sabaghnia et al. (2008) reported that ASV and SIPC were related to static stability. Statistics in section C are the single measures, which differ from those located in section B since they are related to FY. RS and GSI were close to methods based on agronomic stability as I and P indexes. However, only GSI could be considered as AMMI stability derived because ASV rank was used to calculate it.

AMMI stability statistics are indicative of high-, intermediate-, or low-stability, therefore, they do not provide information for definitive conclusions. On the other hand, most of them were associated with the dynamic stability concept, while others with the static concept. In addition, they were not related with fruit yield and would not be appropriate to select high-yielding genotypes. However, the ASV statistic was incorporated in the GSI procedure which identified Fireprince as the most stable and productive peach genotype. Considering the best five genotypes, the average fruit yield obtained with GSI, RS, I and P is nearly equal. Therefore, GSI and RS can be considered efficient selection measures, along with I and P, as was reporter before (Maulión et al., 2014a). The outcomes can be summarized as follows: a- Fireprince was found to be the most stable and high-yielding peach genotype, b- when the dataset is unbalanced DGC is a reliable selection method, c- ASV statistic was found to be useful to detect the phenotypic stability of the peach entries studied, d- GSI and RS procedures can be use to select stable and high-yielding genotypes and e-the significance of GEI and genotype rank changing across environments suggest the selection of a group of genotypes specially adapted to homogenous environments, as breeding strategy.

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