



Study of statistic stability to select high-yielding and stable peach genotypes

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ABSTRACT

In peach breeding, suitable identification methods for performance stability studies as well as the associations between stability parameters are poorly understood. Therefore, the aims of this work were to compare parametric (S_{ij}^2 , $b_i S_{xi}^2$, W_i , θ_i and I_i) and non-parametric ($S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$ and P_i) stability measures, evaluate the level of association among them, select superior accessions and identify major environmental variables as causes of yield variation among years. Fruit yield stability was studied using data of fruit yield from 25 peach genotypes under three environments, arranged in a completely randomized design with three replications. Frosts, chilling, heat, rainfall and the interactions among them were considered as explanatory variables of yield variation through years. Crossover was the main effect of genotype-by-environment interaction indicating that the selection of high-yielding and stable peach genotype would be a laborious task for breeders. The interaction between rainfall and heat accumulation during fruit development period explained 96.7% of yield variation among years. Yield (Y_i) exhibited negative correlation with W_i and θ_i , while W_i showed negative association with P_i . $S_i^{(1)}$, $S_i^{(2)}$, and $S_i^{(3)}$ were positively associated with each other, showing that just one of these three statistics would be sufficient to select stable accessions although they were not correlated with Y_i . Fruit yield was positively correlated with P_i and I_i , these two measures were also positively associated with each other, and therefore, only one of them would be enough for selection of superior peach accessions. Both, P_i and I_i statistics revealed that accessions Sunprince, Flameprince, Mar3a Aurelia, Vega, Starlite and Flavorcrest were the most stable and high-yielding genotypes across environments.

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1. Introduction

Prunus persica (L.) Batsch is one of the most important fruit tree species of the Rosacea family. Among the semi-perennial fruit trees, peach ranks third in the world, and Argentina is the eleventh largest producer with 285,000 tons per year FAOSTAT (<http://faostat.fao.org/>). The northeast of Buenos Aires province, Argentina, represents one of the most important peach producing regions of the country. San Pedro Agricultural Experimental Station of the National Institute of Agricultural Technology (INTA

San Pedro) is located there and has a collection of peach and nectarine accessions introgressed from different regions around the world which is evaluated for yield and quality traits every year. Peach is a crop subjected to an intense breeding activity that allows a fast turnover of varieties, since new cultivars are being created continuously all over the world. However, despite tremendous progress in the selection of superior and high-yielding cultivars, new materials are constantly demanded by both farmers and consumers, and hence further selection activities are necessary. New cultivars for horticulturists and potential parents for breeding programs are selected from a collection of genotypes with diverse pedigree and origin. Since each genotype interacts with several climatic variables, differential performance is expected when a genotype has been selected in one environment and is cultivated in another. This genotype-by-environment interaction (GEI) is a particular problem for plant breeders (Giauffret et al., 2000).

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Non-crossover and crossover are the main effects of GEI (Cruz and Regazzi, 1997). The latter is responsible for the lack of correlation among phenotypic values and changes in genotype ranks masking the potential utility of exotic materials (Giauffret et al., 2000). GEI affects the extent of genetic progress through plant breeding and also disturbs the efficiency of varietal choice for farmers (Becker, 1981). From farmers' standpoint, fruit yield stability is important since horticulturist's major concern is to minimize the chance of poor yield in a particular year. Peach varieties are used as semi-perennial crops, which remain in production for more than 10 years. For this reason, the choice of varietal types with high yield and stability through years would be of utmost importance for peach growers. Lin et al. (1986) identified three concepts of stability, type 1, 2 and 3. Type 1 is also called static (Becker and Leon, 1988) and is useful when considering quality traits, disease resistance or stress characters that should not vary among different environments. Coefficient of variability (Francis and Kannenberg, 1978) and genotypic variance across environments ($S_{\alpha_i}^2$) (Roemer, 1917) are the most common methods associated to type 1 or static stability. Type 2 stability is also called dynamic or agronomic stability (Becker and Leon, 1988). According to this concept, a stable genotype has no deviation from the general response and thus it has a predictable behavior. This concept is accepted by breeders and agronomics, who prefer developing genotypes with high-mean yields and potential to respond to agronomic inputs or better growing conditions (Becker, 1981). Plaisted and Peterson (1959), and Wricke's ecovalence (1962) are based on analysis of the variance (ANOVA) and are used to measure the type 2 stability. Regression methods were also proposed to measure stability (Eberhart and Russell, 1966; Finlay and Wilkinson, 1963). In this methodology the stability is expressed in terms of three empirical parameters: mean yield, the coefficient of regression, b_i , and the sum square deviation from regression, (S_{ij}^2) (Crossa, 1990; Flores et al., 1998). The S_{ij}^2 is strongly related to an unpredictable part of genotype variability and is considered a stability parameter, and b_i characterizes the specific response of genotypes to environmental effects and may be used as a response parameter (Breese, 1969). Genotypes which do not react to environmental factors variations show zero b_i values and would be stable according to the static concept or type 1 stability. On the other hand, genotypes possessing an average response to environmental changing conditions show b_i values equal to one, according to the agronomic concept or type 2 stability. Although the regression methodology is frequently applied to study stability, its coefficient b_i could be biased because the independent variable of the regression analysis, which in this case is the environmental mean, should be measured without error. As this assumption could not be met (Sprent, 1969), it may be considered a serious limitation. Furthermore, the variation of the regression coefficients estimates is usually so small that complicates ranking genotypes based on stability (Farias et al., 1995). Yue et al. (1997) considered the need for satisfying the assumption of normality, the variance homogeneity, the additivity or linearity of genotypes and environmental effects, as well as additional constraints of parametric methods. Since practical interest in combining mean yield and stability in one parameter, based on the safety first-rule (Kataoka, 1963), Eskridge (1990) proposed the use of the yield reliability concept or reliability index (I_i), which is calculated through the consistent high yields across environments.

An alternative for the assessment of a cultivar performance considering GEI with no limitations inherent to the use of regression or ANOVA are the non-parametric methods. They are distribution-free, unlike parametric statistic they do not make any assumptions, are easy to use and their results are simple to interpret (Nassar and Huehn, 1987; Huehn, 1990a). Lin and Binns

(1988) proposal is infrequently quoted in the literature, but it is a good alternative for the assessment of cultivar performance in the presence of GEI. Like reliability index (I_i), it characterizes genotypes with a single parameter (P_i) by associating stability and productivity, and defines a superior cultivar as a genotype whose performance is near the maximum in various environments (Lin and Binns, 1988; Helgad3ttir and Kristj3nsd3ttir, 1991). This definition of superiority is similar to the breeder's objective, since a superior cultivar should be among the most productive all over the possible environments (Farias et al., 1997). Other non-parametric procedures are based on the comparison of genotype ranks in each environment; genotypes with similar ranks across environments are considered stable (Huehn, 1979; Nassar and Huehn, 1987). Huehn (1990a) proposed the following non-parametric measures of phenotypic stability $S_i^{(1)}$, $S_i^{(2)}$, and $S_i^{(3)}$ and defined a stable genotype as that whose position in relation to the others remains unaltered in the set of environments assessed. In contrast to parametric models, this method reduces the bias caused by points outside the adjusted regression equation. The addition or removal of one or few genotypes probably causes less variation in estimates of stability parameters than parametric methods.

Although several models have suggested measuring yield stability and have broadly been used in major crops, they have been poorly applied to understand the nature of GEI in peach. Each methodology shows different aspects of stability but no single method can adequately explain cultivar performance across environments. Evaluation and comparison of various methodologies for stability analysis in peach have not been performed yet. On the other hand, the level of association among stability measures obtained by different models should be considered because it could provide complementary information related to genotype behavior and helps the breeder to choose the best genotype. Association between yield and climatic conditions would provide not only an assessment about the performance and adaptation of accessions, but also reliable information from the perspective of global climate change under different scenarios (Rea and Eccel, 2006). Peach yield is highly correlated with the number of flowers (Okie and Werner, 1996) arising after dormancy period. Dormancy is an important adaptive mechanism that allows the plant to survive under unfavorable conditions during winter. During this period, several events occur simultaneously. Water is important for bud and plant development since it is involved in solute translocation, enzymatic reactions and osmotic regulated events, reason why many studies are focused on its dynamics (Yamamoto et al., 2012). Lang et al. (1987) divided the dormancy period in paradormancy, endodormancy and ecodormancy. Paradormancy refers to correlated inhibitions organ by organ; while in the endodormancy state, the meristem is rendered insensitive to growing-promoting signal (Rohde and Bhalerao, 2007) until the chilling requirement (CR) is completed. During ecodormancy, bud growth mostly depends on heat accumulation, so growing speed increase considerably in warm temperature. Once heat requirement (HR) is fulfilled, blooming takes place. Both traits, CR and HR are determining factors for adaptation (Richardson et al., 1975; Citadin et al., 2001) because lack of chilling or heat results in abnormal patterns of budbreak and fruit development. For successful production, accessions must be chosen to match the thermal regime of a particular location so that adequate chilling is received for normal development but bloom is late enough to avoid frost (Okie and Blackburn, 2011).

The aims of this work were to (i) compare parametric and non-parametric stability statistic of 25 peach accession data sets collected from different environments and evaluate the level of association among stability measures, (ii) select promising high-yielding and stable accession to incorporate into peach germplasm

Table 1
Mean fruit yield (kg/tree), chilling and heat requirements of 25 accessions evaluated in three environments.

Accessions	Origin	Code	Yield (kg/tree)			Average	Requirements	
			2007/08	2010/11	2011/12		CR	HR
81.315.009 P	ITA	A1	3.22	14.20	15.61	11.01	988	5519
84.351.029 N	ITA	A2	8.30	14.72	16.29	13.11	960	5394
86.395.095 N	ITA	A3	14.26	21.14	10.70	15.37	961	5369
87.404.243 N	ITA	A4	4.40	6.72	4.80	5.31	1032	4737
89.424.007 N	ITA	A5	2.51	7.91	4.80	5.08	876	5263
89.429.003 N	ITA	A6	10.42	21.41	11.05	14.30	988	2980
Caldesi 2010 N	ITA	A7	8.11	11.75	10.01	9.96	694	7967
Cotogna del Berti P	ITA	A8	17.42	12.91	8.17	12.60	699	9034
Flavorcrest P	USA	A9	15.22	16.82	13.90	15.32	897	5058
Fred P	MEX	A10	6.10	19.63	5.81	10.52	922	5550
GalA P	USA	A11	7.83	14.44	12.94	11.74	858	5075
LSCr P	MEX	A12	1.54	14.01	6.50	7.35	755	6367
María Anna N	ITA	A13	1.50	9.35	14.53	8.46	1005	4489
María AureliaN	ITA	A14	14.64	24.74	11.37	16.92	976	5838
María Dorata N	ITA	A15	1.62	15.50	1.41	2.95	933	5081
María Emilia N	ITA	A16	4.22	7.79	10.12	7.38	706	7772
María Laura N	ITA	A17	6.56	13.05	17.32	12.31	855	4745
María Lucía N	ITA	A18	7.21	17.45	14.98	13.22	1112	3964
Merrill Carnival P	USA	A19	8.58	10.30	4.20	7.69	1048	3813
Milenio INTA P	ARG	A20	11.26	12.07	12.84	12.06	951	4569
Sirio P	ITA	A21	1.48	1.81	7.21	3.50	1088	7373
Starlite P	USA	A22	15.47	15.62	15.65	15.58	659	6948
Sunprince P	USA	A23	27.46	23.15	14.90	21.84	923	6321
Vega N	ITA	A24	14.92	18.18	13.87	15.66	1030	4171
Flameprince P	USA	A25	20.09	10.75	23.43	17.87	967	3742
Coefficient of variation (%)			15.04	16.03	14.90	15.77		
Grand mean			9.37	13.80	11.27	11.48		

ITA: Italy, USA: United States of America; MEX: Mexico and ARG: Argentina. P: peach and N: nectarine. CR: chilling requirement expressed in Positive Chilling Units (PCU) and HR: heat requirement expressed in Growing Degree Hours (GDH). CR and HR were estimated according Luedeling et al. (2009) based on historical flowering dates recorded at INTA San Pedro experimental station.

banks and (iii) identify major environmental variables as causes of yield variation among years.

2. Materials and methods

Experiments involved 25 peach genotypes, twelve peach (P) and thirteen nectarines (N) whose names, codes, chilling and heat requirement are given in Table 1. The combination of year and location was considered one environment (E). Genotypes were evaluated during 3-season periods: 2007/2008 (E1), 2010/2011 (E2) and 2011/2012 (E3) in 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. Genotypes were arranged in a completely randomized design (CRD) with three replications, each of them consisted of three trees planted at 5 m × 4 m row spacing. Each year the orchard was fertilized at the end of winter with urea (nitrogen 46%). Fruit yield was established weighting all fruits produced by replication and expressed as kg/tree.

Yield variation among years was analyzed. Each season was considered a distinct environment since all trials were carried out in different climatic scenarios. Hourly air temperatures have been recorded at the meteorological station placed in the experimental field since 1965. We extracted temperatures between 1st May and 28th February in each season (2007/2008, 2010/2011 and 2011/2012) from the complete dataset. Then, chilling accumulations were calculated 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: R_a rainfall during endodormancy, R_b rainfall from the beginning of endodormancy to the end of ecodormancy and R_c is the amount of rainfall

from the beginning of endodormancy to harvest season. Frosts number from ecodormancy to harvest date was also included.

2.1. Statistical analysis

Non-crossover (NC) and crossover (C) GEI were determined according to the Cruz and Castoldi (1991) method. Yield data was subjected to combined analysis of the variance (ANOVA) where accessions and environments were considered as random variables. NC and C were expressed in percentage as follows: %NC = 100NC/(MSG × E_{ij}), being NC = MSG × E_{ij} - C, the crossover was obtained by the equation: C = √((1 - r)³MSG_jMSG_{j'}) and expressed in percentage %C = 100C/(MSG × E_{ij}); in which MSG_j and MSG_{j'} stand for the square means of genotypes in environments j and j', respectively, MSG × E_{ij} is the mean square genotype between the environments j and j', and r is the correlation between genotype means in both environments.

The statistical methods for analyzing the stability were those proposed by (i) Eberhart and Russell (1966) using linear regression model; (ii) Roemer (1917), (iii) Plaisted and Peterson (1959), (iv) Wricke (1962) and (v) Eskridge (1990) based on ANOVA and the non-parametric procedures of (vi) Lin and Binns (1988) and (vii) Huehn (1990a,b).

As suggested by (i) Eberhart and Russell (1966) the behavior of the cultivars were assessed by the model: Y_{ij} = β₀ + b_iX_j + S_{ij}² + e_{ij} where Y_{ij} is the observed mean yield of the ith genotype in the jth environment, β₀ is the general mean, X_j is the environmental index obtained by the difference among the mean of each environment and the general mean, b_i is the regression coefficient, S_{ij}² is regression deviation of the ith genotype in the jth environment and e_{ij} is the average of the random errors associated with the ith genotype and the jth environment. Student's t-test employing each genotype's standard error of regression was used to check each

regression coefficient for statistical difference from one, whereas deviations from regression, S_{ij}^2 , were tested by the F -test based on pooled error estimated by combined ANOVA. (ii) Environmental variance (S_{xi}^2) (Roemer, 1917), measures deviation from the genotype mean and is defined as: $S_{xi}^2 = \sum_{j=1}^a (Y_{ij} - \bar{Y}_i)^2 / (a - 1)$, where Y_{ij} is the average yield of the i th genotype in the j th environment, \bar{Y}_i is the mean yield of the i th genotype across environments and a is the number of environments. Thus, a genotype is stable if its environmental variance is small; (iii) Plaisted and Peterson (1959) method quantified genotype stability by the parameter θ_i . A combined ANOVA was computed for all accessions considering the three seasons. If the genotype-by-environment mean square was significant, a combined ANOVA was performed for all pairs of accessions. A total of $g(g - 1/2)$ analyses were computed, being g the accessions number. The θ_i measure is calculated as the mathematical average of GEI variance between a pair of genotypes-by-environments $g - 1$ according to the expression: $\theta_i = 1/(g - 1) \left[\sum_{i'i'} \hat{\sigma}_{(ga)ii'}^2 \right]$ ($i \neq i'$) where $\hat{\sigma}_{(ga)ii'}^2$ is the GEI component estimated by combined ANOVA involving a pair of genotype, $i'i'$. The genotype with the smallest θ_i is considered the most stable since it contributes less to the total GEI; (iv) Wricke's ecovalence was calculated for genotype i as: $W_i = \sum_{j=1}^a (Y_{ij} - \bar{Y}_i - \bar{Y}_j + \bar{Y})^2$, in which Y_{ij} represents the i th genotype mean yield in j th environment, \bar{Y}_i is the i th genotype mean yield across environments, \bar{Y}_j is the j th environment mean yield and \bar{Y} is the general mean yield. Since genotypes with low ecovalence have smaller fluctuations from the mean across different environments, those accessions are more stable. (v) The reliability index (I_i), as proposed by Kataoka (1963) for economic analysis, can be used to estimate the lowest yield expected for a given genotype and the specific probability of negative events, based on values of yield distribution observed across test environments (Eskridge, 1990). Like the superiority index (P_i) (Lin and Binns, 1988), it has the advantage of integrating mean yield and stability into a single index of reliability and can be calculated by the following expression: $I_i = Y_i - Z_{(1-\alpha)} S_i$, where Y_i is the mean yield of the i th genotype, S_i the environmental standard deviation and $Z_{(1-\alpha)}$ the percentile of the standard normal distribution for which the cumulative distribution function reaches the value $(1 - \alpha)$. According to Annicchiarico (2002), P values may vary between 0.70 for modern agriculture in most favorable regions and 0.95 for subsistence agriculture in unfavorable cropping regions. Considering the technological level used in our country we selected $P=0.75$. Then, a genotype is considered to be stable and high-yielding if its reliability index is high. (vi) Lin and Binns (1988) method uses the P_i parameter to assess the superiority of a genotype and is obtained by the expression: $P_i = \sum_{j=1}^a (Y_{ij} - M_j)^2 / 2a$, where the P_i is the superiority index of the i th accession, Y_{ij} is the i th genotype mean yield in the j th environment, M_j is the maximum response in j th environment and a is the number of environments. The expression of P_i was further partitioned into: $P_i = \left[a(\bar{Y}_i - \bar{M})^2 + \sum_{j=1}^a (Y_{ij} - M_j + \bar{M})^2 \right] / 2a$, where \bar{Y}_i is the mean yield of the i th accession across environments and \bar{M} is the mean of the maximum response across environments. According to Lin and Binns (1988), the first part of de P_i expression quantifies the genetic deviation while the second quantifies the GEI. Then, a genotype is considered stable if its superiority index is small. (vii) Huehn (1990a) proposed the following non-parametric measures of phenotypic stability: (i) $S_i^{(1)} = \sum_{j < j'} |r_{ij} - r_{ij'}| / (a - 1) / 2$, (ii) $S_i^{(2)} = \sum_{j=1}^a |r_{ij} - \bar{r}_i|^2 / (a - 1)$, and (iii) $S_i^{(3)} = \sum_{j=1}^a |r_{ij} - \bar{r}_i| / \bar{r}_i$, where r_{ij} is the classification of the i th genotype in the j th environment, \bar{r}_i is the classification of the i th genotype in the j 'th environment, \bar{r}_i is the classification of the i th genotype across

environments and a is the number of environments. $S_i^{(1)}$ is the mean of the absolute rank differences among the classification of the i th genotype in the a environments, $S_i^{(2)}$ is the variance of the classification of the i th genotype in the a environments and $S_i^{(3)}$ is the sum of the absolute deviations in yield units of each classification relative to the mean classification. When these three measures ($S_i^{(1)}$, $S_i^{(2)}$ and $S_i^{(3)}$) are equal or near zero, genotypes are considered stable. The significance test for $S_i^{(1)}$, and $S_i^{(2)}$ was determined according to Nassar and Huehn (1987). The null hypothesis that all genotypes were equally stable was tested by using a χ^2 distribution with g degrees of freedom (df). Individual stability was checked for genotypes according to their Z value and, if this score was higher than the critical value $\chi_{0.05, df=1}^2 = 3.84$, the genotype was considered unstable.

Ranks were assigned to all stability parameters, including the mean yield, in an increasing order, but in a decreasing order for reliability index. Spearman's correlation coefficient (Steel and Torrie, 1980) was estimated for each pair of mean yield and stability statistic. The statistical significance of each correlation coefficient was tested by Student's t -test at 5%.

Peach sensitivity to climate variability was also examined. The statistical procedure employed in the selection of significant explanatory variables was stepwise multiple regression analysis. This approach has been evaluated as the best among others (Drapper and Smith, 1966). The most important feature of the stepwise regression is that a significant variable, which has been added at an earlier stage, may be considered insignificant later and thus deleted. At the end of the study, only the most significant variables which account for the largest portion of the total variance retained in the regression equation. The acceptance or deletion of explanatory variables from the regression equation was based on significance level of 10% using partial F -test. The values computed were the adjusted multiple regression coefficient (R_{adj}^2), regression coefficients of each explanatory variable and its standard error. The null hypothesis of all coefficient regression slopes were equal zero was tested by t -test at risk of 10%. Before performing the multiple regression analysis the data was transformed using Log_N . The model considered was:

$$\begin{aligned} \bar{Y}_j = & \beta_0 + \beta_1 \text{PCU}_j + \beta_2 \text{GDH}_{aj} + \beta_3 \text{GDH}_{bj} + \beta_4 + \beta_5 R_{bj} \\ & + \beta_6 R_{cj} + \beta_7 \text{FN}_j + \beta_8 R_{aj} * \text{PCU}_j + \beta_9 R_{bj} * \text{GDH}_{aj} \\ & + \beta_{10} R_{cj} * \text{GDH}_{bj} + \beta_{11} R_{bj} * \text{FN}_j + \epsilon_j \end{aligned}$$

where \bar{Y}_j is the mean yield or dependent variable observed in the j th year, PCU_j is the chilling accumulation during the endodormancy stage, GDH_{aj} and GDH_{bj} are the heat accumulation during ecodormancy and fruit development period, R_{aj} is the rainfall during endodormancy; R_{bj} is the rainfall during endo- and ecodormancy; R_{cj} is the rainfall from endodormancy to harvest date FN_j is the frost number, $R_{aj} * \text{PCU}_j$, $R_{bj} * \text{GDH}_{aj}$, $R_{cj} * \text{GDH}_{bj}$ and $R_{bj} * \text{FN}_j$ are the interaction terms considered; β_0 is the intersection model, β_1 to β_{11} are regression coefficient and ϵ_j is the random error or yield variation not explained by the model. For statistical analysis, Genes (Cruz, 2006) and InfoStat (Balzarini et al., 2008) programs were used.

3. Results

Fruit yield variation among twenty-five accessions and environments was evident (Table 1). Results of combined ANOVA (Table 2) indicated that every source of yield variation was significant, except for replication-by-environments. However, taking into account the magnitude of the mean square, the environmental effect was the most important source of variation. The significance of the

Table 2
Combined ANOVA of yield (kg/tree) of 25 peach genotypes evaluated in INTA San Pedro.

Source of variation	SS	df	MS	F	P
Replication/environments	6.42	4	1.60	16.29	0.7439
Environments	720.24	2	370.12	112.78	<0.0001
Genotypes	4806.49	24	200.27	61.03	<0.0001
Environments*genotypes	2565.07	48	53.44	16.28	<0.0001
Error	479.12	146	3.28		
Coefficient of variation	15.77%				

SS: sum of squares; df: degrees of freedom; MS: mean square; F: F value and P: probability value.

Table 3
Mean fruit yield (kg/tree) and climatic variables during each season.

Season	Yield	R_a	R_b	R_c	PCU	GDH _a	GDH _b	FN
2007/08	9.37	48.7	180.6	641.2	1222.00	11,974.24	59,046.71	4
2010/11	13.80	186.8	296.4	924.8	855.00	11,694.50	57,334.50	6
2011/12	11.27	168.5	173.5	732.9	912.00	12,630.40	59,081.70	6

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

environmental effect and GEI were used as a starting point to study yield stability among peach accessions.

Crossover and non-crossover GEI values were estimated for all pairs of environments. The crossover GEI ($E1 \times E2 = 61.43\%$; $E1 \times E3 = 66.38\%$ and $E2 \times E3 = 79.70\%$) was more important than the non-crossover GEI ($E1 \times E2 = 38.57\%$, $E1 \times E3 = 33.61\%$ and $E2 \times E3 = 20.29\%$). Climatic conditions as rainfall, frosts number and thermal accumulations for each season were estimated (Table 3) and considered as explanatory variables of yield variation. Final regression model included the intersection and the interaction between total rainfall and heat accumulated in FDP ($R_{cj} * GDH_{bj}$) (Table 4), being the final equation: $Y_j = (\beta_0) - 4.841 - (\beta_{10})0.10R_{cj} * GDH_{bj}$ explained 96.7% of variation yield ($R_{adj}^2 = 0.967$).

Considering the mean fruit yield (Y_i) as the first parameter for peach accession selection, genotypes A2, A3, A6, A8, A9, A11, A14, A17, A18, A20, A22, A23, A24 and A25 would be introduced as high-yielding since their mean fruit yield was higher than the grand mean (Table 1). Stability methods are useful for the classification and selection of genotypes for known environmental conditions. We analyzed the performance of 25 peach accessions using ten stability measures based on regression, ANOVA and non-parametric methods. Mean fruit yield and stability measures obtained for each genotype were used to rank accessions and the Spearman's coefficient correlation were estimated to understand the relationship among stability statistics.

Eberhart and Russell (1966) proposed an assessment of genotype response to environmental changes using a linear regression coefficient (b_i) and the variance of the regression deviations (S_{ij}^2). A stable genotype is considered to be the one whose coefficient b_i equals one and S_{ij}^2 equals zero. Genotypes in which b_i is higher than one respond better to more favorable growing conditions, whereas genotypes in which b_i is lower than one respond better to adverse environmental conditions. According to the values of regression coefficients and deviations of regressions given in

Table 4
Result of association analysis between yield variation and climate variables obtained by stepwise multiple regression.

SV	Constant	SE	t	P
Intersection	$\beta_0 = -4.841$	0.767	-6.310	0.086
$R_{cj} * GDH_{bj}$	$\beta_{10} = -0.100$	0.011	9.477	0.067

SV: source of variation; SE: standard error; t: Student's t value; P: probability value.

Table 5, accessions A4, A5, A7, A9, A11, A15 and A24 had stable and predictable fruit yield ($b_i = 1.0$, $S_{ij}^2 = 0$). Accession A10 responded better to favorable growing conditions ($b_i = 3.19$), while genotype A25 displayed a better response to adverse production conditions ($b_i = -2.25$). However, neither A10 nor A25 have predictable fruit yield. Accession A12 is adapted to favorable growing conditions and its behavior is predictable ($b_i = 2.82$, $S_{ij}^2 = 0$). Environmental variance (S_{xi}^2) (Roemer, 1917) is one of the major stability measures for the static stability concept or type 1 stability (Becker and Leon, 1988). This method detected all deviations from the genotypic mean and allowed us to consider as stable those genotypes with minimum variance under different environments. In multi-environmental trials the static stability concept is associated with genotypes showing low mean yield. However, among the following stable accessions; A4, A9, A20 and A22, the last three had mean yield higher than the general mean (Table 5). Parameters θ_i (Plaisted and Peterson, 1959) and W_i (Wricke, 1962) are associated with dynamic stability or type 2. As parameter values depend on the genotype set included in the test, the inference is confined to that genotype set only and should not be generalized (Lin et al., 1986). According to these stability measures, accessions A4, A5, A7 and A15 should be introduced to peach germplasm as stable genotypes, but neither of them had high mean yield.

Huehn (1990a) proposed that the stability of a cultivar in response to changing growing conditions could be assessed based on its rank in several environments. The $S_i^{(1)}$ statistic, which measures the mean absolute rank difference of a genotype over environments, equals zero for the most stable genotype. On the other hand, $S_i^{(2)}$ represents the variance among ranks across environments. Both statistics are only measures of stability and a strong correlation between them is expected even using uncorrected data. This correlation is perfect when the data set is corrected for genotype effects as suggested by Huehn (1990a) and applied in the present work. The $S_i^{(1)}$ statistic is preferred for practical applications because it is very easy to estimate and allows a clear and objective interpretation. Furthermore, an efficient test of significance is available for $S_i^{(1)}$ and $S_i^{(2)}$ statistics (Nassar and Huehn, 1987; Huehn, 1990a).

For each genotype, Z_i^1 and Z_i^2 values were calculated based on the corrected data and summed over genotypes to obtain Z values; Z_i^1 sum = 22.0762; $P = 0.5747$ and Z_i^2 sum = 21.0863; $P = 0.6336$. Since both statistics were smaller than the critical value $\chi_{\alpha=0.05, df=24}^2 = 36.41$, no significant differences were found in the

Table 5
Mean fruit yield and parametric stability for fruit yield of 25 peach genotypes in three environments.

Codes	Y_i	S_{xi}^2	θ_i	W_i	I_i	b_i	S_{ij}^2
A1	11.01	138.06**	22.45	168.64	77.42	2.31**	38.04**
A2	13.11	53.69**	12.83	57.80	105.45	1.33 ^{ns}	17.05**
A3	15.37	84.52**	16.34	98.27	124.30	1.70*	26.88**
A4	5.31	4.59 ^{ns}	8.43	7.07	45.25	0.53 ^{ns}	0.86 ^{ns}
A5	5.08	22.03**	7.94	1.44	38.10	1.22 ^{ns}	1.93 ^{ns}
A6	14.30	114.14**	17.00	105.82	113.27	2.57**	9.90**
A7	9.96	9.94**	7.92	1.24	86.34	0.81 ^{ns}	1.017 ^{ns}
A8	12.60	64.58**	26.89	219.99	98.75	-1.03**	31.48**
A9	15.32	6.42 ^{ns}	9.42	18.55	129.56	0.40 ^{ns}	1.58 ^{ns}
A10	10.52	187.01**	26.47	214.99	72.93	3.19**	23.41**
A11	11.74	36.02**	9.22	16.17	96.59	1.44 ^{ns}	2.35 ^{ns}
A12	7.35	118.23**	16.39	98.83	46.91	2.82**	1.00 ^{ns}
A13	8.46	129.24**	24.78	195.44	55.43	1.56 ^{ns}	60.90**
A14	16.92	145.70**	23.12	176.31	134.42	2.44**	37.10**
A15	2.95	18.68**	8.51	8.05	19.64	0.99 ^{ns}	1.59 ^{ns}
A16	7.38	26.50**	11.32	40.37	57.41	0.71 ^{ns}	11.55**
A17	12.31	87.96**	19.00	128.89	94.33	1.29 ^{ns}	41.01**
A18	13.22	85.72**	13.75	68.35	103.71	2.24**	6.49**
A19	7.69	29.68**	12.98	59.49	60.20	0.50 ^{ns}	16.24**
A20	12.06	1.87 ^{ns}	9.90	24.07	102.41	0.16**	0.09 ^{ns}
A21	3.50	31.12**	16.02	94.58	23.13	-0.05**	19.63 ^{ns}
A22	15.58	0.03 ^{ns}	10.23	27.85	131.93	0.03**	1.08 ^{ns}
A23	21.84	122.18**	35.42	318.01	174.54	-0.74**	74.89**
A24	15.66	15.17*	8.96	13.23	132.84	0.79 ^{ns}	2.87 ^{ns}
A25	17.87	129.56**	42.66	401.48	144.10	-2.25**	28.37**

Y_i : mean fruit yield, S_{xi}^2 : environmental variance; θ_i : Plaisted and Peterson's method; W_i : Wricke's ecovalance; I_i : reliability index; b_i : coefficient of regression and S_{ij}^2 : deviation of regression.

ns, non-significant.

* Significant at the 0.05 level of probability.

** Significant at the 0.01 level of probability.

rank stability among the 25 peach genotypes evaluated in three different environments. The individual Z value can be used to detect stable or unstable genotypes, Z values were greater than the critical chi-square value, $\chi^2_{\alpha=0.05, df=1} = 3.84$. According to Z_i^1 values, all accessions must be considered as stable since they showed Z values lower than the critical chi-square value. Only genotype 14 should

be considered unstable because Z_i^2 was higher than the threshold chi-square value (Table 6).

Plots of $S_i^{(1)}$ and $S_i^{(2)}$ against Y_i values are depicted in Figs. 1 and 2, respectively. Mean $S_i^{(1)}$ and $S_i^{(2)}$ and grand mean fruit yield divided both figures in four sections. Section 1 contained low-yielding accessions, Section 2 high-yielding accessions both with small

Table 6
Stability measures proposed by Huehn and Lin and Binns for fruit yield of 25 peach accessions evaluated in three environments.

Codes	Huehn					Lin and Binns			
	$S_i^{(1)}$	$Z_i^{(1)}$	$S_i^{(2)}$	$Z_i^{(2)}$	$S_i^{(3)}$	P_i	Deviation		Contribution to interaction (%)
							Genetic	Interaction	
A1	9.33	0.07	54.33	0.00	0.96	125.04	97.74	27.29	9.95
A2	6.00	0.38	24.33	0.47	0.89	84.90	70.62	14.27	5.20
A3	8.66	0.00	52.33	0.00	1.16	55.47	46.28	9.18	3.34
A4	4.00	1.34	9.33	1.12	0.90	196.51	193.65	2.85	1.04
A5	2.00	2.87	3.00	1.48	1.33	204.70	198.25	6.45	2.35
A6	7.33	0.07	34.33	0.19	0.86	73.12	57.20	15.91	5.80
A7	2.00	2.87	2.33	1.52	1	117.62	112.95	4.66	1.70
A8	4.66	0.96	14.33	0.87	0.44	78.58	76.84	1.73	0.63
A9	4.66	0.96	14.33	0.87	0.89	48.53	46.81	1.71	0.62
A10	6.00	0.38	20.33	0.61	0.48	128.31	104.76	23.54	8.58
A11	6.00	0.38	21.00	0.59	1.25	98.06	87.86	10.19	3.71
A12	10.66	0.39	76.00	0.35	1.33	175.30	155.59	19.71	7.18
A13	8.00	0.00	41.33	0.07	0.75	163.16	136.62	26.53	9.67
A14	14.00	2.32	147.00	5.57*	1.75	49.03	32.57	16.45	5.99
A15	2.00	2.87	2.33	1.52	0.56	246.97	242.84	4.12	1.50
A16	4.66	0.96	13.00	0.93	0.72	164.56	155.08	9.47	3.45
A17	6.00	0.38	20.33	0.61	0.52	100.51	80.36	20.14	7.34
A18	6.00	0.38	20.33	0.61	0.60	87.32	69.32	17.99	6.55
A19	10.00	0.20	63.00	0.07	1.63	151.66	149.61	2.04	0.74
A20	7.33	0.07	32.33	0.23	1.18	86.94	83.64	3.29	1.20
A21	12.66	1.36	100.33	1.44	1.83	240.51	230.91	9.59	3.49
A22	8.66	0.00	46.33	0.01	1.43	46.26	44.25	2.00	0.72
A23	9.33	0.07	65.33	0.10	0.91	10.72	4.96	5.75	2.09
A24	6.00	0.38	27.00	0.38	1.71	46.56	43.52	3.03	1.10
A25	2.66	2.30	5.33	1.34	0.23	41.66	25.34	16.31	5.94

* Significant at the 0.05 level of probability.

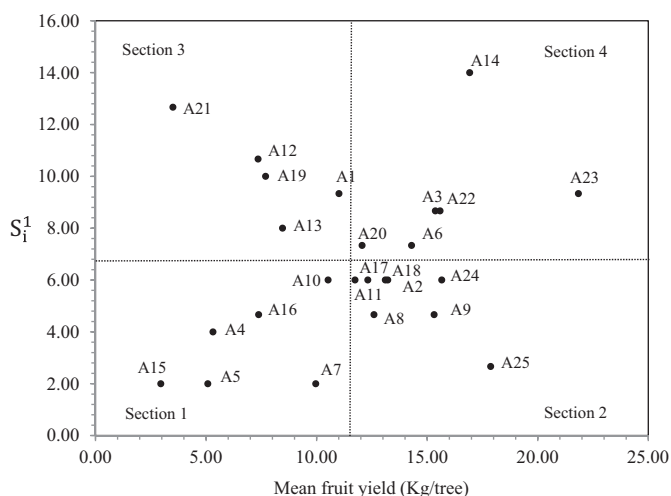


Fig. 1. Plot of mean absolute rank difference of a genotype over environments ($S_i^{(1)}$) against mean fruit yield (kg/tree) for 25 peach accessions over environments.

values of $S_i^{(1)}$ and $S_i^{(2)}$, Section 3 had low-yielding genotypes and section 4 high-yielding genotypes both with large $S_i^{(1)}$ and $S_i^{(2)}$ values. Genotypes were distributed in the different sections of Fig. 1 as follows: Section 1 contained genotype A15, A5, A7, A4, A16 and A10, which showed resistance to environmental fluctuation and therefore increasing adaptability to low-yielding environments, Section 2 included accessions A11, A18, A17, A2, A8, A24, A9 and A25 which could be considered the most stable and the best adapted to all environments; Section 3 incorporated accessions A21, A12, A19, A13 and A1, which appeared to be poorly adapted in all environments. Finally, Section 4 contained the remaining genotypes A20, A6, A3, A22, A23 and A14 which were assumed to be sensitive to growing fluctuations and were specifically adapted to high-yielding environments. Genotypes had the same distribution in Fig. 2, except for accessions A6 and A20 that were located in Section 2. Regarding the choice between $S_i^{(1)}$ and $S_i^{(2)}$ statistics, Nassar and Huehn (1987) suggested that $S_i^{(1)}$ should be used when a genotype shows unusual fluctuations between sections. For example, genotypes A6 and A20 showed some ambiguity in their classification. Since their average yield was higher than the grand mean, both genotypes could be considered as adapted to environments with good

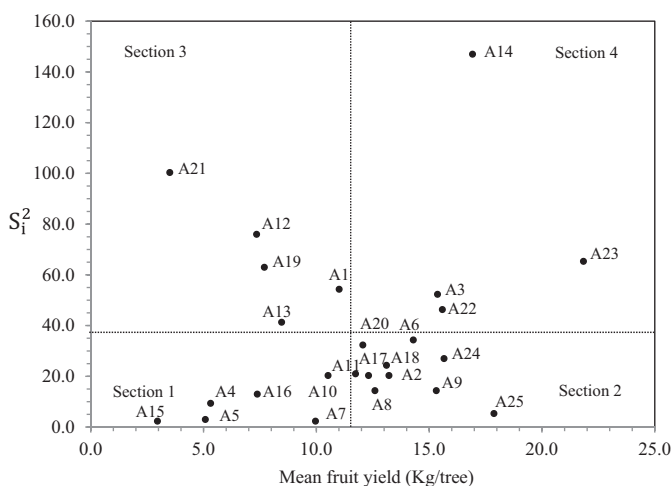


Fig. 2. Plot of the variance between the ranks over environments ($S_i^{(2)}$) against mean fruit yield (kg/tree) for 25 accessions peach over environments.

performance. Accordingly, we located both genotypes in Section 4 instead of Section 2.

The non-parametric statistic $S_i^{(3)}$ was proposed and described in detailed by Huehn (1990a). It can be used when yield and stability are considered simultaneously. In this case, the original data cannot be transformed (Huehn, 1990a). However, we used $S_i^{(3)}$ only to study the stability, therefore, the performance data was corrected. The lowest values of $S_i^{(1)}$, $S_i^{(2)}$ and $S_i^{(3)}$, indicate maximum stability for a particular genotype. For example, according to $S_i^{(1)}$, $S_i^{(2)}$ and $S_i^{(3)}$ values genotypes A15 and A25 were the most stable (Table 6). On the other hand, genotypes A14 and A21 displayed high $S_i^{(1)}$, $S_i^{(2)}$ and $S_i^{(3)}$ values.

The reliability index (I_i) (Eskridge, 1990) ranks accessions according to the lowest average yield that can be expected for each genotype across the environments tested. As this index combined a stability parameter (the S_i value) and yield data, it gave useful information for ranking and selection purposes. According to the I_i values obtained A23, A25, A14, A24, A22 and A9 would be selected as the six most productive and stable peach accessions (Table 5). Another procedure for assessing the behavior of genotype-by-environment interaction proposed by Lin and Binns (1988), is the superiority index (P_i), defined as the deviation of the i th genotype regarding the genotype with the best performance in each environment. The superior genotype, which is the most productive in a given set of environments, would be a cultivar whose P_i value is the lowest. P_i estimates could be partitioned into a portion attributed to genetic deviation: the sum square of genotypes. This would not be a problem for the selection if the genotype rank or portion attributed to GEI is not altered. In this case, as indicated by Lin and Binns (1988), the most valuable genotypes would be those with the lowest P_i values, mostly attributed to genetic deviation. Accessions A23, A25, A22, A24, A9 and A14 had mean yield higher than the general mean and the lowest P_i values, the major part of it could be attributed to a genetic component (Table 6). The exception was genotype A23 because although it showed the highest mean yield and the lowest P_i , the deviation of the interaction is an important fraction of its P_i . However, this accession contributed only 2.09% of the total value of the GEI (Table 6).

3.1. Association among mean yield, parametric and non-parametric measures

Many parametric and non-parametric measures of stability have been described in the literature (Lin et al., 1986; Flores et al., 1998). When exploring high-yielding and stable genotype selection, it is essential to investigate the relationships among parameters because some methodologies are appropriate to study only stability and others stability and yield together. In view of this, Spearman's rank correlation (Steel and Torrie, 1980) was determined for each pair of stability statistics (Tables 7 and 8) and association was analyzed.

Regression coefficient b_i showed positive correlation with S_{xi}^2 and θ_i but was not correlated with Y_i . The Y_i exhibited negative correlation ($P < 0.05$) with W_i and θ_i , and W_i was also negatively associated with P_i . Parameters S_{ij}^2 , S_{xi}^2 , θ_i and W_i showed a positive and significant coefficient correlation with each other ($P < 0.01$). The three non-parametric statistics $S_i^{(1)}$, $S_i^{(2)}$ and $S_i^{(3)}$ were positively and significantly correlated with each other ($P < 0.01$), but they were not correlated with Y_i . Huehn (1990b) recommended using $S_i^{(1)}$ since it is easier to calculate and interpret than $S_i^{(2)}$ or $S_i^{(3)}$. Therefore, $S_i^{(1)}$ could be a useful criterion to select stable genotype with no need to compute $S_i^{(2)}$ and $S_i^{(3)}$ parameters. On the other hand, the non-parametric parameters $S_i^{(1)}$ and $S_i^{(2)}$ were significantly associated

Table 7
Accessions rank based on mean fruit yield and the magnitude of their stability parameters.

Codes	Rank										
	Y_i	S_{xi}^2	θ_i	W_i	I_i	b_i	S_{ij}^2	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	P_i
A1	15	23	19	12	16	21	22	9	15	14	16
A2	10	13	11	11	9	15	15	5	9	10	10
A3	6	15	15	15	7	18	18	8	15	16	7
A4	22	3	3	3	22	6	2	3	4	12	22
A5	23	8	2	2	23	13	8	1	2	19	23
A6	8	18	17	17	8	23	12	6	12	9	8
A7	17	5	1	1	15	10	4	1	1	15	15
A8	11	14	23	23	12	12	20	4	6	2	9
A9	7	4	7	7	6	4	6	4	6	11	5
A10	16	25	22	9	17	25	17	5	7	3	17
A11	14	12	6	6	13	16	9	5	8	18	13
A12	21	21	16	16	21	24	3	11	18	20	21
A13	18	22	21	21	20	17	24	7	13	8	19
A14	3	24	20	20	3	22	21	13	20	24	6
A15	25	22	4	4	25	11	7	1	1	4	25
A16	20	9	10	10	19	7	13	4	5	7	20
A17	12	17	18	18	14	14	23	5	7	5	14
A18	9	16	13	13	10	19	11	5	7	6	12
A19	19	10	12	12	18	5	14	10	16	22	18
A20	13	2	8	8	11	3	1	6	11	17	11
A21	24	11	14	13	24	2	16	12	19	25	24
A22	5	1	9	9	5	1	5	8	14	21	3
A23	1	21	24	24	1	8	25	9	17	13	1
A24	4	6	5	5	4	9	10	5	10	23	4
A25	2	22	25	25	2	20	19	2	3	1	2

Y_i : mean fruit yield; S_{xi}^2 : environmental variance; θ_i : Plaisted and Peterson's method; W_i : Wricke's ecovalance; I_i : Reliability index; b_i : coefficient of regression; S_{ij}^2 : deviation of regression and P_i : superiority index.

with W_i and θ_i ($P < 0.01$). The Y_i showed a nearly perfect positive correlation ($P < 0.01$) with I_i , and P_i . These two parameters were also correlated with each other in a highly significant positive manner ($P < 0.01$). Consequently, only one of them would be suitable for the selection of stable and high-yielding accessions.

4. Discussion

The major objective of plant breeding is to obtain stable and high-yielding genotypes. The success in the development of these materials depends largely on the knowledge that the breeder has of GEI. The effects of GEI on stability are very important because each genotype has an inherent capacity to respond to changes of location. Statistically, these effects are non-additive because the difference in crop yield between cultivars, for example, depend on the environment (Yue et al., 1997). Currently, plant breeders have several methods for the analysis of genotypes yield stability in order to facilitate the identification of superior cultivars in the presence of significant GEI (Eskridge, 1990). However, they frequently have difficulties in choosing the most appropriate methodology to

use in different situations. The choice depends on many factors, such as the number of genotypes and environments available, environmental conditions, model fit to the data set and the facility to apply and interpret the results. The term stability is sometimes used to characterize a genotype which shows a relatively constant yield in spite of environmental condition changes. This idea of stability is in agreement with the concept of homeostasis widely used in quantitative genetics (Becker and Leon, 1988). This concept of stability is not accepted by most breeders and agronomists, who prefer genotypes with high mean yield and the potential to respond to agronomic inputs or better agronomical conditions (Becker, 1981). Therefore, breeders prefer the use of the dynamic stability concept (Becker and Leon, 1988). Both concepts of stability (static or dynamic) are strongly related to fit breeders requirements, i.e. to determine whether the best genotype in one environment is also the best in another, or is the best just in few environments.

By using combined ANOVA we found that the environment and GEI were highly significant and also detected that the crossover GEI was more important than non-crossover GEI. Non-crossover

Table 8
Spearman's correlation between stability parameters for peach fruit yield.

	θ_i	S_{xi}^2	W_i	I_i	b_i	S_{ij}^2	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	P_i
Y_i	-0.402*	-0.097	-0.439*	0.990**	-0.140	-0.327	-0.193	-0.241	0.038	0.942**
θ_i		0.731**	0.916**	-0.321	0.505**	0.803**	0.454**	0.433**	-0.379	-0.341
S_{xi}^2			0.596**	-0.015	0.795**	0.670**	0.261	0.232	-0.352	0.053
W_i				-0.366	0.389	0.748**	0.491**	0.485**	-0.251	-0.400**
I_i					-0.075	-0.239	-0.168	-0.219	-0.012	0.950**
b_i						0.363	-0.108	0.094	-0.309	0.065
S_{ij}^2							0.334	0.334	-0.274	-0.229
$S_i^{(1)}$								0.991**	0.562**	-0.228
$S_i^{(2)}$									0.599**	-0.285
$S_i^{(3)}$										-0.075

* Significant at the 0.05 level of probability.
** Significant at the 0.01 level of probability.

GEI is a consequence of the difference invariability among genotypes in several environments and does not represent a serious limitation for breeding. However, crossover GEI causes the lack of correlation among genotypes (Cruz and Regazzi, 1997). Because crossover GEI and environmental effects become the most important source of variation, selection of peach genotypes cannot be accomplished without variation in their performances (Cruz and Castoldi, 1991; Vencovsky and Barriga, 1992). Since peach yield is sensitive to climatic variability because change in temperature and precipitation can alter blooming and fruit development period, we considered those climatic variables to understand the influence of climatic change in peach yield fluctuation. The highest mean yield was obtained in season 2010/11 whose values of rainfall were the highest and chilling accumulation was the lowest. In this period, we calculated 855 PCU which is lower than the requirement of 19 accessions (Table 1). However, rainfall and chilling accumulation variables were excluded of multiple regression analysis. Only the interaction $R_{cj} * GDH_{bj}$ was included in the final model, whose negative regression coefficient indicates its unfavorable influence on accession performances. This result is not surprising, because proper length of periods with low and warm temperatures and adequate water available, promote better flower bud dormancy breaking (Erez and Couvillon, 1987) and fruit development (Lopez and Dejong, 2007). Therefore, the interaction between rainfall (R_{cj}) and warm temperature during fruit development period (GDH_{bj}) was the major cause of yield variation among the seasons considered.

Our data set was analyzed applying the regression method proposed by Eberhart and Russell (1966). According to this methodology, genotypes whose b_i and S_{ij}^2 parameters are statistically equal to one and zero, respectively, have an average capacity for adaptation to all environments and are predictable. Eberhart and Russell (1966) consider these genotypes as ideals, since they maintained good performances in environments with typical low yields. This concept has been questioned by Hildebrand (1990), who suggested that breeders should find materials which have the capability to maintain productivity in poor environments or excel in superior environments (low and high regression coefficients, respectively) rather than suppressing them in favor of materials with a regression coefficient of unity. The F test showed that some S_{ij}^2 values were statistically equal to zero while others were not. However, S_{ij}^2 values were, in general, relatively high and would indicate an unsatisfactory stability of the genotypes under study. Similar results were found by Rakonjac and Živonović (2008) in peach stability evaluation and they concluded that b_i is a better stability parameter than S_{ij}^2 . Lin et al. (1986) stated that, essentially, the deviation of regression indicates how well the model fits, but does not indicate the level of stability of genotypes and the authors suggested that other approaches should be considered under poor fit or heterogeneous deviation.

Regression coefficient b_i was not correlated with Y_i . Hence, peach genotypes with high yield level were not characterized by high adaptability. Fakorede and Mock (1978) pointed out that the most common phenomenon is that high-yielding genotypes show better response to environmental conditions and vice versa, but was not confirmed by our results. On the other hand, regression coefficient b_i can be interpreted as either type 1 or type 2 stability, depending on the definition of stable genotype (Lin et al., 1986; Becker and Leon, 1988). If a stable genotype is defined by having $b_i = 1$, type 2 is implied and the correlation with θ_i is explained, but if a stable genotype is defined by $b_i = 0$, type 1 is implied and association with S_{xi}^2 is explained. Coefficient b_i and deviations from regression, S_{ij}^2 , were not correlated with Y_i and thus the Eberhart and Russell (1966) method would not be suitable to select high-yielding or stable accessions.

Parameter S_{xi}^2 is associated to type 1 stability, and both W_i and θ_i are related with type 2 stability (Becker and Leon, 1988) and S_{ij}^2 the parameter stability of regression model or type 3 stability. Structural analysis estimators of S_{xi}^2 , W_i and S_{ij}^2 along with simulation studies allowed to conclude that a high correlation between them is expected, while a low correlation is most likely due to sampling error (Piepho, 1995). High correlation between W_i and θ_i is expected because they are estimated in a similar manner. The W_i is obtained by partitioning the sum of squares of GEI while θ_i results from partitioning the variance GEI. Consequently, significant correlation between S_{xi}^2 and θ_i is also expected. Negative correlation of Y_i with W_i and θ_i indicates that these parameters would not be adequate to characterize the genotypes.

According to Huehn (1990a), non-parametric stability analysis procedures have some advantages: they reduce the bias caused by outliers, they make no assumptions regarding normality or variance homogeneity, they are easy to use and interpret and additions or deletions of one or few genotypes do not cause much variation of results. As a consequence, many researchers applied different non-parametric statistic to evaluate stability (Akcura and Kaya, 2008; Farshadfar et al., 2012; Mohammadi and Amri, 2008). In this work, high correlations were estimated among $S_i^{(1)}$, $S_i^{(2)}$ and $S_i^{(3)}$ parameters. Therefore, they can be used interchangeably for classifying accessions according to their stability under different environmental conditions. However, according to Huehn (1990b) the $S_i^{(1)}$ measure would be the most appropriate because it is easier to calculate and simpler to interpret than the other parameters, $S_i^{(2)}$ and $S_i^{(3)}$. On the other hand, although these measures are useful to select stable peach genotypes, neither of them would be appropriate to select high-yielding accession since they were not correlated with Y_i . Huehn (1990b) reports that all three measures are highly correlated in winter wheat. Also Scapim et al. (2000), Mohammadi et al. (2007) and Farshadfar et al. (2012) found highly significant correlation among $S_i^{(1)}$, $S_i^{(2)}$ and $S_i^{(3)}$. The statistics $S_i^{(1)}$ and $S_i^{(2)}$ are associated with the static stability concept (Nassar and Huehn, 1987), while W_i and θ_i are related to the dynamic concept (Becker and Leon, 1988). Piepho and Lotito (1992) demonstrated that $S_i^{(1)}$ and $S_i^{(2)}$ can be regarded as non-parametric measures of dispersion. W_i and θ_i are also measures of dispersion based on their estimation as mentioned above, thus the high correlation obtained among $S_i^{(1)}$, $S_i^{(2)}$, W_i and θ_i is not surprising.

Simultaneous selection for high yield and stability is desirable and few methods have been proposed. As superiority index (P_i) (Lin and Binns, 1988) and reliability index (I_i) (Eskridge, 1990) are two methodologies that evidence genotype performances through only one parameter, they would facilitate breeder work. Superior peach accessions were assessed by both parameters, P_i and I_i , and were highly and positive correlated with Y_i . Mora et al. (2007) studied the prediction of cotton genotypes and reported a high coefficient correlation between P_i and I_i . In addition, P_i was successfully used to select stable and adaptable maize genotypes (Scapim et al., 2000; Pena et al., 2012) and to identify stable rice cultivar (Acevedo et al., 2010). Reliability index was used by many researchers, Annicchiarico (1992) studied the adaptation and recommendation of alfalfa cultivar in Italy, and superior wheat cultivars were selected by Hugo Ferney et al. (2006) and Ilker et al. (2008).

5. Conclusion

Genotype-by-environment interaction (GEI) is the most important issue among plant breeders, geneticists and agronomists involved in performance testing. In the current article we present

information related to yield and stability in peach. Such traits are the less amenable to selection and should be considered simultaneously to reduce the effect of GEI and to make a more accurate and refined choice. Peach accessions were evaluated in three different environments. Their fruit yields were studied by parametric and non-parametric methods, and their interaction with climatic variations, as well. The combined ANOVA indicates that environmental effect and crossover GEI are the main sources of variation in peach fruit yield. Multiple regression analysis showed that the interaction between rainfall and heat accumulation during fruit development period was the major factor of yield fluctuation. Y_i is not associated with S_{xi}^2 , b_i , S_{ij}^2 , $S_i^{(1)}$, $S_i^{(2)}$ and $S_i^{(3)}$, parameters, and shows negative correlations with W_i and θ_i . Our results also reveal that superior accessions: A23 (Sunprince P), A25 (Flameprince P), A14 (María Aurelia N), A24 (Vega N), A22 (Starlite P) and A9 (Flavorcrest P) could be selected by using only one parameter, P_i or I_i , which showed the highest correlations with Y_i . Even though a greater amount of peach than nectarines were selected, we cannot conclude that peach are better adapted because the number of accessions evaluated was not large enough to test a proper null hypothesis. Furthermore, the plot that relates mean fruit yield with non-parametric $S_i^{(1)}$ values could enhance the visual efficiency of selection based on GEI.

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