DOI: 10.5433/1679-0359.2013v34n6p2555

Adaptability and stability of maize landrace varieties

Adaptabilidade e estabilidade de variedades de milho crioulo

Raquel Barboza Reis de Oliveira[1]; Rosângela Maria Pinto Moreira[2]; Josué Maldonado Ferreira[2*]

Abstract

Maize landrace varieties are known to be adaptable to different environmental conditions. The objective of this work was to estimate and compare adaptability and stability parameters of 12 maize landrace varieties during two cycles of recurrent selection. The study used grain yield data from eight experiments in the first selection cycle (Group I) and seven experiments in the second cycle (Group II). The experiments were conducted in Paraná and Santa Catarina states. Each experiment evaluated 12 maize landrace varieties and one control variety, BR106. The experiments involved a randomized complete block design in which four methodologies were used to analyze variety stability and adaptability. The majority of the maize landraces assessed were competitive with the control BR 106 in the environments studied. Different adaptability and stability outcomes were verified for both groups. The varieties Macaco, Amarelão and Carioca, from Group I, and Palha Roxa, Amarelão and Astequinha Sabugo Fino, from Group II, showed superior average grain yield, general adaptability and stability.
Key words: *Zea mays*, genotypes x environments interaction, family farm, participatory breeding

Resumo

As variedades de milho crioulo são tidas como adaptadas a diferentes condições ambientais. O objetivo deste trabalho foi estimar e comparar os parâmetros de adaptabilidade e estabilidade de 12 variedades de milho crioulo em dois ciclos de seleção recorrente. Foram utilizados dados de produtividade de grãos referentes a oito experimentos com variedades crioulas no primeiro ciclo de melhoramento (Grupo I) e sete experimentos no segundo ciclo (Grupo II), instalados no Estado do Paraná e Santa Catarina. Cada experimento avaliou 12 variedades de milho crioulo e a testemunha BR106. Os experimentos foram instalados segundo o delineamento em blocos completamente casualizados, sendo empregados quatro procedimentos para analisar a estabilidade e adaptabilidade das variedades. A maioria das variedades de milho crioulo avaliadas foram competitivas em relação à cultivar BR 106 nos ambientes estudados. Diferentes respostas foram observadas quanto à adaptabilidade e estabilidade nos dois grupos, para os diferentes métodos considerados. As variedades Macaco, Amarelão e Carioca, no Grupo I, e Palha Roxa, Amarelão e Astequinha Sabugo Fino, no Grupo II, apresentaram bom desempenho, adaptabilidade ampla e comportamento previsível.
Palavras-chave: *Zea mays*, interação genótipos x ambientes, agricultura familiar, melhoramento participativo

[1] Bióloga, M.e em Genética e Biologia Molecular, Universidade Estadual de Londrina, UEL, Londrina, PR. E-mail: raquelbarbozabio@yahoo.com.br

[2] Eng[os] Agr[os], Profs. Drs. da UEL, Londrina, PR. E-mail: rosang@uel.br; josuemf@uel.br

[*] Autor para correspondência

Recebido para publicação 18/11/11 Aprovado em 16/08/13

Introduction

Maize landrace varieties have been grown and maintained by several generations of family farmers. These varieties have traits, for example, genes that confer resistance to biotic and abiotic factors (ARAÚJO; NASS, 2002), good husking, and good potential grain yield, mainly in environments with low or no technology (ALMEKINDERS; LOUWAARS; BRUIJIN, 1994), that can be explored by breeding programs.

The wide genetic variability of maize landraces is considered the main reason for their adaptability to different environments (mainly rustic growing conditions) (CECCARELLI, 1994; PATERNIANI; NASS; SANTOS, 2000). Nevertheless, although landrace varieties are an important source of adaptability alleles, there is limited information in the current literature about adaptability and stability studies on them.

Adaptability and stability studies, which provide a detailed description of a genotype's performance under different environmental conditions, identify genotypes with phenotypic stability. They guarantee thus recommendations for the cultivar processes (CRUZ; REGAZZI; CARNEIRO, 2004; HAMAWAKI; SANTOS, 2003).

Several methods of performing adaptability and stability studies can be found in the literature, and studies of release cultivars have been performed to compare their efficiencies (CARGNELUTTI FILHO et al., 2007; FARIAS et al., 1997; MAURO et al., 2000). The methods proposed by Eberhart and Russell (1966) and Cruz, Torres e Vencovsky (1989) employ a linear regression analysis and have been widely used. The method proposed by Lin and Binns (1988) consists of a non-parametric analysis and, although not extensively discussed in the literature, is simpler and addresses the limitations of a linear regression analysis (MURAKAMI et al., 2004; SCAPIM et al., 2000).

Annicchiarico (1992) proposed a reliability index, which is based on the environmental mean deviation, for determining whether to adopt a particular genotype. Schmildt and Cruz (2005) stress that this reliability index is also a general or wide adaptability estimate, as presented in Eberhart and Russell (1966). Cruz, Regazzi e Carneiro (2004) emphasize that some methods are complementary while others are optional, although it is possible to combine different methods. Overall, which maize cultivars will be recommended will depend on the adaptability and stability method the researcher employed (CARGNELUTTI FILHO et al., 2007).

The objective of this work was to estimate and compare adaptability and stability parameters of 12 maize landraces during two cycles of recurrent selection.

Material and Methods

This study used grain yield data obtained in 15 experiments on 12 maize landrace varieties and one control variety, cultivar BR106. Trials were divided into group I (landraces in the first half-sib selection cycle) and group II (landraces in the second half-sib selection cycle). The group I trials were performed in 8 environments and the group II trials in 7 (Table 1). Trials were carried out on the family agricultural properties that have participated in the Participatory Breeding Program of Maize Landrace (FERREIRA et al., 2006). The conventional maize farming system was only adopted in the trial conducted in Londrina.

Trials were set in randomized complete blocks (4 replications) in plots with 4.00 m long rows 1.00 m apart, with 0.20 m between each plant. Grain yield data (t ha^{-1}) were adjusted to 135 grams of water per kilogram of grain and to ideal standards according to the methodology presented in J. B. Miranda Filho (VENCOVSKY; BARRIGA, 1992).

The data from each experiment were analyzed using ANOVA tests, and for the joint analyses, the residual mean squares homogeneity for each group was verified (PIMENTEL-GOMES, 2000). In these analyses, treatments were considered as fixed model effects and environments and blocks in the environments were treated as random model effects (CRUZ; REGAZZI; CARNEIRO, 2004). Joint and individual trial analysis of variance tests were carried out using the SAS GLM procedure (SAS Institute Inc., 2005). The means of the varieties from each experiment were clustered using the Scott-Knott test at $p \leq 0.05$. The Tukey test was used to compare general means among varieties in each group, using the treatments x environments interaction means square (PIMENTEL-GOMES, 2000).

Table 1. Crop years and cities for trials groups I and II, which comprise maize landraces in the first and second recurrent selection cycles, respectively.

Group I		
Environment	Crop Year	Cities
E1	2002/2003	Palmeira-PR
E2	2002/2003	São Mateus do Sul-PR
E3	2002/2003	Bituruna-PR
E4	2003/2004	Irineópolis-SC
E5	2003/2004	Palmeira-PR
E6	2003/2004	São Mateus do Sul-PR
E7	2003/2004	Cruz Machado-PR
E8	2003/2004	Fernandes Pinheiro-PR
Group II		
E9	2004/2005	Palmeira-PR
E10	2004/2005	Fernandes Pinheiro-PR
E11	2004/2005	Cruz Machado-PR
E12	2004/2005	Londrina-PR
E13	2005/2006	Rio Azul-PR
E14	2005/2006	Bituruna-PR
E15	2005/2006	Irineópolis-SC

Source: Elaboration of the authors.

Adaptability and stability parameters were estimated by the Eberhart and Russell (1966) methodology, the Cruz, Torres e Vencovsky (1989) methodologies described by Cruz, Regazzi e Carneiro (2004), the Annicchiarico (1992) methodology introduced by Schmildt and Cruz (2005), which considers only the reliability index (I_i), and the Lin and Binns (1988) methodology described by Gonçalves et al. (1999). Adaptability and stability parameters for each method were obtained by the GENES program (CRUZ, 2001).

Results and Discussion

Joint analysis of variance tests demonstrated that there were significant effects of all sources of variation in the two groups that were evaluated (Table 2). The ratio between the largest and smallest mean square was 6.42 for group I and 2.63 for group II. The coefficient of variation (CV) was 18.42% for group I and 16.86% for group II, indicating that the experiments were accurate. These results demonstrate that there were significant differences among varieties in each environment, among environments and among the performances of the varieties due to environmental variations. The best environments for grain yields were Irienópolis, Palmeira and São Mateus do Sul in the 2003/2004 crop year, the Fernandes Pinheiro in the 2004/2005 crop year and Rio Azul in the 2005/2006 crop year (Table 3). However, there were no significant effects of treatments in these environments, suggesting that an unfavorable environment promoted cultivar adaptation.

Table 2. Mean squares of the joint analyses of variance for grain yield (t ha^{-1}) and coefficients of variation (%) and means for groups I and II, which are based on analyses of landraces in eight and seven environments, respectively.

Source of variation	Group I		Group II	
	d.f.	Mean Square	d.f.	Mean Square
Block/Environment	24	4.8404**	21	4.3489**
Environments	7	95.980**	6	18.975**
Varieties	12	4.4445**	12	3.6409**
Varieties x environments	84	0.9685**	72	0.9613**
Error	285	0.6022	252	0.3801
CV%		18.42		16.86
Mean		4.21		3.66

** $p < 0.01$ (F-test).
Source: Elaboration of the authors.

The presence of a genotypes x environmental interactions determines the varieties that will be recommended for a particular region (RIBEIRO; RAMALHO; FERREIRA, 2000). The varieties Macaco and Amarelão (group I) and Caiano and Carioca (group II) showed the best yields in the tested environments, outperforming the control variety BR106 (Table 3). Thus, because they performed the best in the widest range of environments, these four landraces, as well as the Palha Roxa landrace, are the most highly recommended for the south central region of Paraná,

There are differences between the genotypes in groups I and II (Table 4 and 5), and there were changes in landrace yields between the groups. However, in both groups, Macaco, Amarelão, Caiano, Carioca and Palha Roxa remained among the most productive, as they did not differ among themselves according to the Tukey test (P <0.05), with average productivities (β_0) between 5.07 and 4.38 t ha $^{-1}$ in group I and 4.15 and 3.79 t ha $^{-1}$ in group II. This result demonstrates the important role of adaptability and stability studies in identifying productive, adaptable and stable varieties for family agricultural systems.

The methodology of Eberhart and Russell (1966) uses the linear regression coefficient (β_i) as the adaptability parameter and the regression deviation variance as the stability parameter (σ_{di}^2). Regression deviations are dispersion measures around the regression line and are associated with the performance replicability of materials in the environments. The methodology of Cruz, Torres e Vencovsky (1989) allows for the identification of materials that are adaptable to unfavorable conditions (β_{1i}) and that respond well to environmental improvements ($\beta_{1i} + \beta_{2i}$).

Lin and Binns (1988) proposed a superiority measure, given by the value of $P_{i,}$ for each genotype. According to Gonçalves et al. (1999), the Lin and Binns methodology (1988) presupposes a search for the material with the best performance in most of the environments. Annicchiarico's methodology (1992) takes into consideration genotype yield in the environments assessed and performance variation among environments. This method provides a reliability index (I_i%) for a determined material.

Table 3. Grain yield means (t ha^{-1}) of the thirteen varieties of groups I and II, which were evaluated in fifteen environments (E).

Varieties	Group I								Group II						
	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15
Macaco	4,66a	3,26a	3,33a	6,59a	6,59a	5,92a	5,12a	5,07a	5,15a	4,31a	3,49a	3,78c	4,48a	3,69a	2,98a
Amarelão	3,62a	2,51a	3,08a	6,91a	6,45a	4,81a	4,85a	4,55a	3,73a	4,22a	4,31a	4,09b	4,65a	3,19a	2,30b
Caiano	4,93a	2,49a	3,23a	5,41a	6,70a	4,95a	3,70b	4,47a	4,32a	4,29a	3,63a	5,27a	4,76a	3,36a	3,44a
Carioca	3,49a	2,75a	3,65a	5,90a	6,72a	5,03a	3,35b	4,35a	4,18a	4,61a	3,46a	5,05a	4,74a	3,87a	3,16a
Palha Roxa	3,39a	2,71a	3,68a	6,74a	6,93a	4,23a	3,51b	3,87a	3,92a	4,81a	3,68a	4,28b	4,60a	3,45a	2,72b
Amarelão Antigo	3,28a	2,23b	2,89a	6,82a	6,11b	4,51a	3,27b	4,51a	2,81b	4,70a	3,64a	3,44c	3,82a	3,37a	2,40b
Asteca do Prestupa	2,85b	2,32a	3,18a	6,08a	6,46a	4,70a	3,93b	4,08a	4,17a	4,88a	3,40a	4,18b	4,32a	2,83b	2,39b
Cinquentinha	2,71b	2,90a	2,93a	5,66a	5,77b	4,66a	3,61b	4,50a	3,84a	3,98a	4,15a	3,26c	4,17a	3,06a	2,46b
Astequinha Sabugo Fino	2,43b	2,70a	3,12a	5,13a	6,01b	4,40a	3,46b	4,43a	3,97a	4,58a	3,33a	3,89b	4,51a	3,11a	2,57b
Cravinho do Pretupa	2,76b	2,00b	3,06a	4,99a	6,09b	4,49a	3,68b	4,56a	2,48b	4,46a	3,23a	3,61c	4,30a	3,23a	2,78b
BR106	4,06a	2,42a	2,45b	5,77a	6,21b	3,64a	2,61b	4,18a	3,13b	3,83a	2,85a	4,22b	4,48a	3,44a	3,36a
Branco Sabugo Fino	1,79b	1,88b	2,11b	5,74a	5,87b	4,82a	4,25a	4,08a	3,48b	4,26a	3,19a	2,60d	3,36a	2,53b	2,21b
Tostão	1,85b	1,39b	2,57b	5,36a	5,67b	4,56a	4,52a	3,63a	2,71b	4,37a	4,11a	1,51e	3,86a	2,34b	2,06b
Significance of variety effects	**	**	**	ns	ns	ns	**	ns	**	ns	ns	**	ns	**	ns
Mean overall environment	3,22	2,41	3,02	5,93	6,28	4,67	3,83	4,33	3,68	4,41	3,56	3,76	4,31	3,19	2,68
Environmental index	-0,99	-1,80	-1,19	1,72	2,07	0,46	-0,38	0,12	0,02	0,75	-0,10	0,10	0,65	-0,47	-0,98

ns and **: non-significant and significant (1% probability), respectively, according to the *F*-test.
Means followed by the same letter do not differ statistically from each other according to the Scott-Knott test (5% probability).
E1 = Palmeira (2002/2003); E2 = São Mateus do Sul (2002/2003); E3 = Bituruna (2002/2003); E4 = Irineópolis (2003/2004); E5 = Palmeira (2003/2004); E6 = São Mateus do Sul (2003/2004); E7 = Cruz Machado (2003/2004); E8 = Fernandes Pinheiro (2003/2004); E9 = Palmeira (2004/2005); E10 = Fernandes Pinheiro (2004/2005); E11 = Cruz Machado (2004/2005); E12 = Londrina (2004/2005); E13 = Rio Azul (2005/2006); E14 = Bituruna (2005/2006); E15 = Irineópolis (2005/2006).
Source: Elaboration of the authors.

Table 4. Estimates of the adaptability and stability parameters for grain yield (t ha^{-1}) for group I, which contains landraces evaluated in eight environments in the states of Parana and Santa Catarina.

Varieties	Mean	Eberhart & Russell					Cruz, Torres & Vencovsky									Lin & Binns	Annicchiarico
	(β_{0i})	β_1		σ_{di}^2		R^2(%)	β_1		β_2		$\beta_1+\beta_2$		σ_{di}^2		R^2(%)	P_i general	I_i(%)
Macaco	5,07a	0,8980	ns	0,0477	ns	89,93	0,9471	ns	-0,2407	ns	0,7064	ns	0,0625	ns	90,98	0,0256	119,00
Amarelão	4,60ab	1,0859	ns	0,0123	ns	94,08	1,0616	ns	0,1195	ns	1,1810	ns	0,0387	ns	94,27	0,2773	106,57
Caiano	4,48abc	0,8563	ns	0,2980	**	78,21	0,8410	ns	0,0750	ns	0,9160	ns	0,3853	**	78,31	0,4003	103,10
Carioca	4,41abc	0,9712	ns	-0,0124	ns	93,74	0,9475	ns	0,1161	ns	1,0636	ns	0,0095	ns	93,96	0,4889	102,86
Palha Roxa	4,38bc	1,0867	ns	0,1493	ns	89,63	0,9312	ns	0,7629	**	1,6941	**	-0,0396	ns	96,80	0,5989	100,91
Amarelão Antigo	4,20bc	1,1355	ns	0,0194	ns	94,34	1,1390	ns	-0,0175	ns	1,1215	ns	0,0533	ns	94,34	0,6729	96,11
Asteca do Prestupa	4,20bc	1,0735	ns	-0,1119	ns	98,50	1,0444	ns	0,1429	ns	1,1873	ns	-0,1129	ns	98,78	0,6416	97,43
Cinquentinha	4,09bc	0,8750	ns	-0,0542	ns	94,58	0,9220	ns	-0,2302	ns	0,6918	ns	-0,0576	ns	95,64	0,7947	95,39
Astequinha Sabugo Fino	3,96bc	0,8697	ns	0,0019	ns	91,59	0,9018	ns	-0,1575	ns	0,7443	ns	0,0218	ns	92,08	1,0236	91,83
Cravinho do Pretupa	3,95bc	0,9388	ns	-0,0118	ns	93,31	1,0071	ns	-0,3351	ns	0,6720	ns	-0,0321	ns	95,24	0,9654	91,17
BR106	3,92bc	0,9558	ns	0,3374	**	80,44	0,8842	ns	0,3515	ns	1,2357	ns	0,3821	**	82,20	1,0638	88,40
Branco Sabugo Fino	3,82bc	1,1669	ns	0,1841	*	89,93	1,2455	*	-0,3852	ns	0,8602	ns	0,1875	ns	91,53	1,2296	82,62
Tostão	3,69c	1,0866	ns	0,2734	*	85,94	1,1277	ns	-0,2017	ns	0,9260	ns	0,3408	**	86,42	1,4037	79,50

* and **: non-significant and significant (5% and at 1% probability, respectively) according to the *t*-test and *F*-test.
Means followed by the same letter do not differ statistically from each according to the Tukey test (5% probability).
Source: Elaboration of the authors.

Table 5. Estimates of the adaptability and stability parameters for grain yield (t ha^{-1}) for group II, which contains landraces evaluated in seven environments in the states of Parana and Santa Catarina.

Varieties	Mean	Eberhart & Russell			Cruz, Torres & Vencovsky					Lin & Binns	Annicchiarico
	(β_{0i})	β_1	σ_{di}^2	R^2(%)	β_1	β_2	$\beta_1+\beta_2$	σ_{di}^2	R^2(%)	P_i general	I_i(%)
Caiano	4,15a	0,8029 ns	0,2400 **	45,75	1,0654 ns	-1,4328 **	-0,3674 **	0,1554 *	67,55	0,1257	110,09
Carioca	4,15a	0,9109 ns	0,1182 ns	63,03	1,0749 ns	-0,8950 ns	0,1798 ns	0,1059 ns	72,14	0,1323	110,70
Macaco	3,98a	0,7948 ns	0,2483 **	44,64	1,0399 ns	-1,3378 *	-0,2979 **	0,1874 *	63,57	0,2527	105,32
Palha Roxa	3,92ab	1,1748 ns	-0,0781 ns	97,28	1,2100 ns	-0,1922 ns	1,0178 ns	-0,0769 ns	97,67	0,2603	105,72
Amarelão	3,79abc	1,1941 ns	0,0521 ns	80,95	1,2796 ns	-0,4663 ns	0,8133 ns	0,0710 ns	82,80	0,4003	99,84
Asteca do Prestupa	3,74abc	1,4068 *	-0,0018 ns	90,29	1,5585 *	-0,8279 ns	0,7306 ns	-0,0346 ns	94,97	0,3820	98,23
Astequinha Sabugo Fino	3,71abc	1,2014 ns	-0,0683 ns	95,94	1,2556 ns	-0,2961 ns	0,9595 ns	-0,0687 ns	96,81	0,4105	99,37
BR106	3,62abc	0,5410 *	0,1925 *	30,85	0,4836 *	0,3135 ns	0,7971 ns	0,2563 **	32,40	0,6208	95,48
Cinquentinha	3,56abc	0,8877 ns	0,0632 ns	68,58	0,9234 ns	-0,1951 ns	0,7283 ns	0,0996 ns	69,08	0,6131	94,56
Amarelão Antigo	3,45abc	1,0088 ns	0,1108 ns	68,42	0,7966 ns	1,1583 *	1,9549 *	0,0523 ns	81,92	0,8259	91,16
Cravinho do Pretupa	3,44abc	0,9510 ns	0,1592 *	60,92	0,6620 ns	1,5771 **	2,2391 *	0,0189 ns	85,99	0,8787	90,68
Branco Sabugo Fino	3,09bc	0,9668 ns	0,0822 ns	69,80	0,9144 ns	0,2857 ns	1,2001 ns	0,1198 ns	70,71	1,2035	81,39
Tostão	3,00c	1,1591 ns	0,8159 **	39,26	0,7361 ns	2,3090 **	3,0451 **	0,6066 ns	62,58	1,8172	74,61

* and **: non-significant and significant (5% and at 1% probability, respectively) according to the *t*-test and *F*-test.
Means followed by the same letter do not differ statistically from each other according to the Tukey test (5% probability).
Source: Elaboration of the authors.

Adaptability and stability analyses for group I are considered first (Table 4). Using the Eberhart and Russell (1966) method, the varieties presented β_1 values statistically equal to one, indicating wide adaptability and responsiveness to environmental improvement.

Among the landrace varieties, only the Caiano, Branco Sabugo Fino and Tostão showed significant σ_{di}^2 deviation from zero, suggesting unpredictable behavior due to environmental stimulus. However, this result does not limit the use of these two last varieties because they nevertheless presented determination coefficient values (R^2) above 85%, as recommended by Oliveira, Souza Sobrinho e Fernandes (2004) for maize crops. The determination coefficient reflects the degree of adjustment of the model to the yield means observed for each of the materials assessed. Fonseca Junior (1999) stresses that the R^2 can be considered a more impartial predictability measure than the regression deviations variance itself.

Using the methodology of Cruz, Torres e Vencovsky (1989), the Palha Roxa variety showed adaptability to unfavorable environments (β_{1i} = 1), responsiveness to environmental improvement ($\beta_{1i} + \beta_{2i} > 1$) and highly predictable behavior. The other varieties showed identical behavior in both favorable and unfavorable environments ($\beta_{2i} = 0$).

The methodology of Cruz, Torres e Vencovsky (1989) better adjusted the regression deviations in two straight-line segments, reducing the deviation in relation to the linear regression with negative environment indexes. Overall, however, the results obtained from the Eberhart and Russell (1966) and Cruz, Torres e Vencovsky (1989) methodologies were consistent for most varieties.

Using the Lin and Binns (1988) methodology, the Macaco and Amarelão varieties stood out for showing the lowest estimates for P_i. The lower the P_i, value the higher a genotype's capacity to be among the best and to perform well in the largest number of environments (ARIAS; RAMALHO; FERREIRA, 1996).

Reliability indexes (I_i%) estimated by the Annicchiarico (1992) method showed that the variety which is the least risky to adopt is the Macaco variety, which had a reliability index (19%) that was superior to that of the other varieties. The Amarelão, Caiano and Carioca also had superior indexes of 6,57%, 3,10% and 2,86%, respectively.

Table 5 shows the calculated adaptability and stability parameters for group II. The varieties considered ideal by the Eberhart and Russel (1966) methodology were Palha Roxa, Amarelão and Astequinha Sabugo Fino because they had the highest means (β_0), a wide adaptability ($\beta_1 = 1$) and predictable behavior ($\sigma_{di}^2 = 0$). These varieties did not differ statistically from each other according to the Tukey test ($p < 0.05$).

Using the methodology of Cruz, Torres e Vencovsky (1989), the Caiano, Macaco, Amarelão Antigo, Cravinho do Prestupa and Tostão varieties responded well to improvements in environmental conditions ($\beta_{1i} + \beta_{2i} > 1$) and adjusted best to the bi-segmented regression analysis. These results are supported by their significantly reduced regression deviations (σ_{di}^2).

With both methodologies involving linear regressions, the control variety BR106 showed adaptability to unfavorable conditions and erratic behavior (R^2 = 30%) in group II and wide adaptability in group I. This cultivar has been observed to behave differently in different parts of the country, specifically in Minas Gerais State (HAMAWAKI; SANTOS, 2003), the Northeast (CARVALHO et al., 2005) and Paraná State (ALVES et al., 2006). The results obtained by the non-parametric methods of Lin and Binns (1988) and Annicchiarico (1992) also demonstrate the low stability and reliability of BR106 in the south central region of Parana, compared with the best performing landraces. Overall, the majority of the landraces assessed are competitive with the control BR 106 in the environments studied.

In general, for the experimental varieties, different results were obtained with the four different methodologies. When the linear regression analyses were used the varieties had low yield, wide or condition-specific adaptability and predictable behavior. When the Lin and Binns (1988) and Annicchiarico (1992) methodologies were used, they showed less stable behavior due to environmental variations.

The landraces in the second cycle (group II) showed grain yield means (t ha^{-1}) relatively lower than those observed for group I. This was due to the dry period the plants in the group II trials had to endure. In addition, there was a change in the relative position of varieties from the first to the second group. In both groups, however, the Amarelão, Caiano, Carioca, Macaco and Palha Roxa varieties were among the most productive, with no difference among themselves according to the Tukey test ($p < 0,05$).

Although the Group II trials took place in different environments from the group I trials, the adaptability and stability results were expected to be similar in the two groups, mainly due to improvement by recurrent selection. According to previously reported findings, however, group II underwent a great hydric deficit, which may have resulted in the different responses of the varieties in the two groups under adverse conditions. For a characteristic that is polygenic and highly influenced by the environment, grain yield shows great response variation. The Caiano, Carioca, Macaco and Palha Roxa varieties showed good yields, low P_i values and the highest I_i% values. The Lin and Binns (1988) and Annicchiarico (1992) methodologies associated good yield with performance stability. Thus, the Macaco, Caiano, Carioca and Palha Roxa landrace varieties are recommended for family agricultural systems.

Conclusions

1. The majority of the maize landraces assessed are competitive with the control BR 106 in the environments studied.

2. The Macaco, Amarelão and Carioca varieties from group I, and Palha Roxa, Amarelão and Astequinha Sabugo Fino varieties from group II, are the most productive and widely adaptable and have the most predictable behavior; they are recommended thus for family agricultural systems.

3. This four methodologies adaptability and stability study is recommended because it is easy to implement and interpret.

Acknowledgements

The authors are grateful to CNPq and AS-PTA for their financial support and to the family farmers who work with us.

References

ALMEKINDERS, C. J. M.; LOUWAARS, N. P.; BRUIJIN, G. H. Local seed systems and their importance for an improved seed supply in developing countries. *Euphytica*, Netherlands, v. 78, n. 3, p. 207-216, 1994.

ALVES, S. J.; TOLEDO, J. F. F.; ARAÚJO, P. M.; GARBUGLIO, D. D. Stability and adaptability performance of different genetic classes of maize. *Revista Brasileira de Milho e Sorgo*, Sete Lagoas, v. 5, n. 2, p. 291-303, 2006.

ANNICCHIARICO, P. Cultivar adaptations and recommendation from alfafa trials in Northern Italy. *Journal of Genetics and Breeding,* Rome, v. 46, n. 1, p. 269-278, 1992.

ARAÚJO, P. M.; NASS, L. L. Characterization and evaluation of maize landraces. *Scientia Agricola,* Piracicaba, v. 59, n. 3, p. 589-593, 2002.

ARIAS, E. R. A.; RAMALHO, M. A. P.; FERREIRA, D. F. Adaptability and stability of maize cultivars evaluated in Mato Grosso do Sul State. *Ciência e Agrotecnologia*, Lavras, v. 20, n. 4, p. 415-420, 1996.

CARGNELUTTI FILHO, A.; PERECINI, D.; MALHEIROS, E. B.; GUADAGNIN, J. P. Comparison of adaptability and stability methods related to grain yield of maize cultivars. *Bragantia*, Campinas, v. 66, n. 4, p. 571-578, 2007.

CARVALHO, H. W. L.; CARDOSO, M. J.; LEAL, M. L. S.; SANTOS, M. X. dos; TABOSA, J. N.; SOUZA, E. M. Adaptability and stability of maize cultivars in northeast

Brazil. *Pesquisa Agropecuária Brasileira*, Brasília, v. 40, n. 5, p. 471-477, 2005.

CECCARELLI, S. Specific adaptation and breeding for marginal conditions. *Euphytica,* Netherlands, v. 77, n. 3, p. 205-219, 1994.

CRUZ, C. D. *Programa genes - versão windows*: aplicativo computacional em genética e estatística. Viçosa, MG: UFV, 2001. 648 p.

CRUZ, C. D.; REGAZZI, A. J.; CARNEIRO, P. C. S. *Modelos biométricos aplicados ao melhoramento genético*. Viçosa, MG: UFV, 2004. v. 1, 390 p.

CRUZ, C. D.; TORRES, R. A. A.; VENCOVSKY, R. An alternative approach to the stability analysis proposed by Silva and Barreto. *Revista Brasileira de Genética*, Ribeirão Preto, v. 12, n. 2, p. 567-580, 1989.

EBERHART, S. A.; RUSSEL, W. A. Stability parameters for comparing varieties. *Crop Science*, Madson, v. 6, n. 1, p. 36-40, 1966.

FARIAS, F. J. C.; RAMALHO, M. A. P.; CARVALHO, L. P.; MOREIRA, J. A. N.; COSTA, J. N. Stability parameters proposed by Lin and Binns (1988) compared with the method of regression. *Pesquisa Agropecuária Brasileira* Brasília, v. 32, n. 4, p. 407-414, 1997.

FERREIRA, J. M.; MOREIRA, R. M. P.; TARDIN, J. M.; JANTARA, A. E. Fitomejoramiento participativo de variedades de maíz criollo: una experiencia en la Región Centro Sur de Paraná, Brasil. In: LABRADA, H. R.; ESPINOSA, M. M. H.; SOTOMAYOR, J. C. R. (Ed.). *Fitomejoramiento participativo*: los agricultores mejoran cultivos. La Habana, CUBA: Ediciones INCA, 2006. p. 197-219.

FONSECA JUNIOR, N. S. Interação genótipo x ambiente: aspectos biométricos. In: DESTRO, D.; MONTALVÁN, R. (Ed.). *Melhoramento genético de plantas*. Londrina: Ed. UEL, 1999. p. 141-178.

GONÇALVES, F. M. A.; CARVALHO, S. P. de; RAMALHO, M. A. P.; CORRÊA, L. A. Importance of cultivars x locations and cultivars x years interactions in maize evaluation in the "safrinha". *Pesquisa Agropecuária Brasileira*, Brasília, v. 34, n. 7, p. 1175-1181, 1999.

HAMAWAKI, O. T.; SANTOS, P. G. Adaptability and stability of maize genotypes evaluated by the regression model. *Ciência Rural*, Santa Maria, MG, v. 33, n. 2, p. 195-199, 2003.

LIN, C. S.; BINNS, M. R. A superiority measure of cultivar performance for cultivar x location data. *Canadian Journal of Plant Science*, Ottawa, v. 68, n. 1, p. 193-198, 1988.

MAURO, A. O. D.; CURCIOLI, V. B.; NÓBREGA, J. C. M.; BANZATO, D. A.; SEDIYAMA, T. Correlation measures between parametric and nonparametric stability in soybean. *Pesquisa Agropecuária Brasileira*, Brasília, v. 35, n. 4, p. 687-696, 2000.

MURAKAMI, D. M.; CARDOSO, A. A.; CRUZ, C. D.; BIZÃO, N. Considerations about two methodologies for the analysis of stability and adaptability. *Ciência Rural*, Santa Maria, MG, v. 34, n. 1, p. 71-78, 2004.

OLIVEIRA, J. S.; SOUZA SOBRINHO, F.; FERNANDES, S. B. V. Stratification of environments, adaptability and stability of commercial corn hybrids for silage in southern Brazil. *Ciência Rural*, Santa Maria, MG, v. 34, n. 4, p. 997-1003, 2004.

PATERNIANI, E.; NASS, L. L.; SANTOS, M. X. O valor dos recursos genéticos de milho para o Brasil: uma abordagem histórica da utilização do germoplasma. In: UDRY, C. W.; DUARTE, W. (Ed.). *Uma história brasileira do milho*: o valor dos recursos genéticos. Brasília, DF: Ed. Paralelo, 2000. p. 11-41.

PIMENTEL-GOMES, F. *Curso de estatística experimental*. São Paulo: Livraria Nobel Ed. Nobel, 2000. 468 p.

RIBEIRO, P. H. E.; RAMALHO, M. A. P.; FERREIRA, D. F. Adaptability and stability of maize genotypes under different environmental conditions. *Pesquisa Agropecuária Brasileira*, Brasília, v. 35, n. 11, p. 2213-2222, 2000.

SAS Institute Inc. *Proprietary software release V 6.12 for windows.* Cary, North Carolina, USA, 2005.

SCAPIM. C. A.; OLIVIERA, V. R.; BRACCINI, A. L.; CRUZ, C. D.; ANDRADE, C. A. B.; VIDIGAL, M. C. G. Yield stability in maize (*Zea mays* L.) and correlations among the parameters of the Eberhart and Russel, Lin and Binns and Huehn models. *Genetics and Molecular Biology*, Ribeirão Preto, v. 23, n. 2, p. 387-393, 2000.

SCHMILDT, E. R.; CRUZ, C. D. Analysis of adaptability and stability of maize by the methods of Eberhart and Russel (1966) and Annicchiarico (1992). *Revista Ceres,* Viçosa, v. 52, n. 299, p. 45-58, 2005.

VENCOVSKY, R.; BARRIGA, P. *Genética biométrica no fitomelhoramento*. Ribeirão Preto: Ed. Sociedade Brasileira de Genética, 1992. 486 p.