Crop Breeding and Applied Biotechnology 6:222-227-, 2006
Brazilian Society of Plant Breeding. Printed in Brazil

Yield and combining ability of maize cultivars under different ecogeographic conditions

Adilson Deitos[1], Emmanuel Arnhold[2*], Freddy Mora[1], and Glauco Vieira Miranda[3]

Received 27 March 2006

Accepted 10 August 2006

ABSTRACT - *The objective of this study was to evaluate the yield and combining ability of maize cultivars (AG4051, AL30, AL25, D270, D170, and AG1051) in contrasting environments. The trials were conducted in the growing season 2002/2003, in Viçosa, Capinópolis and Florestal, state of Minas Gerais. The effects of hybrids were significant by the F test, as well as treatments x environments, hybrid combinations x environments, and controls x environments. This indicates the possibility of increasing the yield in these regions by capitalizing on the genotype x environment interaction, by selecting and recombining cultivars for each site. Among the cultivars and their hybrid combinations, AG1051 and AG4051 x AL30, respectively, performed best in the mean of the three locations. The most indicated combinations for each site were: AG4051 X AL30 and AL30 X D270 in Viçosa, AG4051 X AL25 and AL30 X D170 in Florestal and, D170 x AG4051 and AL25 x D270 in Capinópolis.*

Key-words: diallel, hybrids, *Zea mays* L.

INTRODUCTION

The main objective of maize breeders, according to Russel et al. (1992), is the development of lines whose hybrid combinations present superior performance. However, the superiority of a cultivar in a particular environment may not be verified in another, as Allard (1971), Falconer (1987) and Cruz et al. (2004) pointed out. The phenotypic manifestation is result of the action of a genotype under environmental influence, so when different environments are considered, an additional effect, apart from the genetic and environmental effects, is detected, caused by their interaction.

The genotype x environment interaction has been divided into simple and complex parts. The simple interaction is caused by differences of variability between the genotypes in the environments in which the superior performances of genotypes are measured. In this type of alteration the highest yielding genotype is the one that will be recommended. The second interaction is caused by the lack of repeatability of selection performance of the genotypes. It is important to know the type of the interaction so measures can be taken to minimize and/or exploit its effects.

Two important parameters that must be considered as well in the hybrid evaluation are the general combining ability (GCA) and specific combining ability (SCA). These parameters were introduced by Sprague and Tatum (1942), who discussed the use of top-crosses

[1] Universidade Estadual de Maringá, Avenida Colombo, 5790, Bloco 5, Sala 1, 87.020-900, Maringá, PR, Brasil
[2] Universidade Federal do Maranhão. C. P. 09, 65.500-000, Chapadinha, MA, Brasil. *E-mail: emmanuelarnhold@yahoo.com.br
[3] Departamento de Fitotecnia, Universidade Federal de Viçosa, 36.570-000, Viçosa, MG, Brasil

in a new approach. According to Miranda Filho and Gorgulho (2001), the term GCA refers to the mean performance of each line in cross with the other of the set, and the term SCA is interpreted as an effect in the hybrid expression that is additional to the GCA effects of the parents, which can be positive or negative. In other words, Miranda Filho and Gorgulho (2001) point out that the SCA is a result of the interaction of the GCA effects of the parents and that it can improve or deteriorate the hybrid expression compared to the expected effect based on GCA only.

GCA and the SCA were and still are widely used in the diallel cross scheme. Among the different diallel models (partial diallel, circulant partial diallel, etc), those of Griffing (1956) and Gardner and Eberhart (1966) are most noteworthy. They show the significance and magnitude of the GCA and SCA effects, as well as of heterosis and its components, within each parent set. According to Cruz et al. (2004), the methodologies of diallel analysis provide estimates of useful parameters in the selection of parents for hybridization and in the understanding of the genetic effects involved in the determination of the traits.

The objective of this study was to evaluate the grain yield and combining ability of maize cultivars in contrasting environments, recommending the best improvement strategies.

MATERIAL AND METHODS

Six commercial maize cultivars (AG4051, AL30, AL25, D270, D170 and AG1051), with satisfactory yield potential were selected and the hybrid combinations were obtained using the complete diallel scheme. The crosses were realized in a paired row scheme, manually, plant by plant, so that each hybrid combination was represented by at least 50 ears. These were installed in the Experimental Station Diogo Alves de Melo, of the plant science department of the University Federal de Viçosa, in the second semester of 2001.

The trials were conducted in the growing season of 2002, in the Zona da Mata region, state of Minas Gerais (MG), in the Experimental Station Aeroporto and Experimental Station of Coimbra, in the Cerrado (Brazilian savannah), at the Experimental Station CEPET, in Capinópolis-MG and transition Cerrado/Zona da Mata, CEDAF, Florestal-MG, which all belong to the Universidade Federal de Viçosa. The trials at the Experimental Station of Coimbra were installed in October 2002, since this is the most indicated sowing period for maize in the region of the Zona da Mata-MG. The trials were installed in December 2002 in Capinópolis and in November 2002 in Florestal.

Conventional soil preparation was used, with one plowing and two diskings. For fertilization at sowing 400 kg ha^{-1} of the formula 4-14-8 and the topdress using 60 kg ha^{-1} nitrogen, applied in the phenologic stage of six completely developed leaves. Crop treatments were performed whenever necessary, according to the technical recommendation for maize.

The experiments were conducted in the random block design with three replicates. Each experimental plot consisted of two rows of 5.0 m length spaced 0.90 m and plants spaced 0.20 m apart in the row. The controls were the six parents and the cultivars BR101, BR201, UFVm106 and UFVm206. The evaluated trait was grain yield (GY) in kg $plot^{-1}$, transformed into kg ha^{-1} and corrected to 13% moisture.

Analyses of variance in complete random blocks were performed for grain yield in each environment and jointly for environments. The homogeneity of the residual variances was verified beforehand, using a ratio of 4:1 of the highest to the lowest residual variance.

In all analyses this limit was not exceeded. It was therefore possible to perform the joint analysis. The methodology used to estimate the effects of general and specific combining ability was the one proposed by Griffing (1956), using the hybrid combinations and parents.

RESULTS AND DISCUSSION

The F test of the analysis of variance detected significant differences ($P<0.05$) for the effects of treatments x environments, hybrids x environments and controls x environments.

The differences were also significant between the means of the 15 hybrid combinations, by the F test ($P <0.05$), demonstrating a differentiated agronomic performance. The means of the 10 controls did not present significant differences, indicating similar yields. It is therefore possible to obtain high-yielding hybrids in each region, with the capitalization of the genotype x environment interaction.

In this study, the CV's presented values that varied from 5.81 to 19.47%. According to Scapim et al. (1995), based on data of 66 theses in the area of Maize Genetics and Improvement, values bellow 10% can be classified as low, between 10 and 22% as mean, from 22 to 28% as high, and over 28% as very high. At no time the experimental variation coefficient exceeded 20%, which evidences good experimental precision.

The treatment effect was significant by the F test (P<0.05) in Capinópolis and Florestal , but not in Viçosa. This was caused by the parent pre-selection based on the yield performance in this region.

The hybrid combinations presented significant differences in the three environments. When hybrid combinations vs controls were analyzed, different responses were found in the environments. In Viçosa there were no significant differences while in Capinópolis and Florestal the differences were significant at 5%.

In the general mean of the three environments, the most productive parent was AG1051 (5217 kg ha^{-1}) followed by D170 (4440 kg ha^{-1}) (Table 1). The most productive hybrid combinations were: AG4051 X AL30 (4558 kg ha^{-1}), D170 X AG1051 (4517 kg ha^{-1}) and AG4051 X AG 1051 (4460 kg ha^{-1}) (Table 1).

Considering each site, the most productive hybrid combinations were: AG4051 X AG1051 (6244 kg ha^{-1}) and AL25 X AG1051(5814 kg ha^{-1}) in Viçosa, AG4051 X AL25 (4851 kg ha^{-1}) and AL30 X D170 (4129 kg ha^{-1}) in Florestal and, AG4051 X D170 (4787 kg ha^{-1}) and D270 X D170 (4451 kg ha^{-1}) in Capinópolis (Table 1).

In the diallel analysis, the effects of the hybrid combinations were significant by the F test (*P*<0.05) for all environments. The effects of general and specific combining ability were also significant. The SCA and the GCA can therefore be used in the parent selection. Gorgulho and Miranda Filho (2001) did not observe significance for the SCA and, therefore, considered the GCA that was significant, as the most important effect. Nevertheless, Gorgulho and Miranda Filho (2001) used the SCA to identify specific combining abilities.

In the hybrid combinations x environments interaction, significant differences were stated, which indicates that there were changes in the performance of the hybrid combinations in the three locations.

The interaction of combining ability with the environment was reported a long time ago (Rojas and Sprague 1952, Matzinger et al. 1959). In this study, no significant difference was observed for GCA x environment (P<0.05). However, for the SCA x environments interaction, significant differences were observed, which showed that the influence of the non-additive genetic effects (hybrid vigor) is significantly influenced by environmental alterations. Therefore, for a greater efficacy of the selection of specific hybrid combinations, each site must be considered separately. In a similar study, Aguiar et al. (2004) further recommended the selection of specific hybrid combinations for each site, since the SCA x environments was also significant.

Freitas and Ronzelli Júnior (2002), however, did not find significant differences of SCA and SCA x locations, and claimed that this lack of significance indicates predominance of additive genetic effects, because the GCA was significant.

The estimates of the general and specific combining abilities of grain weight in the three evaluated environments are presented in Tables 2 and 3, respectively.

Cultivar AG1051 attained the highest general mean for grain yield (Table 1) as well as the highest GCA, is one of the highest-yielding parents in Viçosa and Florestal, and also presented the highest GCA mean in the three locations (Tables 1 and 2). Therefore, a population derived from this cultivar would be the most indicated for intra-population improvement in the three environments, since according to Vencovsky (1987), high GCA estimates generally occur in genotypes with a higher frequency of favorable alleles.

Besides AG1051 one can also use AG4051 for the formation of synthetic base populations for the three locations, since this cultivar presented the second-highest mean GCA estimate. Considering each site, D170 for Capinópolis, AL25 for Viçosa and AG1051 for Florestal would be the best options, in view of the high grain yield and general combining ability in these locations (Tables 1 and 2).

To establish one adequate hybrid for the three environments, the AG4051-derived population can be improved through reciprocal recurrent selection with the AL30-derived population, since this combination optimizes heterosis (Table 3) and obtained the highest mean in the three locations (Table 1).

In the selection of specific hybrids for each local, Aguiar et al. (2004) pointed out that in the diallel analyses, one must select hybrids of highest specific combining ability in which one of the parental lines presents highest general combining ability. AG1051

Table 1. Means for grain yield (GY, kg ha^{-1}) of hybrid combinations and controls in Viçosa, Capinopólis and Florestal counties

Treatments	GY			
	Mean	Viçosa	Capinópolis	Florestal
AG1051	5217	5467	5259	4927
AG4051 X AL30	4558	5544	3962	4168
D170 X AG1051	4517	5808	3351	4391
AG4051 X AG1051	4460	6244	3889	3248
D170	4440	5049	2944	5327
AL25	4438	5621	3907	3787
AG4051 X AL25	4370	5696	4851	2564
AG4051 X D170	4362	4337	3962	4787
D270 X AG1051	4314	5665	3926	3351
AL25 X D270	4301	5202	3536	4164
BR201	4270	5053	3888	3871
AG4051	4232	5048	3147	4502
UFVM100	3453	4395	2944	3020
AL25 X AG1051	4122	5814	3370	3181
AL25 X D170	4008	5450	2499	4076
AL30 X D270	3965	4386	3814	3696
AL30 X D170	3947	3664	4129	4050
D270 X D170	3920	3403	3907	4451
D270	3843	4454	3962	3113
BR106	3797	4010	2962	4420
AG4051 X D270	3715	4141	3185	3821
AL30 X AG1051	3622	5353	2518	2994
AL30	2857	1859	2629	4082
AL30 X AL25	2759	3671	2296	2310
UFVM200	1770	1480	2111	1720
Mean	3970	4672	3477	3760

Table 2. Estimates of the general combining ability (GCA) for grain yield (GY, kg ha^{-1}) in the experiments realized in Viçosa, Capinópolis and Florestal counties

Hybrids	Viçosa	Capinópolis	Florestal	Mean
AG1051	732.43	2.78	319.53	351.58
AG 4051	262.39	74.36	154	159.3
D170	-149.86	676.61	-159.76	122.33
AL25	389.43	-391.05	-81.01	-27.55
D270	-281.74	-160.89	159.74	-94.3
AL 30	-952.65	-201.81	-379.64	-511.36

however, which had the highest GCA mean, in general, did not form the best hybrids in SCA We therefore decided to select the hybrids of highest yield and SCA of each site, with AG4051 present in at least one of these combinations. Note (Table 2) that AG4051 had the second highest GCA mean.

In Viçosa, the most indicated combinations were AG4051 X AL30 with an SCA estimate of 1383.7 and grain

Table 3. Estimates of the specific combining ability (SCA) for grain yield (GY, kg ha^{-1}) in experiments realized in Viçosa, Capinópolis and Florestal counties

Hybrid combinations	Viçosa	Capinópolis	Florestal	Mean
AG1051 X AG1051	-848.99	1064.43	1046.07	420.50
AG1051 X AG4051	398.05	-686.15	-145.55	-144.55
AG1051 X AL25	-158.99	-287.07	-442.06	-296.04
AG1051 X AL30	722.09	-663.66	-995.43	-312.33
AG1051 X D170	373.97	-144.74	-381.97	-50.91
AG1051 X D270	362.85	-347.24	-127.14	-37.17
AG4051 X AG4051	-328.24	496.59	-708.51	-180.05
AG4051 X AL30	1383.47	438.76	627.28	816.50
AG4051 X AL25	193.05	-975.99	1217.66	144.91
AG4051 X D270	-691.11	50.51	-689.76	-443.45
AG4051 X D170	-626.99	179.68	407.41	-13.30
D170 X D170	497.93	117.09	-310.01	101.67
D170 X AL25	358.97	-66.57	-833.42	-180.34
D170 X AL30	-84.95	-281.49	1094.53	242.70
D170 X D270	-1016.86	78.93	333.48	-201.48
AL25 X AL25	-9.32	712.09	495.48	399.42
AL25 X D270	242.85	859.60	-115.93	328.84
AL25 X AL30	-617.24	-954.15	-817.22	-796.20
D270 X D270	166.34	-421.91	69.32	-62.08
D270 X AL30	769.60	202.01	460.70	477.43
AL30 X AL30	-1086.50	629.27	-184.93	-214.05

yield of 5544 kg ha^{-1} and AL30 X D270 with SCA of 769.598 and mean yield of 4386 kg ha^{-1} (Tables 1 and 3).

In Capinópolis, the highest SCA estimate was obtained for AL25 X D270 with 859.598 and yield of 4164 kg ha^{-1}. In this case, the most productive combinations were not the ones that presented the highest SCA values (Tables 1 and 3). The best yields were obtained with AG4051 X D170 (4787 kg ha^{-1}) and D270 X D170 (4451 kg ha^{-1}). The two most productive combinations present homology, since both have cultivar D170. In spite of cultivar D170 not having presented the highest SCA with AG4051, it achieved the best yield among the hybrid combinations (4787 kg ha^{-1}). In this region, the most indicated combinations are therefore D170 x AG4051 for high yield and AL25 x D270 for high SCA and high yield (Tables 1 and 3).

In Florestal, the most indicated cultivars were AG4051 X AL25 (4851 kg ha^{-1}) and AL30 X D170 (4129 kg ha^{-1}), which presented highest specific combining ability (Tables 1 and 3).

ACKNOWLEDGEMENTS

This study was supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), and the Fundação de Amparo a Pesquisa de Minas Gerais (FAPEMIG).

Produtividade e capacidade de combinação de cultivares de milho em diferentes condições ecogeográficas

RESUMO - *O objetivo deste trabalho foi avaliar a produtividade e a capacidade de combinação de cultivares de milho (AG4051, AL30, AL25, D270, D170 e AG1051) em ambientes contrastantes. Os ensaios foram conduzidos na safra 2002/2003, em Viçosa, Capinópolis e Florestal, Minas Gerais. Os efeitos de híbridos foram significativos pelo teste F, como também, tratamentos x ambientes, combinações híbridas x ambientes e testemunhas x ambientes, indicando a possibilidade de aumentar a produção nestas regiões com a capitalização da interação genótipo x ambiente, selecionando e recombinando cultivares em cada local. Entre os cultivares e suas combinações híbridas, AG1051 e AG4051 x AL30, respectivamente, obtiveram os melhores desempenhos na média dos três locais. As combinações mais indicadas em cada local foram: AG4051 X AL30 e AL30 X D270 em Viçosa, AG4051 X AL25 e AL30 X D170 em Florestal e, D170 x AG4051 e AL25 x D270 em Capinópolis.*

Palavras-chave: dialelo, híbridos, *Zea mays* L.

REFERENCES

Aguiar CG, Scapim CA, Pinto RJB, Amaral Júnior AT, Silvério L and Andrade CAB (2004) Análise dialélica de linhagens de milho na safrinha. **Ciência Rural 34**: 1731-1737.

Allard RW (1971) **Princípios de melhoramento genético de plantas**. USAID, Rio de Janeiro, 381p.

Cruz CD, Regazzi AJ and Carneiro PCS (2004) **Modelos biométricos aplicados ao melhoramento genético**. Editora UFV, Viçosa, 480p.

Falconer DS (1987) **Introdução à genética quantitativa**. Editora UFV, Viçosa, 279p.

Freitas MA and Ronzelli Júnior P (2002) Capacidade de combinação de linhagens obtidas pelo método de dihaploidização na cultura do milho. **Scientia Agraria 3**: 113-132.

Gardner CO and Eberhart SA (1966) Analysis and interpretation of the variety cross diallel and related populations. **Biometrics 22**: 439-52.

Gorgulho EP and Miranda Filho JB (2001) Estudo da capacidade combinatória de variedades de milho no esquema de cruzamento dialélico parcial. **Bragantia 60**: 1-8.

Griffing B (1956) Concept of general and specific combining ability in relation to diallel crossing systems. **Australian Journal of Biological Sciences 9**: 463-493.

Matzinger DF, Sprague GF and Cockerhan CC (1959) Diallel crosses of maize in experiments repeated over locations and years. **Agronomy Journal 51**: 346-350.

Miranda Filho JB and Gorgulho EP (2001) Cruzamentos com testadores e dialelos. In: Nass LL, Valois ACC, Melo IS and Valadares-Inglis MC (eds.) **Recursos genéticos & melhoramento: plantas.** Fundação MT, Rondonópolis, p. 649-672.

Rojas BA and Sprague GF (1952) A comparison of variance components in corn yield trials: III. General and specific combining ability and their interaction with locations and years. **Agronomy Journal 44**: 462-466.

Russel WA, Blackburn DJ and Lamkey KR (1992) Evaluation of a modified reciprocal recurrent selection procedure for maize improvement. **Maydica 37**: 61-7.

Scapim CA, Carvalho CGP and Cruz CD (1995) Uma proposta de classificação dos coeficientes de variação para a cultura do milho. **Pesquisa Agropecuária Brasileira 30**: 683-86.

Sprague GF and Tatum L (1942) A General vs specific combining ability in single crosses of corn. **Journal American Society Agronomy 34**: 923-32.

Vencovsky R (1987) Herança quantitativa. In: Paterniani E (ed.) **Melhoramento e produção de milho no Brasil**. ESALQ/USP, Piracicaba, p. 277-340.