Acta Scientiarum

http://www.uem.br/acta
ISSN printed: 1679-9275
ISSN on-line: 1807-8621
Doi: 10.4025/actasciagron.v37i2.19329

Diallel analysis of maize hybrids for agronomic and bromatological forage traits

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ABSTRACT. The aim of this study was to evaluate a diallel of maize hybrids for traits related to forage production and nutritional value. Six commercial hybrids were used as parents. The crosses were made according to a complete diallel design, obtaining the F1 and reciprocal crosses. The evaluations were performed in the main and second crop seasons in the 2010/2011 crop year at the Center for Technological Development in Agriculture of the Federal University of Lavras, located in Lavras, Minas Gerais State, Brazil. The experimental precision indicated by the coefficient of variation was good for all the traits measured. Significant differences were not observed among the crosses for traits related to the nutritional value of the forage. For fresh matter yield and dehusked ear yield, the general combining ability (GCA) and specific combining ability (SCA) effects were significant. Sowing in the second crop season reduced the yield and nutritional value of the forage. The interaction among the crosses and sowing seasons was not significant. For the beginning of an intrapopulational breeding program, the parent BM 3061 stands out by showing high estimates of GCA for the grain and forage yields.

Keywords: mating designs, general combining ability, specific combining ability, interaction genotypes x environments.

Análise dialélica de híbridos de milho para características agronômicas e bromatológicas da forragem

RESUMO. O objetivo deste trabalho foi avaliar um dialelo de híbridos de milho para caracteres relacionados à produção e valor nutricional da forragem. Como genitores foram utilizados seis híbridos comerciais. Os cruzamentos foram feitos segundo esquema de dialelo completo, obtendo-se os F1's e os recíprocos. As avaliações foram realizadas na safra e safrinha, no ano agrícola 2010/2011, no Centro de Desenvolvimento Tecnológico em Agropecuária, da Universidade Federal de Lavras, no município de Lavras, Estado de Minas Gerais. A precisão experimental, avaliada pelo coeficiente de variação, foi boa para todas as características mensuradas. Apenas não foram observadas diferenças significativas entre os cruzamentos para as características relacionadas ao valor nutricional da forragem. Para produtividade de matéria verde e produtividade de espigas despalhadas os efeitos da capacidade geral (CGC) e específica (CEC) de combinação foram significativos. A semeadura na safrinha reduziu a produtividade e o valor nutricional da forragem. A interação entre os cruzamentos e as épocas de semeadura foi não significativa. Para início de um programa de melhoramento intrapopulacional destaca-se o genitor BM 3061, por apresentar elevadas estimativas da CGC para a produtividade de grãos e produtividade de forragem.

Palavras-chave: delineamentos de cruzamentos, capacidade geral de combinação, capacidade específica de combinação, interação genótipos x ambientes.

Introduction

Plants used as forage crops, such as cultivated pastures, have variable development according to the season of the year. This variation occurs for the yield and nutritional value of the feed. Due to greater technical development in the dairy and beef production sectors, supplying quality forage has become an important factor for achieving high yield. Maize stands out as a forage plant due to its high dry matter yield, easy growth conditions and high energy content.

For forage production, farmers use cultivars available on the market that have high grain yield, but these cultivars are not always recommended for forage production (COORS et al., 1994). Thus, evaluation of the nutritional value of the forage is necessary (PEREIRA et al., 2011; TANG et al., 2008).

The main traits used to evaluate the nutritional value of maize forage are the neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin contents and forage digestibility (FANCELLI; DOURADO NETO, 2000).

Among the diverse factors that affect maize forage digestibility, grain texture is among the most important. According to Pereira et al. (2004), ruminal degradability of the kernels of dent corn cultivars is greater than that of flint corn. The forage that has better ruminal availability of the starch is that made with dent corn cultivars (CORRÊA et al., 2002; PEREIRA et al., 2004). In Brazil, most of the cultivars available have flint corn kernels.

Due to the need for cultivars that produce forage with high nutritional value, various studies have been conducted with the purpose of obtaining information so that breeders can define adequate strategies in their programs. This was the aim of Gomes et al. (2006), who studied existing variability among inbred lines for traits related to yield and the nutritional value of the corn silage. According to this author, the best strategy for making hybrids that produce silage with high nutritional value is to cross parents that have high degradability of their silage.

The use of mating designs in the choice of populations is a routine practice among breeders. One of the most commonly used designs is the diallel design. Diallel analyses can be used to estimate the effects of general combining ability (GCA), which provide information on the concentration of alleles of additive effect, and the effects of the specific combining ability (SCA), which highlight the importance of alleles that exhibit non-additive effects or are predominantly involved in dominance or epistasis (CRUZ et al., 2004).

Therefore, the aim of this study was to evaluate a diallel of maize hybrids for the agronomic and bromatological traits of the forage.

Material and methods

Six commercial hybrids were used as parents (Table 1). They were chosen due to their forage yield potential in the southern region of Minas Gerais and based on the following information: recommendation, type, kernel type and grain yield.

Table 1. Information about the parents used in the diallel.

Cultivars	Recommendation	Type	Kernel type	Company
AG 1051	Silage	Double	Dent	Agroceres
AG 8060	Grain	Single	Flint	Agroceres
AG 4051	Silage	Three-way	Dent	Agroceres
BM 3061	Silage	Three-way	Dent	Biomatrix
DOW8420	Grain	Single	Flint	DAS
IPR 127	Grain	Single	Flint	Iapar

In the 2009/2010 crop year, crosses were made two by two to obtain the F1 and reciprocal crosses. Pollination was performed manually. The pollen was collected from a number of different plants, depending on the genetic structure of each population, and was then distributed among the plants of the other cultivars with the aid of a salt shaker.

The crosses were evaluated in two growing seasons (main and second crop) in the 2011/2012 crop year for the purpose of quantifying the genotype x environment interaction. In the main crop season, the experiment was grown in November, and in the second crop season, it was grown in February. A complete randomized block design was used, with three replications. The parents themselves were used as controls. The experiments were conducted at the Center for Technological Development in Agriculture of the Federal University of Lavras, located in Lavras, Minas Gerais State, Brazil, at the geographic coordinates of 44° 58' (West), 21° 12' (South) and 936 m altitude.

In each crop season, two contiguous experiments were conducted. In the first experiment, the plot consisted of 2-meter rows, with between row spacing of 0.6 m, resulting in a population of 83,333 plants per hectare. The following traits were evaluated related to the yield and nutritional value of the forage: total fresh matter yield – all the plants of the experimental plot were weighed; dry matter yield – mean weight estimated in $t.ha^{-1}$, resulting from fresh matter yield multiplied by a correction factor for dry matter at 105°C; *in vitro* dry matter digestibility (IVDMD); acid detergent fiber (ADF), neutral detergent fiber (NDF) and lignin contents. For the evaluation of the traits related to the nutritional value of the forage, near-infrared spectroscopy (NIRS) was used, with the analyses performed on dried samples ground with a one-millimeter at the Embrapa Dairy Cattle research station in Juiz de Fora, Minas Gerais State. In this experiment, the morphological traits of the plant were also evaluated: plant height, measured in centimeters after tasseling, from the soil level to the flag leaf node in five competitive plants per plot; ear height, measured in centimeters after tasseling, from the soil level to the first ear height in the same five plants; stalk diameter of five competitive plants representative of each plot, with the measurement made using a digital caliper rule at the first internode above the soil level; and number of leaves – the leaves above the first ear were counted from five competitive plants representing each plot. In the second experiment, the plot consisted of two three-meter rows, with between-row spacing of 0.6 m, also with a population of 83,333 plants per hectare, and the dehusked ear yield (DEY) was evaluated. All the ears of the plot were weighed, with a correction for moisture content of 13% being made.

Analysis of variance was conducted for each environment. The homogeneity of the residual variances was verified by means of the Hartley test. After the presuppositions for performing joint analysis were met, it was conducted according to Ramalho et al. (2012). Analyses were performed using the General Linear Models (GLM) procedure of SAS (SAS, 2002).

Based on the results of the analyses of variance, the sums of squares of the treatments were decomposed into the sum of squares of the general combining ability, specific combining ability and reciprocal effects, according to the procedure from Griffing (1956), method three (CRUZ et al., 2004). The sum of the squares due to the effect of the interaction between the crosses and the sowing times was orthogonally decomposed into the effect of the interactions among the general abilities, specific abilities and reciprocal effects with the sowing periods. The analyses were performed according to the procedure described by Zhang et al. (2005).

Results and discussion

The coefficient of variation showed that the experimental precision was good for all the traits evaluated. It is important to highlight that the experimental coefficient of variation depends on the trait evaluated, on the unit of evaluation and on the genetic structure of the populations evaluated. The coefficient of determination (R^2) may also be observed for the purpose of evaluating experimental precision, which estimates the proportion of variation explained by the model adopted (FERREIRA, 2005). The estimates observed in the present study were always greater than 50%, indicating that for most of the traits, the model of analysis explained the variation in the data in a satisfactory manner (Tables 2 and 3). The coefficient of determination of the model is indicated for the evaluation of experimental precision because it is associated with high variance among the treatments and low residual variance. It does not depend on the mean value of the test and may be interpreted in a more general manner, without dependence on classification tables (CARGNELUTTI FILHO; STORCK, 2007; 2009).

The Hartley test showed that the residual variances in the two environments were homogeneous. The F test of the joint analyses of variance indicated significant differences ($p \leq 0.01$) among the crosses for the traits related to forage yield, indicating that there is genetic variability, manifesting the possibility of success in the selection (Table 2). For the traits related to the nutritional value of the forage, significant differences among the crosses were not detected (Table 3). Similar results were reported by Chaves et al. (2008), who did not observe significant GCA and SCA effects for traits related to the nutritional value (NDF and ADF) of the forage, indicating that the genitors did not differ in the frequency of favorable alleles for the traits in question. In the literature, there are reports of the existence of genetic variability for the bromatological traits of the forage (ARGILLIER et al., 2000; MENDES et al., 2008; TANG et al., 2008); however, in the present study, such variation was not observed.

The sum of the squares of the cross effect was decomposed in the GCA, SCA and reciprocal effects. For the trait dry matter yield, only the GCA effect was significant ($p < 0.01$).

Table 2. Summary of the joint analysis of variance for the traits of total fresh matter yield (FMY), in tons ha^{-1}; dry matter yield (DMY), in $ton.ha^{-1}$; dehusked ear yield (DEY), in tons ha^{-1}, plant height (PH), in centimeters; number of leaves (NL) and stalk diameter (SD), in millimeters; with decomposition of the cross effect (F1 and reciprocal crosses) in the general combining ability (GCA) and specific combining ability (SCA).

Effect	DF	MS					
		FMY	DMY	DEY	PH	NL	SD
Crosses (C)	29	**	**	**	**	**	**
GCA	5	**	**	**	**	**	**
SCA	9	**	ns	*	ns	ns	ns
Reciprocal	15	ns	ns	ns	ns	ns	ns
Seasons (S)	1	**	**	**	**	ns	**
C x S	29	ns	ns	ns	ns	*	ns
GCA x S	5	ns	ns	ns	ns	**	ns
SCA x S	9	ns	ns	ns	ns	ns	ns
Reciprocal x S	15	ns	ns	ns	ns	ns	ns
Error	116						
R^2 (%)		90.95	82.25	89.04	86.46	61.42	84.91
CV (%)		18.36	19.7	17.89	5.97	5.09	8.07
Overall mean		41.96	18.83	7.69	205.31	6.11	21.28
F1 mean		44.79	15.45	7.98	202.00	6.12	21.23
Reciprocal Mean		42.7	15.18	7.82	204.12	6.11	21.32
Main Crop Season Mean		55.15	18.1	9.70	226.02	6.20	24.17
Second Crop Mean		24.5	9.78	5.10	184.38	6.11	18.47

*, ** Significant by the F test at 5 and 1% probability, respectively; ns: not significant.

Table 3. Summary of the joint analysis of variance for the traits of *in vitro* dry matter digestibility (IVDMD) and neutral detergent fiber (NDF), acid detergent fiber (ADF) and lignin (Lig.) contents, all as percentages, with the decomposition of the cross effect (F1 and reciprocal crosses) on the general combining ability (GCA) and specific combining ability (SCA).

Effect	DF	MS			
		IVDMD	NDF	FDA	Lig.
Crosses (C)	29	ns	ns	ns	Ns
GCA	5	*	ns	ns	ns
SCA	9	ns	ns	ns	ns
Reciprocal	15	*	*	*	ns
Seasons (S)	1	**	**	**	**
C x S	29	ns	ns	ns	ns
GCA x S	5	ns	ns	ns	ns
SCA x S	9	ns	ns	ns	ns
Reciprocal x S	15	ns	ns	ns	ns
Error	109				
R^2 (%)		83.94	51.97	56.59	48.79
CV (%)		4.9	7.15	9.97	12.41
Overall mean		62.98	59.57	28.4	5.08
F1 mean		62.13	59.73	28.53	5.08
Reciprocal mean		63.8	59.45	28.29	5.09
Main crop mean		68.28	57.34	26.47	4.88
Second crop mean		58.15	60.49	29.29	5.08

*, ** Significant by the F test at 5 and 1% probability, respectively; ns: not significant.

The parents BM 3061 and Dow 8420 stood out due to their greater GCA estimates, with $\hat{g} = 0.96$ and $\hat{g} = 0.79$, respectively (Table 4). These values indicate that these parents led to increases of 0.96 and 0.79 tons of dry matter in the crosses in which they participated, respectively. A low value of $\hat{g}_i$ indicates that the mean value of the hybrids in which the parent participates does not differ greatly from the overall mean of the experiment. A high value, either positive or negative, indicates that parent i is much better or worse than the other parents involved in the diallel with respect to the mean of their hybrids. The parent that has a greater frequency of favorable alleles will show a greater $\hat{g}_i$ (CRUZ; VENCOVSKY, 1989).

An interesting observation was made for the trait of *in vitro* dry matter digestibility because significant differences were not detected among the crosses and the decomposition of this effect verified that both the GCA and reciprocal effects were significant ($p < 0.05$) (Table 3). These results are an indication that the parents differed in regard to the frequency of favorable alleles and that there are differences when a parent is used as the male or female in the cross for the trait in question. The parent BM 3061 stands out as having the highest estimate of ($\hat{g}_i = 0.62$) (Table 4).

For the traits plant height (PH), number of leaves (NL) and stalk diameter (SD), significant differences were detected among the crosses, and in the decomposition of this effect, only the GCA was significant ($p < 0.05$), indicating that the parents differed with respect to the frequency of favorable alleles for these traits (Table 2). The parents AG 4051 and AG 8060 stand out as having high values for GCA and for PH and NL, respectively. With respect to SD, the parent Dow 8420 stands out as having a high and negative estimate of GCA because, for this trait, low phenotypic values are desired (Table 4).

Table 4. Estimates of the general combining ability ($\hat{g}_i$) for the following traits: dry matter yield (DMY), in tons ha^{-1}; *in vitro* dry matter digestibility (IVDMD), in percentage; plant height (PH), in centimeters; number of leaves (NL) and stalk diameter (SD), in millimeters.

Parent	$\hat{g}_i$				
	DMY	IVDMD	PH	NL	SD
Dow 8420	0.79	0.23	-10.35	-0.21	-0.75
BM 3061	0.96	0.62	8.11	-0.07	0.61
AG8060	-0.06	0.01	7.13	0.32	-0.03
AG 4051	0.33	-0.16	12.36	0.04	0.48
IPR 127	0.02	-1.42	-1.16	0.11	-0.43
AG 1051	-2.04	0.72	-16.10	-0.20	0.12

For fresh matter yield (FMY) and dehusked ear yield (DEY), the deviations not explained by the CGC effects were significant, as shown by the significance of the specific combining ability (SCA) effect (Table 2), which justifies the calculation of the estimates of the SCA effects for each cross (Tables 5 and 6). The SCA is estimated as a deviation of a determined cross with respect to what was expected based on the GCA of the parents. These estimates provide evidence of the importance of genes that exhibit non-additive effects (CRUZ et al., 2004). For the fresh matter yield, the cross AG 8060 x DOW 8420 stood out, showing a high estimate of SCA ($\hat{s} = 3.39$). The cross BM 3061 x AG 4051 also showed a high estimate of CEC ($\hat{s} = 3.09$), whereas the parent BM 3061 showed a high estimate for GCA ($\hat{s} = 2.53$) (Table 5). For the dehusked ear yield, the cross BM 3061 x AG 1051 stood out, showing the greatest estimate of SCA ($\hat{s} = 0.44$), whereas the parent BM 3061 showed a high estimate of GCA ($\hat{s} = 0.59$) (Table 6).

In terms of selection, crosses that present a high SCA estimate and in which at least one of the parents shows a high GCA, are of interest to the breeder.

Table 5. Estimates of the general combining ability (GCA) and specific combining ability (SCA) effects for fresh matter yield, in tons ha^{-1}.

	Dow8420	BM3061	AG8060	AG4051	IPR127	AG1051
Dow8420	-0.13	0.90	3.39	-3.72	-2.85	2.28
BM3061		2.53	-2.31	3.09	-4.09	2.41
AG8060			0.94	0.54	2.95	-4.57
AG4051				0.03	-2.10	-2.01
IPR127					2.08	1.88
AG1051						-5.45

[1]The GCA effects are on the diagonal, and the SCA effects are above the diagonal.

Table 6. Estimates of the general combining ability (GCA) and specific combining ability (SCA) effects for dehusked ear yield, in tons ha^{-1}.

	Dow8420	BM3061	AG8060	AG4051	IPR127	AG1051
Dow8420	-0.10	0.35	0.20	-0.74	-0.15	0.35
BM3061		0.59	0.19	-0.20	-0.78	0.44
AG8060			0.31	0.43	-0.36	-0.46
AG4051				-0.08	-1.07	-0.56
IPR127					0.48	0.23
AG1051						-1.19

[1] The GCA effects are on the diagonal, and the SCA effects are above the diagonal.

The reciprocal effect, which measures the differences provided by parent i or j, when used as male or female in the ij cross, was significant ($p < 0.05$) for the traits of *in vitro* dry matter digestibility (IVDMD), neutral detergent fiber (NDF) content and acid detergent fiber (ADF) content, showing that there are differences when a parent is used as male or female in the crosses in question (Table 3). This effect is caused by the expression of extranuclear genes or by the interaction among these genes with nuclear factors (CAI et al., 2012).

The effect of the sowing time was observed to be significant and of great intensity, such that in the second crop, the yield and nutritional value of the forage were reduced compared with the main crop season. A significant effect of the sowing time was not detected only for the trait of the number of leaves (Tables 2 and 3).

With respect to the interaction between the crosses and sowing times, this effect was only significant ($p < 0.05$) for the trait of the number of leaves, and after decomposition, only the GCA effect showed a significant interaction with the sowing time. This result implies that the estimates of GCA were not consistent in the times evaluated. However, attention should be paid to the estimates of R^2, which provide information about the quality of the fit of the model to the data and which was only 61.42% for the said trait (Table 2). The lack of significance of the effect of the interaction between the effects of the GCA with the sowing time agrees with the results of Gomes et al. (2004), who showed that a significant interaction was not detected between the GCA effects and the sowing times for the trait of *in situ* dry matter degradability.

Conclusion

Sowing in the second crop season reduced the yield and digestibility of the forage.

For the beginning of an intrapopulational breeding program, the parent BM 3061 stood out as having high estimates of GCA for the grain yield, forage yield and *in vitro* dry matter digestibility.

If the breeder is interested in beginning an interpopulational breeding program, the crosses AG 8060 x Dow 8420 and BM 3061 x AG 4051 stand out as having high estimates of SCA for the grain and forage yields.

Acknowledgements

The authors thank the National Council of Scientific and Technological Development (CNPq) for granting scholarships and the Universidade Federal de Lavras (Federal University of Lavras) for making the infrastructure available for conducting the experiments, thereby enabling the present study to be performed. Sincere thanks also to the researcher Dr. Fausto de Souza Sobrinho for assistance in undertaking the analyses related to the nutritional value of the forage, which were performed entirely at Embrapa Gado de Leite, Juiz de Fora (MG). The professors Dr. Marcos Neves Pereira and Dr. Magno Antônio Patto Ramalho should also be acknowledged for their valuable advice in regard to the methodology used.

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Received on November 30, 2012.
Accepted on March 12, 2013.