

Mean components for choosing maize populations to extract inbred lines

Componentes de média para escolha de populações de milho para extração de linhagens

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ABSTRACT

The choice of germplasm is one of the most important phases of a genetic improvement program to the fact that it is the initial development stage of superior hybrids. Hence, the objectives of this study were to obtain the estimates of $m+a$ and d , and inbreeding depression for grain yield and plant height traits, for cultivars lacking this information, and thus to predict the potential of maize hybrids for the extraction of lines. The F_1 and F_2 generations of 12 maize hybrids were tested at two sites, during the crop years of 2017-18 and 2018-19, accounting for four environments. Both the generations were evaluated in contiguous experiments in randomized blocks design with three and two repetitions during the years 2017-18 and 2018-19, respectively. The data on plant height and grain yield were collected, per plot, from both the generations, utilizing which, the $m+a$ and d mean components were estimated. The effects of dominance had greater importance for the character grain yield. The most promising hybrids for extraction of lines were AG1051, AG8025, BG7046, DKB455, and OMEGA due to their greater estimates of $m+a$. The hybrids AG8025 and BG7046 were associated with high values of $m+a$ and grain yield. For the plant height trait, there was a greater contribution of additive effects. Therefore, greater inbreeding depression was observed for the grain yield trait when compared to the height of the plant.

Index terms: *Zea mays*, L.; heterosis; inbreeding depression.

RESUMO

A escolha do germoplasma é uma das fases mais importantes do programa de melhoramento genético do milho pois é o início do desenvolvimento de híbridos superiores. Em vista disso, os objetivos deste estudo foi obter as estimativas de $m+a$ e d , e a depressão por endogamia para as características produtividade de grãos e altura de plantas, e assim prever o potencial dos híbridos de milho para extração de linhagens. Foram testadas as gerações F_1 e F_2 de 12 híbridos de milho, em dois locais durante os anos agrícolas de 2017/18 e 2018/19, contabilizando quatro ambientes. As duas gerações, F_1 e F_2 , foram avaliadas em experimentos contíguos no delineamento de blocos casualizados, com três e duas repetições durante os anos 2017/18 e 2018/19, respectivamente. Foram coletados dados de altura de plantas e produtividade de grãos por parcela das duas gerações, e a partir destes dados, foram estimados os componentes de média, $m+a$ e d , para ambas características. Para o caráter produtividade de grãos, os efeitos de dominância apresentaram maior importância. Os híbridos mais promissores para extração de linhagens foram AG1051, AG8025, BG7046, DKB455 e OMEGA uma vez que apresentaram maiores estimativas de $m+a$. Destacando-se os híbridos AG8025 e BG7046 os quais mostraram altos valores de $m+a$, além de médias de produtividade elevadas. Para o caráter altura de plantas, houve maior contribuição dos efeitos aditivos. Portanto, observou-se maior depressão por endogamia para o caráter produtividade de grãos quando comparado com altura de plantas.

Termos para indexação: *Zea mays*, L.; heterose; depressão por endogamia.

INTRODUCTION

Maize crop has great importance in food security and economic development of many countries. Due to the actual global scenario, which involves climate changes, population growth, increasing demand for quality foods,

and others, the importance of genetic improvement of maize will increase in the near future. In Brazil, maize production had significant growth in maize productivity due to an increase of 348% in the last 41 years (Companhia Nacional de Abastecimento, CONAB, 2019).

The development of superior genotypes is an extensive and long-term process; thus, it is crucial to pay attention to the choice of base populations since they are essential to plant breeding programs (Hallauer et al., 2010). The choice of base populations has to be based on very clear goals and focused on a few traits, aiming to get segregating populations with high grain yield means, and also variability for the traits under selection. Since most plant traits of commercial interest have complex genetic controls, the definition and choice of the best parental becomes a difficult task (Ramalho et al., 2012). To circumvent these challenges, one of the procedures that help the breeders is the estimation of $m+a$ and d , as proposed earlier by Vencovsky and Cruz (1991). This method allows us to evaluate the potential of early generations more simply, thereby facilitating the choice of new populations to be used, and thus reducing the costs and time to obtain the hybrids. The $m+a$ component corresponds to the mean of all lines in F_{∞} generation, while d represents the variabilities between the lines. Therefore, in order to obtain the lines with good agronomic performance, high values of $m+a$ and d are desirable.

This methodology has been widely adopted by several authors earlier, aiming to obtain the best populations for line extraction, and consequently reducing self-fertilization and evaluation costs of lines (Kuki et al., 2017). However, due to the dynamic of hybrid releases in the market, many maize hybrids do not have information about either their inbreeding depression or $m+a$ and d , even in the case when this information is very valuable to initiate new breeding populations and continue the breeding cycles.

Hence, the objectives of this study were to obtain $m+a$ and d estimates, as well as the inbreeding depression for grain yield and plant height traits, and thus to predict the potential of commercial maize hybrids for new lines extraction.

MATERIAL AND METHODS

The experiments were conducted at two sites, namely, the Center of Scientific and Technological Development in Agriculture of the Federal University of Lavras (UFLA), lat. 21°20' S and long. 44°98' W, at 918 m of altitude, and the experimental area of the Agriculture Department of UFLA, lat. 21°13' S and long. 44°58' W, at 919 m of altitude, both located in the southern region of the state of Minas Gerais, Brazil.

Twelve commercial maize hybrids, which have not been characterized for promising inbred lines extraction, were used in correspondence to their F_1 generation (Table 1). The F_2 generation was obtained by self-pollinization of twenty-five plants, on average, of each F_1 hybrid during the 2016-17 crop season.

In comparison, the data to obtain the $m+a$ and d estimates, in the F_1 and F_2 generations, were evaluated under two experiments, which were carried out during two agricultural years 2017-18 and 2018-19. The seeds were sown on November 24th, 2017 and November 26th, 2018, respectively. The combination of the two sites and the two agricultural years accounted for four environments were: 1–Muquém (2017/18); 2–UFLA (2017/18); 3–Muquém (2018/19), and 4–UFLA (2018/19).

Table 1: Identification and main characteristics of F_1 commercial hybrids.

Hybrids	Company	Cycle ¹	Texture of the grain	Type of hybrid
AG1051	Agroceres	Semi-early	Dent	Double-cross
AG5055	Agroceres	Early maturity	Dent	Three-way cross
AG8025	Agroceres	Early maturity	Dent	Single-cross
Alfa_9020C	Alfa Pesquisa e Sementes	Early maturity	Semi-hard	Single-cross
BG7046	Biogene	Super early	Semi-hard	Single-cross
BM810	Biomatrix	Early maturity	Semi-hard	Single-cross
2B587	Dow AgroSciences	Early maturity	Semi-Dent	Single-cross
DKB455	Dekalb	Early maturity	Semi-hard	Three-way cross
Impacto	Syngenta	Early maturity	Hard	Single-cross
Omega	Syngenta	Early maturity	Hard	S. Modified
PRE_32D10	Prezzotto	Early maturity	Semi-hard	Double-cross
RK3014	Riber-KWS	Early maturity	Hard	Three-way cross

Source: Author's (2019). ¹ Data provided by the company.

The experiments of F_1 and F_2 generations were contiguous, conducted through randomized blocks design with three and two repetitions for the agricultural years of 2017-18 and 2018-19, respectively. The two 4 m wide rows plots spaced in 0.6 m apart from each other were adopted. Additionally, extra maize plants were thinned manually to get a population of 60000 plants per hectare for each plot. Due to the planting, 400 kg ha⁻¹ of formulated fertilizer, 08-28-16 (N, P₂O₅, K₂O), and other micronutrients were used. The top application of dressing fertilizer was 300 kg ha⁻¹ of 20-00-20 (N, P₂O₅, K₂O). The other farming practices were conducted according to the necessities of the crop, climate, and location.

Grain yield data were collected for each plot (4.8 m²), and humidity corrections (13%) were also performed. Plant stand corrections to 60000 plants were done through Vencovsky and Cruz (1991) method to obtain accurate in kg ha⁻¹. For plant height trait, which corresponds to the distance between the ground level and the insertion of flag leaf, data from five random plants per plot were collected.

The $m+a$ and d estimates were obtained by following estimators, $m+a = (2 \times \bar{F}_2) - \bar{F}_1$, $d = 2(\bar{F}_1 - \bar{F}_2)$, in which \bar{F}_1 and \bar{F}_2 represent the means of F_1 and F_2 generations for an evaluated trait, respectively. It was also estimated that the mean of inbreeding depression in percentage by the estimator $\left[\frac{(\bar{F}_1 - \bar{F}_2)}{\bar{F}_1} \right] \times 100$. The collected phenotypic data were submitted for analysis of variance using the package *agricolae* (Mendiburu, 2019) in the R software (R Core Team, 2019). The grain yield and the plant height means of the treatments were grouped by the Scott-Knott method. The experimental precision was verified through estimates of accuracy and coefficient of variation.

RESULTS AND DISCUSSION

The results obtained from the joint analysis of variance showed a significant difference between the genetic treatments for grain yield and the plant's height traits in both the generations, as well as for all other sources of variation (Table 2). Even though, the Genotype x Environment (GxE) interactions were significant for both the traits, in this work, the results were based on the mean values of the environments, aiming to select the best populations for line extractions. Evaluating genotypes at several sites during a couple of years enabled the selection of the base population more assertively.

The grain yield means ranged from 5623 (kg ha⁻¹) to 7836 (kg ha⁻¹), the hybrids were allocated into three different groups by the Scott-Knott test (Table 3). For this trait, the hybrids AG1051, AG5055, AG8025, ALFA_9020C,

BG7046, and DKB455 showed the highest grain yield performance and the lowest by the hybrid 2B587. For plant height traits, four different groups were determined, in which mean plant height ranged from 1.89 to 2.19 m (Table 3).

Table 2: Summary of a joint analysis of variance for grain yield (GY) and plant height (PH) traits for F_1 and F_2 generations of the 12 maize hybrids evaluated in four environments.

FV	GL	QM	
		GY	PH
Environments (E)	3	32782598**	1.33**
Blocks/E/G	12	1251535	0.02
Generations (G)	1	380299021**	2.86**
E*G	3	2646166*	0.18**
Hybrids (H)	11	7950937**	0.21**
H*E	33	2773591**	0.03*
H*G	11	4439145**	0.12**
H*G*E	33	2122355**	0.04**
Residual	132	948295	0.02
General mean		6813.088	2.039242

** , significant by F test at the level of 1%; * , significant by F test at the level of 5%.

Table 3: Grain yield (GY) and plant height (PH) means of the 12 maize hybrids in both generations, in four environments.

Hybrids	GY	PH
AG1051	7183 a	2.11 a
AG5055	7382 a	2.07 b
AG8025	7836 a	2.05 b
Alfa_9020C	7265 a	2.14 a
BG7046	7321 a	2.14 a
BM810	6394 b	1.95 c
2B587	5623 c	1.82 d
DKB455	6970 a	1.98 c
Impacto	6254 b	2.01 c
Omega	6605 b	1.97 c
PRE_32D10	6158 b	2.04 b
RK3014	6767 b	2.19 a

Means followed by the same letter in the columns belong to the same group by the Scott-Knott test (1974) to the level of 5% of probability.

Source: Authors (2019).

The grain yield means in F_1 generation for each environment ranged from 7287 kg ha⁻¹ to 8878 kg ha⁻¹, for Muquém (2017/18) and UFLA (2017/18) environments, respectively (Table 4). For the F_2 generation, reductions in the grain yields, in comparison to the F_1 generation, were observed. Due to the higher soil fertility of the UFLA site, the highest grain yield means were observed at this site for both the years. In addition, the greatest pest incidence was observed at Muquém compared to UFLA, which negatively affected the grain yield mean. According to Valicente et al. (2017), the plant diseases and insects, such as *Spodoptera frugiperda*, may reduce maize crop grain yielding up to 52% depending on plant stage, levels of infestation, and environment.

For plant height trait, the environments were divided into four different groups, in which the highest mean was observed in UFLA (2017-18) and the lowest mean in Muquém (2018-19) (Table 4).

It was possible to observe the significant difference for both the evaluated traits, in terms of means, between F_1 and F_2 generations. Data analysis showed a reduction of 2518 kg ha⁻¹ in grain yield mean for F_1 in relation to F_2 generations (Table 5). A similar pattern was observed in plant height trait, in which F_2 generation showed a reduction of 22 cm in the plants' mean height.

The reductions of the means of both traits are due to the inbreeding depression phenomenon, in which the frequency of homozygous loci increases with about 50% in each self-fertilization round (Hallauer et al., 2010). This phenomenon causes a reduction in the adaptive value or mean of genotypes derived from crossing between

related individuals, and it is dependent on the frequency of deleterious and lethal recessive alleles involved in the control of a given biological character (Freitas et al., 2016).

Based on the results of joint analysis of variance for $m+a$ and d estimates, it was significant differences were observed for both the evaluated traits (Table 6).

Observing the d estimates for grain yield and plant height traits, Muquém 2018/19 and UFLA 2018/19 showed higher means than the other. For $m+a$ estimates, the highest grain yield means were observed on UFLA and Muquém, both in 2017-18. However, the highest mean of plant height $m+a$ estimate was observed in Muquém 2017-18 (Table 4). This lack of coincidence is due to the presence of GxE interaction.

The comparisons between estimates of $m+a$ from different hybrids enabled us to classify them in relation to the mean frequency of favorable alleles that are in homozygosis. The higher the value of $m+a$, the higher the frequency of these alleles will be (Ramalho et al., 2012). Therefore, considering the estimate of $m+a$ for grain yield, the hybrids AG1051, AG8025, BG7046, DKB455, and OMEGA were the most promising hybrids for lines extraction for the trait in the study because of their higher mean of $m+a$ values. The hybrids AG8025 and BG7046 showed high values of $m+a$ and high means of grain yielding (Table 7). It was demonstrated by Abreu, Ramalho and Santos (2002) that there is a high correspondence between the $m+a$ estimates and the F_∞ generation. Thus the information obtained in this work showed the importance of these estimates for line extraction, aiming high grain yielding.

Table 4: Grain yield (GY) and plant height (PH) means of F_1 and F_2 generations, estimates of $m+a$ and d components for grain yield ($m+a$ GY and d GY) and plant height ($m+a$ PH and d PH), for the four environments.

Environments	GY		PH		d GY	d PH	$m+a$ GY	$m+a$ PH
	F1	F2	F1	F2				
Muquém (2017/18)	7287b	5264c	1.95d	1.75d	4047b	0.39b	3241a	1.55c
UFLA (2017/18)	8878a	6371a	2.18c	2.08a	5014a	0.20c	3864a	1.98a
Muquém (2018/19)	7503b	4669d	2.24b	1.89c	5670a	0.69a	1834c	1.54c
UFLA (2018/19)	8609a	5651b	2.32a	2.02b	5917a	0.60a	2692b	1.72b

¹ Means followed by the same letter in the same column do not differ among them by the Scott-Knott test (1974) at the level of 5% of probability.

Table 5: Grain yield (GY) and plant height (PH) means of F_1 and F_2 generations in four environments.

Generations	GY	PH
F1	8072a	2.15a
F2	5554b	1.93b

Means followed by the same lower case letters in the columns do not differ among them by the F-test. Source: Authors (2019).

Table 6: Summary of joint analysis of variance for the estimates of $m+a$ and d components for grain yield ($m+a$ GY and d GY) and plant height ($m+a$ PH and d PH), involving the 12 commercial maize hybrids, in the four environments.

FV	GL	QM			
		d GY	$m+a$ GY	d PH	$m+a$ PH
Environments (E)	3	21169346*	21238244**	1.46**	1.39**
Hybrids (H)	11	35513178**	24607179**	0.93**	0.36**
Blocks/E	6	15077398*	11397366**	0.29*	0.18*
H*A	33	16978837**	12717760**	0.30**	0.22**
Residue	66	6165516	2957705	0.11	0.07
General mean		5035.2	3036.69	0.43617	1.71217

** , significant by F-test at the level of 1%; * , significant by F-test at the level of 5%.

Table 7: Mean of F_1 and F_2 generations, estimates of $m+a$, and d , inbreeding depression for grain yield trait (GY), considering the four evaluation environments for the 12 evaluated hybrids.

Hybrids	GY F1	GY F2	ID(%)	($m+a$)GY	% ²	(d) GY	% ²
AG1051	7868b	6498a	17.42	5126.89a	65.16	2741.29c	34.84
AG5055	9372a	5392c	42.47	1411.26b	15.06	7960.51a	84.94
AG8025	8589a	7083a	17.53	5578.11a	64.95	3010.66c	35.05
Alfa_9020C	8888a	5641b	36.53	2393.90b	26.93	6494.55a	73.07
BG7046	8601a	6041b	29.77	3480.27a	40.46	5120.93b	59.54
BM810	7686b	5102c	33.62	2517.54b	32.75	5168.47b	67.25
2B587	6766b	4480c	33.78	2194.54b	32.44	4571.26b	67.56
DKB455	7829b	6112b	21.94	4393.78a	56.12	3435.48c	43.88
Impacto	7836b	4672c	40.38	1507.47b	19.24	6328.07a	80.76
Omega	7305b	5905b	19.16	4505.70a	61.68	2799.06c	38.32
PRE_32D10	7330b	4986c	31.97	2642.72b	36.05	4687.09b	63.95
RK3014	8793a	4741c	46.09	688.07b	7.83	8105.08a	92.17
General Mean	8072	5554	30.89	3036.69	38.22	5035.20	61.78

¹ Means followed by the same letter in the same column do not differ among them by the Scott-Knott test (1974) at the level of 5% of probability.

² Percentage contribution of $m+a$ and d for the manifestation of the character obtained from the expressions $\left[\frac{(m+a)}{\bar{F}_1} \right] \times 100$ and $\left[\frac{(d)}{\bar{F}_1} \right] \times 100$.

Source: Authors (2019).

For the estimates of d for grain yield, the highest values were observed in the hybrids AG5055, ALFA_9020C, IMPACTO, and RK3014. Considering the loci have an equal contribution, the d estimate provided information about the frequency of heterozygous loci. In other words, the higher the d estimate, the higher the number of loci in heterozygosis will be so will be the variation. According to Abreu, Ramalho and Santos (2002), this association between

the estimate of d and heterosis was positive and high ($r = 0.95$), indicating an association between the estimate of d and genetic variance.

For grain yield there was higher contribution, on an average, for d estimate, and it contributed with 61.78% for the grain yield performance of the hybrids, while $m+a$ contributed with 38.22% (Table 7). Earlier, Ramalho et al. (2012), showed similar results when making a compilation of works from the year 1987-2001.

Once the values of d are associated with heterozygosis, that is worth highlighting since the contribution of heterosis has been decreasing through the years, while the increase in the productivity *per se* of the lines (Troyer; Wellin, 2009). From 1905 to 2005, the lines' productivity increased from 1.9 to 3.5 times faster than the contribution of heterosis. Likewise, the contribution of the lines in the production of commercial hybrids increased (Ramalho et al., 2012). Despite the importance of the heterosis in the hybrids mean, the additive effects, like higher values of $m+a$ estimates, should be considered in the choice of the base population for the plant breeding program.

When considering the contribution of the estimates for plant height, it is observed on an average, as a higher contribution of $m+a$ (80.43%) in relation to d (19.57%) (Table 8). Similar results were reported by several authors demonstrating that this characteristic has a greater influence of additive effects than others (Oliveira et al., 2020; Somera et al., 2018; Viana et al., 2009).

On the other hand, considering plant height traits, lower estimates of $m+a$ are desirable, since lower plants increase the plant populations per hectare without having problems with topping and/or lodging, which makes the

mechanical harvest difficult. Lower values of $m+a$ were observed for the hybrids AG5055 and ALFA_9020C, followed by the hybrids AG1051, AG8025, and DKB455, which also showed high values of $m+a$ for grain yield (Table 8). In the case of an estimate of d , higher values were observed for the hybrids AG5055 and ALFA_9020C.

The inbreeding depression (ID%) for the grain yield trait was, on an average, 30.89%, and it ranged from 17.42 to 46.09% for the hybrids AG1051 and RK3014, respectively (Table 7). Other results corroborate with the values obtained in this work (Oliveira et al., 2020; Somera et al., 2018).

The hybrids showed a lower percentage of inbreeding depression for characteristic plant height, on an average of 9.79%, varying from 0.77 to 21.27% (Table 8). Similar values to these were observed by Senhorinho et al. (2015); and Tolentino et al. (2017).

The variation in inbreeding depression is related to different levels of dominance, allele frequency, the relationship between genotypes, and the characteristics under study (Hallauer et al., 2010). The present study showed that grain yield trait had higher inbreeding depression, emphasizing the higher level of dominance related to this trait.

Table 8: Mean of F1 and F2 generations, estimates of $m+a$, d , inbreeding depression for plants height trait (PH), considering the four evaluation environments for the twelve evaluated hybrids.

Hybrids	PH F1	PH F2	ID(%)	($m+a$) PH	% ²	(d) PH	% ²
AG1051	2.27a ¹	1.96B	13.76	1.64b	72.35	0.63b	27.65
AG5055	2.31a	1.82C	21.27	1.33c	57.46	0.98a	42.54
AG8025	2.21a	1.89C	14.27	1.58b	71.47	0.63b	28.53
Alfa_9020C	2.36a	1.91C	19.05	1.46c	61.94	0.90a	38.06
BG7046	2.26a	2.02B	10.74	1.78a	78.52	0.49b	21.48
BM810	2.02b	1.89C	6.49	1.76a	87.07	0.26c	12.93
2B587	1.83c	1.81C	0.77	1.80a	98.52	0.03c	1.48
DKB455	2.10b	1.86C	11.57	1.61b	76.82	0.49b	23.18
Impacto	2.06b	1.97B	4.28	1.88a	91.49	0.18c	8.51
Omega	2.01b	1.94B	3.78	1.86a	92.54	0.15c	7.46
PRE_32D10	2.08b	2.00B	3.99	1.91a	92.01	0.17c	7.99
RK3014	2.27a	2.10A	7.52	1.93a	84.96	0.34c	15.04
General Mean	2.15	1.93	9.79	1.71	80.43	0.44	19.57

¹ Means followed by the same letter in the same column do not differ among them by the Scott-Knott test (1974) at the level of 5% of probability.

² Percentage contribution of $m+a$ and d for the manifestation of the character obtained by the expressions $\left[(m+a) \div \bar{F}_1 \right] \times 100$ and $\left[(d) \div \bar{F}_1 \right] \times 100$.

Source: Authors (2019).

For the grain yield, the dominance effects have a greater contribution; thus the selection based only in the general hybrids means is not a good criterion for choosing the populations for line inbred line extraction. Likewise, the estimate of $m+a$ has to be considered once it will provide information about the mean of F_{∞} generation. On the other hand, the d estimate provides the number of loci in heterozygosis and the genetic variation. Thus, considering the estimates of $m+a$, the hybrids AG1051, AG8025, BG7046, DKB455, and OMEGA were the most promising ones for the inbred lines extraction for the characteristic in study due to the fact of showing higher $m+a$ estimates. Highlighting the hybrid AG8025 and BG7046, which presented high values of $m+a$ and high grain yield means, once the ideal is to associate both. In relation to the plant height trait, there was a higher contribution of additive effects. Aiming the development of lines that will provide lower height and high grain yielding hybrids, the superiority of the hybrid AG8025 must be reinforced, being the most promising hybrid for inbred lines as it showed higher values of $m+a$ estimates and grain yield, besides showing the third lower value of $m+a$ for plant height.

CONCLUSIONS

For the grain yield trait, there was a greater contribution of dominance effects in the hybrids mean, whereas, on the other hand, there was a greater contribution of additive effects for plant height. Also, there was greater inbreeding depression for grain yield than for plant height. The hybrids AG1051, AG8025, BG7046, DKB455, and OMEGA were the most promising ones for the inbred line extraction. Highlighting the hybrids AG8025 and BG7046, which also had high grain yield means.

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