Genetic parameter estimates and identification of superior white maize populations

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ABSTRACT. In Brazil, there is a shortage of white maize cultivars and genetic studies for special maize breeding programs. This study aimed to identify populations and promising hybrid white maize for main agronomic traits and grits processing and to estimate the genetic parameters of parents and heterosis. In the 2012/13 growing season, fifteen hybrids were obtained by complete diallel crosses, and six parental and commercial check varieties were evaluated for: female flowering (FF), ear height (EH), grain yield (GY), ear length (EL), volumetric mass (VM) and grits processing (GP) in two locations in São Paulo State, Campinas and Mococa, using a randomized block design. Analyses of variance were carried out, and diallel crosses were performed using the Gardner and Eberhart model. The populations P3 and P6 stood out because of the estimated effects of the parents and of heterosis; the studied characters are promising for obtaining new lines and forming composites. For GP, the treatments showed no differences, implying the need to introduce new sources of germplasm.

Keywords: Zea mays L., complete diallel, Gardner and Eberhart, grits production.

Estimativas de parâmetros genéticos e identificação de populações superiores de milho branco

RESUMO. No Brasil, há uma escassez de cultivares e de estudos genéticos para programas de melhoramento de milho. Este trabalho teve por objetivos identificar híbridos promissores de milho branco quanto à produtividade e rendimento de canjica e estimar parâmetros genéticos dos genitores e a heterose. Na safra de 2012/13, quinze híbridos obtidos por dialelo completo, seis genitores e uma testemunha comercial foram avaliados quanto aos caracteres: florescimento feminino (FF), altura de espiga (EH), massa de grãos (GY), comprimento de espiga (EL), massa volumétrica (VM) e rendimento de canjica (GP), em dois locais do estado de São Paulo sob delineamento de blocos ao acaso. Efetuaram-se análises de variância e dialélica pelo modelo de Gardner e Eberhart. As populações P3 e P6 destacaram-se por reunir estimativas de efeitos de genitores e de heterose de variedades promissoras para os caracteres estudados, podendo ser utilizados para obtenção de linhagens e formação de compostos. Detectaram-se híbridos promissores para o mercado de milho branco. Para GP os tratamentos não apresentaram diferenças, inferindo a necessidade da introdução de novas fontes de germoplasma.

Palavras-chave: Zea mays L., dialelo completo, Gardner e Eberhart, rendimento de canjica.

Introduction

Maize is a versatile crop with wide genetic variability and the ability to successfully develop in tropical, subtropical and temperate regions under different agro-climatic conditions. The cultivated area of maize and its production have an upward growing trend globally, especially with the introduction of hybrids due to high yield potential (Izhar & Chakraborty, 2013).

In Brazil, there is increasing production of specialty corns, such as popcorn, mini-corn, sweet corn and white corn for grits because it adds value to the product, generates higher profits for the farmer and represents specific market niches. In particular, a 60 kg bag of white maize for grits can reach twice the commercial value of a 60 kg bag of maize, which provides a considerable economic advantage to the producer.

The so-called “canjica”, a dessert appreciated in many regions of Brazil, originated in São Paulo in 1710 due to the restriction of the use of salt, which was monopolized by some of the king’s agents at that time. This restriction persuaded people to prepare this nutritious and sweet dish, which was adapted from indigenous food (Ferreira, 2002).
The availability of registered cultivars for the production of corn grits is very scarce, highlighting the need to develop new hybrids for this sector. In 2014, among 467 cultivars of grain corn available for commercialization, only five white maize cultivars were recommended for production (Bignotto et al., 2015).

Specialty corn breeding programs aim to develop more productive and adapted cultivars to supply the market demand. However, these programs will only be successful if they are effective in the selection of populations to be used for crossings that result in hybrids that possess traits of interest (Rodrigues, Pinho, Albuquerque, Faria Filho, & Goulart, 2009).

The use of diallel crosses is one of the methods available in plant breeding that allows the selection of parents to improve the performance of the progeny (Ramalho, Abreu, & Santos, 2001). Moreover, diallel crosses are used to analyze the genetic design, providing estimates of useful parameters that allow for the selection of the best genitors to obtain hybrids, and to understand the genetic effects of a trait (Gonçalves et al., 2014; Melani & Carena 2005; Cruz, Regazzi, & Carneiro, 2004). This method has been used to evaluate several agronomic traits in hybrids obtained from common maize populations (Tonette & Carena, 2014; Bernini, & Paterniani, 2012; Doná, Paterniani, Gallo, & Duarte, 2011) and in specialty corns, such as popcorn (Cabral et al., 2015; Solalinde et al., 2014) and sweet corn (Assunção et al., 2010; Rodrigues et al., 2009), allowing the identification of the best parents and their hybrid combinations for the evaluated traits.

Cruz et al. (2004) reported several types of diallel analysis, such as balanced, partial, circulating, incomplete and unbalanced, highlighting that the most applicable type was the balanced diallel proposed by Hayman (1954), Griffing (1956) and Gardner and Eberhart (1966). The last method provides detailed information on the potential of populations per se as well as the heterosis manifested in the hybrids. This method presents the advantage of evaluating the specific effects of varieties and varietal heterosis separate from the effects of their general combining ability (Gardner & Eberhart, 1966).

In diallel crosses that are used to evaluate populations in Hardy-Weinberg equilibrium, the effects $v_i$ can be translated as the performance of a given population “i” compared to the average of other populations, and the $h_i$ effect is the contribution, in terms of heterosis, from crosses where “i” variety is involved. According to Bernini and Paterniani (2012), this method is superior to the others when open pollinated varieties are crossed, since it provides useful genetic information to the breeder from the mean values of the population and not from the variances.

This study aimed to identify populations and promising hybrids of white maize for main agronomic traits and grits processing and to estimate genetic parameters of the parents, as well as the heterosis and its components.

**Material and methods**

In the growing season 2011/12, six populations of white maize were crossed under a full diallel design (Table 1), thereby obtaining 15 intervarietal hybrids. The parent populations and their hybrids were evaluated in the growing season 2012/2013 at the Central Experimental Center of the Agronomic Institute (IAC) in Campinas, São Paulo State (latitude, 22º 54’S; longitude, 47º 3’W; altitude, 600 m) and at the Regional Pole of Paulista Northeast (APTA) in Mococa, São Paulo State (latitude, 21º 28’S; longitude, 47º 01’W; altitude, 665 m). The experiment was installed under a randomized block design with four replicates for agronomic traits and two replicates for grits processing. The plot consisted of four rows 5 m long, spaced apart 0.85 m between rows and 0.2 m between plants, with two plants per hole, totaling 25 plants per row after thinning. To collect agronomic data, the two center rows were used, and, in the two outside rows, industrial characters, such as grits processing yield, were measured. In both trial locations, fertilization was performed using 350 kg ha$^{-1}$ of 8-28-16 (NPK), and the topdressing fertilization was performed using 150 kg ha$^{-1}$ of N supplied as urea.

**Table 1. Description of the white maize genotypes used for obtaining the intervarietal hybrids for this study.**

| Population (origin) | Company/Institution | Cultivar original type | Grain type |
|--------------------|---------------------|------------------------|-----------|
| P1 (F, IPR 127)    | IAPAR               | Single-cross hybrid    | Flint     |
| P2 (IAC Nelore)    | IAC                 | Intervarietal hybrid   | Flint     |
| P3 (F, Murano)     | Syngenta México     | Three-way cross hybrid | Semi Flint|
| P4 (Al Bianco)     | CATI-DSMM           | Variety                | Semi Flint|
| P5 (RS 21)         | FAPEAGRO            | Variety                | Semi Flint|
| P6 (F, IPR 119)    | IAPAR               | Double-cross hybrid    | Semi Flint|
The traits evaluated were as follows: female flowering (FF), measured in days after sowing when 50% of the plants in the plot presented the stigma-style off the ear; ear height (EH), sampled at 5 competitive plants per plot, taken from ground level to the insertion of the main ear, and expressed in centimeters (cm); grain yield (GY), total grains resulting from the mechanical threshing of ears of useful lines in the plot (corrected to 14% moisture and ideal stand), expressed in kg ha\(^{-1}\); ear length (EL), obtained in 5 husked ears randomly sampled within each parcel and expressed in centimeters; volumetric mass (VM), measured in a volumetric mass determiner indicating the density of whole grains expressed in kilograms per 100 liters.

The collection of grits processing (GP) data was carried out in grams and then converted into percentage obtained in percentage (%) from 10 kg samples from each plot for two replications. For grits processing (GP), each sample was processed in a gritting processor for about 2 minutes and 45 seconds depending on the humidity of the sample. After chiseling, the resulting material was separated into bran and grits by the shaking motion of the gritting processor, using a Tyler5 sieve available on the machine. The sample was weighed on an electronic scale. GP assessment was conducted at the Experimental Farm of Iguatemi of the State University of Maringa (UEM) in Maringa, Paraná State, Brazil.

Grits processing data were transformed to percentage according to the formula below:

\[
GP = \frac{mm}{ma} \times 100%,
\]

where GP is grits processing; mm: degerminated maize mass obtained by the gritting processor, expressed in grams (g); ma: total sample mass, expressed in grams (g).

Individual and joint analyses of variance were carried out, assuming the model as fixed. Means were compared using the Scott-Knott test (1974) at 5% probability.

The complete diallel analysis was conducted according to the model proposed by Gardner and Eberhart (1966):

\[
Y_{ij} = \mu + (v_i + v_j)/2 + 0(h_i + h_j + s_{ij}) + \bar{e}_{ij},
\]

where: \(Y_{ij}\): average value observed in a parent (i = j) or in a hybrid combination (i); \(\mu\): mean of varieties; \(v_i\): the effect of the i variety; \(v_j\): the effect of the j variety; \(\theta=0\), when i=j, and \(\theta=1\) when i \(\neq\) j; \(h_i\): average heterosis effect; \(h_j\): the effect of the variety i heterosis; \(h_{ij}\): the effect of the variety j heterosis; \(s_{ij}\): the effect of specific heterosis; and \(\bar{e}_{ij}\): average experimental error.

The experimental design allowed to detect significant differences with the F test \(p < 0.01\) for treatments and genotypes for most of the evaluated traits, indicating differences in the performance of the parent, hybrid and commercial check varieties. However, for volumetric mass (VM) and grits processing (GP), no significant differences were observed (Table 2). The effects of T x L and G x L interactions were significant only for GY and VM, so their means are presented by location (Table 2). For all other traits, significance was not observed; therefore, the discussion of the results is based on the mean of the experiments in both locations. Significance in these interactions implies that genotypes with good results at a given location may not have the same satisfactory results in a different location (Cruz & Regazzi, 1997).

The coefficients of variation obtained in this study ranged from low to medium, indicating that the experimental design was satisfactory in controlling environmental variation and allowed reliable data to be obtained (Fritsche-Neto, Vieira, Scapim, Miranda, & Rezende, 2012; Gomes, 2000).

The means for FF, EH, EL, VM and GP of the genotypes at two locations are presented in Table 3, along with their groupings by the Scott-Knott test \((p < 0.05)\).

For FF, the formation of two groups (b and c) was observed between the hybrids, with means ranging from 55 to 58 days. Eight hybrids stood out as earlier in female flowering (group b) with no statistical differences from the check variety ‘Al Bianco’. For the EH trait, the means of the hybrids ranged from 135.79 cm (P1xP3) to 180.27 cm (P4xP5), marking hybrids P1xP3 (135.79 cm) and P2xP3 (137.55 cm) due to the lower means presented. For GY, means were grouped into four distinct groups only at Mococa (a, b, c, and d). The most promising hybrids showed GY percentages ranging from 130% (P3xP6) to 109.4% (P2xP3) compared to the check varieties. For VM, the formation of two distinct groups was observed only at Campinas. Eleven hybrids significantly differed from the check variety, with means that ranged from 83.01 to 81.47%.
Table 2. Mean squares (MS) in the joint analysis of variance for female flowering (FF), ear height (EH), grain yield (GY), ear length (EL), volumetric mass (VM) and grits processing (GP) of hybrids and parental populations of white maize in Campinas and Mococa, São Paulo State. Season 2012/13.

| Source of variation | df | FF (days) | EH (cm) | GY (kg ha\(^{-1}\)) | EL (cm) | VM (kg 100 L\(^{-1}\)) | GP (%) |
|---------------------|----|-----------|---------|----------------------|--------|------------------------|-------|
| Blocks              | 6  | 0.88      | 1280.07 | 4130.91              | 0.34   | 1.19                   | 4.8   |
| Treatments (T)      | 21 | 13.25 **  | 1771.41 | 5220.17              | 4.85 **| 2.72                   | 6.22  |
| Genotypes (G)       | 20 | 13.9 **   | 1859.83 | 5455.78              | 4.62 **| 2.69                   | 6.48  |
| Groups (Gr)         | 1  | 0.09      | 2.95    | 508.00               | 9.39   | 3.26 **                | 1.12 **|
| Environments (E)    | 1  | 2212.36 **| 23360.30| 10788.48             | 10.86 **| 571.6 **               | 155.69 *|
| T x E               | 21 | 1.95      | 172.31  | 1742.38              | 1.23   | 4.51 **                | 4.46  |
| G x E               | 20 | 2.03      | 172.27  | 1742.38              | 1.23   | 4.51 **                | 4.46  |
| Gr x E              | 1  | 0.24      | 173.19  | 1254.91              | 0.04   | 0.04                   | 0.09  |
| Error               | 126| 1.88      | 169.95  | 693.34               | 1.21   | 1.40                   | 5.20  |
| Total               | 175|           |         |                      |        |                        |       |

General means: 57 147.32 7474 17.38 79.7 79.14 79.14
Population means: 58 147.80 7336 17.20 79.57 78.98 79.94
Hybrids means: 57 149.60 7806 17.40 79.65 78.98 79.94

CV(%) 2.39 8.85 11.14 6.32 1.48 2.88

*MS’s multiplied by 10\(^{-3}\); *, ** significant at 5% and 1% probability.

Table 3. Means for female flowering (FF), ear height (EH), grain yield (GY), ear length (EL), volumetric mass (VM) and grits processing (GP) of the hybrids, parental and check variety of the white maize populations in Campinas and Mococa, São Paulo State. Season 2012/13.

| Hybrids | FF (days) | EH (cm) | GY (kg ha\(^{-1}\)) | EL (cm) | VM (kg 100 L\(^{-1}\)) | GP (%) |
|---------|-----------|---------|----------------------|--------|------------------------|-------|
| P1xP2   | 56 c      | 143.41 b | 6893 a               | 7259 c  | 17.03 b                | 81.6 a |
| P1xP3   | 55 c      | 135.79 b | 7538 a               | 9173 a  | 16.69 b                | 83.01 a|
| P1xP4   | 57 c      | 145.54 b | 6732 a               | 8272 b  | 17.76 a                | 81.60 a|
| P1xP5   | 57 c      | 158.54 a | 7785 a               | 7542 c  | 16.39 b                | 82.31 a|
| P1xP6   | 58 b      | 138.61 b | 7597 a               | 7758 a  | 17.45 a                | 82.28 a|
| P2xP3   | 56 c      | 137.55 b | 7319 a               | 8294 b  | 17.45 a                | 82.28 a|
| P2xP4   | 57 c      | 148.93 b | 7250 a               | 7774 c  | 18.16 a                | 82.40 a|
| P2xP5   | 59 b      | 168.08 a | 7516 a               | 6088 d  | 19.92 a                | 81.60 a|
| P2xP6   | 58 b      | 146.25 b | 7366 a               | 8176 b  | 17.43 a                | 80.11 b|
| P3xP4   | 56 c      | 138.89 b | 7674 a               | 9014 a  | 17.35 a                | 81.81 a|
| P3xP5   | 58 b      | 150.31 b | 7176 a               | 7316 c  | 16.73 a                | 81.37 a|
| P3xP6   | 56 c      | 139.76 b | 8437 a               | 9860 a  | 16.37 a                | 80.67 a|
| P4xP5   | 57 c      | 180.24 a | 7375 a               | 7613 c  | 17.30 a                | 81.47 a|
| P4xP6   | 58 b      | 152.35 b | 7919 a               | 7970 c  | 17.37 a                | 80.89 b|
| P5xP6   | 58 b      | 161.40 a | 7519 a               | 7345 c  | 17.76 a                | 79.63 a|

Populations
P1: 57 c 127.67 c 5900 b 7237 c 16.25 b 82.56 a 78.47 a 79.16 a
P2: 57 c 148.51 b 6625 b 7156 c 17.51 a 81.24 a 75.94 a 79.28 a
P3: 55 c 113.56 c 5810 b 7733 c 15.8 b 82.90 a 78.12 a 81.29 a
P4: 58 b 150.64 b 7817 a 6545 d 18.38 a 82.12 a 77.86 a 77.4 a
P5: 61 a 173.16 a 5906 c 7316 c 16.73 a 80.36 a 78.90 a 78.88 a
P6: 58 b 137.10 b 6382 b 7497 c 18.04 a 79.2 b 78.96 a 81.05 a

Check Variety
Al Bianco 57 c 146.73 b 7859 a 7580 c 18.44 a 82.2 78.45 79.66 a

General Mean 57 147.32 7018 17.19 81.5 77.9 79.14

CV(%) 2.39 8.85 11.07 11.19 1.48 1.08 1.82 2.88

Although not statistically different from some hybrids and parents, the hybrid P3xP6 stood out for the best performance of the traits: FF, EH, GY, and VM. However, for grits processing (GP), there was no separation of genotypes in the groups, precluding the identification of the most promising parent or hybrid. GP means presented in this paper do not differ with those presented by Castro, Naves, Oliveira, and Froes (2009), who obtained GP values ranging from 70 to 80%, and with those presented by Mestres, Matencio, and Dramé (2003), who observed values ranging from 78-80% for GP.

In the joint diallel analysis (Table 4), significant differences in the effects of treatments (T) and populations (P) were observed, indicating that there is variability among treatments for FF, EH, GY, VM, and EL traits. Heterosis (h) was significant only for GY and EL, implying that there is heterosis manifestation in the hybrids for these two traits.

The significance of the mean squares of heterosis effects on average heterosis (\(\bar{h}\)) for FF, EH, and GY indicates that there is enough genetic diversity among the parents, resulting in a favorable situation for the application of a breeding program in order to...
obtain hybrids and to detect heterogeneity in the values of gene frequencies (Kvitschal et al., 2004).

The GY trait showed significance in the heterosis parental effects ($h_i$), which reveals the existence of variation in the contribution of each parent to the performance of the hybrid, indicating dispersion of allele frequencies in the population (Oliveira et al., 2004). Similar results for GY were found by other authors and enabled the selection of the best parents and their respective hybrids (Tonette & Carena, 2014; Bernini & Paterniani, 2012; Doná et al., 2011; Silva & Miranda Filho, 2003; Scapim et al., 2002).

The specific heterosis effects ($s_{ij}$) showed significance only for the EL trait, indicating that there are epistasis and dominance effects in trait expression. According to Vencovsky and Barriga (1992), this significance shows that there is specific complementation between pairs of parents in loci with allelic dominance effects, contributing to the better performance of certain hybrid combinations where one can supplement for any deficiencies found in another.

For the other traits, no significant differences were observed for $s_{ij}$. This absence of significance suggests the lack of differences among the degrees of complementation with each other, in relation to the frequency of alleles at loci with some dominance (Kvitschal et al., 2004) and predominating additive effects.

In relation to the decomposition in the sum of squares of heterosis in the analysis of variance, it was observed that for GY, the effects of $h_i$, $h_p$ and $s_{ij}$ corresponded to 73, 17 and 9% of the total of their effects, respectively. A greater contribution from average heterosis in relation to the other effects was noted and provided evidence of the significant superiority of hybrids compared with the average of the parents.

**Table 4.** Mean squares (MS) in the diallel analysis for female flowering (FF), ear height (EH), grain yield (GY), ear length (EL), volumetric mass (VM) and grits processing (GP) of hybrids and parental populations of white maize in Campinas and Mococa, São Paulo State. Season 2012/13.

| Source of variation | df | FF (days) | EH (cm) | GY (kg ha$^{-1}$) | EL (cm) | VM (kg L$^{-1}$) | GP (%) |
|---------------------|----|-----------|---------|-------------------|--------|-----------------|--------|
| Treatments (T)      | 20 | 13.90 **  | 1859.98 ** | 5455.77 **       | 4.02 ** | 2.69 *          | 6.48   |
| Populations (P)     | 5  | 49.46 **  | 6949.54 ** | 8211.36 **       | 11.7 ** | 5.79 **         | 8.24   |
| Heterosis ($h_i$)   | 15 | 2.69 **   | 281.66   | 4537.24 **       | 2.26 *  | 1.66 **         | 5.89   |
| Mean heterosis ($h_p$) | 1  | 9.13 *    | 2048.33 ** | 4976.48 **       | 0.27   | 0.17            | 7.14   |
| Parental heterosis ($h_p$) | 5  | 1.08      | 95.41    | 2324.36 **       | 1.70   | 1.44            | 6.41   |
| Specific heterosis ($s_{ij}$) | 9  | 2.87      | 184.37   | 740.04           | 2.78 *  | 1.95            | 5.46   |
| Environments (E)    | 1  | 2258.70 ** | 23143.8 ** | 11887.92 **      | 10.2 ** | 543.74 **       | 150.10 ** |
| $T \times E$        | 20 | 2.27      | 172.26   | 1742.39 **       | 1.23   | 4.51 **         | 4.46   |
| $x$ $E$             | 5  | 1.87      | 159.08   | 4957.35 **       | 1.41   | 13.29 **        | 2.54   |
| $h \times E$        | 15 | 2.40      | 176.66   | 670.73           | 1.18   | 1.58            | 5.1    |
| $s_{ij}$ $E$        | 1  | 4.23      | 296.72   | 1.63             | 1.15   | 0.91            | 14.81  |
| Combined error      | 120| 1.94      | 177.03   | 704.97           | 1.23   | 1.39            | 5.28   |
| Mean                | 57 | 147.34    | 7461.98  | 17.30            | 79.67  | 79.12           |
| CV (%)              | 2.43 | 9.03   | 11.25 | 6.40 | 1.48 | 2.90 |

* MS’s multiplied by 10$^{-3}$. ** significant at 5% and 1% probability; $b$: Residual degrees of freedom = 42.
The parental P2 was the only one to show positive \( \hat{p}_i \) estimate results for GY in both locations, Campinas (285.21 kg ha\(^{-1}\)) and Mococa (293.88 kg ha\(^{-1}\)), showing its potential for recurrent selection programs and inbred lines extraction. Conrado et al. (2014) evaluated 28 hybrids of white maize and observed results that agree with the use of P2 (IAC Nellore) for breeding programs.

The parents P3 and P6, with its promising \( \hat{p}_i \) estimates for FF, EH, GY, EL, and VM, can be subjected to different breeding methods, such as intrapopulation recurrent selection, inbred lines obtainment and reciprocal recurrent selection, in maize breeding programs.

Estimates of parental heterosis (\( h_i \)) showed low values for the traits FF and EL in all parental populations (Table 6). Garbuglio and Araújo (2006), evaluating intervarietal hybrids, found estimates with higher values for FF, ranging from -0.7 to 0.6 days. According to Scapim et al. (2006), when there is a low level of heterosis, the parental selection used to make the hybrid should be carried out based on the parental means.

For EH, values ranged from -4.28 cm to 2.71 cm, and P2 parental (-4.28 cm) stood out as having a more negative estimate, indicating that their participation in crosses is promising for reducing ear height. Assunção et al. (2010), evaluating sweet corn cultivars, found \( h_i \) estimates of AE ranging from -1.889 to 1.556 days, which are lower values than those found in this study.

The parents P3, P6 and P1 stood out with promising \( h_i \) effects for GY, highlighting the P3 population estimate of 360.46 kg ha\(^{-1}\), characterizing it as the most heterotic within the parental group (Table 6). These values demonstrated that these parents are promising in crosses for hybrids by raising the heterosis for GY. Silva, Amaral Jr, Gonçalves, Freitas Jr, and Ribeiro (2011) evaluated ten popcorn lines and obtained GY estimates that ranged from -492.14 to 525.37 kg ha\(^{-1}\). Doná et al. (2011) observed high \( h_i \) estimates for GY while evaluating maize F\(_2\) population hybrids in Campinas (1,079 kg ha\(^{-1}\)) and Mococa (429 kg ha\(^{-1}\)). For VM and GP traits, \( h_i \) estimates were not presented because there was no significance in the diallel analysis.

### Table 5.

| Populations | FF (days) | EH (cm) | GY (kg ha\(^{-1}\)) | EL (cm) | VM (kg 100 L\(^{-1}\)) |
|-------------|-----------|---------|---------------------|---------|------------------------|
|            | Average Campinas | | Mococa | Avg. Campinas | Mococa |
| P1          | -0.8     | -14.1  | 375.18              | -1.02   | 1.14                   | 0.42     |
| P2          | -0.3     | 6.74   | 285.21              | 293.88  | 0.23                   | -0.2     | 2.09     |
| P3          | -2.8     | -28.2  | 529.61              | 870.73  | -1.46                  | 1.52     | 0.08     |
| P4          | -0.3     | 8.86   | 1476.81             | -317.23 | 1.11                   | 0.74     | -0.18    |
| P5          | 3.25     | 31.39  | -834.14             | -1857.6 | 0.35                   | -1       | 0.85     |
| P6          | 0.75     | -4.67  | 42.13               | 635.04  | 0.76                   | -2.2     | 0.91     |

As emphasized by Jesus et al. (2008), one of the plant breeding objectives is to find hybrid combinations with differing parental populations and good genetic potential. Thus, if the objective of the breeding program is to obtain hybrids with high grain yields associated with smaller size and higher precocity, P6 parents have \( h_i \) effects that are more favorable for all studied traits. This fact was demonstrated by Cruz et al. (2004), who reported that crosses involving parental populations with higher \( h_i \) effects would result in hybrids that are more heterotic.

### Table 6.

| Populations | FF (days) | EH (cm) | GY (kg ha\(^{-1}\)) | EL (cm) | VM (kg 100 L\(^{-1}\)) |
|-------------|-----------|---------|---------------------|---------|------------------------|
|             | Average Campinas | | Mococa | Avg. Campinas | Mococa |
| P1          | -0.04    | 0.05    | 177.97              | -1.00   | 177.97                 | 0.42     |
| P2          | 0.20     | -4.28   | -659.87             | 0.23    | 0.20                   | -4.28    | 2.71     |
| P3          | 0.20     | 2.71    | 360.46              | -1.5    | 0.20                   | -0.14    | 1.11     |
| P4          | -0.41    | 1.97    | 71.35               | 0.35    | -0.41                  | 1.97     | 71.35    |
| P5          | -0.16    | -0.03   | 273.02              | 0.76    | -0.16                  | -0.03    | 273.02   |
| P6          | 0.45     | 4.29    | 270.98              | 0.35    | 0.45                   | 4.29     | 270.98   |
| SD (\( \hat{h}_i \)) | 0.70   | 6.65    | 419.81              | 0.55    | 0.70                   | 6.65     | 419.81   |
| Mean heterosis (\( \bar{h}_i \)) | -0.51 | 7.80   | 1204.91             | 0.08    | -0.51                  | 7.80     | 1204.91  |
| SD (\( \bar{h}_i \)) | 0.11 | 10.32  | 202.78              | 0.26    | 0.11                   | 10.32    | 202.78   |
According to the diallel analysis (Table 4), significance in specific heterosis effects ($\hat{s}_{ij}$) was observed only for the EL trait. The $\hat{s}_{ij}$ estimates for EL ranged from -0.55 to 0.93 cm (Table 6). The hybrid combination that showed promising estimates for this trait was P2xP5 (0.93 cm) and was evidence of good genic complementation of parental populations in loci with a dominance effect.

According to the Gardner and Eberhart (1966) model, the best hybrids will be those that have a wider range of beneficial effects for the desired trait. The hybrid P3xP6 stood out for FF, EL, GY and VM traits and by collecting the $\hat{p}_i$ and $\hat{h}_i$ effects of both parental populations in the expression of these traits.

Conclusion

Significant effects in heterosis average, parental heterosis and specific heterosis is evidence of the heterotic potential of the parent populations in study.

Parents P3 (F2 Murano) and P6 (F2 IPR 119) stood out for $\hat{p}_i$ effects for female flowering, ear length, grain yield and volumetric mass traits, and parents P2 (IAC Nellore) stood out for grain yield traits in both locations, showing its potential to be used per se and for obtaining new maize lines.

Parents P3 (F2 Murano), P6 (F2 IPR 119) and P1 (F2 IPR 127) appeared to be promising in hybrid combinations with high $\hat{h}_i$ effects for grain yield. These populations may be used for the synthesis of composite hybrids in breeding programs.

There was a predominance of additive effects in the expression of female flowering, ear height, grain yield and volumetric mass traits, while for the ear length trait, the dominance effects predominated.

For the grits processing trait, the genotypes showed no performance differences, implying the need to introduce new sources of germplasm that contribute to the diversity of this trait.

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