



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 milhos especiais. 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, 22° 54'S; longitude, 47° 3'W; altitude, 600 m) and at the Regional Pole of Paulista Northeast (APTA) in Mococa, São Paulo State (latitude, 21° 28'S; longitude, 47° 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 ₂ IPR 127)	IAPAR	Single-cross hybrid	Flint
P2 (IAC Nelore)	IAC	Intervarietal hybrid	Flint
P3 (F ₂ 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 ₂ 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 Maringá (UEM) in Maringá, 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):

$$Y_{ij} = \mu + (v_i + v_j)/2 + \theta(\bar{h} + h_i + h_j + s_{ij}) + \bar{e}_{ij},$$

where: Y_{ij} : average value observed in a parent ($i = j$) or in a hybrid combination (i); μ : 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 $i \neq j$; \bar{h} : average heterosis effect; h_i : the effect of the variety i heterosis; h_j : the effect of the variety j heterosis; s_{ij} : the effect of specific heterosis; and \bar{e}_{ij} : average experimental error.

The biometric analyses were performed using the software package Genes 2006 (Cruz, 2006).

Results and discussion

The joint analyses of variance detected 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	Mean Squares (MS)					
		FF (days)	EH (cm)	GY ^a (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	1719.17 **	1.18	4.29 **	4.25
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
Population means		58	147.80	7336	17.20	79.57	78.98
Hybrids means		57	149.60	7806	17.40	79.65	78.94
CV (%)		2.39	8.85	11.14	6.32	1.48	2.88

^a 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	EH	GY		EL	VM		GP
	(days)	(cm)	(kg ha ⁻¹)		(cm)	(kg 100 L ⁻¹)		(%)
	Average		Campinas	Mococa	Average	Campinas	Mococa	Average
P1xP2	56 c	143.41 b	6893 a	7259 c	17.03 b	81.6 a	77.91 a	79.96 a
P1xP3	55 c	135.79 b	7538 a	9173 a	16.69 b	83.01 a	77.32 a	76.73 a
P1xP4	57 c	143.54 b	7732 a	8272 b	17.76 a	81.60 a	77.73 a	78.80 a
P1xP5	57 c	158.54 a	7758 a	7542 c	16.39 b	82.31 a	78.13 a	79.63 a
P1xP6	58 b	138.61 b	7597 a	9588 a	17.61 a	81.56 a	77.00 a	79.39 a
P2xP3	56 c	137.55 b	7319 a	8294 b	17.45 a	82.28 a	78.04 a	78.74 a
P2xP4	57 c	148.93 b	7250 a	7774 c	18.16 a	82.40 a	78.29 a	79.99 a
P2xP5	59 b	168.08 a	7516 a	6088 d	19.92 a	81.60 a	76.88 a	76.56 a
P2xP6	58 b	146.25 b	7366 a	8176 b	17.43 a	80.11 b	76.86 a	80.25 a
P3xP4	56 c	138.89 b	7674 a	9014 a	17.35 a	81.81 a	76.40 a	77.69 a
P3xP5	58 b	150.31 b	7176 a	7316 c	16.73 b	81.37 a	78.24 a	78.94 a
P3xP6	56 c	139.76 b	8437 a	9860 a	16.37 b	80.67 b	78.02 a	79.85 a
P4xP5	58 b	180.24 a	7375 a	7613 c	17.30 a	81.47 a	78.73 a	78.76 a
P4xP6	58 b	152.35 b	7919 a	7970 c	17.37 a	80.89 b	78.25 a	79.91 a
P5xP6	58 b	161.40 a	7519 a	7345 c	17.76 a	79.63 b	79.27 a	78.85 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	5506 b	5004 e	17.62 a	80.36 b	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	7196	79.70	81.5	77.9	79.14
CV(%)	2.39	8.85	11.07	11.19	1.48	1.08	1.82	2.88

P1: F₂ IPR 127, P2: IAC Nelore, P3: F₂ Murano, P4: Al Bianco, P5: RS 21, P6: F₂ IPR 119. Means followed by the same letter do not differ by the Scott-Knott test (p < 0.05).

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 h_i 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 locos 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 \bar{h} , \hat{h}_i , 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.

For plant architecture traits such as plant height and ear height (Table 5), it is interesting to select genotypes that present negative estimates and contribute to the reduction of these traits (Solalinde et al., 2014). Thus, the parental P3 stood out with the lowest estimate of parental effect (\hat{p}_i) for FF, and the parents P1, P3 and P6 had the lowest estimates for EH. Studies presented by Dhasarathan, Babu, and Iyanar (2015), Bernini and Paterniani (2012), Doná et al. (2011), Garbuglio and Araújo (2006) and Gorgulho and Miranda Filho (2001) verified the significance of parental effects on EH, concluding that for the control of these traits, there is a predominance of the additive effects and only partial dominance effects.

For the traits GY, EL and VM, it is interesting that the parents show high and positive estimates. The parental P4 (1,476.81 kg ha⁻¹) and P2 (285.21 kg ha⁻¹) in Campinas and P3 (870.73 kg ha⁻¹), P6 (635.04 kg ha⁻¹) and P1 (375.18 kg ha⁻¹) in Mococa, stood out with high estimates for GY, showing their potential *per se* (Table 5). Promising \hat{p}_i estimates for GY were presented by Doná et al. (2011), who evaluated intervarietal hybrids of maize and saw yield amounts of 1,388 kg ha⁻¹ in the P3 genotype (DAS 2B710). Bernini and Paterniani (2012) observed yields of 901 kg ha⁻¹ in Pop. 15, which are superior values to those found in this work.

The EL estimates of the parental effects (\hat{p}_i) ranged from -1.46 to 1.11 cm, and the parents P4 (1.11 cm) and P6 (0.76 cm) stood out with the highest estimates. For VM, the parents with highest \hat{p}_i estimates in both locations were P1 and P3 (Table 5).

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	MS						
		FF (days)	EH (cm)	GY ^a (kg ha ⁻¹)	EL (cm)	VM (kg L ⁻¹)	GP ^b (%)	
Treatments (T)	20	13.90 **	1859.88 **	5455.77 **	4.62 **	2.69 *	6.48	
Populations (P)	5	49.46 **	6594.54 **	8211.36 **	11.7 **	5.79 **	8.24	
Heterosis (h)	15	2.69	281.66	4537.24 **	2.26 *	1.66	5.89	
Mean heterosis (\bar{h})	1	9.13 *	2088.53 **	49776.48 **	0.27	0.17	7.14	
Parental heterosis (h_i)	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 x E	20	2.27	172.26	1742.39 **	1.23	4.51 **	4.46	
P x E	5	1.87	159.08	4957.35 **	1.41	13.29 **	2.54	
h x E	15	2.40	176.66	670.73	1.18	1.58	5.1	
\bar{h} x E	1	4.23	296.72	1.63	1.15	0.91	14.81	
h_i x E	5	1.99	146.58	969.15	0.76	0.72	6.26	
s_{ij} x E	9	2.42	180.02	579.28	1.41	2.14	3.38	
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	

^a 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 \hat{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 \hat{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 \hat{h}_i estimates for GY while evaluating maize F₂ population hybrids in Campinas (1,079 kg ha⁻¹) and Mococa (429 kg ha⁻¹). For VM and GP traits, \hat{h}_i estimates were not presented because there was no significance in the diallel analysis.

Table 6. Estimates of the effects of parental heterosis (\hat{h}_i), average heterosis (\bar{h}) and estimates standard deviations (sd) for female flowering (FF), ear height (EH), grain yield (GY) and ear length (EL) of white maize parental in Campinas and Mococa, São Paulo State. Season 2012/13.

Populations	FF (days)	EH (cm)	GY (kg ha ⁻¹)	EL (cm)
P1	-0.04	0.05	177.97	-1.00
P2	0.20	-4.28	-659.87	0.23
P3	0.20	2.71	360.46	-1.5
P4	0.20	-0.14	-222.93	1.11
P5	-0.41	1.97	71.35	0.35
P6	-0.16	-0.03	273.02	0.76
sd (\hat{h}_i)	0.45	4.29	270.98	0.35
sd ($\hat{h}_i - \hat{h}_j$)	0.70	6.65	419.81	0.55
Mean heterosis (\bar{h})	-0.51	7.80	1204.91	0.08
sd (\bar{h})	0.11	10.32	202.78	0.26

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 \hat{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 \hat{h}_i effects would result in hybrids that are more heterotic.

Table 5. Estimates of the effects of parental populations (\hat{p}_i) and estimates standard deviations (sd) for female flowering (FF), ear height (EH), grain yield (GY), ear length (EL) and volumetric mass (VM) of white maize parental in Campinas and Mococa, São Paulo State. Season 2012/13.

Populations	FF	EH	GY		EL	VM	
	(days)	(cm)	(kg ha ⁻¹)		(cm)	(kg 100 L ⁻¹)	
	Average		Campinas	Mococa	Avg.	Campinas	Mococa
P1	-0.8	-14.1	-440.4	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
sd (\hat{p}_i)	0.63	6.07	366	399	0.5	0.4	0.64
sd ($\hat{p}_i - \hat{p}_j$)	0.98	9.4	567	618	0.78	0.63	0.99

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 locos 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 (F_2 Murano) and P6 (F_2 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 (F_2 Murano), P6 (F_2 IPR 119) and P1 (F_2 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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