

# Heterosis for ether extract production and its components in seed of *Cucurbita argyrosperma*

## Heterosis para producción de extracto etéreo y sus componentes en semilla de *Cucurbita argyrosperma*

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### ABSTRACT

Twenty-one genotypes (six parental lines and 15 direct crosses) of butternut squash (*Curcubita argyrosperma* subsp. *sororia*) were evaluated at the Experimental Center of the Universidad Nacional de Colombia in Candelaria (Valle del Cauca, Colombia) during the second semesters of 2012 (2012B) and the first semester of 2013 (2013A). Heterotic effects (average, variety, and specific) were determined for ether extract production per plant (EEPP) and the following components: percentage ether extract (EE) in seed, seed weight per fruit (SWF), 100-seed weight (100-SW), and number of fruits per plant (NFP). The methodology of Gardner and Eberhart (1966) was used in a randomized complete block experiment design with four replicates (five plants per replicate). Variety heterosis accounted for 48% of the variation of total heterosis for EEPP. Variety heterosis was better expressed in 2013 first semester, with significant differences for EEPP, SWF, and 100-SW; average heterosis was significant for EEPP and EE. In 2012 second semester, heterosis was significant for SWF, indicating genetic divergence between hybrids and parents. Introductions 256 and 132 expressed the greatest effects of variety heterosis for EEPP and superior segregants should be selected from these two parental lines. No significant differences were observed on specific heterosis; however, the best hybrid in terms of EEPP at 2013 first semester came from crosses 256×132 and 140×260.

**Key words:** heterosis, pumpkins, oilseeds, diallel analysis

### RESUMEN

En el Centro Experimental de la Universidad Nacional de Colombia (Candelaria, Valle del Cauca, Colombia), se evaluaron 21 genotipos de *Curcubita argyrosperma* subsp. *sororia* (6 padres y 15 cruzamientos directos) en semestres 2012B y 2013A, para estimar los efectos heteróticos promedio, varietal y específico para producción de extracto etéreo por planta (EEPP) y sus componentes: extracto etéreo en la semilla (EE), peso de semilla por fruto (PSPF), peso de 100 semillas (PUS) y número de frutos por planta (NFP). Se utilizó la metodología de Gardner y Eberhart (1966) y bloques completos al azar con cuatro repeticiones (cinco plantas por repetición). La heterosis varietal explicó el 48% de la variación de la heterosis total para el carácter EEPP y se expresó mejor en 2013A, con diferencias significativas ( $P \leq 0,05$ ) para EEPP, PSPF y PUS. La heterosis promedio fue significativa para EEPP y EE. En 2012B fue significativa ( $P \leq 0,05$ ) para PSPF, indicando que hay divergencia genética entre híbridos y padres. Las introducciones 256 y 132 expresaron los mayores efectos de heterosis varietal para EEPP. Se sugiere seleccionar segregantes superiores provenientes de estos dos padres. La heterosis específica no presentó diferencias significativas; sin embargo, los mejores híbridos para EEPP en 2013A provenían de los cruzamientos 256×132 y 140×260.

**Palabras clave:** heterosis, calabaza (*Cucurbita*), semillas oleaginosas, análisis diallelo.

## Introduction

The Cucurbitaceae family is composed of approximately 118 genera and 825 species. One of its most important genus is *Cucurbita*, which is composed of 20 to 27 species according to Esquinas and Gulick (1983), 15 species according to Lira (1995), and 12 to 13 species according to Nee (1990).

Five species of the genus *Cucurbita* were domesticated in the New World and have been grown for centuries (Merrick, 1990; Smartt and Simmonds, 1995; Valdés, 2014):

*C. argyrosperma* Huber, *C. ficifolia* Bouché, *C. maxima* Duchesne, *C. pepo* L., and *C. moschata* (Duchesne ex lam) Duchesne ex Poir.

Nee (1990) and Lira (1995) suggested that the species *C. argyrosperma* is constituted by two subspecies: *argyrosperma* and *sororia*. The subspecies *argyrosperma* is formed by four varieties: *argyrosperma*, *callicarpa*, *stenosperma*, and *palmieri*. The first three varieties include all cultivated types, while the fourth corresponds to related wild populations. The subspecies *sororia* L.H. Bailey comprises wild

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populations distributed extensively from Mexico to Nicaragua. Whitaker (1981) and Lira (1995) suggested that the subspecies *sororia* is the wild ancestor of the domesticated species based on both its reproductive compatibility and its morphological similarity. Its scarce diffusion worldwide is probably attributable to its poor pulp quality as compared to *C. moschata* or *C. pepo*. Different parts of the plant (flowers, young stems, tender or mature fruits) are consumed as vegetables (Lira, 1995), and its seeds are consumed whole, roasted, toasted, or ground, being the main ingredient in an array of sauces (Valdés *et al.*, 2010). Due to their high oil (39%) and protein (44%) contents, seeds are the most important product of the fruit (Ortiz *et al.*, 2009; Nawirska *et al.*, 2013; Valdés, 2014).

In Colombia, a native or *creole* butternut squash variety, *C. moschata*, produces, on average, 400 kg ha<sup>-1</sup> of seed, and an average yield of 200 L ha<sup>-1</sup> ether extract. This variety may be consumed as food or destined to medicinal and agroindustrial uses (Ortiz *et al.*, 2009). Its oil is characterized by a high unsaturated fatty acids content (55.28%), in particular linoleic acid (55.11%). Oilseed cake contains approximately 51.11% protein and 4604.66 kcal kg<sup>-1</sup> energy (Ortiz *et al.*, 2009).

In Greece, the oil obtained from *C. pepo* is well-known as an alternative source of biodiesel (Schinas *et al.*, 2009). The seed of this species has a high oil content and is rich in polyunsaturated fatty acids, such as linoleic (43-56%) and oleic (24-38%), beta and gamma tocopherols (vitamin E), and carotenoids such as luteolin and beta-carotene (López *et al.*, 2009).

The seed oil of *C. maxima* has antioxidant properties (Nawirska-Olszańska *et al.*, 2013) and it is well known for its multiple health benefits such as the prevention of prostate growth, reduction of hypertension, mitigation of hypercholesterolemia and arthritis, reduction of gastric levels, and prevention of cancer.

Most of the studies conducted on *Cucurbita* seed have focused on oil content, fatty acid profile and intrinsic seed properties. To date no studies have been reported on the heterosis for ether extract production in seeds of *Cucurbita argyrosperma* subsp. *sororia*.

This study aimed to evaluate the average, variety, and specific heterotic effects related to the character of ether extract production per plant and its components in *C. argyrosperma* subsp. *sororia*.

## Materials and methods

### Study area

The Fieldwork was carried out at the Experimental Centre of the Universidad Nacional de Colombia (UNAL, as its Spanish acronym), located in the municipality of Candalaria, Valle del Cauca, Colombia (2°6' N and 63°3' W) (Espitia *et al.*, 2006). The experimental Centre, located at 972 m above sea level, presents an average annual temperature of 26°C, average annual precipitation of 1100 mm, and 76% relative humidity. Based on rainfall and sunshine rates, the climate is classified as sub-humid (Valdés *et al.*, 2010). The macromolecular evaluation was carried out at the Seeds Laboratory of UNAL-Palmira Campus.

### Genetic material

Twenty-one genotypes of *C. argyrosperma* subsp. *sororia*, obtained from diallel crosses between six selected parental lines (introductions 256, 140, 260, and 132 from Central America and 107 and 68 from Mexico) and their corresponding 15 direct F1 crosses, were evaluated (Fig. 1, 2, 3, 4, 5, and 6). A randomized complete block design was used with four replicates and five plants per replicate, and the three central plants of each plot were evaluated. A planting distance of 3 m between and within the furrow was used. The diallel cross was evaluated in two consecutive semesters: 2012B and 2013A.

### Evaluated features

- Ether extract production per plant (EEPP): the number of fruits per plant (NFP) multiplied by seed weight per fruit (SWF) and percentage ether extract (EE) in seed, expressed in g.
- Ether extract (EE) in seed: ether extract content (%) in seed.
- Seed weight per fruit (SWF): average weight (g) of three fruits randomly taken from each genotype and conditioned at 12% moisture.
- 100-seed weight (100-SW): weight (g) of 100 seeds randomly taken from three fruits of each genotype and conditioned at 12% moisture.
- Number of fruits per plant (NFP): average number of fruits per plant based on three plants of each genotype.

### Heterosis analysis

The fixed model (selected parental lines) (Griffing, 1956) and method 2 (parental lines and direct hybrids) of the



FIGURE 1. Introduction 256 of *Cucurbita argyrosperma* subsp. *sororia*.



FIGURE 2. Introduction 140 of *Cucurbita argyrosperma* subsp. *sororia*.



FIGURE 3. Introduction 132 of *Cucurbita argyrosperma* subsp. *sororia*. A, whole fruit; B, fruit cut open at the equatorial diameter.



FIGURE 4. Introduction 260 of *Cucurbita argyrosperma* subsp. *sororia*. A, whole fruit; B, fruit cut open at the equatorial diameter.



FIGURE 5. Introduction 107 of *Cucurbita argyrosperma* subsp. *sororia*. A, whole fruit; B, fruit cut open at the equatorial diameter.



FIGURE 6. Introduction 68 of *Cucurbita argyrosperma* subsp. *sororia*. A, whole fruit; B, fruit cut open at the equatorial diameter.

methodology proposed by Gardner and Eberhart (1966) was used. The statistical genetic model is the following:

$$Y_{jj'} = \mu_v + \frac{1}{2} (V_j + V_{j'}) + \theta \hat{h}_{jj'}$$

Where:

$Y_{jj'}$ : expected average value of a parental variety ( $j = j'$ ) or hybrid ( $j \neq j'$ ). If  $j = j'$ , then  $\theta = 0$  and if  $j \neq j'$ , then  $\theta = 1$ .

$\mu_v$ : mean of  $n$  parental varieties.

$V_j$ : variety effect of the  $j$ -th parental variety.

$\hat{h}_{jj'}$ : effect of heterosis that results when variety  $j$  is crossed with variety  $j'$ .

Total heterosis ( $\hat{h}_{jj'}$ ) break down as follows:

$$\hat{h}_{jj'} = (h_j + h_{j'}) + S_{jj'}$$

Where:

$\hat{h}$ : mean heterosis of all hybrids.

$h_j$  and  $h_{j'}$ : variety heterosis produced by the  $j$ -th variety.

$S_{jj'}$ : specific heterosis for the cross between varieties  $j$  and  $j'$ ; this is a deviation from the expected mean based on the effects  $\hat{h} + h_{j'}$ .

The analysis of variance proposed by Gardner and Eberhart (1966) included the main sources of variation: replicates, genotypes (parental lines and hybrids), error, and total. The source of variation "genotypes" was broken down into effects of varieties ( $V_j$ ) (parental lines), and heterosis ( $h_{jj'}$ ). On the other hand, total heterosis effect was broken

down into average heterosis ( $\hat{h}$ ), variety heterosis ( $h_j$ ), and specific heterosis ( $S_{jj'}$ ).

- Average heterosis ( $\hat{h}$ ) is the difference between the average of all hybrids and the average of all parental lines.
- Variety heterosis ( $h_j$ ) is the difference between the heterosis given by parental lines or variety  $j$  in its corresponding hybrids and the average heterosis of all the parental lines.
- Specific heterosis ( $S_{jj'}$ ) between parental lines or varieties  $j$  and  $j'$  measures the deviation between the observed performance of a specific hybrid and its expected performance, based on variety effect ( $V_j$ ), average heterosis ( $\hat{h}$ ), and variety heterosis ( $h_j$ ) (Espitia *et al.*, 2006).

Software developed by SAS Institute Inc. (2000), SAS-9.1 (Windows version), and Microsoft Excel 2010 were used to process results.

## Results and discussion

### Analysis of averages

In both semesters, prevailing environmental conditions affected the performance of parental lines and hybrids. In semester 2012B, evaluated features presented higher averages due to the semester precipitation and temperature and how they influenced the phenotypic expression. In 2013A, the excess precipitation negatively affected the evaluated features.

Tab. 1 shows the parental lines and hybrids averages regarding EEPP and its components on *C. argyrosperma* subsp. *sororia*. The average of both parental lines and hybrids in 2012B was higher than that of 2013A to all the evaluated features, except to the character EE for which parental lines presented a lower average in 2012B.

For the feature EEPP, the average of hybrids was superior to that of parental lines in both semesters, indicating high genetic diversity. However, no hybrid exceeded the best parental line 107, which presented 293.8 g/plant in 2012B and 86.3 g/plant in 2013A. Only hybrid 256×107 yielded a similar value: 216.8 g/plant in 2012B and 125.1 g/plant in 2013A.

For the components of the feature EEPP (EE, SWF, 100-SW, and NFP), the performance of hybrids was similar to that of parental lines in both semesters evaluated, indicating low genetic diversity for these components.

Table 2 presents the mean squares of the analysis of variance for the character EEPP and its components in semesters 2012B and 2013A.

For the character EEPP, the average squares associated with varieties (six parental lines) and heterosis (15 hybrids) for semester 2012B were highly significant, confirming the existence of genetic diversity between parental lines and between hybrids for this feature. There were no significant differences in semester 2013A, possibly because its genetic expression was affected by unfavorable environmental conditions. These data agree with the environmental effects found in other experiments on the agroindustrial traits of *C. moschata* Duch. (Valdes *et al.*, 2010; Valdes *et al.*, 2013).

The average heterosis of the character EEPP and two of its components, EE and 100-SW, was significant in semester 2012B, indicating that genetic variation exists between parental lines to explore heterosis. For the remaining components (SWF, 100-SW, and NFP), average heterosis was non-significant, indicating absence of genetic diversity between parental lines to explore heterosis.

Variety heterosis was highly significant for the character EEPP and two of its components, SWF and 100-SW, only in semester 2012B, confirming the presence of genetic diversity between the parental lines and these features. Variety heterosis was non-significant for components EE and NFP in both semesters, showing little genetic divergence between parental lines.

Specific heterosis was non-significant to the character EEPP and its components in both semesters, indicating that parental lines did not present favorable gene complements in the different hybrids. Similar results were observed on the species *Cucurbita moschata* (Valdés *et al.*, 2014).

### Estimating heterosis effects on *C. argyrosperma* subsp. *sororia*

#### Effect of average heterosis

Table 3 shows the effect of average heterosis on the character EEPP and its components. Average heterosis was best expressed in 2012B, where there were significant differences for EEPP and the component EE. In 2013A, only the component SWF presented significant differences. The significance of these characters indicated that, overall, the parental lines used are suitable to explore the effect of heterosis on hybrids regarding the aforementioned features. Regarding the other characters (100-SW and NFP), the parental lines used are not suitable to tapping heterosis.

**TABLE 1.** Averages of parental lines and hybrids for the character of ether extract production per plant (EPPP) and different components in *Cucurbita argyrosperma* subsp. *sororia* for two semesters (2012B and 2013A).

Parental line	EPPP		EE		SWF		100-SW		NFP	
	2012B	2013A	2012B	2013A	2012B	2013A	2012B	2013A	2012B	2013A
256	62.6	25.9	40.00	43.21	16.30	11.87	7.62	6.33	9.17	4.83
140	52.4	85.0	37.17	36.84	41.23	30.18	15.86	13.83	3.17	4.00
260	37.5	43.5	30.96	36.12	6.58	8.62	2.55	3.45	19.50	11.00
107	293.8	86.3	36.92	47.05	61.05	21.10	12.17	6.30	13.00	6.25
68	80.8	57.8	36.67	33.58	57.25	39.48	19.77	16.89	3.75	3.13
132	40.1	34.0	34.15	34.60	55.57	54.15	21.91	22.12	2.42	2.13
Average of parental lines	94.5	55.4	35.98	38.57	39.66	27.57	13.31	11.49	8.50	5.22
Hybrids										
256X140	122.9	49.1	40.36	38.64	39.54	29.69	12.55	11.04	7.50	4.42
256X260	108.4	51.6	39.93	36.30	17.27	14.22	5.91	5.73	15.67	9.71
140X260	158.0	61.8	38.35	33.33	32.46	15.83	9.88	5.73	13.00	11.75
256X107	216.8	125.1	40.78	39.95	31.80	28.40	9.49	9.21	17.42	7.67
140X107	189.4	59.1	45.29	40.42	38.38	21.70	13.04	10.10	11.25	6.75
260X107	114.4	32.3	35.44	39.61	16.36	10.97	4.56	4.19	16.75	6.75
256X68	104.1	110.4	41.31	41.30	23.63	29.40	8.79	9.90	10.21	8.83
140X68	85.5	50.1	34.56	37.58	51.12	43.87	15.01	14.13	4.75	2.92
260X68	55.7	64.9	36.94	36.73	19.90	26.40	6.85	7.85	6.42	7.13
107X68	111.1	44.0	39.00	37.22	35.57	27.57	9.25	9.39	7.50	4.42
256X132	199.8	50.4	40.70	36.26	57.76	37.57	17.53	13.05	7.83	3.33
140X132	106.4	54.5	36.07	36.76	67.97	64.93	22.62	20.86	4.50	2.08
260X132	72.3	58.5	38.99	37.35	34.55	25.10	10.20	7.67	5.54	5.38
107X132	119.8	86.1	36.48	40.08	47.90	44.82	15.08	17.46	6.75	4.25
68X132	157.5	95.3	40.93	38.98	60.86	50.30	18.17	15.94	5.50	4.25
Average of hybrids	128.1	66.2	39.01	38.03	38.34	31.38	11.93	10.82	9.37	5.98
LSD (5%)	8.99	9.43	6.41	7.31	19.38	21.28	3.88	4.64	6.26	4.51

**TABLE 2.** Square means of variance analysis of ether extract production per plant (EPPP) and its components according to the methodology of Gardner and Eberhart (1966) in a diallel cross, evaluated in two semesters (2012B and 2013A) in *Cucurbita argyrosperma* subsp. *sororia*.

Source of variation	G.L.	EPPP		EE		SWF		100-SW		NFP	
		2012B	2013A	2012B	2013A	2012B	2013A	2012B	2013A	2012B	2013A
Replicates	3	22.59 ns	118.25 ns	4.63 ns	37.92 ns	3.17 ns	527.93 ns	9.05 ns	14.795 ns	52.40 ns	24.56 ns
Genotypes	20	168.87**	26.80 ns	39.27*	41.04 ns	1254.23**	912.8**	126.43**	115.084**	101.78**	31.20**
Varieties (vj)	5	358.57**	15.66 ns	54.67*	104.40**	3876.32**	3091.21**	447.45**	408.570**	329.61**	85.97**
Heterosis (h <sub>ij</sub> )	15	105.64**	30.51 ns	34.13 ns	19.92 ns	380.20*	186.77 ns	19.42**	17.256 ns	25.83 ns	12.94 ns
Average heterosis	1	193.54*	20.08 ns	157.68**	4.87 ns	30.13 ns	249.62 ns	32.86*	7.700 ns	13.04 ns	9.71 ns
Variety heterosis	5	150.20**	34.15 ns	4.62 ns	33.66 ns	936.16**	136.51 ns	39.72**	18.665 ns	30.81 ns	5.15 ns
Specific heterosis	9	71.12 ns	29.64 ns	36.80 ns	13.96 ns	110.24 ns	207.70 ns	6.65 ns	17.535 ns	24.49 ns	17.63 ns
Error	60	40.42	44.52	20.55	26.75	187.75	226.51	7.55	10.802	19.61	10.20

\* Significant effect (Pr>F)<0.05; \*\* Highly significant effect (Pr>F)<0.01; ns: not significant.

**TABLE 3.** Effect of average heterosis of the feature ether extract production per plant (EPPP) and its components during two semesters (2012B and 2013A) to the species *Cucurbita argyrosperma* subsp. *sororia*.

Character	Semester	
	2012B	2013A
EPPP	3.36*	1.08
EE	3.03*	-0.53
SWP	-1.33	3.82*
100-SW	-1.38	-0.67
NFP	0.87	0.75

\* Significant effect (Pr>F)<0.05

### Effect of variety heterosis

Table 4 shows the effects of variety heterosis for all evaluated characters.

Variety effects varied between semesters. However, parental line 256 presented positive effects in both semesters to the character EPPP and its components SWF, 100-SW, and NFP, indicating that it is a stable parental line and can be used in recurrent selection programs to multiply these characters.

Parental line 132 presented positive effects for both semesters to the character EEPP and its components EE and SWF, indicating that this parental line also has important additive genetic effects that can be used in selection programs to multiply these characteristics.

If the objective of a breeding program is to increase the percentage of ether extract on seed and, at the same time, ether extract production per plant, parental lines 256 and 132 should be considered for hybridization and selection programs.

### Effect of specific heterosis

Specific heterosis helps identify hybrids with better characteristics than those of their parental lines. The significance of this heterosis indicates presence of dominance effects,

probably attributable to favorable gene complementation in the crosses in which they form part.

Table 5 shows the effects of specific heterosis, which varied between semesters. For the character EEPP, the effects of hybrids 256×132 and 140×260 were significant for semester 2012B, indicating that these hybrids were superior to the average of their parental lines and the overall average. In semester 2013A, no significant values were obtained.

Hybrid 140×107 was outstanding in terms of percentage of EE in semester 2012B, presenting positive, significant values. In semester 2013A, although there were hybrids presenting positive values, these were non-significant, suggesting a reduced variability among parental lines and possibly a marked environmental effect even on hybrids.

**TABLE 4.** Effects of variety heterosis of the character ether extract production per plant and its components during two semesters (2012B and 2013A) for *Cucurbita argyrosperma* subsp. *sororia*.

Parental line	Character				Component					
	EEPP		EE		SWF		100-SW		NFP	
	2012B	2013A	2012B	2013A	2012B	2013A	2012B	2013A	2012B	2013A
256	4.38	2.87	-0.001	-1.75	6.26	3.44	1.50	1.29	2.61	1.22
140	2.64	-2.89	-0.70	0.001	8.66	3.47	2.09	0.78	1.20	0.12
260	-0.45	-0.95	1.16	-0.49	-1.25	-6.63	-0.18	-1.71	-2.87	-0.18
107	-7.19	-1.16	0.02	-2.46	-16.11	-2.63	-1.49	1.66	0.95	-0.52
68	-2.48	0.72	-0.92	2.91	-8.95	-0.80	-3.62	-1.92	-0.75	0.47
132	3.10	1.42	0.44	1.80	11.38	3.16	1.69	-0.10	-1.14	-1.10

**TABLE 5.** Effects of specific heterosis of the character ether extract production per plant and its components during two semesters (2012B and 2013A) for *Cucurbita argyrosperma* subsp. *sororia*.

Hybrid	Character				Component					
	EEPP		EE		SWF		100-SW		NFP	
	2012B	2013A	2012B	2013A	2012B	2013A	2012B	2013A	2012B	2013A
256×140	-3.85 ns	-1.69 ns	-0.56 ns	0.90 ns	-2.82 ns	-2.06 ns	-1.40 ns	-0.44 ns	-3.35 ns	-2.09 ns
256×260	-1.46 ns	-1.30 ns	0.26 ns	-0.59 ns	2.15 ns	3.35 ns	0.89 ns	1.93 ns	0.72 ns	0.00 ns
256×107	3.32 ns	4.11 ns	-0.72 ns	-0.43 ns	4.31 ns	7.29 ns	0.96 ns	0.62 ns	1.90 ns	0.68 ns
256×68	-2.02 ns	2.19 ns	0.87 ns	2.28 ns	-9.14 ns	-2.73 ns	-1.40 ns	-0.41 ns	1.02 ns	2.42 ns
256×132	4.01 *	-3.31 ns	0.15 ns	-2.16 ns	5.51 ns	-5.86 ns	0.95 ns	-1.70 ns	-0.30 ns	-1.02 ns
140×260	5.75 *	2.52 ns	0.79 ns	-2.13 ns	2.46 ns	-4.23 ns	0.15 ns	-1.30 ns	2.46 ns	3.56 ns
140×107	2.82 ns	0.31 ns	5.90 *	1.47 ns	-3.98 ns	-8.60 ns	-0.20 ns	-1.73 ns	0.14 ns	1.28 ns
140×68	-1.63 ns	-1.04 ns	-3.77 ns	-0.01 ns	3.49 ns	2.56 ns	0.11 ns	0.59 ns	-0.04 ns	-1.99 ns
140×132	-3.09 *	-0.10 ns	-2.36 ns	-0.23 ns	0.85 ns	12.32 ns	1.34 ns	2.88 ns	0.78 ns	-0.76 ns
260×107	-0.84 ns	-2.23 ns	-2.71 ns	1.51 ns	1.23 ns	1.55 ns	0.25 ns	0.04 ns	1.55 ns	-1.92 ns
260×68	-0.78 ns	0.58 ns	-0.14 ns	0.00 ns	-0.50 ns	5.96 ns	0.88 ns	1.98 ns	-2.46 ns	-0.98 ns
260×132	-2.66 ns	0.44 ns	1.80 ns	1.21 ns	-5.34 ns	-6.63 ns	-2.16 ns	-2.64 ns	-2.28 ns	-0.66 ns
107×68	-1.31 ns	-3.45 ns	0.08 ns	-3.00 ns	2.80 ns	-3.10 ns	-0.23 ns	-1.27 ns	-1.95 ns	-0.96 ns
107×132	-3.98 ns	1.25 ns	-2.55 ns	0.45 ns	-4.36 ns	2.85 ns	-0.78 ns	2.35 ns	-1.64 ns	0.93 ns
68×132	5.73 ns	1.73 ns	2.96 ns	0.72 ns	3.34 ns	-2.69 ns	0.65 ns	-0.88 ns	3.43 ns	1.50 ns

It is therefore recommended to conduct studies on the response of parental lines and hybrids in additional contrasting environments.

The effects of specific heterosis to components SWF, 100-SW, and NFP presented positive but non-significant values, indicating that no genetic complementation exists between their parental lines, even though their geographic origin differs.

## Conclusions

The group of parental lines used allowed the effect of average heterosis to be explored to the character EEPP and its EE components.

Parental lines 256 and 132 proved best to tap heterotic effects, based on the effect of average and variety heterosis. Furthermore, of all the parental lines evaluated, their stability was the highest to begin a crossbreeding program to select superior-performing segregants to the character EEPP.

The average heterosis of hybrids 256×132 and 140×260 was superior to that of their parental lines and the overall average to the character EEPP in 2012B. Hybrid 140×107 was outstanding regarding the EE component, also during 2012B.

In the case of semester 2013A, although several hybrids presented positive values, these were non-significant.

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