



## Heterosis in papaya hybrids from partial diallel of 'Solo' and 'Formosa' parents

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**ABSTRACT** - The high cost of imported papaya seed in Brazil has motivated the conduction of the present study, which aimed at estimating heterosis effects and the indication of superior papaya hybrids, by means of a partial diallel scheme of eight genotypes from the groups 'Solo' and 'Formosa'. Parents and hybrids were evaluated in a randomized complete block design with four replications and 80 treatments (64 hybrids and 16 parents). Nine traits were evaluated and heterobeltiosis was verified for all traits. It was concluded that the diallel is a suitable strategy for the generation of papaya hybrids that meet national and international market standards. Superior hybrids with a view to further evaluation and cultivar release are those formed by the parents 'JS11' and 'JS 12' with the parents: 'Sunrise Solo-TJ', 'Sunrise Solo-72/12-IS', 'Santa Bárbara', 'Baixinho de Santa Amália', 'São Mateus' and 'Sunrise Solo-783'.

**Key words:** hybrid vigor, *Carica papaya*, diallel, breeding.

### INTRODUCTION

Heterosis or the gene expression of the beneficial effects of hybridization (Barelli et al. 1998) can be explained by effects of intra and inter loci gene action. It has become commonly accepted by researchers that in the former situation there must be dominance for the occurrence of heterosis; however, if some loci are dominant in one direction and others in another, their effects tend to cancel each other out and no heterosis is observed, in spite of the dominance in the individual loci (Ramalho et al. 1993). Epistasis can explain heterosis through the action of complementary genes (Borém 2001). In complementary gene action, the F<sub>1</sub> population is superior to both parents, as a consequence of the dihybrid heterozygosis when two gene pairs are considered. This is justified because in this case the parents carry contrasting genes, although one of

them presents homozygous recessiveness. The limiting reaction uses a biochemical approach to demonstrate that in contrasting lines the gene product inhibits its ulterior and vice-versa, while no such inhibition occurs in the F<sub>1</sub> hybrid (Barelli et al. 1998).

Breeders have exploited heterosis, also known as hybrid vigor, in practice even before Shull (1952) proposed the concept of the term (Paterniani 2001). Likewise, the term heterobeltiosis has been used in the identification of hybrids that perform better than the superior parent (Vencovsky and Barriga 1992). In papaya, heterosis was observed and pointed out by Mekako and Nakasone (1975) in interspecific crossings of *Carica cauliflora* x *C. goudotiana* and *C. cauliflora* x *C. monoica*. In both crossings the plant height, stem diameter, fruit number and mean fruit weight in the F<sub>1</sub> generation were

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significantly higher than in most vigorous parents. It is however worth remembering that breeding studies with papaya ought to aim at a reduction of the ground-up insertion height of the fruit on the stem for an enhanced utilization of the stem in fruit production.

In turn, Vasconcelos et al. (1982) stated heterotic effects for earliness and plant height, as well as fruit yield, weight and number in papaya hybrid combinations. Nevertheless, Kulasekaran and Muthuswami (1983), who evaluated two Indian hybrids, designated 'CO<sub>3</sub>' and 'CO<sub>4</sub>', verified positive heterotic effects for stem diameter, fruit size and pulp quality.

In spite of the efforts of some researchers, studies on the practical use of heterosis in papaya in Brazil are rare. This has contributed to the high import value of hybrid seed from Kaohsiung – Taiwan, which comes at a cost of 3000 to 4000 dollars per kg (Ruggiero 1980, Pereira 2003).

The varieties used for cultivation in Brazil are genotypes of the group 'Solo', originally introduced from Hawaii; and hybrids of the group 'Formosa'. Their high purchase value causes producers to use advanced hybrid generations, leading to vigor loss and high heterogeneity on plantations.

In this setting, the present study aimed at an evaluation of the heterotic effect of hybrids derived from partial diallel and the indication of combinations with a view to future cultivar releases and commercialization on the international market.

## MATERIAL AND METHODS

Sixteen papaya parents from gene banks of the Universidade Estadual do Norte Fluminense – UENF and the Centro Nacional de Mandioca e Fruticultura – CNPMF – EMBRAPA were used. They had been selected based on divergent morpho-agronomic traits, forming two groups ('Solo' and 'Formosa') with eight genotypes each, whose main traits are described in Tables 1 and 2.

The plantlet production of the parents as well as the installation of the block of crossings for the establishment of the hybrid combinations was realized on the Experimental Farm of Korin Agrícola, a decentralized unit of the Mokiti Okada Foundation, in the county of Casimiro de Abreu, state of Rio de Janeiro. To establish the hybrids, the parent crossings and selfings were carried out in a partial diallel system, by the transference of hermaphrodite or male plant pollen of the 'Formosa' group to stigma of female plants of the group 'Solo'. All 64 (8 x 8) hybrid combinations and 16 (8 + 8) selfings were obtained.

The parents and hybrids were grown from January 2000 to March 2001 on the Fazenda Romana, of the Caliman Agrícola company, in the county of Linhares, state of Espírito Santo. The experimental design consisted in randomized complete blocks with 80 treatments (64 hybrids and 16 parents) and four replications with eight plants per plot.

Six plantlets were planted per hole for each treatment, spaced 20 cm apart. Thinning left a single papaya plant after the determination of the gender. In the case of the treatments derived from dioic populations, the highest possible number of female and lowest number of male plants, which are only pollen grain donors, was maintained after sexing. For the treatments derived from ginoic and andromonoic papaya populations, the highest possible number of hermaphrodite plants, whose fruits are of high market value, was maintained. The spacing between plants was 1.80 m in single rows spaced 3.60 m apart. The field crop management was handled according to Marin et al. (1995).

The following traits were evaluated: a) plant height (PH) - expressed in cm, measured by a ruler graded in cm, from ground level up to the last leaf pair on the stem apex of the papaya tree, 120 days after transplanting the plantlets to the field; b) insertion height of the first fruit (IHFF) - expressed in cm, measured with a ruler graded in cm, from ground level up to the point of insertion of the first papaya fruit on the leaf axil, 150 days after transplanting c) stem diameter (SDIA) - expressed in cm, measured 10 cm above ground level with a digital pachymeter, 270 days after transplanting; d) number of fruits per plant (NF1 and NF2) - obtained by counting the number of all fruits with commercial traits, respectively, 180 and 270 days after transplanting e) mean fruit weight (MFW) - expressed in gram, obtained by weighing a three-fruit sample of each plant of each weekly harvest on an analytical scale; f) total fruit yield (TFY) - expressed in gram, obtained by the multiplication of the fruit number by the mean fruit weight per plant, 270 days after transplanting; g) soluble solids (BRIX) content - of a three-fruit sample of each plant and each harvest expressed in degree Brix, obtained by a manual refractometer; and h) taste degustation (TD) - obtained by scoring the fruit pulp taste of a three-fruit sample of each plant and each harvest, according to a scale established by the Laboratory of Quality Control and Post Harvest of the Caliman Agrícola company (4 = optimum, 3 = good, 2 = regular, 1 = poor).

**Table 1.** Pedigree and descriptive information of the eight parents in the ‘Solo’ group

Code	Pedigree	Origin	Generation <sup>1</sup>	Genotype type	Description <sup>2</sup>
EEM-056	‘Sunrise Solo-TJ’	Papaya Ceres Linhares-ES	OP (94) S <sub>2</sub> (96)	Variety	IHFF: 0.70 mFruit weight: 0.45 kgPulp: red orange
EEM-0398	‘Sunrise Solo -72/12-IS’	Papaya Ceres Linhares-ES	OP (98)	Variety	IHFF: 0.60 mFruit weight: 0.40 kgPulp: red orange
EEM-0798	‘Santa Bárbara’	Petrolina-PE	OP (98)	Elite line	IHFF: 0.60 mFruit weight: 0.40 kgPulp: red orange
EEM-1098	‘Baixinho de Santa Amália’	Papaya Ceres Linhares-ES	OP (98)	Variety	IHFF: 0.50 mFruit weight: 0.55 kgPulp: red orange
EEM-011	‘São Mateus’	Papaya Ceres Linhares-ES	OP (94) S <sub>1</sub> (96)	Elite line	IHFF: 0.70 mFruit weight: 0.55 kgPulp: red orange
MOA 0598	‘Sunrise Solo-783’	Korin Kaohsiung Taiwan	S <sub>1</sub> (98)	Variety	IHFF: 0.70 mFruit weight: 0.45 kgPulp: red orange
CMF-087	‘Waimanalo’	CNPMFT Cruz das Almas-BA	OP (92) OP (95)	Variety	IHFF: 0.60 mFruit weight: 0.55 kgPulp: yellow
CMF-086	‘Kapoho-Solo’	CNPMFT Cruz das Almas-BA	S <sub>1</sub> (92) S <sub>2</sub> (95)	Variety	IHFF: 1.20 mFruit weight: 0.45 kgPulp: yellow

<sup>1</sup> OP: open pollination; S<sub>1</sub>: first selfing generation; S<sub>2</sub>: second selfing generation; and F<sub>1</sub>: first hybrid generation

<sup>2</sup> IHFF: insertion height of the first flowering

**Table 2.** Pedigree and descriptive information of the eight parents in the ‘Formosa’ group

Code	Pedigree	Origin	Generation <sup>1</sup>	Genotype type	Description <sup>2</sup>
EEM-3598	‘Dióico Amarelo’	Papaya Ceres Linhares-ES	OP (98)	Variety	IHFF: 0.80 mFruit weight: 0.90 kgPulp: yellow
EEM-101	‘Maradol Roxo’	Tabasco. Mexico	OP (92) S <sub>2</sub> (98)	Variety	IHFF: 0.60 mFruit weight: 1.10 kgPulp: red
CMF-041	‘JS 12’ Cruz das Almas-BA	CNPMFT	S <sub>1</sub> (92) S <sub>2</sub> (95)	Variety	IHFF: 0.70 mFruit weight: 0.90 kgPulp: red
CMF-040	‘JS 11’ Cruz das Almas-BA	CNPMFT	S <sub>1</sub> (92) S <sub>2</sub> (95)	Variety	IHFF: 0.70 mFruit weight: 0.90 kgPulp: red
CMF-055	‘Tailândia A’	CNPMFT Cruz das Almas-BA	S <sub>1</sub> (92)S <sub>2</sub> (95)	Variety	IHFF: 0.60 mFruit weight: 0.90 kgPulp: red
CMF-032	‘DCG 440-3’ Costa Rica’	CNPMFT Cruz das Almas-BA	S <sub>1</sub> (92) S <sub>2</sub> (95)	Elite line	IHFF: 0.80 mFruit weight: 0.70 kgPulp: red
EEM-2198	‘Tainung	South Africa 01/781’	F <sub>3</sub> (98)	3 <sup>rd</sup> hybrid generation	IHFF: 0.70 mFruit weight: 1.10 kgPulp: red
EEM-4498	‘Cariflora’	UNESP Jaboticabal-SP	OP (97)	Variety	IHFF: 0.90 mFruit weight: 0.65 kgPulp: red

<sup>1</sup> OP: open pollination; S<sub>1</sub>: first selfing generation; S<sub>2</sub>: second selfing generation; and F<sub>1</sub>: first hybrid generation

<sup>2</sup> IHFF: insertion height of the first flowering

The mean heterosis for each evaluated trait was obtained by the expression (Falconer 1987):  $h = F_1 - MP$ , where:  $h$  = mean heterosis;  $F_1$  = mean of all the hybrids;  $MP$  = mean of all the parents. The relative heterosis (in percentage) was obtained by the expression (Falconer 1987):  $h(\%) = \frac{h}{MP} \times 100$ , where:  $h(\%)$  = relative heterosis;  $h$  = mean heterosis; and  $MP$  = parent means. The software Genes (Cruz 2001) was used to conduct the analyses.

## RESULTS AND DISCUSSION

The estimates of the effects of the mean heterosis indicated that for the traits IHFF and PH the combinations 8 x 7', 3 x 1', 6 x 1', 2 x 6' and 6 x 6' attained highest negative magnitudes of mean heterosis, respectively, -6.00 and -6.58, -3.73 and -3.84, -2.61 and -3.78, -1.48 and -6.28, -0.89 and -0.14, although in general terms the heterosis expressed in percentage was 13.11 and 8.52 respectively (Table 3). Furthermore, among these combinations 8 x 7' and 3 x 1' for IHFF, and 8 x 7' and 2 x 6' for PH presented negative heterosis values in relation to the parents of groups 'Solo' and 'Formosa', indicating an effect of heterobeltiosis, since the mean in  $F_1$  was inferior to that of the best parent. Vasconcelos et al. (1982) observed the expression of heterotic effects for plant height in papaya as well.

For trait SDIA, the combinations 8 x 8', 1 x 8', 5 x 8',

8 x 1', 4 x 8', 6 x 8' and 5 x 1' expressed the highest positive magnitudes of heterosis and heterosis of groups 'Solo' and 'Formosa'. This is evidence for the occurrence of heterobeltiosis, reflected by the occurrence of  $F_1$  plants with a greater stem diameter than the most vigorous parent.

The following hybrids had the best heterotic performance for the trait NF2: 8 x 7', 8 x 8', 6 x 8', 8 x 1', with the values 19.67, 11.19, 9.10 and 7.24, although for all the combinations this trait showed negative values for mean and relative heterosis (Table 3).

The heterosis estimates evidenced that the trait MFW expressed high value of mean and relative heterosis (Table 3) and the best combinations were, hierarchically: 7 x 2', 7 x 5', 3 x 6', 5 x 5', 4 x 5', 3 x 4', 3 x 5', 7 x 4', 1 x 5', and 3 x 2'. In contrast, negative heterosis was observed in the hybrids 4 x 2', 2 x 8', 2 x 7' and 2 x 6', indicating clearly that the parents 2 ('Sunrise Solo 72/12'), 8 ('Kapoho Solo'), 6' ('Tailândia') and 7' (Tainung 01) are not promising for the generation of progenies with a higher fruit weight.

Since the fruit size of the 'Formosa' genotypes is already expressive, hybrids of interest regarding mean fruit weight should not express the effect of heterobeltiosis, to facilitate adequate packing in wraps, above all for exportation. For example, the combinations of parents 1, 2, 3, 4 and 5 with 3' and 4' are promising when focusing on fruit exportation, since their heterosis values are lower than the phenotypic means expressed

**Table 3.** Estimates of mean, mean heterosis and relative heterosis for nine traits evaluated in a diallel of papaya of the groups 'Solo' and 'Formosa'

Traits <sup>1</sup>	Mean	Range	Mean heterosis	Relative heterosis (%)
PH	133.22	77.59 – 151.41	10.46	8.52
IHFF	74.63	32.60 – 92.54	8.65	13.11
SDIA	100.99	65.14 – 122.77	6.33	6.69
NF1	18.44	12.00 – 26.35	0.15	0.83
NF2	30.02	16.79 – 48.63	-1.58	-5.00
MFW	1214.18	441.50 – 2348.75	299.16	32.69
TFY	35846.28	10317.50 – 57694.50	9483.16	35.97
BRIX	9.63	7.85 – 12.65	0.26	2.79
TD	2.52	1.00 – 4.00	-0.28	-9.89

<sup>1</sup> PH: Plant height; IHFF: Insertion height of the first fruit; SDIA = stem diameter 270 days after transplanting; NF1: number of fruits per plant 180 days after transplanting; NF2: number of fruits per plant 270 days after transplanting; MFW = mean fruit weight; TFY: total fruit production 270 days after transplanting; BRIX: soluble solids content of the fruit pulp; TD: Taste degustation

by the parents of the 'Formosa' group.

The highest value for relative heterosis was observed for the trait TFY (Table 3), and the best combinations were as following: 6 x 8', 1 x 6', 3 x 1', 7 x 5', 6 x 2', 8 x 8', 7 x 8', 8 x 1' 5 x 1' and 4 x 5'. Yet these hybrid combinations presented heterobeltiosis, indicating the success in using genotypes of divergent papaya groups. This implies that the establishment of superior hybrids in papaya is more likely to occur in crossings of genotypes from distinct gene pools.

For BRIX, parent 3' ('JS 11') presented high heterotic value in all crossings with parents of the 'Solo' group. It is further worth mentioning that apart from the crossings with cultivars 3 ('Santa Bárbara'), 7 ('Waimanalo Solo') and 8 ('Kapoho Solo'), all other crossings with 'JS 11' presented hybrids with heterobeltiosis for taste degustation. This evidences that cultivar 'JS 11' can be used in interpopulation breeding programs, aiming at an improved taste and increased soluble solids content in papaya fruit. Nonetheless, considering the premise of Marin et al. (1995) in respect to pulp coloration, this result

confirms that fruits with a yellow pulp, as 'Kapoho Solo' and 'Waimanalo Solo', do not present desirable taste qualities and have therefore not been sufficiently accepted on the Brazilian market.

The traits MFW, BRIX and TD are the most decisive for bringing the product on the internal and external market, with a special view to the latter. In conclusion, for all the traits, specially the last ones, the combinations of 'JS11' and 'JS 12' with: 'Sunrise Solo-TJ', 'Sunrise Solo-72/12-IS', 'Santa Bárbara', 'Baixinho de Santa Amália', 'São Mateus' and 'Sunrise Solo-783' have the potential for a future release.

## CONCLUSIONS

1. Heterobeltiosis is a common effect in papaya hybrids derived from distinct gene pools.

2. Hybrids with a potential for release in internal market and for commercialization on the international market are the combinations of 'JS11' and 'JS 12' with: 'Sunrise Solo-TJ', 'Sunrise Solo-72/12-IS', 'Santa Bárbara', 'Baixinho de Santa Amália', 'São Mateus' and 'Sunrise Solo-783'.

# Heterose em híbridos de dialelo parcial entre mamoeiros dos grupos 'Solo' e 'Formosa'

**RESUMO** - O alto preço das sementes híbridas de mamoeiro importadas pelo Brasil, motivou o desenvolvimento deste trabalho, que teve como objetivo estimar os efeitos heteróticos e indicar híbridos superiores de mamoeiro, por meio de dialelo parcial entre oito genótipos do grupo 'Solo' e oito do grupo 'Formosa'. Na avaliação dos genitores e híbridos, empregou-se o delineamento em blocos ao acaso com 80 tratamentos (64 híbridos e 16 genitores) e quatro repetições, utilizando-se oito plantas por parcela. Nove características foram avaliadas e a heterobeltiose destacou-se pela prevalência em todas. Detectou-se que a técnica dos cruzamentos dialélicos é uma estratégia útil na obtenção de híbridos de mamoeiro para atendimento aos mercados nacional e internacional. Os híbridos superiores, a serem avaliados para pretensão lançamento são as combinações de 'JS11' e 'JS 12' com: 'Sunrise Solo-TJ', 'Sunrise Solo-72/12-IS', 'Santa Bárbara', 'Baixinho de Santa Amália', 'São Mateus' e 'Sunrise Solo-783'.

**Palavras-chave:** vigor híbrido, *Carica papaya*, dialelo, melhoramento.

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