Crop Breeding and Applied Biotechnology 9: 60-66, 2009
Brazilian Society of Plant Breeding. Printed in Brazil

Use of testers for combining ability and selection of papapya hybrids

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Received 22 May 2008

Accepted 07 January 2009

ABSTRACT – *Using methods for estimating combining ability with the use of testers, where one or more genotypes are crossed with all the plant material to be investigated, is simpler and faster than a diallel. The objective was to make use of testers to select hybrids with a level of yield capacity and fruit quality that justifies their selection. A test was performed with 20 papaya hybrids from the crossing of 13 'Solo'with tester' Formosa '(JS-12), and seven 'Formosa' lines, crossed with tester 'Solo' (SS 72/12) in Linhares, state of Espirito Santo, between August 2006 and July 2007. The specific combining ability was determined for 14 traits of papaya by the difference between the overall mean and the mean of each hybrid crossed with the testers. The genotypes with the best values of Specific Combining Ability (SCA) for yield traits and fruit quality were: JS-12 x SS 72/12; JS-12 x São Mateus and SS72/12 x Sekati, particularly the latter.*

Key words: *Carica papaya* L., genetic parameters, combining ability, specific combining ability, selection index.

INTRODUCTION

Hybrid breeding is directly related to the degree of genetic divergence of the parents involved (Hallauer and Miranda Filho 1995). However, a high genetic divergence does not necessarily increase the expression of heterosis. It is therefore important to use methods that can identify the best combinations (Duarte et al. 2003).

The analysis of combining ability is appropriate to obtain information on the action of genes associated with a particular trait, as well as for the selection of parents in terms of general combining ability (GCA) and their respective hybrid combinations as related to the specific combining ability (SCA). The existing estimation methods of combining ability are rather time-consuming, especially in the case of perennial species such as papaya (Dinesh 1995). A possible method is the choice of one or more genotypes, so-called testers, which are crossed with all study genotypes. This way it is possible to select the best combinations for the desired features.

According to Hull (1945) all unfavorable loci would be fixed in the ideal tester. For Hallauer (1975) however, the ideal tester should allow genetic gain maximization. In general, for any program of hybrid development, the tester must comply with the following criteria: ease of use, generate information that classifies the potential for the crossings correctly, and genetic gain maximization (Duarte et al. 2003).

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The SCA is the parameter used to assess the value of a cross between a narrow-based tester and a line. The SCA is therefore associated with the hybrid combinations. This parameter is obtained by the difference between the mean of a specific cross in relation to the overall mean of crosses with a particular tester.

The performance of crosses evaluated depends on the GCC, associated to the additive effects, as well as on the SCA, associated to partial or complete dominance deviation (Nestares et al. 1999).

The SCA values are related with the genetic distance between the tester and the line and show the importance of non-additive interactions, characterized by complementarity in relation to the allele frequency in loci with some dominance among parents (Duarte et al. 2003), i.e., SCA is linked to the dominance effects.

The GCA is a parameter that is related to the parents evaluated, considering the mean performance of the tested crosses. SCA can be interpreted as deviations of hybrid combinations from the expected in the GCA of the parents (Marin et al. 2006). These deviations are due to the action of dominance or epistatic effects.

The use of different testers can also serve as classification criterion of genotypes in different heterotic groups (Nestares et al. 1999). In breeding programs for high performance with great potential, elite lines are used whenever possible. For this reason, in most cases, the testers used are also elite, by which genotypes with market potential can be obtained, besides a prediction of the performance of potential hybrids (Duarte, et al. 2003)

From a practical point of view, the main purpose of the use of testers is to eliminate lines with unsatisfactory performance from the selection process. In this way, the hybrid development program can be rationalized and becomes more efficient (Elias et al. 2000).

A tester may be a broad or narrow-based, a poor or an elite, or yet a related or unrelated genotype. A more detailed discussion of this issue is given by Sprague (1946) and Hallauer and Lopez-Perez (1979).

The purpose of this study was to evaluate the use of testers in the selection of papaya hybrids, considering a set of agronomic traits.

MATERIAL AND METHODS

This investigation consisted of a trial of papaya hybrids from the cross of 20 elite genotypes, 13 from the 'Solo' and seven from the 'Formosa' group, and two testers, SS-72/12 ('Solo' group) and JS-12 ('Formosa' group) on the farm Macuco, owned by "Caliman Agrícola S / A" Company, in Linhares, State of Espírito Santo. The experiment was set up in August 2006 and lasted over a year. The tester from 'Solo' was crossed with the genotypes from 'Formosa' and the tester from 'Formosa' was crossed with the genotypes from 'Solo'. A randomized complete block design with two replications was used with the 20 papaya hybrids and eight plants per plot.

The following traits were evaluated:

Plant height (PH) and height of first fruit (HFF) were measured by an appropriate scale. The stem diameter (DC) was obtained by measuring the circumference with a graduated tape 20 cm above the soil surface and dividing the values by ?. Petiole length (PetL) and - peduncle length (PedL), of leaves were determined by a graduated tape, preferably of leaves with a flower at anthesis in the axil.

The total number of fruits (NTF) was obtained by counting the fruits on each plant (in the plot) at two stages, six and nine months after planting. The dead plants or those removed during this period were not recorded. The normal fruits (NNF) were counted together with the total fruits, but any defective (pentandric and carpelloid) fruits were subtracted from the total number.

The fruit mean weight (MFW) was evaluated in only one harvest, when all fruits of each plot were counted and weighed. The weights were divided by the total number of fruits per plot on that day.

The total fruit yield (TFYie) for each plot was obtained by multiplying the NTF by MFW and the Normal Fruit yield (NFYie - marketable fruit) by the multiplication of NNF by MFW. The percentage of normal fruit (NFYie%) was calculated by the ratio of NFYie by TFYie, multiplied by 100.

The values of total soluble solids were measured using a field refractometer and internal and external pulp firmness by a penetrometer.

Computer program "Genes" (Cruz 2006) was used to obtain the analysis of variance (ANOVA) and group of means. The means were grouped by the method of Scott-Knott at 5% probability.

Calculations of specific combining ability (SCA) were obtained by the differences between the mean of each individual hybrid crossed with the tester (Xg) with

the overall mean of the crosses (Xe) with each one of the testers.

SCAgT1 = Xg.T1 - Xe.T1

SCAgT2 = Xg.T2 - Xe.T2

Where T1 - tester 1 (JS-12) and T2 - Tester 2 (SS-72/12)

RESULTS AND DISCUSSION

Among the morpho-agronomic traits evaluated in the experiment involving hybrids, significant differences were only observed for the trait height of first fruit (HFF) by the F test at 5% probability. All yield and fruit quality traits were significant by the F test at 1% probability. Results of analysis of variance are listed in Table 3.

Use of tester JS-12 of the 'Formosa' group

The specific combining ability (SCA) was calculated for the parents of the 13 hybrids used in crosses with a narrow-based elite line of the variety JS-12, tester 'Formosa', which consisted of 13 lines of 'Solo' (Table 1).

In the process of hybrid selection, shorter plants should be included, to increase the lifetime of the orchard and make lodging less likely. In this case, genotypes with negative SCA values should be selected. Similarly, in the selection for fruit insertion, negative values are desirable to facilitate the harvest and extend the lifetime of the plantation. Whenever possible, plants with greater stem diameter should be chosen in papaya selection (positive SCA), to increase lodging resistance as well as the support to bear a greater number of fruits.

The traits total number of fruit (NTF) and number of normal fruits (NNF) are directly related to the productivity level of a plant. The fruit yield per plant (NFYie) is the most important trait to be considered, since it is directly linked to the production volume.

The percentage of normal fruits (NFYie%) expresses the level of perfect fruits, which are marketable, so the SCA must be positive.

Positive SCA values must also be obtained in the measurements of total soluble solids (TSS), indicating sweeter fruits.

The internal and external pulp firmness has been a bottleneck for papaya commercialization in the country, in view of the transport problems. In this study, pulp firmness along with yield per plant are strategically considered as the most important traits in papaya hybrid selection. However, plants producing fruits with low soluble solids content can not be accepted.

The following hybrids tested have special features (Table 1).

The crossing involving the genotype 'CALIMAN GB' resulted in tall plants with high insertion of the first fruit. Compared with the other hybrids it produced a large number of fruits with and elevated mean fruit weight, resulting in high-yielding plants. But total soluble solids and pulp firmness were low for this hybrid.

The crossing of the tester with variety Sunrise Solo 72/12 produced relatively tall plants, but with low insertion of the first fruit. Yield per plant was regular for the other hybrids. The value of total soluble solids was high and external pulp firmness good. The internal firmness was regular. This hybrid was noted for the balance between the morphological, yield and quality traits.

The hybrid involving the genitor 'Baixinho de Santa Amália' produced shorter plants and low height of the first fruit. The number of fruits per plant was high and fruit weight medium, compared to the hybrids tested (SCA = -0056). It was highly productive, with one of the highest means. The values of soluble solids as well as pulp firmness were however low.

The cross between JS-12 and genotype São Mateus resulted in short plants with low insertion of the first fruit. It produced heavy fruits, and was rather productive. There was little susceptibility to carpelloidy and pentandry. The external firmness was excellent and internal firmness good. It can be used in selection in view of the good morphological traits, yield and quality.

Use of tester SS 72-12 of 'Solo'

In this test, an elite and narrow-based line of the variety SS-72/12 was used as 'Solo' tester. The tester was crossed with seven genotypes of the heterotic 'Formosa ' group.

The following hybrids tested have special features (Table 2):

The cross involving the genotype 'Thailand' produced tall plants with low insertion of the first fruit. The hybrid was highly productive due to the number of fruits per plant above the mean and high fruit weight. Pulp firmness and total soluble solids were however low.

Table 1. Mean and specific combining ability (SCA) of the hybrids with the tester, JS12 from the 'Formosa' papaya group

PARENT SOLO	PH*		SD		HFF		PetL		PedL		NTF		NNF	
	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA
CALIMAN SG	220.00	19.99	11.68	0.68	64.69	-0.66	88.69	5.045	5.47	0.44	48.92	0.58	44.38	0.23
TRIWAN ET	192.50	-7.51	11.12	0.13	57.38	-7.97	94.69	11.045	5.34	0.31	43.71	-4.63	41.44	-2.72
DIVA	203.12	3.11	10.70	-0.29	76.88	11.52	79.25	-4.392	4.81	-0.22	43.12	-5.21	38.50	-5.66
GRAMPOLA	183.12	-16.88	10.28	-0.71	57.50	-7.85	74.81	-8.830	3.91	-1.13	37.38	-10.96	35.56	-8.59
SUNRISE SOLO	218.75	18.74	11.68	0.68	74.94	9.59	84.38	0.733	5.19	0.15	45.49	-2.85	41.26	-2.89
CALIMAN GB	217.50	17.49	11.94	0.94	75.69	10.34	83.44	-0.205	5.72	0.68	56.04	7.70	48.96	4.80
CALIMAN SGB	208.75	8.74	11.36	0.36	69.56	4.21	88.31	4.670	5.66	0.62	53.12	4.79	50.44	6.28
CALIMAN G	191.88	-8.14	10.30	-0.69	66.12	0.78	78.62	-5.017	4.69	-0.35	47.18	-1.16	45.14	0.98
SS 72/12**	210.62	10.61	11.52	0.52	61.00	-4.35	87.94	4.295	5.12	0.09	49.44	1.10	46.44	2.28
BSA	174.17	-25.84	10.59	-0.40	60.35	-4.99	78.50	-5.142	4.41	-0.63	60.69	12.35	55.19	11.03
SÃO MATEUS	172.86	-27.15	10.17	-0.83	57.73	-7.62	82.60	-1.044	4.78	-0.25	46.81	-1.52	45.24	1.08
SS CALIMAN S	183.12	-16.89	10.21	-0.79	63.00	-2.35	78.69	-4.955	4.94	-0.10	53.38	5.04	45.00	0.84
SS TJ	223.75	23.74	11.38	0.39	64.68	-0.66	87.44	3.795	5.41	0.37	43.11	-5.23	36.49	-7.67

PARENT SOLO	MFW		TFYie		NFYie		%NFYie		TSS		Ext Firm		Int Firm	
	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA
CALIMAN SG	1.21	0.042	58.23	2.13	52.66	1.34	90.16	-1.22	12.80	1.12	193.74	2.74	133.99	-2.05
TRIWAN ET	1.22	0.059	53.45	-2.65	50.67	-0.65	94.64	3.25	10.95	-0.73	182.70	-8.31	135.78	-0.26
DIVA	1.11	-0.052	47.92	-8.18	42.75	-8.574	89.18	-2.21	12.30	0.62	188.19	-2.82	118.95	-17.09
GRAMPOLA	1.38	0.223	51.79	-4.31	49.25	-2.071	95.08	3.69	11.30	-0.38	186.57	-4.44	129.52	-6.52
SUNRISE SOLO	1.07	-0.096	48.58	-7.52	44.07	-7.26	90.71	-0.68	12.35	0.67	185.33	-5.68	126.42	-9.62
CALIMAN GB	1.23	0.067	69.18	13.08	60.51	9.19	87.11	-4.28	11.25	-0.43	189.62	-1.40	123.45	-12.59
CALIMAN SGB	1.11	-0.055	59.12	3.02	56.24	4.92	94.84	3.46	10.75	-0.93	204.46	13.44	151.69	15.65
CALIMAN G	1.26	0.101	59.08	2.98	56.54	5.21	95.68	4.30	11.75	0.07	195.02	4.02	134.88	-1.16
SS 72/12**	1.02	-0.146	50.68	-5.42	47.50	-3.82	93.99	2.60	12.15	0.47	196.84	5.83	135.63	-0.41
BSA	1.11	-0.056	67.30	11.20	61.16	9.84	91.00	-0.39	9.70	-1.98	176.94	-14.06	138.18	2.14
SÃO MATEUS	1.29	0.126	60.94	4.84	58.88	7.56	96.70	5.32	11.40	-0.28	195.81	4.80	159.60	23.56
SS CALIMAN S	1.17	0.005	62.37	6.27	52.59	1.27	84.33	-7.06	12.40	0.72	184.34	-6.67	137.96	1.93
SS TJ	0.94	-0.219	40.69	-15.42	34.37	-16.95	84.62	-6.76	12.75	1.07	203.56	12.56	142.48	6.44

BSA – Baixinho de Santa Amália, SS - Sunrise Solo,

* PH – plant height (cm), SD – stem diameter (cm), HFF – height of first fruit (cm), PetL – petiole length (cm), PedL – peduncle length (cm), NTF – number of total fruits, NNF – number of normal fruits, MFW – mean fruit weight (g), TFYie – total fruit yield (g), NFYie – normal fruit yield (g), %NFYie – percentage of normal fruits, TSS – total soluble solids (°Brix), Ext Firm – external fruit firmness (Pa), Int Firm – internal pulp firmness (Pa),

** SS – Sunrise Solo.

Table 2. Means and specific combining ability (SCA) of the hybrids having as tester, SS-72/12 from the 'Solo' papaya group

PARENT FORMOSA	PH*		SD		HFF		PetL		PedL		NTF		NNF	
	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA
COSTA RICA	174.38	-3.02	10.64	-0.26	75.12	13.74	68.38	-11.93	4.03	-0.70	90.43	19.59	89.84	21.50
TAILÂNDIA	181.50	4.10	10.56	-0.36	57.15	-4.23	76.79	-3.52	5.00	0.27	75.69	4.84	73.10	4.75
MAMÃO BENÉ	174.38	-3.02	10.40	-0.50	67.50	6.12	77.94	-2.36	4.47	-0.26	50.46	-20.38	47.52	-20.83
MAMÃO ROXO	187.14	9.75	11.02	0.11	69.67	8.29	76.29	-4.02	3.94	-0.79	105.75	34.91	98.28	29.94
MARADOL (Méx.)	180.00	2.60	10.54	-0.36	56.62	-4.76	90.12	9.82	5.25	0.52	53.70	-17.15	52.16	-16.19
MARADOL (G.L.)	198.12	20.73	12.37	1.47	53.69	-7.69	99.31	19.01	5.88	1.15	58.94	-11.91	58.44	-9.91
SEKATI	146.25	-31.14	10.76	-0.14	49.92	-11.46	73.292	-7.01	4.53	-0.20	60.94	-9.905	59.08	-9.26

PARENT FORMOSA	MFW		TFYie		NFYie		%NFYie		TSS		Ext Firm		Int Firm	
	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA
COSTA RICA	0.54	-0.45	48.97	-15.06	48.65	-13.37	99.34	2.91	11.20	0.81	167.70	0.83	122.30	2.03
TAILÂNDIA	1.14	0.14	85.68	21.65	82.72	20.70	96.57	0.14	8.80	-1.59	165.20	-1.67	115.78	-4.49
MAMÃO BENÉ	1.12	0.13	56.65	-7.38	53.34	-8.68	94.22	-2.21	10.10	-0.29	191.56	24.69	142.48	22.21
MAMÃO ROXO	0.36	-0.63	38.32	-25.72	35.54	-26.48	91.81	-4.63	13.50	3.11	136.77	-30.10	100.62	-19.65
MARADOL (Méx.)	1.33	0.34	71.47	7.44	69.47	7.44	97.16	0.72	9.85	-0.54	165.12	-1.76	119.67	-0.60
MARADOL (G.L.)	1.40	0.40	82.04	18.00	81.35	19.32	99.14	2.70	9.35	-1.04	177.24	10.37	114.73	-5.54
SEKATI	1.07	0.08	65.09	1.06	63.10	1.07	96.80	0.36	9.95	-0.44	164.52	-2.36	126.29	6.02

* See footnote to Table 1

Table 3. Analysis of variance of evaluated traits, considering the two heterotic groups ('Solo' and 'Formosa') jointly

Traits	MS Block	MS Genotype	MS Error	F Test
PH *	395.148	5.021.153	1.343.065	3.7386**
HFF	6.715.806	2.663.246	3.197.854	0.8328ns
SD	29.478	12.792	0.2501	5.114**
PedL	159.576	133.318	64.464	2.0681ns
PetL	2.657.961	62.824	54.445	1.1539ns
NTF	8.032.916	1.779.414	380.051	4.682**
NNF	7.037.877	1.743.040	389.441	4.4757**
MFW	0.0750	0.0980	0.0075	12.9831**
TFYie	10.227.626	717.985	605.608	1.1856ns
NFYie	8.244.429	587.101	535.277	1.0968ns
%NFYie	20.926	376.293	158.773	2.37*
TSS	0.5329	0.7744	0.3212	2.4107*
Ext Firm	954.012	25.113.129	5.402.870	4.6481**
Int Firm	5.142.432	9.979.715	1.612.788	6.1879**

* PH – plant height (cm), HFF – height of first fruit (cm), SD – stem diameter (cm), PetL – petiole length (cm), PedL – peduncle length (cm), NTF – number of total fruits, NNF – number of normal fruits, MFW – mean fruit weight (g), TFYie – total fruit yield (g), NFYie – normal fruit yield (g), %NFYie – percentage of normal fruits, TSS – total soluble solids (°Brix), Ext Firm – external pulp firmness (Pa), Int Firm – internal pulp firmness (Pa).

The hybrid involving the variety 'Maradol Grande Limão' resulted in very tall plants, but with low insertion of the first fruit. It produced few but very heavy fruits per plant. The yield per plant was very high, but the level of soluble solids low. The external pulp firmness was high and the internal low.

The cross of 'Sunrise Solo 72/12' with the genotype 'Sekati' produced short plants and low insertion of the first fruit. The number of fruits produced was below the mean, with medium fruit mean weight; the plant yield was above the mean, but not outstanding. The total soluble solids content and external firmness were close to the mean. The internal pulp firmness was good. This hybrid was noteworthy for the regularity of the characteristics.

In the literature no studies were found on combining ability, using testers for papaya. It is believed that at least in Brazil, this approach is novel for this crop. A few studies on combining ability in papaya are based on diallels. A study of combining ability, using a diallel scheme (Griffing model 1) with three papaya cultivars, was performed by Subhadrabandhu and Nontaswatsri (1997). They determined the GCA and SCC for conditions in Thailand, for the traits number of days until opening of the first flower; height of first flower; stem circumference; height of first fruit; number of nodes until the first fruit; fruit weight; number of fruits; fruit width and length; width and length of the ovarian cavity; pulp firmness and TSS.

In another study, Marin et al. (2006) used a partial diallel, inter-crossing eight papaya varieties of 'Formosa' with eight Solo 'varieties'. The experiment was conducted in Linhares, state of Espirito Santo, in the growing season 2000/2001. Among other traits, number of fruits, fruit weight, plant height, TSS and tasting test were analyzed. The GCA for the varieties 'Marado ' and 'Califlora' of the 'Formosa' group, and SS-783 and SS-TJ, of the 'Solo' group, was higher for high yield, while the SCA were higher for the set of traits for the hybrid combinations 'Sunrise Solo 72/12 × JS 12 ', 'Sunrise Solo TJ × JS 12', 'Baixinho de Santa Amália × JS 12', 'Sunrise Solo TJ × JS 11' and 'Sunrise Solo 72/12 × Costa Rica'.

The test of Marin et al. (2006), although performed at the same location with the two genotypes that were used as testers in our study cannot serve as a basis for revalidation because, aside from methodological differences, evaluation were performed at another time and there were few coincidences in the crosses.

CONCLUSIONS

Genotypes that combine fruit yield per plant with the traits of fruit quality, such as total soluble solids and pulp firmness were difficult to find.

It was not possible to find a genotype with desirable specific combining ability for all traits, however it was possible to select the best hybrids, based on the SCA, restricted to the experimental conditions used here, considering the morphological, fruit yield and quality traits.

The hybrid combinations with best balance between the values of specific combining ability (SCA) for the morphological, fruit yield and quality traits were: JS-12 x SS 72/12, JS-12 x São Mateus, SS72/12 x Sekati, particularly the latter.

ACKNOWLEDGEMENTS

The authors thank the Company CALIMAN AGRÍCOLA S/A for supporting the experiments, and the Financiadora de Estudos e Projetos (FINEP), for financial support.

Uso de testadores na capacidade combinatória e na seleção de híbridos de mamoeiro

RESUMO - *Os métodos de estimação da capacidade combinatória com o uso de testadores, onde um ou mais genótipos são cruzados com todo o material genético que se pretende investigar, são mais simples e mais rápidos do que os dialelos. O objetivo do trabalho foi fazer uso de testadores para selecionar híbridos que tenham capacidade produtiva e qualidade suficiente que justifique sua seleção. Foi realizado um ensaio de vinte híbridos de mamoeiro oriundos do cruzamento entre treze linhagens 'Solo', cruzados com testador 'Formosa' (JS-12), e sete linhagens 'Formosa', cruzados com testador 'Solo' (SS 72/12), em Linhares/ES, entre agosto de 2006 e julho de 2007. Obtiveram-se a Capacidade Específica de Combinação para 14 características do mamoeiro pela diferença entre a média geral e a média de cada um dos híbridos cruzados com os testadores. Os genótipos que apresentaram melhor comportamento entre seus valores de Capacidade Específica de Combinação (CEC) para características produtivas e qualidade dos frutos foram: JS-12 x SS 72/12; JS-12 x São Mateus e SS72/12 x Sekati, com destaque para o segundo.*

Palavras-chave: *Carica papaya* L., parâmetros genéticos, capacidade combinatória, Capacidade Específica de Combinação, índice de seleção.

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