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Combining ability and heterosis for agronomic traits in chili pepper

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ABSTRACT

The *Capsicum* breeding has been developed with emphasis in bell pepper (*Capsicum annuum*) and few studies are available in other species, especially *C. baccatum*, which has potential use not only as disease resistance source but also in obtaining new genotypes suitable for farmers' production. In the present work, the combining ability of ten *C. baccatum* hybrids, along with their five parentals, were tested considering 12 agronomic traits. The hybrids were produced from a complete diallel without reciprocals and assessed in greenhouse conditions, in Campos dos Goytacazes, Rio de Janeiro state, Brazil, during the period July to December 2009. The experimental design was a randomized block with three replications and the following agronomic traits evaluated: canopy diameter (CD), plant height (PH), days to fructification (DF), number of fruits per plant (NFP), mean fruit weight (FW), dry fruit matter weight (FDM), dry matter content (DM), fruit length (FL), fruit diameter (FD), pulp thickness (PT), total soluble solids (TSS) and yield per plant (PP). Significant differences were observed only for general combining ability (GCA) in regard to PH, FW, FDM, DM, PT and TSS, indicating that additive effects were involved on the control of these characters. For CD, DF, NFP, FL, FD and PP, there was significance not only for GCA but also for specific combining ability (SCA) indicating that non-additive and additive effects were important in genetic control of these traits. The hybrids UENF 1629 X UENF 1732, UENF 1616 X UENF 1732 and UENF 1624 X UENF 1639 were considered superior because they have favorable agronomic traits.

Keywords: *Capsicum baccatum* var. *pendulum*, seed hybrid production, diallel analysis, Griffing method, plant breeding.

RESUMO

Capacidade combinatória e heterose para características agronômicas em pimenta

O melhoramento de *Capsicum* tem sido desenvolvido dando-se ênfase à espécie *C. annuum*, com pouca pesquisa sendo conduzida em outras espécies, sobretudo com *C. baccatum*, que possui potencial de uso não somente como fonte de resistência a doenças, mas também na obtenção de novos genótipos para uso pelos produtores. Neste trabalho, a capacidade combinatória de dez híbridos de *C. baccatum*, bem como dos cinco parentais, foram testados considerando-se 12 características agronômicas. Os híbridos foram produzidos a partir de um dialelo completo, sem recíprocos e foram avaliados sob cultivo protegido, em Campos dos Goytacazes-RJ, no segundo semestre de 2009. O delineamento experimental foi de blocos casualizados com três repetições, e as características avaliadas foram: diâmetro da copa (DC); altura de planta (ALTP); dias para a frutificação (DF); número de frutos por planta (NFP); peso médio do fruto (PMF); massa seca do fruto (MSF); teor de massa seca (TMS); comprimento do fruto (CF); diâmetro do fruto (DIAM); espessura da polpa (ESP); teor de sólidos solúveis totais (TSS) e produção por planta (PP). Houve significância apenas para capacidade geral de combinação (CGC) em relação à ALTP, PMF, MSF, TMS, ESP e TSS, indicando que efeitos adititvos estão envolvidos no controle genético dessas características. Para DC, DF, NFP, COMP, DIAM e PP, houve significância tanto para capacidade geral de combinação (CGC) quanto para CEC, indicando que efeitos aditivos e não-aditivos são relevantes no controle das características. Os híbridos UENF 1629 x UENF 1732, UENF 1616 x UENF 1732 e UENF 1624 x UENF 1639 foram indicados como promissores por possuírem características agronômicas favoráveis.

Palavras-chave: *Capsicum baccatum* var. *pendulum*, produção de híbridos, análise dialélica, método de Griffing, melhoramento de plantas.

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The market for hot peppers of the *Capsicum* genus in Brazil has become very important in the vegetable economic scenario mainly because of the great variety of products and by-products, uses and forms of consumption (Moreira *et al*., 2006; Bento *et al*., 2007; Henz & Ribeiro, 2008; Sudré *et al*., 2010). Although it is difficult to measure the real size and importance of this market since no reliable statistics and systematized information are available, obtaining improved cultivars in the various species that comprise this genus is a potential area to amplify and sustain the pepper agribusiness (Moura *et al*., 2010).

Of the 31 species of *Capsicum* found and described to date, only five are cropped commercially: *C. annuum*, *C. baccatum*, *C. chinense*, *C. frutescens* and *C. pubescens* (Moscone *et al*., 2007; Moura *et al*., 2010). The *C. baccatum* species has high genetic variability, shown principally in the fruit that can have different shapes, coloring, sizes and pungency levels (Lannes *et al*., 2007; Rêgo *et al*., 2009). The most cultivated types of this species in Brazilian conditions include 'Dedo de moça' and 'Cambuci' (Carvalho *et al*., 2003).

In Brazil, five pepper cultivars

of *C. baccatum* are registered in the National Cultivar Register (RNC) of the Ministry of Agriculture, Fishing and Supply (Mapa, 2011). This number is lower than registrations observed for *C. annuum*, *C. frutescens* and *C. chinense* cultivars (491, 56 and 19 registrations, respectively). Further, most of the registrations of *C. baccatum* cultivars were made by private seed companies that do not have *Capsicum* breeding programs in Brazil. Only two cultivars have been developed by Brazilian public research institutions, 'BRS Mari', released by Embrapa Hortaliças (Carvalho *et al*., 2009) and 'IAC Ubatuba', registered by the Instituto Agronômico de Campinas (IAC), in 2001 (Mapa, 2011). In the case of 'BRS Mari' the breeding method used was mass selection over six generations with controlled self-pollination, from the CNPH0039 accession. There are no registrations in Brazil of *C. baccatum* commercial hybrids to date, and this segment is little exploited for hot pepper cropping in Brazil.

The characteristics yield, disease and pest resistance, plant architecture, earliness, easy fruit picking during harvest and the fruit characteristics (coloring, flavor, aroma, shape, size, pulp thickness and pungency) are the main targets of the *Capsicum* breeding programs (Rêgo *et al*., 2009). Thus knowledge of the genetic control of these characteristics is very important for efficient breeding programs, orientation for choosing selection procedures and the most efficient breeding methods in advancing segregant populations (Cruz & Regazzi, 2001). Genetic designs include the diallel crosses that are outstanding because they allow the plant breeding to obtain large amount of information helping in tasks, such as parent choice for hybridization, identification of the most efficient selection and knowledge of the genetic bases that control the characteristics (Ramalho *et al*., 1993).

The few studies carried out with diallel in *Capsicum* in Brazil have concentrated almost exclusively on crosses among sweet pepper cultivars (Souza & Maluf, 2003). Most studies on the *C. baccatum* species have researched pre-breeding conditions. However, this situation tends to change, especially because of farmer's interest in new genotypes that meet the requirements of greater yield, fruit uniformity and quality. An example is the study published by Rêgo *et al*. (2009), who estimated the general combining ability (GCA) and the specific combining ability (SCA) of eight *C. baccatum* accessions for the characteristics fruit quality and yield. The authors observed that both additive and non-additive effects influenced the hybrid performance for all the characteristics tested. Line selection from segregant generations and obtaining hybrids to exploit heterosis or heterobeltiosis can be used appropriately in breeding these genotypes.

The objective of the present research were to study the combining ability of *C. baccatum* var. *pendulum* accession lines regarding their agronomic characteristics, to identify superior hybrid combinations and to determine the genetic action involved in the expression of the studied traits.

MATERIAL AND METHODS

Five *Capsicum baccatum* var. *pendulum* lines from the germplasm collection from Universidade Estadual do Norte Fluminense Darcy Ribeiro (UENF) identified as UENF 1616, UENF 1624, UENF 1629, UENF 1639 and UENF 1732, were studied. These accessions were previously characterized by Bento *et al*. (2007, 2009) and Moura *et al*. (2010). The crosses involving the five parents were carried out in a complete diallel scheme without reciprocals, obtaining a total of ten hybrids. The hybridizations were carried out in a greenhouse using eight pots per parent, each pot containing one plant, and the crosses were made between April and June 2008.

The pollen was collected from each male parent as soon as the flower buds were opened. Recently opened flower buds from each one of the male parents were collected to remove the pollen. The pollen obtained from each parent was stored in a refrigerator in labeled recipients containing silica gel. The flower buds from plants of the five female parents were emasculated in the morning before anthesis, using pincers. In the same period, to pollinate, pollen grains from each one of the male parents were placed on the stigma of each emasculated flower. Labels were used to identify the fruits resulting from each different type of cross.

To assess the agronomic characteristics, the hybrids and parents were cultivated n greenhouse in Campos dos Goytacazes. A randomized block design was used with three replications and 12 plants per plot, considering all the plants as useful area of the experiment. The IAC Ubatuba cultivar was used as a border. The spacing adopted was 1.1 x 0.9 m between rows and plants.

During the experiment, pepper plants were grown according to the regular recommendations for the pepper crop made by Filgueira (2005) such as weeding, tutoring, fertilization and drip irrigation. Five harvests were made and the following agronomic characteristics were assessed: canopy diameter (CD) (measured in centimeters, when 50% of the plants in the plot produced ripe fruits); plant height (PH) (measured in centimeters when 50% of the plants in the plot produced ripe fruits); days to fructification (DF) (number of days from transplant until 50% of the plants in the plot produced ripe fruits in the first and/or second bifurcations); number of fruits per plant (NFP) (sum of the number of fruits obtained in the five harvests); mean fruit weight (FW) (mean weight in grams using the ratio between total weight of fruit per plant and number of fruits per plant); dry fruit matter weight (FDM) (mean weight in grams of five dried fruits per plant, using a forced air circulation chamber at 65°C during 72 hours); dry matter contents (DM) (ratio between FDM and FW, multiplied by 100); fruit length (FL) (measured in centimeters considering five fruits per plant); fruit diameter (FD) (measured in millimeters considering five fruits per plant); pulp thickness (PT) (measured in millimeters considering five fruits per plant); total soluble solids content (TSS) (measured in five fruits per plant, using a digital refractometer); and yield per plant (PP) (multiplication of NFP and

FW (kg/plant)).

Analysis of variance was performed for each characteristic and the mean of the 15 treatments was compared by the Scott-Knott cluster test (1974). Diallel analysis was performed according to Griffing's method (1956) considering method 2 and fixed model to estimate the general and specific combining abilities of the parents and hybrids. The analysis were carried out with the Genes software (Cruz, 2006).

RESULTS AND DISCUSSION

The genotypes effect for all the traits was significant by the F test (data not shown). The coefficient of experimental variation values were lower than 20% for most of the characteristics assessed except for NFP and PP, that had values of 24.17 and 23.90%, respectively (Table 1). These results reflected the good experimental accuracy and guaranteed

Table 1. Averages of 12 agronomic traits evaluated in five genitors and 10 hybrids of *Capsicum baccatum* var. *pendulum*, followed by the group averages between Scott-Knott (médias de 12 características agronômicas avaliadas em cinco genitores e 10 híbridos de *Capsicum baccatum* var. *pendulum*, seguidas pelo agrupamento entre médias de Scott-Knott). Campos dos Goytacazes, UENF, 2010.

Genotypes	Agronomic characteristics[1]					
	CD	PH	DF	NFP	FW	FDM
UENF 1616	65.31 b	59.60 a	147.00 a	50.88 c	24.25 a	3.96 a
UENF 1624	45.93 c	62.89 a	140.67 b	58.33 c	9.36 c	1.44 c
UENF 1629	77.22 a	63.99 a	138.33 b	37.64 c	28.06 a	4.79 a
UENF 1732	64.96 b	68.20 a	140.00 b	75.52 b	12.64 c	2.09 c
UENF 1639	75.62 a	71.82 a	137.33 c	51.61 c	23.54 a	3.83 a
UENF 1616 X UENF 1624	77.75 a	66.37 a	137.00 c	72.65 b	16.23 c	2.63 c
UENF 1616 X UENF 1629	79.99 a	56.59 a	135.33 c	56.94 c	20.98 b	4.18 a
UENF 1616 X UENF 1732	70.89 a	63.94 a	134.00 c	68.92 b	22.29 b	3.61 b
UENF 1616 X UENF 1639	76.92 a	68.89 a	133.67 c	67.62 b	19.84 b	3.13 b
UENF 1624 X UENF 1629	79.96 a	68.73 a	136.67 c	54.34 c	18.54 b	3.05 b
UENF 1624 X UENF 1732	70.24 a	65.19 a	132.67 c	87.13 b	13.07 c	2.08 c
UENF 1624 X UENF 1639	83.97 a	74.85 a	131.67 c	108.90 a	12.85 c	1.98 c
UENF 1629 X UENF 1732	88.48 a	73.52 a	133.33 c	79.52 b	22.01 b	3.47 b
UENF 1629 X UENF 1639	72.08 a	61.32 a	132.67 c	44.54 c	25.76 a	4.06 a
UENF 1732 X UENF 1639	79.77 a	75.07 a	134.00 c	64.23 c	20.63 b	3.34 b
CV (%)	11.81	9.65	2.06	24.17	15.08	13.81
	DM	FL	FD	PT	TSS	PP
UENF 1616	18.45 a	105.80 a	25.99 d	2.47 b	11.15 a	1.23 b
UENF 1624	15.38 a	82.20 b	18.73 e	2.10 b	8.12 b	0.55 c
UENF 1629	17.11 a	91.74 b	33.79 c	3.11 a	9.71 a	1.06 b
UENF 1732	16.73 a	40.89 d	42.60 b	2.55 b	7.82 b	0.94 b
UENF 1639	16.56 a	44.64 d	48.66 a	3.09 a	9.85 a	1.19 b
UENF 1616 X UENF 1624	16.23 a	99.97 a	24.42 d	2.30 b	9.05 b	1.18 b
UENF 1616 X UENF 1629	17.82 a	105.70 a	29.09 c	2.64 b	9.87 a	1.18 b
UENF 1616 X UENF 1732	16.25 a	71.50 c	37.86 b	2.90 a	9.97 a	1.53 a
UENF 1616 X UENF 1639	15.82 a	80.86 b	31.76 c	2.65 b	10.37 a	1.35 b
UENF 1624 X UENF 1629	16.60 a	109.55 a	25.42 d	2.41 b	8.72 b	0.95 b
UENF 1624 X UENF 1732	16.07 a	64.88 c	25.28 d	2.38 b	8.01 b	1.16 b
UENF 1624 X UENF 1639	15.46 a	68.45 c	27.14 d	2.39 b	8.92 b	1.40 a
UENF 1629 X UENF 1732	15.81 a	67.56 c	37.68 b	2.77 a	9.90 a	1.74 a
UENF 1629 X UENF 1639	15.80 a	84.64 b	36.52 b	3.16 a	9.06 b	1.13 b
UENF 1732 X UENF 1639	15.30 a	42.47 d	51.47 a	2.89 a	8.76 b	1.31 b
CV (%)	6.46	7.86	10.29	10.01	8.01	23.90

[1]CD= canopy diameter (diâmetro da copa (cm)); PH= plant height (altura da planta (cm)); DF= days for fruiting (dias para frutificação); NFP= number of fruits per plant (número de frutos por planta); FW= mean fruit weight (peso médio do fruto (g)); FDM= fruit dry mass (massa seca do fruto (g)); DM= dry matter (teor de matéria seca (%)); FL= fruit lenght (comprimento do fruto (mm)); FD= fruit diameter (diâmetro do fruto (mm)); PT= pulp thickness (espessura da polpa (mm)); TSS= total soluble solids content (teor de sólidos solúveis totais (%)); PP= yield per plant (produção por planta (kg planta^{-1})).

Table 2. Estimates of the effects of general combining ability ($\hat{g}_i$) for 12 agronomic traits in five parents of *Capsicum baccatum* var. *pendulum* evaluated in complete diallel without reciprocal (estimativas dos efeitos da capacidade geral de combinação ($\hat{g}_i$) para 12 características agronômicas avaliadas em cinco genitores de *Capsicum baccatum* var. *pendulum* em esquema de dialelo completo, sem os recíprocos). Campos dos Goytacazes, UENF, 2010.

Parents	Agronomic characteristics[1]					
	CD	**PH**	**DF**	**NFP**	**FW**	**FDM**
UENF 1616	-1.066	-3.628	2.324	-3.375	1.688	0.345
UENF 1624	-5.696	0.076	0.229	6.882	-5.229	-0.920
UENF 1629	4.473	-1.751	-0.438	-11.553	3.912	0.755
UENF 1732	-0.618	1.963	-0.533	8.474	-1.820	-0.338
UENF 1639	2.906	3.340	-1.581	-0.428	1.450	0.159
	DM	**FL**	**FD**	**PT**	**TSS**	**PP**
UENF 1616	0.695	15.042	-3.351	-0.069	0.835	0.079
UENF 1624	-0.434	6.130	-8.405	-0.322	-0.682	-0.196
UENF 1629	0.299	12.370	-0.326	0.181	0.180	-0.007
UENF 1732	-0.180	-19.450	5.561	0.017	-0.490	0.066
UENF 1639	-0.380	-14.092	6.521	0.193	0.156	0.058

[1]CD= canopy diameter (diâmetro da copa (cm)); PH= plant height (altura da planta (cm)); DF= days for fruiting (dias para frutificação); NFP= number of fruits per plant (número de frutos por planta); FW= mean fruit weight (peso médio do fruto (g)); FDM= fruit dry mas (massa seca do fruto (g)); DM= dry matter (teor de matéria seca (%)); FL= fruit lenght (comprimento do fruto (mm)); FD= fruit diameter (diâmetro do fruto (mm)); PT= pulp thickness (espessura da polpa (mm)); TSS= total soluble solids content (teor de sólidos solúveis totais (%)); PP= yield per plant (produção por planta (kg planta^{-1})).

the validity of the conclusions inferred.

By the Scott-Knott (1974) cluster test, five groups were formed for FD, four groups for FL, three groups for CD, DF, NFP, FW, FDM and PP, two groups for PT and TSS and only one group for PH and DM (%) (Table 1). These results ratified the results obtained by the F test and showed the variability among the genotype studied.

For CD, all the hybrids were placed in the group of the highest mean. The UENF 1629 x UENF 1732 hybrid had the highest value (88.48 cm), while the lowest value was recorded for the UENF 1624 x UENF 1732 combination (70.24 cm). Regarding the parents, the highest values were for UENF 1629 and UENF 1639 (77.2 and 75.6 cm, respectively), and these were placed in the same group as the hybrids while the UENF 1624 parent had the lowest CD (45.93 cm). This characteristic is important in crop management related to spacing. Genotypes with smaller canopy diameters allow smaller spacing, placing a greater number of plants per area unit, and can favor better use of the cropping area and increased yield.

The UENF 1616 parent was the latest with 147 days to fructification, while UENF 1639 had the shortest cycle (137.33 days) and was placed in the group with the lowest DF values, together with the hybrids that ranged from 131.67 (UENF 1624 x UENF 1639) to 137 days (UENF 1616 x UENF 1624).

For the NFP characteristic, UENF 1732 was outstanding with a yield of 75.52 fruits per plant. Regarding the hybrids, the greatest NFP was recorded for UENF 1624 x UENF 1639 with 108.9 fruits per plant.

Regarding the FW and FDM traits, the parents UENF 1616, UENF 1629 and UENF 1639 produced the heaviest fruits (24.25, 28.06, and 23.54 g, respectively) and consequently greatest dry matter (3.96, 4.79, and 3.83 g, respectively). The UENF 1629 x UENF 1639 hybrid had the greatest FW and FDM, with 25.76 g and 4.06 g, respectively. Rêgo *et al*. (2011) assessed diversity in 40 *C. baccatum* accessions and observed wide variation for FW (1.38 to 25.07 g) and FDM (0.40 to 3.96 g). According to Rêgo *et al*. (2009) the *C. baccatum* species has high genetic variability shown principally because the fruits can have different shapes, sizes and weights.

Variability was observed for FL and FD among the parents, ranging from 40.89 to 105.80 mm for length and 18.75 to 48.66 mm for diameter. This was reflected in greater amplitude among the hybrids that ranged from 42.47 to 109.55 mm for length and 24.42 to 51.47 mm for diameter. The variation was smaller for PT and TSS, from 2.10 to 3.11 m and 7.82 to 11.15° Brix, respectively, among the parents, and from 2.30 to 3.16 mm and 8.01 to 10.37° Brix, respectively, among the hybrids. Rêgo *et al*. (2009) assessed TSS and observed the formation of three groups, with a variation of 6.70 to 13.10° Brix. According to Lannes *et al*. (2009) and Rêgo *et al*. (2009, 2011), fruit with higher TSS concentrations are more suitable for dehydrating and paprika production.

Among the parents, UENF 1624 obtained the lowest yield per plant, with 0.55 kg/plant followed by UENF 1732, UENF 1629, UENF 1639 and UENF 1616, with 0.94, 1.06, 1.19 1.23 kg/plant, respectively. Among the hybrids, UENF 1629 x UENF 1732, UENF 1616 x UENF 1732 and UENF 1624 x UENF 1639 were the most productive, with 1.74, 1.53 and 1.40 kg/plant, respectively.

The partitioning of the sum of the squares of the genotypes, in the sum

Table 3. Estimates of the effects of specific combining ability ($\hat{s}_{ii}$ and $\hat{s}_{ij}$) for 12 agronomic traits in five parents of *Capsicum baccatum* var. *pendulum* evaluated in complete diallel without reciprocal (estimativas dos efeitos da capacidade específica de combinação ($\hat{s}_{ii}$ e $\hat{s}_{ij}$) para 12 características avaliadas entre cinco genitores de *Capsicum baccatum* var. *pendulum* em esquema de dialelo completo, sem os recíprocos). Campos dos Goytacazes, UENF, 2010.

Effects ($\hat{s}_{ii}$ and $\hat{s}_{ij}$)	Agronomic characteristics[1]					
	CD	PH	DF	NFP	FW	FDM
UENF 1616	-6.49	0.12	6.06	-7.63	1.54	0.09
UENF 1616 X UENF 1624	10.57	3.19	-1.84	3.89	0.44	0.03
UENF 1616 X UENF 1629	2.64	-4.76	-2.84	6.62	-3.96	-0.10
UENF 1616 X UENF 1732	-1.36	-1.12	-4.08	-1.43	3.08	0.43
UENF 1616 X UENF 1639	1.14	2.45	-3.36	6.17	-2.63	-0.55
UENF 1624	-16.62	-3.99	3.92	-20.68	0.49	0.10
UENF 1624 X UENF 1629	7.24	3.67	0.59	-6.24	0.52	0.04
UENF 1624 X UENF 1732	2.61	-3.58	-3.32	6.52	0.78	0.16
UENF 1624 X UENF 1639	12.82	4.70	-3.27	37.19	-2.71	-0.43
UENF 1629	-5.67	0.76	2.92	-4.50	0.90	0.10
UENF 1629 X UENF 1732	10.69	6.58	-1.98	17.35	0.58	-0.12
UENF 1629 X UENF 1639	-9.24	-7.00	-1.60	-8.73	1.07	-0.03
UENF 1732	-7.74	-2.45	4.78	-6.68	-3.05	-0.41
UENF 1732 X UENF 1639	3.54	3.04	-0.17	-9.07	1.67	0.34
UENF 1639	-4.13	-1.59	4.21	-12.78	1.30	0.34
	DM	FL	FD	PT	TSS	PP
UENF 1616	0.70	-1.67	-0.40	-0.04	0.19	-0.12
UENF 1616 X UENF 1624	-0.39	1.41	3.09	0.04	-0.39	0.11
UENF 1616 X UENF 1629	0.47	0.90	-0.33	-0.13	-0.43	-0.09
UENF 1616 X UENF 1732	-0.63	-1.48	2.55	0.30	0.34	0.19
UENF 1616 X UENF 1639	-0.86	2.52	-4.50	-0.13	0.10	0.02
UENF 1624	-0.11	-7.45	2.45	0.09	0.20	-0.25
UENF 1624 X UENF 1629	0.38	13.66	1.06	-0.11	-0.06	-0.04
UENF 1624 X UENF 1732	0.33	0.81	-4.97	0.03	-0.10	0.09
UENF 1624 X UENF 1639	-0.09	-0.98	-4.07	-0.13	0.16	0.34
UENF 1629	0.15	-10.39	1.35	0.09	0.07	-0.12
UENF 1629 X UENF 1732	-0.67	-2.75	-0.65	-0.08	0.92	0.49
UENF 1629 X UENF 1639	-0.48	8.97	-2.77	0.13	-0.56	-0.11
UENF 1732	0.73	2.40	-1.61	-0.13	-0.49	-0.38
UENF 1732 X UENF 1639	-0.49	-1.37	6.29	0.02	-0.19	-0.01
UENF 1639	0.96	-4.57	2.52	0.05	0.25	-0.12

[1]CD= canopy diameter (diâmetro da copa (cm)); PH= plant height (altura da planta (cm)); DF= days for fruiting (dias para frutificação); NFP= number of fruits per plant (número de frutos por planta); FW= mean fruit weight (peso médio do fruto (g)); FDM= fruit dry mas (massa seca do fruto (g)); DM= dry matter (teor de matéria seca (%)); FL= fruit lenght (comprimento do fruto (mm)); FD= fruit diameter (diâmetro do fruto (mm)); PT= pulp thickness (espessura da polpa (mm)); TSS= total soluble solids content (teor de sólidos solúveis totais (%)); PP= yield per plant (produção por planta (kg planta^{-1})).

of the squares for GCA and SCA, showed that GCA was significant for all characteristics studied indicating that additive effects were involved in the genetic control of these traits. This result is important, especially when dealing with a self- pollinating species such as *C. baccatum*, implying that the higher values for these characteristics can be fixed over successive self-pollination generations to obtain lines superior to those existing today. It is emphasized that there was no significance in terms of SCA for PH, FW, FDM, DM, PT and TSS indicating that non-additive effects were not involved in the control of these traits. On the other hand, for CD, DF, NFP, FL, FD and PP additive and non-additive effects are relevant in the genetic control of these characteristics since there was significant difference for GCA and SCA.

Rêgo *et al*. (2009) assessed different characteristics for food quality and

Table 4. Estimates of the heterosis (%) for 12 agronomic traits in five parents of *Capsicum baccatum* var. *pendulum* evaluated in complete diallel without reciprocal (estimativas de heterose (%) para 12 características agronômicas entre cinco genitores de *Capsicum baccatum* var. *pendulum* em esquema dialelo, sem recíprocos). Campos dos Goytacazes, UENF, 2010.

Hybrids	Agronomic characteristics[1]					
	CD	PH	DF	NFP	FW	FDM
UENF 1616 X UENF 1624	39.77	8.37	-4.75	33.05	-3.41	-2.42
UENF 1616 X UENF 1629	12.23	-8.41	-5.14	28.66	-19.78	-4.47
UENF 1616 X UENF 1732	8.83	0.07	-6.62	9.05	20.82	19.39
UENF 1616 X UENF 1639	9.16	4.84	-5.97	31.95	-16.96	-19.71
UENF 1624 X UENF 1629	29.85	8.33	-2.03	13.24	-0.92	-1.93
UENF 1624 X UENF 1732	26.67	-0.55	-5.46	30.18	18.78	17.88
UENF 1624 X UENF 1639	38.16	11.13	-5.27	98.09	-21.92	-24.78
UENF 1629 X UENF 1732	24.46	11.23	-4.19	40.55	8.15	0.83
UENF 1629 X UENF 1639	-5.67	-9.70	-3.75	-0.19	-0.12	-5.85
UENF 1732 X UENF 1639	13.49	7.22	-3.36	1.04	14.05	12.83
	DM	FL	FD	PT	TSS	PP
UENF 1616 X UENF 1624	-4.07	6.35	9.23	0.68	-6.08	32.51
UENF 1616 X UENF 1629	0.23	7.02	-2.68	-5.41	-5.41	2.79
UENF 1616 X UENF 1732	-7.64	-2.51	10.39	15.42	5.11	40.77
UENF 1616 X UENF 1639	-9.65	7.50	-14.90	-4.74	-1.19	11.81
UENF 1624 X UENF 1629	2.19	25.96	-3.19	-7.51	-2.15	18.80
UENF 1624 X UENF 1732	0.11	5.41	-17.55	2.28	0.56	54.89
UENF 1624 X UENF 1639	-3.20	7.93	-19.44	-7.73	-0.72	60.87
UENF 1629 X UENF 1732	-6.55	1.89	-1.36	-2.21	12.93	74.10
UENF 1629 X UENF 1639	-6.16	24.13	-11.42	2.06	-7.39	0.80
UENF 1732 X UENF 1639	-8.04	-0.67	12.80	2.35	-0.83	22.88

[1]CD= canopy diameter (diâmetro da copa (cm)); PH= plant height (altura da planta (cm)); DF= days for fruiting (dias para frutificação); NFP= number of fruits per plant (número de frutos por planta); FW= mean fruit weight (peso médio do fruto (g)); FDM= fruit dry mas (massa seca do fruto (g)); DM= dry matter (teor de matéria seca (%)); FL= fruit lenght (comprimento do fruto (mm)); FD= fruit diameter (diâmetro do fruto (mm)); PT= pulp thickness (espessura da polpa (mm)); TSS= total soluble solids content (teor de sólidos solúveis totais (%)); PP= yield per plant (produção por planta (kg planta^{-1})).

yield in *C. baccatum* and observed significance for GCA and SCA effects for most of the characteristics, except for height of the first bifurcation that was significant only for SCA.

The estimates of the quadratic components indicated that the characteristics PH, FW, FDM, DM, FL, FD, PT and TSS expressed superiority of the additive genetic effects, compared to non-additive, indicating the possibility of satisfactory gains with selection for these characteristics in segregant generations. The opposite was observed for CD, FD, NFP, and PP, that is, non-additive effects predominated that could be exploited in the hybrids or alternatively could require the implementation of more complex breeding strategies, in the case of avancing segregant populations to obtain recombinant lines. Gonçalves *et al.* (2011) assessed the same set of hybrids and observed that effects of dominance were predominant for fruit production per plant, based on Hayman (1954) method for diallel analyses that corroborated the results according to Griffing (1956).

Although there are few studies published on *C. baccatum* genetics and breeding, there was agreement between the results obtained for a set of characteristics studied by Rêgo *et al*. (2009) and the results reported in the present study, except for TSS. Non-additive effects for TSS were reported by Rêgo *et al*. (2009), while in the present study both additive and non-additive effects were observed.

The choice of parents to form segregant populations is crucial for successful breeding programs and the combining ability, with the presence of complementary genes, is largely responsible for the success. According to Sprague & Tatum (1942) low GCA value indicates that the mean of the hybrids in which line **i** participates do not differ from the general mean of the diallel cross. On the other hand, high positive or negative values, show that line **i** is much better or worse than the other lines included in the diallel cross, in relationship to the mean of its hybrids.

The UENF 1624 parent can be recommended in crosses for combinations with smaller canopy diameter and a greater number of fruits per plant, because this parent had negative GCA values and high values for CD and positive values for NFP. However, this parent is unsuitable for crosses when the objective is to increase the dry matter content, pulp thickness, total soluble solids content and production per plant, because it had negative GCA values for the respective characteristics (Table 2). The parent UENF 1616 can also be recommended for use in crossings to decrease canopy sizes and the PH because it had negative GCA values and high values for CD and PH. The genitor UENF 1616 also presented positive and high values of GCA for DM (%) and TSS, contributing to increased dry matter and solid soluble content in the crosses in which took part. In contrast, this accession obtained negative GCA values for NFP.

The UENF 1732 parent also obtained negative GCA values for CD and FD and a high GCA value for NFP and PP. However, negative GCA values were observed for DM (%) and TSS for this parent. This indicated that this accession, when used in crosses, contributes to reducing CD and FD, thus producing more compact and early plants, with high yield in terms of NFP and PP. For the parents UENF 1629 and UENF 1639, high negative GCA values for FD were observed, and these results are of interest for breeding because they shorten the crop cycle in the field. However, the same parents obtained negative GCA values for NFP that is not desirable because it implies a negative contribution to yield. Regarding production, the UENF 1639 parent obtained positive GCA values unlike the UENF 1629 parent who obtained negative values.

According to Sprague & Tatum (1942) the SCA effect is interpreted as the deviation of the hybrid in relation to the expected based on the GCA of its parents. Thus, s_{ij} values close to zero indicate that the hybrids perform as expected based on the GCA values, while high absolute s_{ij} values indicate a better or worse performance than expected.

Regarding the hybrids, the combinations UENF 1616 x UENF 1732 and UENF 1629 x UENF 1639 gave the best results for the CD characteristic because they registered negative values for s_{ij}. This result was not expected for the UENF 1629 x UENF 1639 combination because none of its parents had negative GCA value (Table 3). Regarding the heterosis value, only the UENF 1629 x UENF 1639 combination presented negative values, that showed that this hybrid was better than expected based on the GCA of the parents (Table 4).

Five combinations were outstanding for NFP: UENF 1624 x UENF 1639, UENF 1629 x UENF 1732, UENF 1616 x UENF 1629, UENF 1624 x UENF 1732 and UENF 1616 x UENF 1639 with the highest s_{ij} estimates (Table 3). However, according to the estimates of the mean GCA effect, only the UENF 1624 and UENF 1632 parents were superior, because they had high positive values. Thus only the UENF 1624 x UENF 1639, UENF 1629 x UENF 1732 and UENF 1624 x UENF 1732 combinations are promising because they had at least one superior parent for the mean GCA effect compared to the characteristic assessed. These combinations had heterosis values of 98.09%, 40.55% and 30.80%, respectively (Table 4).

The best combinations for FD resulted from the UENF 1732 and UENF 1639 parents because they expressed negative values for the s_{ij} estimate for all the combinations in which they took part. The UENF 1616 x UENF 1632 hybrid registered the lowest s_{ij} and heterosis values (Table 3 and 4).

The best combinations for DM (%) were UENF 1616 x UENF 1629, UENF 1624 x UENF 1629 and UENF 1624 x UENF 1732 because they expressed high positive values for the s_{ij} estimate (Table 3). However, only the combinations UENF 1616 x UENF 1629 and UENF 1624 x UENF 1629 had at least one other parent with desirable values to estimate the mean GCA effect. These hybrids obtained heterosis values of 0.23%, 2.19% 0.11%, respectively (Table 4).

It was endeavored to find for the TSS characteristic combinations with higher total soluble solid content. Thus the most promising combinations were those that expressed positive value for the characteristic, which were UENF 1616 x UENF 1732, UENF 1624 x UENF 1639 and UENF 1629 x UENF 1732. However, positive heterosis values, 5.11% and 12.93%, respectively, were observed only for the combinations UENF 1616 x UENF 1732 and UENF 1629 x UENF 1732 (Table 4).

For the PP characteristic, combinations were sought with high, positive s_{ij} values. It was observed that the parents UENF 1616 x UENF 1624, UENF 1616 x UENF 1732, UENF 1624 x UENF 1732, UENF 1624 x UENF 1639 and UENF 1629 x UENF 1732 had high, positive values for s_{ij} and heterosis, especially the UENF 1624 x UENF 1639 and UENF 1629 x UENF 1732, with s_{ij} values of 0.34 0.49 and heterosis of 60.87% and 74.10%, respectively (Tables 3 and 4).

The results showed that the UENF 1629 x UENF 1732, UENF 1616 x UENF 1732 and UENF 1624 x UENF 1639 hybrid combinations were promising for testing in experiments with replications for possible commercial indication and also to derive segregant populations and start a *C. baccatum* var. *pendulum* breeding program with the objective of obtaining recombined lines, because they combine favorable agronomic characteristics, such as yield per plant and soluble solid contents.

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