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Gene effect and heterosis in C*apsicum baccatum* var. *pendulum*

Efeito gênico e heterose em cruzamentos de *Capsicum baccatum* var. *pendulum*

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ABSTRACT

*Heterosis has been exploited in **Capsicum annuum** commercial hybrids; however, the use of heterosis in **C. baccatum** still remains to be explored, and studies related to the genetics and breeding of this species are scarce. The present study aimed to estimate the combining ability of five parents of **C. baccatum** var. **pendulum**, representatives of two distinct types of fruits (namely, lady's finger and cambuci), to calculate heterosis and to evaluate the agronomic potential of the hybrids for yield and fruit quality. The hybrids were produced from a complete diallel without reciprocals. The parents and hybrids were evaluated under field conditions in a randomized block design with three replications, and the following traits were assessed: number of fruits per plant, fruit weight, yield per plant, fruit length, fruit diameter and soluble solids. All traits were significant for general and specific combining ability, indicating that additive and non-additive effects are involved in the genetic control of these traits. The hybrid combinations between the types lady's finger and cambuci provided elongated fruits with smaller diameters and greater weight compared with the parents of the cambuci type. However, these factors did not lead to a significant increase in the yield per plant due to the decreased number of fruits except in hybrid UENF 1616 x UENF 1732. Considering only the parents and hybrids within each type of fruit, the genitor UENF 1624 (lady's finger) and the hybrid UENF 1639 x UENF 1732 (cambuci x cambuci) stood out for achieving a high yield per plant.*

Key words: *chili peppers, combining ability, diallel analysis, cambuci chili pepper, lady's finger chili pepper.*

RESUMO

*Embora heterose seja bem explorada na produção de híbridos comerciais de **C. annuum**, em **C. baccatum,** o uso da heterose permanece como um potencial e estudos relacionados à genética e ao melhoramento dessa espécie são escassos. Os objetivos deste trabalho foram estimar a capacidade combinatória entre cinco genitores de **C. baccatum** var. **pendulum**, representantes de dois grupos distintos de tipos de frutos (dedo-de-moça e cambuci); calcular a heterose e avaliar o potencial agronômico dos híbridos produzidos em termos de produção e qualidade dos frutos. Os híbridos foram produzidos a partir de um dialelo completo, sem recíprocos. Os genitores e os híbridos foram avaliados em condições de campo, no delineamento de blocos ao acaso, com três repetições, sendo avaliadas as seguintes características: número de frutos por planta, massa média do fruto, produção por planta, comprimento do fruto, diâmetro do fruto e teor de sólidos solúveis. Todas as características foram significativas para a capacidade geral e específica de combinação, indicando que efeitos aditivos e não-aditivos estão envolvidos no controle genético dessas características. As combinações híbridas entre os tipos dedo-de-moça e cambuci proporcionaram frutos alongados, com menores diâmetros e maior peso, quando comparado com os genitores do tipo cambuci. Contudo, esses fatores não favoreceram um aumento expressivo na produção por planta em virtude da diminuição do número de frutos, com exceção para o híbrido UENF 1616 x UENF 1732. Considerando somente os genitores e os híbridos dentro de cada tipo de fruto, destaca-se a linhagem UENF 1624 (dedo-de-moça) e o híbrido UENF 1639 x UENF 1732 (cambuci x cambuci) em relação à produção por planta.*

Palavras-chave: *pimentas, capacidade de combinação, análise dialélica, pimenta cambuci, pimenta dedo-de-moça.*

INTRODUCTION

The cultivation of peppers (***Capsicum*** spp.) has played an important role in the market of fresh vegetable crops, condiments, spices and preserved food in Brazil (FONSECA et al., 2008; MOURA et al., 2010; SUDRÉ et al., 2010). This market is

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quite diverse, with a great variety of colors, shapes and flavors, and the most well-known species are ***C. annuum*** (sweet pepper and jalapeño), ***C. chinense*** (*pimenta de cheiro*, *pimenta-bode*, *cumari-do-pará*, *biquinho* and *habanero*), ***C. frutescens*** (*malagueta* and *tabasco*) and ***C. baccatum*** (lady's finger, ají, *cambuci* and *cumari*).

Among these species, ***C. baccatum*** is considered the most widely consumed in Brazil, mainly in the southern and southeastern areas of the country. In addition, there is increasing interest from the scientific community in these fruits because, among other reasons, they are rich in antioxidant compounds (FERRÃO et al., 2011; ZIMMER et al., 2012). Nevertheless, there are few studies on the breeding of this species, and until June2012, only 15 cultivars of ***C. baccatum*** were listed in the National Register of Cultivars (RNC) of the Brazilian Ministry of Agriculture, Livestock and Supply (MAPA). Most of these cultivars belong to private seed companies that do not develop ***Capsicum*** breeding programs in Brazil (MAPA, 2012; RODRIGUES et al., 2012). Therefore, the development of breeding programs aimed at providing inbred lines and/or hybrids with high agronomic potential, resistance to pests and diseases and adaptation to different edaphoclimatic conditions in Brazil is of paramount importance to increase ***C. baccatum*** production in Brazil.

The commercial use of F_1 hybrids in peppers has been considered a viable and commercially attractive alternative, mainly to achieve traits whose predominant effects are non-additive (RÊGO et al., 2011). However, the results of intra-specific hybridization in ***C. baccatum*** are scarce in the literature (RÊGO et al., 2009; GONÇALVES et al., 2011; RODRIGUES et al., 2012).

This study aimed to determine the combining abilities of five parents of ***C. baccatum*** var. ***pendulum***, which represent two distinct types of fruits (lady's finger and cambuci), to calculate heterosis and to evaluate the agronomic potential of hybrids for fruit production and quality.

MATERIALS AND METHODS

Ten hybrids of ***C. baccatum*** var. ***pendulum*** produced by GONÇALVES et al. (2011), using a genetic full diallel design without reciprocals, were evaluated. The following accessions were used as parents: UENF 1616, UENF 1624, UENF 1629, UENF 1639 and UENF 1732 from the Germplasm Collection of the Universidade Estadual do Norte Fluminense Darcy Ribeiro (UENF), characterized by MOURA et al. (2010) and evaluated for resistance to pepper yellow mosaic virus by BENTO et al. (2009) (Table 1).

The ten experimental hybrids and five parents were grown in a field in the Research Support Unit at the Center for Agricultural Science and Technology (UAP/CCTA), on the *campus* of the UENF, located in Campos dos Goytacazes, RJ. The experiment was arranged in a randomized block design with three replications. The spacing between rows and between plants in the row was 1.2m and 1.0m, respectively. Each plot was composed of two rows of 4.0m in length, with a total of eight plants.

During the experiment, the cultural treatments commonly recommended for the chili pepper crop were performed (FILGUEIRA, 2005), including weeding, guiding, fertilization and irrigation. Five harvests were carried out, and the following agronomic traits were assessed: number of fruits per plant (NFP); fruit weight (FW), in g; yield per plant (YP), in kg plant^{-1}; fruit length (FL), in mm; fruit diameter (FD), in mm; and content of total soluble solids (TSS), in °BRIX.

Analyses of variance were carried out for each trait. The general and specific combining ability were estimated using the fixed model method defined by GRIFFING (1956). The analyses were performed using the Genes software system (CRUZ, 2006).

RESULTS AND DISCUSSION

Significant differences were observed during the analysis of variance for the sources of variation "genotypes" for all traits under study, which demonstrates a wide variation in the genotypes assessed (Table 2). The values of the experimental coefficient of variation ranged from 6.33% to 24.92% for FL and NFP, respectively. These results reflect good experimental precision and ensure the validity of the conclusions inferred.

The splitting of the sum of squares of the genotypes into the sum of squares for general and specific combining ability (GCA and SCA, respectively) demonstrated that both GCA and SCA were significant for all traits studied, indicating that both additive and non-additive effects are involved in the genetic control of these traits. RODRIGUES et al. (2012) assessed the same genotypes under greenhouse conditions and found significance for the GCA and SCA effects for most traits except for FW and TSS, which were significant only for SCA.

The quadratic component estimates indicated that the traits NFP, FW, FL and FD expressed

Table 1 - Identification, procedence and agronomic traits of five ***C. baccatum*** var. ***pendulum*** genotypes.

Nº-UENF	Procedence	Fruit type	Plant growth habit	Fruit Color	Fruit Shape	Resistance to PepYMV
1616	Viçosa – MG	lady's finger	Intermediate	Orange	Elongate	-
1624	Campos – RJ	lady's finger	Erect	Red	Elongate	+
1629	Campos – RJ	lady's finger	Intermediate	Red	Elongate	-
1639	Commercial company	cambuci	Intermediate	Red	Campanulate	-
1732	Campos - RJ	cambuci	Intermediate	Red	Campanulate	+

[1/](-) = susceptible to PepYMV; (+) resistant to PepYMV.

a superiority of additive genetic effects compared with non-additive effects, which indicates that satisfactory gains can be achieved with the selection for these traits in segregating generations. In turn, for YP and TSS, the reverse was observed; i.e., there was a prevalence of non-additive effects that can be explored in the hybrids or may alternatively require the use of more complex breeding strategies. These results agree with the findings of RODRIGUES et al. (2012), except for TSS in which the authors observed a predominance of additive effects compared with non-additive, thus demonstrating the effect of the environment on character expression.

According to the estimates of the effects of general combining ability ($\hat{g}_i$), the parent UENF 1624 expressed the greatest $\hat{g}_i$ effects for NFP and YP and achieved the highest mean values for these two characters (200.21 and 1.62kgplant^{-1}, respectively) (Table 3). However, these results are different from those reported by RODRIGUES et al. (2012), who found negative effects of $\hat{g}_i$ for these characters. Thus, this parent had a better performance in open field conditions, where its favorable alleles have greater expression, compared with cultivation under greenhouse conditions. For FW, the parents UENF 1629 and UENF 1616 expressed the highest $\hat{g}_i$ values, and both parents produce the lady's finger fruit type.

Evaluation of the traits FL and FD for $\hat{g}_i$ values demonstrated that the parents that produce the cambuci fruit type contributed negatively to FL and positively to FD, while the opposite was observed for the parents of the type lady's finger. These results were expected because of the difference in fruit shape characteristic of these types. For TSS, the parent UENF 1616 expressed the highest value of $\hat{g}_i$, corroborating the results obtained by RODRIGUES et al. (2012).

Regarding the effects of specific combining ability ($\hat{s}_{ij}$), hybrids UENF 1616 x UENF 1629 and UENF 1616 x UENF 1732 recorded the highest values

Table 2 - Estimate of the mean squares for general and specific combining abilities (GCA and SCA), residue, and GCA and SCA quadratic component for six agronomic traits assessed in five parents of ***Capsicum baccatum*** var. ***pendulum*** evaluated in complete diallel without reciprocals.

Sources of variation	DF	Mean squares[1/]					
		NFP	FW	YP	FL	FD	TSS
Repetitions	2	301.34	27.03	7.45	109.98	23.69	3.64
Genotypes	14	4727.55**	213.83**	0.34**	2223.08**	398.60**	2.00**
GCA	4	12508.24**	680.80**	0.30**	7298.16**	1272.04**	2.83**
SCA	10	1615.28**	27.04**	0.36**	193.05**	49.22**	1.68*
Error	28	494.84	6.36	0.06	32.80	7.13	0.62
Quadratic componentes							
GCA		572.06	32.11	0.011	345.97	60.23	0.10
SCA		373.47	6.89	0.098	53.41	14.03	0.35
CV (%)[2/]		24.92	11.02	23.02	6.33	7.08	11.62

[1/]NFP = number of fruits per plant; FW = fruit weight; YP = yield per plant; FL = fruit length; FD = fruit diameter; and TSS = content of total soluble solids. [2/]CV = coefficient of variation.
** = Significant at the 0.01 level; and
*= Significant at the 0.05 level.

Table 3 -Estimates of the general and specific combining ability effects for six agronomic traits in five parents of ***Capsicum baccatum*** var. ***pendulum*** evaluated in complete diallel without reciprocals.

Parents	Agronomic traitss[1/]					
	NFP	FW	YP	FL	FD	TSS
General combining ability						
UENF 1616	-14.27	2.3	-0.13	14.04	-2.70	0.519
UENF 1624	38.48	-7.68	0.13	0.63	-10.83	0.10
UENF 1629	-26.17	7.57	0.02	22.42	-1.46	-0.28
UENF 1639	-1.28	0.54	-0.11	-17.89	8.68	0.072
UENF 1732	3.25	-2.75	0.08	-19.21	6.32	-0.41
Specific combining ability						
UENF 1616 X UENF 1616	-4.06	-2.4	-0.20	0.77	-3.86	0.819
UENF 1616 X UENF 1624	-18.71	-1.25	0.25	-9.73	0.20	-1.19
UENF 1616 X UENF 1629	13.60	3.26	-0.15	13.22	1.06	-0.207
UENF 1616 X UENF 1639	-3.31	0.49	0.02	-8.58	2.56	0.049
UENF 1616 X UENF 1732	16.55	2.36	0.29	3.54	3.89	-0.28
UENF 1624 XUENF 1624	32.90	3.31	0.23	1.73	4.45	-0.36
UENF 1624 X UENF 1629	3.00	-4.51	0.09	0.82	1.79	0.71
UENF 1624 X UENF 1639	3.34	-2.12	-0.04	2.50	-6.74	0.92
UENF 1624 X UENF 1732	-53.43	1.25	-0.75	2.85	-4.17	0.28
UENF 1629 X UENF 1629	-1.62	-1.77	0.03	-12.82	1.05	-0.13
UENF 1629 X UENF 1639	-7.80	4.23	0.02	7.45	-1.51	-0.035
UENF 1629 X UENF 1732	-5.54	0.56	-0.04	4.15	-3.46	-0.208
UENF 1639 X UENF 1639	4.43	-1.46	-0.26	-0.95	0.38	0.092
UENF 1639 X UENF 1732	-1.09	0.323	0.52	0.45	4.93	-1.12
UENF 1732 X UENF 1732	21.76	-2.25	-0.01	-5.50	-0.60	0.665

[1/]NFP = number of fruits per plant; FW = fruit weight; YP = yield per plant; FL = fruit length; FD = fruit diameter; and TSS = content of total soluble solids.

for $\hat{s}_{ij}$ and consequently for heterosis for the trait NFP (Table 3; Figure 1). However, the combination UENF 1616 x UENF 1629 was not indicated for the respective trait due to the low performance of its parents. For FW, the best combinations were UENF 1629 x UENF 1639, UENF 1616 x UENF 1629 and UENF 1616 x UENF 1732 because they expressed high positive values for the $\hat{s}_{ij}$ estimate. Regarding the percentage heterosis values, only one cross, UENF 1624 x UENF 1639 (lady's finger x cambuci), showed a negative value for FW, indicating that crosses between these two types of fruit increase fruit mass in relation to the average of the parents. Considering crosses between parental types that produce lady's finger, only the cross UENF 1616 x UENF 1629 obtained positive values for percentage heterosis.

Regarding YP, the cross between parents with cambuci fruit type (UENF 1639 x UENF 1732) provided the greatest $\hat{s}_{ij}$ value, and this hybrid obtained a value higher than that of the best parent (UENF 1732 - 1.27kgplant^{-1}) (Figure 1). This result corroborates RODRIGUES et al. (2012), who also found heterobeltiosis for the respective cross for the same trait. For crosses between parents with fruits of the type lady's finger, only the cross UENF 1616 x UENF 1624 showed positive values of percentage heterosis, although this cross has obtained negative values of heterosis for NFP and FW. This fact can be characterized as a mathematical heterosis due to the relationship between production per plant and the average fruit weight and number of fruits per plant. Regarding the crosses between the types lady's finger and cambuci, the hybrid UENF 1616 x UENF 1732 is distinctive for achieving an average higher than that of the best parent.

The combinations UENF 1616 x 1629 (lady's finger x lady's finger) and UENF 1629 x UENF 1639 (lady's finger x cambuci) obtained the highest $\hat{s}_{ij}$ values for FL, while the highest values for FD were obtained by UENF 1639 x UENF 1732 (cambuci x cambuci) and UENF 1616 x UENF 1732 (lady's finger x cambuci). In crosses between the types lady's finger and cambuci, there was positive heterosis for most hybrids for FL (except for UENF 1616 x UENF 1639), while the opposite was observed for FD; i.e., most hybrids showed negative heterosis (except for

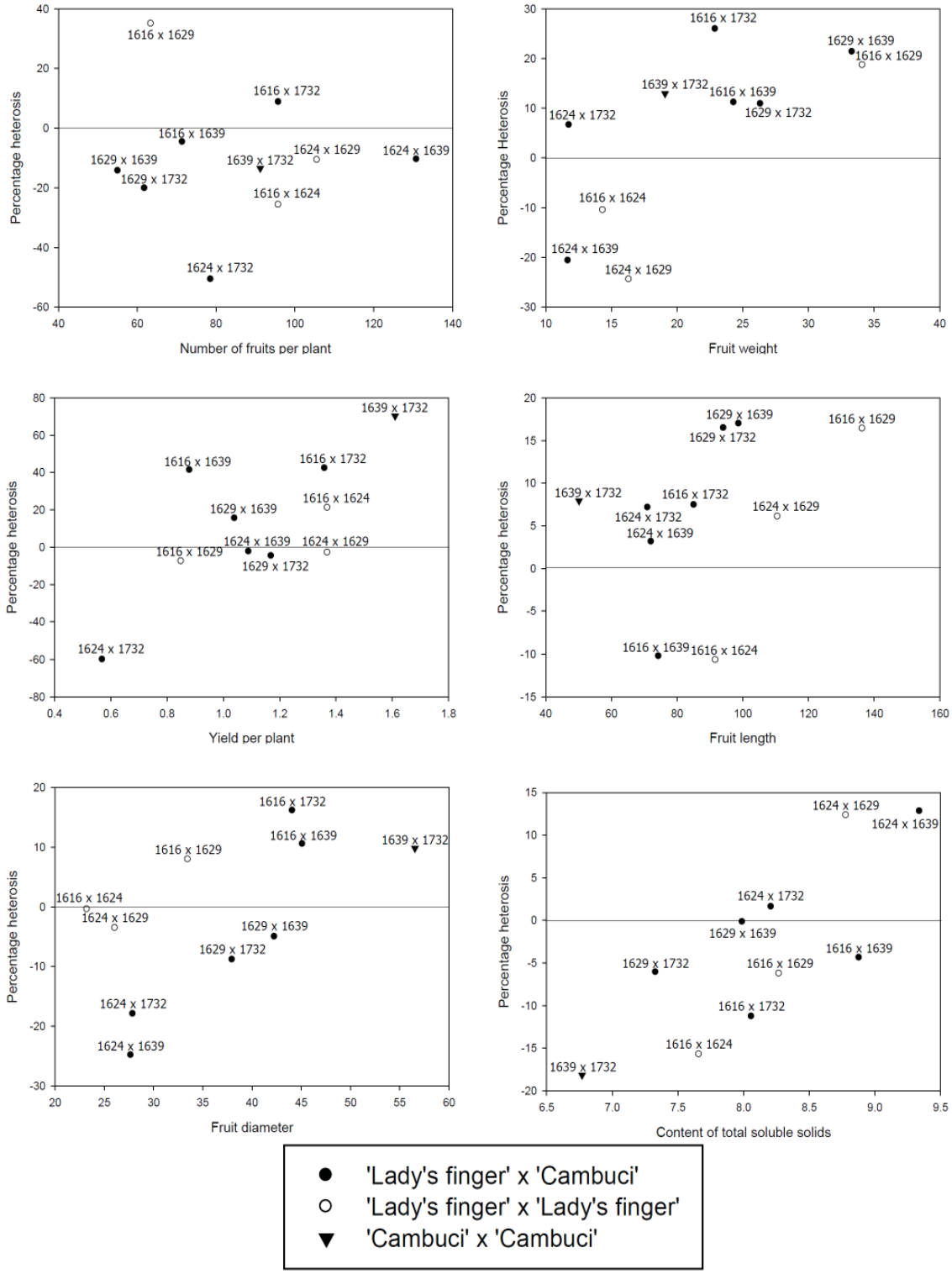

Figure 1- Percentage of heterosis, relative to six agronomic traits, calculated for ten hybrids of ***Capsicum baccatum*** var. ***pendulum*** evaluated in complete diallel without reciprocals.

UENF 1616 x UENF 1732 and UENF 1616 x UENF 1639) (Figure 1). Studies concerning the inheritance of agronomic characters in one of the crosses (UENF 1616 and UENF 1732) tested here are in progress.

The hybrids UENF 1624 x UENF 1629 and UENF 1624 x UENF 1639 recorded the highest $\hat{s}_{ij}$ values for TSS. The hybrid formed by the parents of the type cambuci (UENF 1639 x UENF 1732), which provided high value for productivity, did not achieve the same performance for TSS, recording a value lower than that of their parents. This result was also observed by RODRIGUES et al. (2012) with the same hybrids cultivated in a greenhouse. Most crosses between lady's finger and cambuci achieved negative heterosis, except for the cross UENF 1624 x UENF 1732, with a positive but very low percentage heterosis (1.6%).

The results presented here reveal that the hybrid combinations between lady's finger and cambuci types provided elongated fruits with smaller diameter and more weight compared with the parental type cambuci. However, these factors did not lead to a significant increase in yield per plant due to the decreased number of fruits, except for hybrid UENF 1616 x UENF 1732, which was higher than the best parent for yield per plant. Considering only the parents of the type lady's finger, a high potential is observed for the pure line UENF 1624, which produced 1.62kgplant^{-1}, the highest value for all hybrids. However, this pure line did not achieve good performance when cultivated under greenhouse conditions. Regarding the cambuci type, the hybrid UENF 1639 x UENF 1732 is also distinctive for yield per plant, and although the heterosis was negative for levels of total soluble solids, the mean value observed for TSS (6.77^{o}BRIX) in this cross was overall superior to other commercial chili pepper genotypes (4.88^{o}BRIX for 'Guaraciaba' and 5.40^{o}BRIX for 'Ibirajá', both from Isla Sementes S.A.).

CONCLUSION

Considering the exploitation of commercial hybrids in ***C. baccatum***, in terms of fruit yield, the crosses UENF 1616 x UENF 1732 and UENF 1639 x UENF 1732 should be chosen for field trials aiming to release new cultivars.

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