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Heterosis and combining ability for ornamental chili pepper

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ABSTRACT

Ornamental use of *Capsicum* genus chili peppers has expanded due to easy seed propagation, short germination period, diversified fruit colors and harmony of potted plants. The ornamental plant sector requires cultivars adapted to different cultivation conditions in pots and gardens. Breeding programs can use heterosis and combining ability information, aiming to commercially explore hybrids or develop populations for lineage selection with desirable characteristics. However, the ornamental chili pepper field lacks studies with this data. In this study, combining ability of *C. annuum* accessions was determined for ornamental purposes and hybrid combinations were identified based on heterosis values. Fifteen hybrids were obtained from diallel crosses of six genotypes of *C. annuum*, from March to September 2014, under greenhouse conditions, grown in five-liter pots in experimental design of randomized blocks with 10 repetitions and one plant per plot. Morpho-agronomic characterization was conducted based on eight quantitative descriptors: plant height (before and after fruiting); canopy diameter; days to flourishing; days to fruiting; fruit length and diameter, and number of fruits per plant. Both additive and dominance effects play important role in controlling the studied characters, indicating hybrid exploitation as well as development of superior lineages from the progress of segregating generations. Negative heterosis values resulted in reduction in height, time for flourishing and fruiting, as well as fruit diameter and length, which are desirable for ornamental *Capsicum* breeding program. Considering an ideotype for ornamental chili pepper cultivars, the hybrids UENF 1626 x UENF 1750, UENF 1750 x UENF 2030 and UENF 1626 x UENF 2030 can be recommended for cultivation with ornamental purposes.

Keywords: *Capsicum annuum*, ornamental breeding, ideotype, diallel analysis.

RESUMO

Heterose e capacidade combinatória em pimentas ornamentais

O uso ornamental das pimentas do gênero *Capsicum* tem se expandido em função da fácil propagação das sementes, do curto espaço de tempo de germinação, da coloração diversificada de seus frutos e da harmonia das plantas em vasos. O setor de plantas ornamentais demanda cultivares adaptadas a diversas condições de cultivo em vasos e jardins. Os programas de melhoramento podem utilizar as informações sobre heterose e capacidade combinatória, a fim de explorar comercialmente híbridos ou desenvolver populações de trabalho para seleção de linhagens com as características desejáveis. Em pimentas para uso ornamental ainda são escassos trabalhos com estas informações. Neste trabalho determinou-se a capacidade combinatória de acessos de *C. annuum* para fins ornamentais e identificaram-se combinações híbridas superiores com base em seus valores de heterose. Quinze híbridos foram obtidos a partir de cruzamentos dialélicos entre seis acessos de *C. annuum*, de março a setembro de 2014, em casa de vegetação, cultivados em vasos de cinco litros em delineamento experimental de blocos ao acaso, com 10 repetições e uma planta por parcela. A caracterização morfoagronômica foi realizada com base em oito descritores quantitativos: altura de planta (antes e depois da fase de frutificação); diâmetro de copa; dias para o florescimento; dias para frutificação; comprimento e diâmetro do fruto, e número de frutos por planta. Efeitos aditivos e de dominância foram importantes no controle dos caracteres estudados neste trabalhando indicando a exploração de híbridos assim como o desenvolvimento de linhagens superiores a partir do avanço das gerações segregantes. Valores de heterose negativos resultaram na redução da altura, no tempo para florescimento e frutificação, diâmetro e comprimento do fruto, desejáveis para o programa de melhoramento de *Capsicum* ornamental. Considerando um ideótipo para cultivar de pimenta ornamental se destacaram os híbridos UENF 1626 x UENF 1750, UENF 1750 x UENF 2030 e UENF 1626 x UENF 2030.

Palavras-chave: *Capsicum annuum*, melhoramento de ornamentais, ideótipo, análise dialélica.

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The production of flowers and ornamental plants in Brazil has as main destination, the domestic market, being more than 90% of the financial volume marketed by producers. Consumption in Brazil still has much to evolve, especially when compared to consumption in more mature markets, such as the European (Neves *et al*., 2015). To the expansion and valorization of this market segment, new products are required to supply the demand and attract potential supporters of the ornamental plant consumption.

Chili peppers (*Capsicum annuum*) for ornamental purpose has gained scope representing new options such as cultivation of potted plants in gardens and also as cut foliage. The diverse application forms are mainly related to fruit, foliage and plant height characteristics (Carvalho *et al*., 2006; Rêgo *et al*., 2012). The growing demand in ornamental market for chili pepper cultivars associated to high variability of *Capsicum* genus plants has recently provided establishment of chili pepper breeding programs aiming to obtain new cultivars (Rêgo *et al*., 2013).

Capsicum annuum is the most studied species of the genus, including in genetic and breeding terms, and several investigations report results of diallelic crossings. Patil & Bhalekar (2012) highlighted the importance of obtaining and applying hybrids to increase fruit production and pepper earliness (*C. annuum*). Pandey *et al.* (2012) identified five promising hybrids in terms of fruit production, by evaluating *C. annuum* parental and hybrids. Hasanuzzaman *et al*. (2013), evaluating heterosis in local varieties of *Capsicum annuum* in Bangladesh, found high heterosis values and suggested the use of six studied lineages for further hybrid development. Nascimento *et al.* (2014) observed that non-additive effects, epistasis and/or dominance were the most relevant to control fruit production per plant and days until fruiting, among other traits, in a complete diallel, with reciprocals, in *Capsicum annuum*, demonstrating complexity in the genetic control of these characters. In addition, in this regard, the authors recommend hybridization as a strategy for obtaining ornamental chili peppers.

Nevertheless, data from genetic control studies of *Capsicum* plants specifically for ornamental purposes are limited in literature, having just a few works about it and those works belong the *Capsicum* working group of Paraíba Federal University (UFPB), resulting in a lack of information that lead to a low application of *Capsicum* genotypes of ornamental potential and a reduced number of cultivars developed to serve this niche market.

This study discloses results of combining ability of *Capsicum annuum* accessions and identifies superior hybrid combinations that are potentially useful as new cultivars of ornamental chili pepper.

MATERIAL AND METHODS

Parental genotypes and obtainment of F_1 hybrids

Six accessions of *Capsicum annuum* from germplasm bank of the Universidade Estadual do Norte Fluminense Darcy Ribeiro (UENF) (Table 1) were selected based on preliminary studies for indication of genitors with potential ornamental use (Silva *et al*., 2015) and crossed in a complete diallelic mating system without reciprocal crosses to obtain F_1 generation.

In hybridization stage, the plants were cultivated in greenhouse (structure 11.5 m long x 7 m wide, covered with plastic additive against UV rays of 150 μ and 70% shade), located in the Unidade de Apoio à Pesquisa of UENF, in Campos dos Goytacazes, Rio de Janeiro State, Brazil, from June to December 2013 and the average results for relative humidity and temperature were 69% and 30°C, respectively, recorded throughout the trial period. Seedlings were produced in polystyrene trays with 128 cells containing commercial subtract and transplanting was conducted when the seedlings had four to six pairs of definitive leaves, by transferring them into 5-liter plastic pots filled (spacing 1.0 x 0.5 m) with mixture of soil, sand and cattle manure in the proportion 1:1:1 and 5 g/pot of NPK formulation (4-14-8), keeping one plant per pot.

Cultural practices used in culture were manual removal of weeds, maintenance fertilization, prevention and control of pests and diseases and the irrigation was done manually.

Crossings were managed by sampling newly opened floral buds of each male parent for pollen withdrawal. Pollen of each parent was stored in refrigerator inside of properly identified amber glasses containing silica gel. Female parent floral buds were emasculated in the morning before anthesis using tweezers. Pollination was carried out by placing pollen grains of each male parent on each emasculated flower stigma. Woolen yarns of different colors were used to identify fruits derived from each crossing. Hybridization efficiency (HE) percentage was calculated based on the following expression:

HE = (number of effective crossings/ number of performed crossings) x 100

Evaluation of genitors and hybrids

The experiment was conducted from March to September 2014 under the same greenhouse conditions used for the F_1 hybrids obtainment in a completely randomized block design, with ten replications and one plant per plot. Seedling production, transplanting period and cultural treatments were the same adopted for plant cultivation in the hybridization period.

Morpho-agronomic characterization was accomplished considering different parts of plants, according to *Capsicum* genus descriptors proposed by IPGRI (1995) and some modifications proposed by Silva *et al*. (2015) for prompt data acquisition.

Eight quantitative descriptors were analyzed with basis on average values of each access: plant height (HGT) (cm), measured from the plant base to the highest point of the canopy, using measurement tape, before and afterwards fruiting, HGT1 and HGT2, respectively; greater canopy diameter (GCD) (cm) measured simultaneously to plant height with the aid of a measurement tape. Number of days to flourishing (DFL) was computed counting from sowing to the moment in which at least half of the plants were with a minimum of one open flower.

The following fruit characteristics were evaluated: total number of fruits (TNF) (sum of ripe fruits harvested during crop cycle); days to fruiting (DFR) (counting from transplanting date to the moment in which 50% of the plants had ripe fruits in the first and second bifurcation); fruit length (LOF) (mm) and fruit diameter (DOF) (mm); LOF and DOF were evaluated in laboratory, using average of five ripe fruits randomly obtained; the measurements were done with digital caliper.

Statistical and genetic analysis of data

Analysis of variance (ANOVA) with basis on the averages of each treatment was conducted for quantitative data. The means were grouped by Scott-Knott test ($p<0.05$). In order to conduct diallel analysis, combination general capacity (GCA) and combination specific capacity (SCA) were determined in accordance with the model proposed by Griffing and conforming to method

2, which includes genitors and F_1 hybrids, and considering model 1 (fixed effect genotypes and random effect error). Heterosis calculation was carried out based on the average of parents according to formula: Hmp = (F_1 – MP/MP) x 100, wherein MP = (P_1 + P_2)/2. All the analyses were performed using Genes software (Cruz, 2016).

RESULTS AND DISCUSSION

Hybridization efficiency

Three hundred and seventy four pollinations were performed and the crossing success rate varied from 42 to 95%, resulting in 11 to 48 fruits, in accordance with the number of pollinations conducted for hybrid combinations, and the number of produced seeds for some crossings was above 500 (Table 1). Cardoso (2005), when studying pollination with zucchini, suggested that the increment in number of seeds per plant is explained by the use of high quantity of pollen. In this study, an increased number of crossings for a determined hybrid combination contributed to a greater harvested fruit number. Except for four hybrid combinations (UENF 1626 x UENF 1750; UENF 1626 x UENF 1627; UENF 1627 x UENF 2030, and UENF 1627 x UENF 1632) the others had success rate above 80%, supporting data from studies of manual pollination in pepper conducted by Godoy *et al.* (2006), which achieved values from 80 to 94% success of pollinated flowers.

Table 1. Hybrid combinations, number of crosses performed, number of fruits, crossing success rate and number of seeds produced in crosses between six parents of *Capsicum annuum*. Campos dos Goytacazes, UENF, 2014.

Identification of crosses	Number of crosses	Number of fruits	Crossing success rate (%)	Number of seeds
1626 x1750	26	11	42.30	107
1626x1627	21	15	71.43	341
1626x2030	18	17	94.44	448
1626x1632	22	19	86.36	444
1626x1623	20	19	95.00	425
1627x2030	18	13	72.22	413
1627x1632	20	15	75.00	497
1627x1623	17	15	88.24	547
1632x1623	58	48	82.21	878
1750x1627	22	19	86.36	551
1750x2030	23	20	91.30	541
1750x1632	23	21	91.30	843
1750x1623	21	19	90.48	633
2030x1623	36	34	94.44	1051
2030x1632	29	26	89.65	915

ANOVA and diallelic analysis

Among 15 hybrids, only the combination UENF 1632 x UENF 1623 did not obtain seed germination, resulting in 14 evaluated hybrids. The variance analysis evidenced highly significant difference ($p<0.01$) for all evaluated characters concerning treatment variation source (Table 2). The coefficient of variation (CV) values were between proposed limits for *Capsicum* genus according to Silva *et al.* (2011), who studied classification criteria of CVs for six variables in peppers, and also in the same magnitude of CV values

Table 2. Estimates of general and specific combining ability (GCA and SCA), and mean square effects for eight agronomic traits in diallel crosses from six chili peppers parents, according to Method 2, Model 1 (Griffing, 1956). Campos dos Goytacazes, UENF, 2014.

Source of variation	DF	Mean square							
		HGT1 (cm)[1]	HGT2 (cm)	GCD (cm)	DFL	DFR	LOF (mm)	DOF (mm)	TNF
Treatment	20	27.71**	148.65**	21.60**	44.58**	77.49**	1320.53**	86.37**	7269.99**
GCA	5	69.58**	476.14**	49.36**	136.00**	171.06**	4708.75**	329.94**	26307.33**
SCA	15	13.75**	39.49**	12.35**	14.11**	46.30**	191.12**	5.19**	924.21**
Residue	180	2.91	19.18	22.14	4.59	11.90	24.40	1.38	318.38
		Mean Squares of effect							
GCA		3.06	142.02	1.55	11.60	18.74	13865.31	68.04	432725.37
SCA		2.61	24.88	7.48	2.89	30.16	493.64	0.38	12515.19
Residue		0.09	4.09	5.45	0.23	1.57	6.61	0.02	1126.26

[1]HGT1,2= plant height before and afterwards fruiting; GCD= canopy diameter; DFL= number of days to flourishing; DFR= days to fruiting. LOF= fruit length; DOF= fruit diameter; TNF= total number of fruits. **p≤0.01 by F test.

Table 3. Estimates of general combining ability (ĝi) effects for eight agronomic traits evaluated in six genotypes of *Capsicum annumm*. Campos dos Goytacazes, UENF, 2014.

Genotypes	HGT1 (cm)[1]	HGT2 (cm)	GCD (cm)	DFL	DFR	LOF (mm)	DOF (mm)	TNF
1626	-0.98	-2.60	-0.63	1.24	1.08	-9.24	-0.85	10.94
1750	0.31	-0.14	0.75	0.74	1.08	-9.71	-1.58	27.63
1627	0.95	1.34	0.16	1.24	1.60	7.66	-0.62	-3.06
2030	0.60	-0.03	-0.42	-0.45	-1.12	6.70	-1.86	2.07
1632	-1.35	-2.49	-0.91	-0.73	-0.53	2.86	3.31	-23.33
1623	0.46	3.88	1.04	-2.04	-2.09	1.72	1.60	-14.26
DP (G_i-G_j)	0.27	0.69	0.74	0.34	0.55	0.78	0.18	2.82

[1]HGT1,2= plant height before and afterwards fruiting; GCD= canopy diameter; DFL= number of days to flourishing; DFR= days to fruiting. LOF= fruit length; DOF= fruit diameter; TNF= total number of fruits.

found by Rodrigues *et al*. (2012) in studies with *Capsicum baccatum*.

There was a highly significant difference for all characteristics in terms of GCA and SCA, indicating that additive and dominance effects are important to control the studied traits. Therefore, there is a possibility of hybrid exploitation as well as development of superior lineages from the progress of segregating generations. However, estimations of genitor effects and F_1 hybrid mean squares, in accordance with Method 2 and model 1 from Griffing, evidenced predominance of additive effects for almost every evaluated characteristic, except for GCD and DFR that had greater influence of dominance effects (Table 2). In general, these results indicated predominance of GCA effects in relation to SCA ones, which means predominance of additive effects on height characteristic (before and afterwards fruiting); days to flourishing; fruit length and diameter, and number of fruits per plant. Rodrigues *et al*. (2012) and Medeiros *et al*. (2014) identified additive and non-additive effects for characteristics of canopy diameter; days to fruiting; number of fruits per plant, and fruit length and diameter when evaluating similar traits in *Capsicum baccatum* under greenhouse and field conditions, respectively. However, these authors observed that additive effects were predominant for plant height. Similarly, Nascimento *et al*. (2014), when evaluating *Capsicum annuum* genetic effects on fruit production and quality, verified that additive effects are more important in regarding fruit length and diameter, while non-additive effects were more significant for the days to fruiting.

Negative values of GCA estimation (ĝi) for plant height were expressed in the parental UENF 1626 and UENF 1632 in both measurements (HET1 -0.98 and -1.35; HET2 -2.60 and -2.49, respectively) (Table 3). When used in crossings, these genotypes contribute to small-sized plant obtainment, generating individuals for potted plant market with indoor decorative purposes. Silva *et al*. (2015), whose research studied parental selection for ornamental purposes, and Carvalho *et al*. (2006), who discussed what characteristics grant ornamental trait to peppers, both observed small-sized plant preference by consumers for pot cultivation and stated that these traits are related to growth trend. From the other side, values of ĝi observed for UENF 1627 and UENF 1623 genitors showed that they could contribute to increasing plant height, subsequently to fruiting (HET2). Another desirable usage for chili pepper is garden cultivation, in which higher plants can be used.

Regarding GCD, UENF 1623 contributed with positive values of ĝi (1.04) (Table 3), favoring excellent canopy diameters, which means that this genotype when used in crossings might produce more visually attractive hybrids due to their bigger canopy (larger foliage). In regards of earliness, lower values of ĝi for DFL and DFR were achieved by genitor UENF 1623 (-2.04 and -2.09, respectively). Concerning LOF and DOF, in general, negative values of ĝi are required for ornamental purpose, since it favors small-size fruit production but in higher number. In regards of TNF, positive values of ĝi are preferred. Genotypes UENF 1626 and UENF 1750 contributed with lower values of ĝi for LOF and DOF (-9.24 and -9.71) and (-0.85 and -1.58), respectively and with positive values of ĝi for TNF (10.94 and 27.63). Such characteristics were also approached by Rêgo *et al*. (2010), with chili peppers (*C. baccatum*), and Silva *et al*. (2015) with *Capsicum* spp. These studies described a negative correlation between fruit size and number of fruits per plant, indicating that lower values of fruit size enable greater production of fruits per plant, an association that grants better attractiveness and harmony in ornamental ambiance.

Effect of SCA estimations (Ŝii and *Ŝij*) (Table 4) indicated the effect of hybrid combination between genitors and its interpretation is according its relation with GCA values of its parents (Griffing). Ornamental in-pot cultivation for indoor decoration requires low plant height (Carvalho *et al*., 2006; Neitzke *et al*., 2010; Silva *et al*., 2015). Regarding the character HET1, 11 hybrid combinations had satisfactory results, with negative values for the following characters: UENF 1626 x UENF 1627 (-1.74); UENF 1626 x UENF 2030 (-1.20); UENF 1626 x UENF 1632 (-0.85); UENF 1626 x UENF 1623 (-0.36); UENF 1750 x UENF 1627 (-0.13); UENF 1750 x UENF 1632 (-0.63); UENF 1750 x UENF 1623 (-0.40); UENF 1627 x UENF 2030 (-0.57); UENF 1627 x UENF 1623 (-1.58); UENF 2030 x UENF 1632 (-1.07) and UENF 1632 x UENF 1623 (-0.56). However, these results were not expected for UENF 1750 x UENF 1627, UENF 1750 x UENF 1623, UENF 1627 x UENF 2030 and UENF 1627 x UENF 1623, since none of their parents presented effects of negative GCA for this characteristic, evidencing that these hybrid combinations presented better results in relation to SCA of their parents. Some combinations stood out

Table 4. Estimates of specific combining ability (Ŝii and Ŝij) effects for eight traits evaluated in six genotypes of *C. annuum.* Campos dos Goytacazes, UENF, 2014.

Effects (Ŝii and Ŝij)[1]	HGT1 (cm)[2]	HGT2 (cm)	GCD (cm)	DFL	DFR	LOF (mm)	DOF (mm)	TNF
1x1	1.45	1.07	-0.47	-0.63	-2.14	1.34	0.38	-2.66
1x2	1.25	0.63	-0.00	-1.63	-2.64	0.88	-0.41	23.65
1x3	-1.74	-0.96	2.23	0.87	2.86	-1.26	0.33	-3.66
1x4	-1.20	0.53	0.36	-0.45	-0.45	-5.05	-0.24	1.71
1x5	-0.85	-0.26	-0.95	1.83	4.97	3.02	-0.55	-7.40
1x6	-0.36	-2.94	-0.70	0.64	-0.47	-0.28	0.12	-8.96
2x2	0.00	-2.55	-0.35	1.37	2.36	-1.89	0.50	1.46
2x3	-0.13	0.37	-0.16	-0.63	0.86	1.75	0.17	-3.85
2x4	-0.08	-0.15	-0.17	-0.44	-0.45	-0.61	-0.73	0.52
2x5	-0.63	2.31	-0.08	0.33	-1.03	1.37	-0.83	-11.59
2x6	-0.40	1.93	1.12	-0.35	-1.47	0.39	0.80	-11.65
3x3	1.78	-0.41	-2.12	0.37	0.36	-4.38	-0.22	-5.66
3x4	-0.57	0.42	0.12	-0.44	-1.95	2.33	0.62	10.21
3x5	0.47	3.18	1.50	0.83	-1.03	7.78	-1.01	0.10
3x6	-1.58	-3.05	0.55	-1.35	-1.47	-1.83	0.33	8.54
4x4	1.12	-0.25	-0.75	1.74	1.74	-2.86	0.06	-3.92
4x5	-1.07	-2.40	1.30	-1.98	-1.34	-0.14	1.06	-3.52
4x6	0.71	2.12	-0.11	-0.17	0.72	9.19	-0.84	-1.08
5x5	1.07	-1.33	-0.92	-0.70	-0.92	-6.35	0.97	10.37
5x6	-0.56	-0.16	0.08	0.39	0.29	0.67	-0.64	1.67
6x6	0.85	1.05	-0.47	0.42	1.20	-4.07	0.11	5.74
DP (Sii-Sjj)	0.54	1.38	1.49	0.68	1.09	1.56	0.37	5.64
DP (Sij-Sik)	0.71	1.83	1.96	0.89	1.44	2.06	0.49	7.46
DP (Sij-Skl)	0.66	1.69	1.82	0.83	1.33	1.91	0.45	6.91

[1]UENF 1626 (1); UENF 1750 (2); UENF 1627 (3); UENF 2030 (4); UENF 1632 (5); UENF 1623 (6); [2]HGT1,2= plant height before and afterwards fruiting; GCD= canopy diameter; DFL= number of days to flourishing; DFR= days to fruiting; LOF= fruit length; DOF= fruit diameter; TNF= total number of fruits.

for HET1, and showed favorable results for HET2, such as: UENF 1626 x UENF 1627 (-0.96); UENF 1626 x UENF 1632 (-0.26); UENF 1626 x UENF 1623 (-2.94); UENF 1750 x UENF 2030 (-0.15); UENF 1627 x UENF 1623 (-3.05); UENF 2030 x UENF 1632 (-2.40) and UENF 1632 x UENF 1623 (-0.16). In the same manner, it is highlighted that combinations that did not include parental UENF 1626 and UENF 1632 overcame the expectations concerning values of GCA.

Canopy diameter requires positive values of Ŝii, providing attractive visual effects as it presents more foliage, a desired trait for ornamental purposes. Thus, the best results were found in crossings UENF 1626 x UENF 1627 (2.23), UENF 1750 x UENF 1623 (1.12); UENF 1627 x UENF 1632 (1.50) and UENF 2030 x UENF 1632 (1.30). Nevertheless, in accordance with the effect values of GCA, only the combinations UENF 1750 x UENF 1623 have both parents as superior.

Silva Neto *et al.* (2014) showed in their study the significance of plant structure and its aesthetical-visual harmony, considering plant height and canopy diameter important for ornamental purposes.

The best combinations concerning earliness values (negative values of Ŝii for DFL and DFR) were identified in hybrids UENF 1626 x UENF 1750 (-1.63 DFL and -2.64 DFR), UENF 1626 x UENF 2030 (-0.45 DFL and DFR), UENF 1750 x UENF 2030 (-0.44 DFL and -0.5 DFR); UENF 1750 x UENF 1623 (-0.35 DFL and -1.47 DFR), UENF 1627 x UENF 2030 (-0.44 DFL and -1.95 DFR), UENF 1627 x UENF 1623 (-1.35 DFL and -1.47 DFR) and UENF 2030 x UENF 1632 (-0.70 DFL and -0.92 DFR), with combinations resulted from parents UENF 1623, UENF 1632 and UENF 2030 expressing expected earliness results according to estimations of GCA.

Regarding LOF and DOF, the combinations with lower values of these characteristics, obtaining negative values of Ŝii, were the crossings UENF

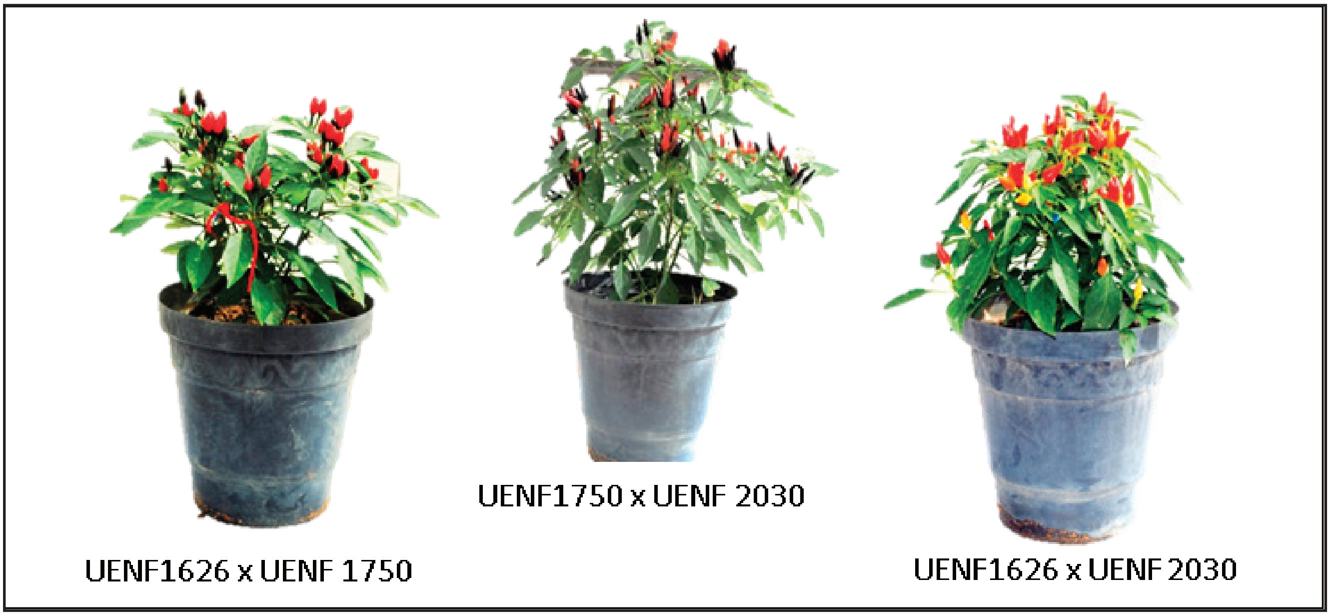
Table 5. Means[1] and heterosis percentage compared to parent mean (H) for eight characteristics evaluated in complete diallel without reciprocals, among six parents of *Capsicum annuum*. Campos dos Goytacazes, UENF, 2014.

Genotypes[2]	HGT1 (cm)		HGT2 (cm)		GCD (cm)		DFL	
	Mean	H(%)	Mean	H(%)	Mean	H(%)	Mean	H(%)
1x1	9.33c	0.00	19.26d	0.00	31.84a	0.00	50.00b	0.00
1x2	10.61b	5.20	21.13c	6.92	34.45a	1.17	49.00b	-3.92
1x3	8.40c	-28.94	23.05c	-1.89	34.79a	10.74	52.00a	1.96
1x4	9.03c	-22.73	22.05c	0.59	34.17a	2.96	50.00b	-2.00
1x5	6.77d	-23.55	17.62d	-0.69	31.82a	-0.77	52.00a	5.15
1x6	9.01c	-14.16	21.89c	-15.56	33.23a	-0.65	48.00b	1.57
2x2	10.70b	0.00	20.16c	0.00	35.46a	0.00	51.00a	0.00
2x3	11.37b	-8.42	24.21c	8.03	36.00a	3.14	50.00a	-2.91
2x4	11.28b	-5.65	23.40c	5.75	34.40a	1.09	49.00b	-3.96
2x5	8.18c	-12.33	22.28c	22.67	35.15a	1.63	49.00b	0.00
2x6	10.50b	-7.35	26.86b	10.16	31.95a	4.24	47.00c	-2.59
3x3	12.90a	0.00	26.86b	0.00	33.10a	0.00	51.00a	0.00
3x4	11.03b	-15.55	24.72c	3.09	35.46a	4.71	49.00b	-2.97
3x5	9.44c	-8.69	25.60b	19.01	35.71a	9.36	51.00a	2.04
3x6	10.01b	-22.74	25.55b	-11.68	36.71a	5.36	47.00c	-3.63
4x4	12.04a	0.00	23.28c	0.00	32.74a	0.00	48.00b	0.00
4x5	7.86c	-20.96	18.07d	-8.00	33.60a	6.55	46.00c	-5.21
4x6	11.77a	-2.28	27.45b	6.25	35.88a	1.44	46.00c	-2.64
5x5	8.37c	0.00	17.66d	0.00	31.06a	0.00	47.00c	0.00
5x6	-	-	-	-	-	-	-	-
6x6	11.79a	0.00	31.19a	0.00	35.81a	2.29	44.00d	1.16

Genotypes[2]	DFR		LOF (mm)		DOF (mm)		TNF	
1x1	25.00c	0.00	18.78e	0.00	10.91e	0.00	76.00c	0.00
1x2	26.00c	-10.28	16.98e	7.82	9.48f	-8.56	107.00a	27.17
1x3	31.00a	14.28	30.13c	0.86	10.12e	2.31	62.00d	0.91
1x4	25.00c	-1.03	26.58d	-13.96	9.10f	-4.90	71.00c	8.20
1x5	30.00b	27.66	30.63c	21.96	13.88c	-8.20	32.00e	-26.31
1x6	24.00d	0.00	26.26d	4.33	12.81d	-0.96	40.00e	-21.21
2x2	29.00b	0.00	12.80f	0.00	9.35f	0.00	108.00a	0.00
2x3	28.00b	-1.75	34.08c	16.95	9.92e	0.30	69.00c	-2.37
2x4	25.00c	-9.43	29.33d	6.15	8.08g	-11.45	85.00b	2.19
2x5	25.00c	-6.79	29.07d	23.78	12.91d	-10.89	47.00e	-28.45
2x6	25.00c	-12.87	26.25d	14.60	12.64d	4.06	56.00d	-22.34
3x3	29.00b	0.00	45.89b	0.00	10.57e	0.00	39.00e	0.00
3x4	24.00d	-11.54	50.38a	13.28	10.24e	7.43	56.00d	32.96
3x5	27.00b	-2.97	52.23a	33.52	13.73c	-9.26	25.00f	-8.26
3x6	23.00d	-9.09	41.10b	6.11	12.91d	3.02	45.00e	25.00
4x4	23.00d	0.00	42.87b	0.00	8.80f	0.00	59.00d	0.00
4x5	21.00d	-7.53	43.49b	11.44	14.40c	3.90	28.00f	-20.30
4x6	22.00d	-3.30	49.92a	32.46	10.85e	-7.87	37.00e	-5.00
5x5	23.00d	0.00	33.74c	0.00	19.23a	0.00	18.00f	0.00
5x6	-	-	-	-	-	-	-	-
6x6	23.00d	0.71	32.43c	0.00	14.76c	0.00	29.00f	0.0

[1]Means followed by the same letter do not differ significantly by the Scott-Knott test, 0.05%; [2]UENF 1626 (1); UENF 1750 (2); UENF 1627 (3); UENF 2030 (4); UENF 1632 (5); UENF 1623 (6). [2]HGT1.2= plant height before and afterwards fruiting; GCD= canopy diameter; DFL= number of days to flourishing; DFR= days to fruiting; LOF= fruit length; DOF= fruit diameter; TNF= total number of fruits.

Figure 1. The hybrids UENF 1626 x UENF 1750, UENF 1750 x UENF 2030 and UENF 1626 x UENF 2030 recommended for cultivation with ornamental purposes. Campos dos Goytacazes, UENF, 2014.



1626 x UENF 2030 (LOF -5.05 and DOF -0.24) and UENF 1750 x UENF 2030 (LOF -0.61 and DOF -0.73); therefore, the parentals UENF 1626 and UENF 1750 were superior for GCA values. Concerning TNF, positive values of Ŝ*ii* are appealing for ornamental character, which is present in the following combinations: UENF 1626 x UENF 1750 (23.65), UENF 1626 x UENF 2030 (1.46), UENF 1627 x UENF 2030 (10.21), UENF 1627 x UENF 1623 (8.54) and UENF 1632 x UENF 1623 (1.67). Exclusively the combinations UENF 1627 x UENF 1623 and UENF 1632 x UENF 1623 obtained non expected values in accordance with effects of general capacity of parental combination.

Silva *et al.* (2015) discussed plant earliness importance in ornamental chili peppers, considering that early plants are desirable to reduce producer costs and promptly meet consumer market expectations. These authors also reported the importance of small-sized fruits and in large quantity per plant, providing greater attractiveness for chili pepper plants.

Scott-Knott grouping test of averages

The grouping test of averages enabled identification of four classes for HET1, HET2, DFL and DFR; one class for GCD; seven classes for DOF and six classes for LOF and TNF (Table 5). These results suggest the presence of variability among the studied genotypes. The averages for HET1 varied from 6.77 to 12.90 cm while HET2 varied from 17.62 to 31.19 cm. The highest plants in after-fruiting evaluation (HET2) were observed for UENF 1623 genitor while UENF 1626 genitor and UENF 1626 x UENF 1632 hybrid produced smaller-sized plants. Melo *et al.* (2014) identified low accessions with heights varying from 19.75 to 31.50 cm, when selecting plants with ornamental potential.

Regarding canopy diameter, there was no significant difference among treatments and values varied from 31.06 to 36.71 cm. Days to fruiting varied from 44 to 52 days after transplanting, enabling a selection of early genotypes. Moreover, expressive differences among genotypes were found and values varied from 21 to 31 days. Early genotypes are compelling for producers to commercialize their product quickly (Patil & Bhalekar, 2012; Silva *et al.*, 2015), thereby reducing its production costs.

Fruit diameter had the greatest variation amplitude in averages, varying from 8.08 cm to 19.23 cm, divided into seven classes. In sequence, fruit length and number of fruits per plant had also great amplitude of variation in averages, both composing six classes. Regarding fruit length, the variation was from 12.80 to 52.23 cm, and number of fruits per plant varied from 18 to 108 fruits.

Heterosis

Heterosis varied from -28.94 (HET1) to 33.52% (LOF) (Table 5), demonstrating quite a few negative values, which indicates reduction of plant height, time to flourishing and fruiting, as well as fruit diameter and length. Such reductions are desirable for ornamental *Capsicum* breeding programs. Additionally, Blat *et al.* (2007), conducting studies in pepper hybrids with basis on heterosis estimation, found negative heterosis for plant height and according to these authors, medium heights are ideal for pepper plants. However, for ornamental purposes, small-sized plants are preferred for pot cultivation. Nascimento *et al.* (2010), analyzing combinatorial ability of pepper lineages, identified that the heterosis estimation varied considerably for four traits (productivity, fruit average mass, early production of fruits and plant height). Specifically for plant height, these authors observed variations of -18.23 to 15.07. Sousa & Maluf (2003) observed values of heterosis varying from -93 to 55% for number of seeds per fruit in a chili pepper diallel (*Capsicum chinense*). Rodrigues *et al*. (2012) reported heterosis of approximately -24.78 for fruit dry mass (g) and 98.09 for number of fruits per plant, in a diallel of *C. baccatum* var. *pendulum*. Afroza *et al*. (2013), in studies of heterosis in *C. annuum*, found variations from -44.88 for number of fruits per plant to 106.69 for fruit yield per plant (g). These investigations lead to the conclusion that data obtained in this study are in the limits of heterosis observed for studies with *Capsicum*. It is important to highlight that the genitors used in this diallel were indicated based on their agronomic performance and genetic divergence, according to Silva *et al.* (2015).

Concerning HET1, almost all hybrids had lower average compared to their parents and negative heterosis, except for UENF 1626 x UENF 1750 that obtained higher height average than parents and positive heterosis. Values of negative heterosis for height indicate smaller plants, ideal for pot cultivation. Nascimento *et al.* (2010), whose aim was to evaluate combining ability in pepper lineages, highlighted the importance of obtaining smaller-sized plants, identifying heterosis values up to -15.49. Regarding HET2, six hybrid combinations (UENF 1626 x UENF 1627; UENF 1626 x UENF 1632; UENF 1626 x UENF 1623; UENF 1627 x UENF 2030; UENF 1627 x UENF 1623 and UENF 2030 x UENF 1632) presented lower values than their parents did; however, only UENF 1627 x UENF 2030 did not present negative heterosis.

Except for UENF 1626 x UENF 1623 and UENF 1750 x UENF 1623 hybrids, all others presented GCD superior to their parents and positive heterosis. UENF 1626 x UENF 1632 hybrid presented negative heterosis (-0.77) for this characteristic. On the other hand, UENF 1626 x UENF 1627 stood out with heterosis value of 10.74. Rodrigues *et al.* (2012), evaluating hybrids of *Capsicum baccatum*, found positive values of heterosis for canopy diameter varying from 1.14 to 12.82 cm.

Concerning DFL, five hybrids and two genitors (UENF 1750 x UENF 1623; UENF 1627 x UENF 1623; UENF 2030 x UENF 1632; UENF 2030 x UENF 1623; UENF 1632 and UENF 1623) had the lowest values, characterizing them as early for flourishing. In terms of DFR, five hybrids and three genitors (UENF 1626 x UENF 1623; UENF 1627 x UENF 2030; UENF 1627 x UENF 1623; UENF 2030 x UENF 1632; UENF 2030 x UENF 1623; UENF 2030; UENF 1632 and UENF 1623) showed the greatest earliness. Negative heterosis for DFL and DFR indicate reduced number of days to flourishing and fruiting, with the early genotypes acting as the most appealing for producers (Blat *et al*., 2007; Patil & Bhalekar, 2012; Silva *et al*., 2015). Gomide *et al*. (2003) and Patil & Bhalekar (2012) achieved negative heterosis (-4.50 to -75.76) and (-1.31 to -17.61) for earliness in peppers and chilies (*Capsicum annuum*), respectively.

Among the hybrids, the lowest LOF was registered for UENF 1626 x UENF 1750 (16.98 cm) and the hybrid combination UENF 1626 x UENF 2030 obtained the greatest negative value of heterosis for this character. Still among hybrids, the greatest values of fruit length were observed for UENF 1627 x UENF 2030, UENF 1627 x UENF 1632 and UENF 2030 x UENF 1623. In relation to fruit diameter, the hybrid UENF 1750 x UENF 2030 was the one with the lowest average and heterosis with the greatest negative value.

In regards of TNF, UENF 1626 x UENF 1750 hybrid together with UENF 1750 genitor produced greater number of fruits, with more than 100 fruits per plant, although the greatest heterosis values were observed for UENF 1627 x UENF 2030 and UENF 1627 x UENF 1623 hybrids (+32.96 and +25.00, respectively). Positive heterosis for this character was observed only for six hybrids (UENF 1626 x UENF 1750; UENF 1626 x UENF 1627; UENF 1626 x UENF 2030; UENF 1750 x UENF 2030; UENF 1627 x UENF 2030 and UENF 1627 x UENF 1623). Rodrigues *et al*. (2012) found values of positive heterosis from 3.89 to 37.19 for number of fruits in *C. baccatum*. It must be highlighted that small-sized fruits and in higher number are ideal for ornamental chili pepper production.

Aiming to develop new cultivars for ornamental chili pepper market, and considering a chili pepper ideotype proposed, which consists in small-sized plants (up to 30 cm), precocious in days to flourishing and fruiting, and in high number of fruits per plant, the following hybrids could be recommended: UENF 1626 x UENF 1750 and UENF 1750 x UENF 2030 (Figure 1). Besides that, UENF 1626 x UENF 2030 hybrid can also be recommended as it attends parameters proposed for the ideotype, and presents satisfactory esthetical structure, although having a lower performance compared to hybrids previously cited in terms of fruits per plant.

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