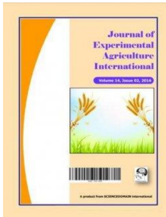

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General and Specific Combining Abilities for Flower Characters of *Capsicum annuum* L.

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Authors' contributions

This work was carried out in collaboration between all authors. The author AMSP did the experimental study, wrote the protocol, and wrote the first draft of the manuscript. Authors ERR and MMR designed the study and performed the statistical analysis. All authors managed the literature searches, read and approved the final manuscript.

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ABSTRACT

The study was carried out with the objective of estimating the combinatorial capacity of ornamental pepper (*Capsicum. annuum* L.) genotypes for flower traits, aiming to identify the best hybrids and the best parents for the synthesis of new populations. The experiment was conducted in a greenhouse in the Biotechnology Laboratory, Agrarian Center, Federal University of Paraíba (Laboratório de Biotecnologia Vegetal of Centro de Ciências Agrárias, Universidade Federal da Paraíba), State of Paraíba, Brazil. Seven accessions of Capsicum annuum were hand-crossed. Seven flower traits were evaluated including days for flowering, flower diameter, petal length, number of petals, number of stamens, anther length, and filament length. The diallel analysis using the Griffing method I of the data recorded showed that accessions 001, 004 and 099 were the best for flower characteristics based on their GCA values. There were significant reciprocal effects for

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days to flowering, filament length and anther length. The additive effects of the genes were predominant for most of the flower characteristics and the non-additive effects for the days for flowering only. Genotypes 001, 004 and 099 are indicated for crosses that aim to increase flower characteristics. In general, these genitors were involved in almost hybrids combinations with best SCA values. Those combinations should be used for to advance genarations in the breeding program. On the other hand, the best hybrids to be release for propagation were: 134 x 004, 137 x 001, 390 x 004, 77.3 x 099, 001 x 390, 001 x 77.3, and 099 x 77.3.

Keywords: Breeding; diallel analysis; genetic effects; ornamental pepper.

1. INTRODUCTION

Capsicum annuum L. species belong to the Solanaceae family, which has numerous members admired for their ornamental value [1]. *Capsicum* is native to the New World and comprises 33 - 34 species, five of them domesticated [2,3,4]. The chromosome number and ploidy level were described, and all analyzed species were diploid, with 2n = 24 chromosomes [5,6]. It is an autogamous species easily propagate by seeds and to grow, with short vegetative phases and high aesthetic value [7,8,9]. Aesthetic value is associated with a great variety of fruit shapes and coloring, with the variation of foliage color [9,10], plant architecture, fruit and leaf quantity [11,12,13]. In addition to the characteristics of the plant, leaves, and fruits, the characterization of pepper flowers is an interesting aspect for ornamentation since, despite their small size; they have attractive colors and upright position, which allows greater visualization [14,15].

The study on flower characters is important for the ornamental aspect, with the selection of accessions that have large flowers [14] and can also facilitate other phases of a breeding program, such as crossing, and subsequently, the obtaining of hybrid or genetic seeds and the advancement of segregating generations [7].

In breeding programs, hybridization is a strategy used to gather favorable alleles from different parents [16]. Among the methodologies, diallel analysis provides estimates of useful parameters in the selection of parents for hybridization [17,18].

The Griffing diallelic method [19] makes it possible to estimate the general combining ability obtained from hybrid populations, indicating how much it differs from the general average of the diallel population's parents [20] (SCA), which is the result of the concentration of non-additive genes [21]. This work was carried out with the objective of determining the general and specific combining abilities, by means of diallel crossing, for flower characters of 7 accessions of ornamental peppers.

2. MATERIALS AND METHODS

The plant materials were the 7 accessions of ornamental pepper 001, 004, 77.3, 099, 134, 137 and 390 and their 42 hybrids. The accessions were selected based on genetic diversity [13].

Manual crosses were performed in pre-anthesis floral buds. The floral buds were emasculated in the morning, immediately pollinated by placing the pollen from a donor plant on the stigma of an acceptor flower from another plant, labeled and covered with aluminum foil to avoid contamination [22]. Fruits were collected when ripe, and seeds were removed. Seeds from the 7 seven parents and 42 hybrids were sown in polystyrene trays with 128 cells, which were filled with commercial substrate (Plantmax®). Thirty day-old seedlings were transferred into plastic pots containing 900 mL of the same substrate (Plantmax®).

The experiment was developed at the Biotechnology Laboratory, Agrarian Center, Federal University of Paraíba (Laboratório de Biotecnologia Vegetal of Centro de Ciências Agrárias, Universidade Federal da Paraíba),

Flower characteristics evaluated were days for flowering (DFL), flower diameter (FD), petal length (PL), number of petals (NP), number of stamens (NS), anther length (AL), and filament length (FL) [23]. To obtain data on the dimensions, a digital caliper was used (Leetools® digital caliper, Lotus Plus Commercial LTDA, China) and the quantity were obtain by direct counting.

The 49 accessions and hybrids were displayed in a completely randomized block design with eight replicates. Each repetition consisted of a vase with a plant from each of the 49 accessions and hybrids. The data were subjected to Griffing Diallel.

General combining ability (GCA) and specific combining ability (SCA) were estimated using the Griffing's [18] method I (fixed model). The statistical model was:

$$X_{ijk} = \mu + g_i + g_j + s_{ij} + r_{ij} + b_k + e_{ijk}$$

Where,

X_{ijk} = observation value for a cross between the *i*th and *j*th parents in the *k*th replication; μ population mean; g_i and g_j = GCA effect for the *i*th and *j*th parents, respectively; s_{ij} = SCA effect for the hybrid between the *i*th and *j*th parents; r_{ij} = reciprocal effect for the hybrid; b_k = repetition effect and e_{ijk} = experimental error.

Treatments, GCA, SCA, and reciprocal (maternal) effects were detected by an analysis of variance. The differences between reciprocal hybrids were detected by Student's t test.

3. RESULTS

The mean squares of general combining ability (GCA) were highly significant ($p \leq 0.01$) for all the flower characteristics viz. days for flowering, flower diameter, petal length, number of petals, number of stamens and filament length. The anther length also showed significant differences ($p \leq 0.05$) (Table 1).

The specific combining ability (SCA) displayed highly significant effect ($p \leq 0.01$) for days for flowering, number of petals, and filament length traits, as well as a significant effect ($p \leq 0.05$) for the number of stamens. The accessions displayed a non-significant SCA for flower diameter, petal length, and anther length (Table 1).

Estimates of reciprocal effects were non-significant for flower diameter, petal length, number of petals, and number of stamens traits. Only the characters days for flowering ($p \leq 0.01$), filament length ($p \leq 0.01$) and anther length ($p \leq 0.05$) presented significant reciprocal effects (Table 1).

GCA effects were higher than SCA effects for number of stamens traits (Table 1).

The GCA values ($\hat{g}i$) obtained for the characteristic days for flowering, showed negative values for accessions 001, 004, and 099 (Table 2).

For flower diameter, petal length, number of petals and number of stamens traits, accessions 001, 004 and 099 recorded high and positive estimates of $\hat{g}i$ whereas accessions 77.3 and 390 presented high and negative values (Table 2).

In relation to filament length trait, the accessions 004, 099 and 77.3 influenced in the crossings reducing this characteristic, with negative values of $\hat{g}i$, whereas the accessions 134 and 137 contributed to the increase of this character (Table 2).

When it comes to SCA, the hybrid combination 77.3 x 099 (-4.912) recorded the highest significant negative estimate for the character days for flowering (Table 3) and only the hybrid 134 x 001 (0.045) presented significant and positive value for petal length trait (Table 3).

The hybrid 134 x 77.3 showed the highest significant positive value of S_ij for number of petals and number of stamens traits. For anther length trait, only 390 x 77.3 and 77.3 x 004 hybrids revealed positive and significant values. In the other hand, the reciprocal 004 x 77.3 (-0.051) had a greater significant negative effect for anther length trait. The hybrid combination 77.3 x 001 (0.027) presented the highest positive and significant estimates for filament length trait, whereas, the hybrid 390 x 77.3 showed the highest negative value (-0.031) (Table 3).

4. DISCUSSION

The significant effect of the general combining ability (GCA) for flower traits was indicative of additive effects involved in the genetic control of these traits. The significance of GCA for these characteristics reflects the high importance of the additive gene effects on the expression of the characters [11,24].

The mean value of the GCA indicated that for a few of the evaluated characteristics (FDL, NP, FL, NS), the additive gene effects were involved in the control of these characteristics [25,26], and that the hybrid combinations differ from the parents [27].

The additive effects of the genes have been predominant for most of the flower characteristics and the non-additive effects were higher only for the days for flowering character. In relation to this, Pessoa et al. [28] found that the additive effects influenced the performance of the hybrids for the characteristics of flowers in ornamental pepper. Santos et al. [29] in a study with C. annuum for ornamental pepper, found a similar result to that work, and identified the control of the additive effects for the characteristic corolla diameter.

These accessions presented negative values which influenced in the crossings decreasing the number of days to the beginning of the flowering, while accessions 77.3 and 390 contributed to increase the number of days for flowering in pepper. For the days for flowering, filament length, and anther length that presented significant reciprocal effects, there was a maternal effect translated by a difference between the hybrids and their reciprocals. Accessions may be used as a male parent or as a female parent in the hybridization, according to their performance as donor or as pollen recipient [20].

For the traits flower diameter, petal length, number of petals and number of stamens that showed no significant reciprocal effect, the direction in which the cross is made does not influence the results [30] indicating that there was no significant influence of the cytoplasmic genes [31].

The 001, 004, and 099 genitors were considered good parents because they presented high GCA for the flower characteristics and should be prioritized in hybrid combinations, favoring the selection of homozygous lines [32]. The GCA variability allows us to infer that the parents contributed differently at the crosses involved [30]. Medeiros et al. [33] evaluating the genetic and heterosis effects in crosses of C. baccatum, selected the characteristics with greater general combining ability (ĝi) according to the characteristics of interest.

Thus, GCA values are good criteria for selection of genotypes in a breeding program, evidencing increments for petal length characteristics, number of petals and number of stamens showing positive and significant results, and reduction for days for flowering and filament length which presented significant and negative results. When the GCA effects are positive or negative for a given parent, it may be considered superior or inferior to the other parents included in the diallel [34,35].

The estimates of the effects of specific combining ability (SCA) indicate that the effects of the hybrid combinations obtained between the parents and their interpretation are in accordance with their relationship with the GCA values of their parents [18].

For flower diameter, petal length and anther length for which accessions did not show significant SCA, Gomide et al. [34] reported that, in this case, non-additive effects are nonexistent or irrelevant to the characteristics evaluated. Therefore, when there is a magnitude of additive effects of the genes for certain traits of interest, it is suggested to make a selection after continuous self-fertilization until obtaining pure desirable lines [36].

The hybrid combinations indicated in obtaining early plants in flower production were 134 x 004, 137 x 001, 390 x 004, 77.3 x 099, 001 x 390, 001 x 77.3 and 099 x 77.3 for which heterosis was predictable.

Table 1. Summary of the analysis of variance and quadratic components associated with general combining ability (ϕ_g^2), specific combining ability (ϕ_s^2) and reciprocal effects ($\phi_r^2 e$) for ornamental pepper flower traits (*Capsicum annuum* L.)

Source of variation	DF	Trait			
		DFL	FD	PL	NP
Treatments	48	86.250**	0.149**	0.020**	0.480**
GCA	6	222.296**	0.989**	0.114**	2.529**
SCA	21	75.790**	0.040^{ns}	0.007^{ns}	0.225**
Reciprocal effect	21	57.839**	0.017^{ns}	0.007^{ns}	0.150^{ns}
Residual	343	8.400	0.047	0.008	0.116

Source of variation	DF	Trait		
		NS	AL	FL
Treatments	48	0.456**	0.003*	0.010**
GCA	6	2.448**	0.006*	0.043 **
SCA	21	0.189*	0.002^{ns}	0.007**
Reciprocal effect	21	0.155^{ns}	0.004*	0.003**
Residual	343	0.107	0.002	0.003

*DF degrees of freedom, ^{ns} Not significant, **and* Significant according to the F test, at p ≤ 0.01 and p ≤ 0.05, respectively. Days for flowering (DFL), flower diameter (FD), petal length (PL), number of petals (NP), number of stamens (NS), anther length (AL), filament length (FL)*

Table 2. Estimates of the effects of general combining ability (ĝi) for seven quantitative characteristics of ornamental pepper flowers (*Capsicum annuum* L.)

Accessions	Traits			
	DFL	FD	PL	NP
001	-1.284**	0.077**	0.023*	0.177**
004	-1.195**	0.060**	0.033**	0.073*
77.3	2.099**	-0.174**	-0.046**	-0.162**
099	-1.338**	0.096**	0.025**	0.171**
134	-0.025^{ns}	0.010^{ns}	0.004^{ns}	0.019^{ns}
137	0.126^{ns}	-0.008^{ns}	0.001^{ns}	-0.096**
390	1.617**	-0.062**	-0.041**	-0.183**
Accessions	**Traits**			
	NS	**AL**	**FL**	
001	0.166**	0.004^{ns}	-0.007^{ns}	
004	0.085*	0.006^{ns}	-0.019**	
77.3	-0.147**	-0.002^{ns}	-0.012*	
099	0.166**	0.004^{ns}	-0.018**	
134	0.017^{ns}	0.007^{ns}	0.027**	
137	-0.090**	-0.006^{ns}	0.025**	
390	-0.197**	-0.012*	0.003^{ns}	

*^{ns} Not significant **and* Significant according to the Student's t-test, at p ≤ 0.01 and p ≤ 0.05, respectively. Days for flowering (DFL), flower diameter (FD), petal length (PL), number of petals (NP), number of stamens (NS), anther length (AL), filament length (FL)*

Table 3. Estimates of the effects of specific combining capacity (S_{ij}) for seven characteristics of flowers in ornamental pepper (*C. annuum* L.)

Hybrid/Reciprocal	Traits							
	DFL		FD		PL		NP	
001x004 (004x001)	-0.483^{ns}	1.187^{ns}	0.079^{ns}	-0.005^{ns}	0.002^{ns}	-0.020^{ns}	0.147*	0.021^{ns}
001x099 (099 x 001)	-0.215^{ns}	-0.937^{ns}	0.020^{ns}	-0.091^{ns}	-0.000^{ns}	0.012^{ns}	0.153*	0.022^{ns}
004x099 (099 x 004)	0.570^{ns}	0.688^{ns}	-0.079^{ns}	0.016^{ns}	-0.026^{ns}	0.035^{ns}	0.028^{ns}	-0.021^{ns}
77.3x001 (001x77.3)	2.159**	-2.750**	0.013^{ns}	0.002^{ns}	-0.006^{ns}	0.002^{ns}	-0.076^{ns}	-0.062^{ns}
77.3x004 (004x77.3)	-0.242^{ns}	0.687^{ns}	-0.044^{ns}	-0.021^{ns}	0.006^{ns}	-0.012^{ns}	-0.222**	-0.021^{ns}
77.3x099 (099x77.3)	-4.912**	-1.625**	-0.011^{ns}	0.003^{ns}	-0.007^{ns}	0.015^{ns}	-0.008^{ns}	-0.250**
134x137 (137x134)	0.561^{ns}	1.188^{ns}	0.041^{ns}	-0.040^{ns}	0.003^{ns}	-0.019^{ns}	0.079^{ns}	0.055^{ns}
134x390 (390x134)	-1.492*	2.500**	-0.001^{ns}	-0.019^{ns}	-0.018^{ns}	0.030^{ns}	-0.085^{ns}	-0.083^{ns}
134x77.3 (77.3x134)	0.275^{ns}	-0.125^{ns}	0.074^{ns}	-0.022^{ns}	-0.014^{ns}	-0.016^{ns}	0.165*	0.062^{ns}
134x001 (001x134)	-0.466^{ns}	2.625**	-0.060^{ns}	-0.018^{ns}	0.045*	0.022^{ns}	0.034^{ns}	-0.021^{ns}
134 x004 (004x134)	-1.492*	3.437**	0.013^{ns}	0.028^{ns}	0.009^{ns}	0.019^{ns}	-0.028^{ns}	-0.062^{ns}
134x099 (099x134)	0.338^{ns}	0.625^{ns}	0.023^{ns}	-0.016^{ns}	-0.014^{ns}	-0.022^{ns}	0.040^{ns}	-0.021^{ns}
137x390 (390x137)	-0.769^{ns}	-2.000**	0.077^{ns}	-0.049^{ns}	0.021^{ns}	-0.016^{ns}	0.093^{ns}	-0.062^{ns}
137x77.3 (77.3x390)	-0.564^{ns}	-0.312^{ns}	0.047^{ns}	0.048^{ns}	0.030^{ns}	-0.031^{ns}	0.114^{ns}	-0.021^{ns}
137x001(001x137)	-1.492*	2.500**	-0.044^{ns}	0.037^{ns}	-0.022^{ns}	0.039*	-0.058^{ns}	0.229**
137x004 (004x137)	-0.332^{ns}	2.250**	-0.035^{ns}	-0.041^{ns}	-0.021^{ns}	0.002^{ns}	-0.016^{ns}	-0.083^{ns}
137x099 (099x137)	2.124**	3.687**	-0.035^{ns}	0.026^{ns}	0.029^{ns}	-0.024^{ns}	-0.240**	-0.125^{ns}
390x77.3 (77.3x390)	-2.742**	-1.000^{ns}	-0.046^{ns}	0.016^{ns}	0.011^{ns}	-0.025^{ns}	0.076^{ns}	-0.021^{ns}
390x001 (001x390)	0.954^{ns}	-1.312**	-0.029^{ns}	-0.006^{ns}	-0.009^{ns}	0.001^{ns}	-0.180*	0.104^{ns}
390x004 (004x390)	-1.760**	1.312**	0.002^{ns}	0.031^{ns}	-0.002^{ns}	0.018^{ns}	0.070^{ns}	-0.042^{ns}
390x099 (099x390)	0.195^{ns}	1.500**	0.022^{ns}	0.008^{ns}	0.013^{ns}	-0.009^{ns}	-0.008^{ns}	0.146^{ns}

Table 3 (Continued)

Hybrid/Reciprocal	Traits					
	NS		AL		FL	
001x004 (004x001)	0.135*	-0.032^{ns}	0.001^{ns}	-0.016^{ns}	0.004^{ns}	-0.004^{ns}
001x099 (099x001)	0.117^{ns}	-0.062^{ns}	0.006^{ns}	-0.002^{ns}	-0.008^{ns}	-0.002^{ns}
004x099 (099 x 004)	0.031^{ns}	-0.021^{ns}	0.016^{ns}	-0.008^{ns}	-0.014^{ns}	0.007^{ns}
77.3x001 (001x77.3)	-0.070^{ns}	-0.062^{ns}	-0.011^{ns}	0.007^{ns}	0.027*	0.014^{ns}
77.3x004 (004x77.3)	-0.136*	0.083^{ns}	0.021*	-0.051**	0.005^{ns}	-0.019^{ns}
77.3x099 (099x77.3)	-0.008^{ns}	-0.250**	0.001^{ns}	-0.026*	0.003^{ns}	-0.001^{ns}
134x137 (137x134)	0.084^{ns}	-0.023^{ns}	0.000^{ns}	-0.010^{ns}	0.009^{ns}	-0.008^{ns}
134x390 (390x134)	-0.079^{ns}	-0.104^{ns}	0.003^{ns}	0.002^{ns}	-0.002^{ns}	-0.003^{ns}
134x77.3 (77.3x134)	0.166*	0.062^{ns}	-0.016^{ns}	-0.007^{ns}	0.022*	-0.004^{ns}
134x001 (001x134)	0.037^{ns}	-0.042^{ns}	0.015^{ns}	0.002^{ns}	0.005^{ns}	0.022^{ns}
134 x004 (004x134)	-0.029^{ns}	0.062^{ns}	-0.004^{ns}	0.002^{ns}	0.001^{ns}	0.023^{ns}
134x099 (099x134)	0.057^{ns}	-0.021^{ns}	-0.006^{ns}	-0.001^{ns}	0.021*	0.001^{ns}
137x390 (390x137)	0.111^{ns}	-0.062^{ns}	0.003^{ns}	-0.000^{ns}	0.010^{ns}	0.008^{ns}
137x77.3 (77.3x390)	0.081^{ns}	-0.023^{ns}	0.014^{ns}	-0.023*	0.017^{ns}	-0.004^{ns}
137x001(001x137)	-0.044^{ns}	-0.229**	-0.006^{ns}	0.007^{ns}	0.001^{ns}	0.036**
137x004 (004x137)	-0.026^{ns}	-0.083^{ns}	-0.014^{ns}	0.004^{ns}	-0.026*	-0.009^{ns}
137x099 (099x137)	-0.231**	-0.125^{ns}	0.002^{ns}	-0.008^{ns}	-0.023*	0.006^{ns}
390x77.3 (77.3x390)	0.042^{ns}	-0.021^{ns}	0.021*	-0.026*	-0.031**	-0.003^{ns}
390x001 (001x390)	-0.187**	0.062^{ns}	-0.003^{ns}	-0.002^{ns}	0.006^{ns}	0.006^{ns}
390x004 (004x390)	0.060^{ns}	-0.021^{ns}	-0.007^{ns}	0.004^{ns}	0.032**	0.018^{ns}
390x099 (099x390)	0.022^{ns}	0.146^{ns}	-0.014^{ns}	0.001^{ns}	0.017^{ns}	0.001^{ns}

*^{ns} Not significant **and* Significant according to the Student's t-test, at p ≤ 0.01 and p ≤ 0.05. Days for flowering (DFL), flower diameter (FD), petal length (PL), number of petals (NP), number of stamens (NS), anther length (AL), filament length (FL)*

5. CONCLUSION

The Griffing diallel analysis showed that the genotypes 001, 004 and 099 are indicated for crosses when the scope of the program is to increase flower characteristics. In general, these genitors were involved in almost hybrids combinations with best SCA values. Those combinations should be used for to advance generations in the breeding program. On the other hand, the best hybrids to be release for propagation are: 134 x 004, 137 x 001, 390 x 004, 77.3 x 099, 001 x 390, 001 x 77.3 and 099 x 77.3.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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