Bioagrica 1 (1) 1-6
Article ID : *bioagrica-2003312112238*

Bioagrica

Journal homepage: http://www.htpub.org/Bioagrica/

Combining Ability Analyses of Fruit Characteristics in Bell Pepper (*capsicum annuum* L.) Lines Using Half Diallel Cross Design

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Article Information

Article History
Received: 12/11/2019
Accepted: 28/02/2020
Available online: 31/03/2020

Keywords
Capsicum annuum L.
General combining ability
Specific combining ability
Half diallel design

Abstract

Selection of parents based on their combining ability is an important approach in hybrid breeding programs. In this study, nine inbred lines were used to obtain 36 crosses (direct cross without parents) for analyzing the general combining ability (GCA) and specific combining ability (SCA) for six agronomic and fruit characters including vigor of plant (VoP), pedicel length (PeL), pericarp thickness (PT), fruit length (FL), fruit diameter (FD), single fruit weight (SFW) and Fruit yield per plant (FY). The results showed that GCA was significantly different among parents for all of evaluated traits and SCA was also significantly different among crosses for all traits except vigor of plant. P165, P102-2, P103-1, P174-2, P188-3, P209-2 and P213-1 were excellent parents with greater general combining ability for various characteristics. Five crosses P174-2×P209-2, P102-2×P102-3, P209-2×213-1, P188-3×P174-2 and P102-3×P103-1 showed high SCA effect value for different characters. It also revealed that there is an inconsistent relationship between GCA and SCA effects suggesting that parents' selection for further breeding program should be based on GCA effects.

1. Introduction

Pepper (*Capsicum annuum*L) as one of the most important vegetables in the world is considered an important source of vitamins and minerals. Estimated total production of this favorable crop is about 53.914 million tonnes in 2017 (FAOSTAT, 2017). This vegetable shows a wide variability, including paprika, spicy peppers, bell peppers and etc, (Casali and Couto, 1984; Rêgo *et al*., 2012). Peppers are important not only because of the large usage range, but also because of their high nutritional value in the human diet. It is a proper source of various bioactive compounds along with significant ratio of beta-carotene (pro vitamin A) and other similar compounds (Shotorbani *et al*., 2013). Development of new hybrid cultivars in any crops requires confirmation of the best lines which can be used as parents in future crosses (Fasahat *et al*., 2016).

Diallel mating system is the one of the appropriate means to find parents with suitable general combining ability (i.e., generally giving good hybrids), as well as specific combinations of parents that result in exceptionally good hybrids (Acquaah, 2009). This strategy provides average degree of dominance,the estimates of genetic parameters regarding combining ability and presence or absence

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of epistasis, and distribution of dominant and recessive genes in the parent lines is extracted by this procedure (Rego *et al*., 2011; Nascimento *et al*., 2012). Combining ability is a strong tool in estimating the best combiners for hybridization particularly, when a large number of advance parental lines are available and most promising ones are to be chosen on the basis of their ability to give superior fruit quality pepper hybrids.

The general combining ability (GCA) is the comparative capability of the parental lines to combine with others whereas Specific combining ability (SCA) is defined as those specific cross perform better or poorer than would be expected on GCA effects of the parents involved in the cross (Sprague and Tatum, 1942). Griffing (1956) described statistical procedures for analyzing four various diallel methods for use in crop (for more information see Pooni *et al*., 1984) that clearly define GCA and SCA. The objective of this study was to estimate general and specific combining ability for fruit traits in pepper, using a diallel set of crosses among various inbred lines with different fruit characteristics.

2. Materials and methods

Nine promising inbred were sown and crossed at the Research Greenhouse of the Islamic Azad University of Isfahan (Khorasgan) Branch, Iran, (lat. 32863', long. 51836') in September 2016 to February 2018. This nine inbred lines were crossed following a 9 ×9 half diallel design and the first filial generation (F1) of progenies was obtained. Lines used as female were crossed to each male parent by hand pollination at the pre-anthesis stage (Do Rêgo *et al*. 2012). Fruits were collected when ripe, and seeds were removed. The 36 F1 progenies were grown in a randomized complete block design with three replications. The space between and within couple rows were 110 (cm) and 40 (cm), respectively, and 160 (cm) between every couple rows.

Morpho-agronomic characterization was performed based on the Capsicum descriptors defined by IPGRI (1995). Traits measurement included vigor of plant (VoP), pedicel length (PeL, cm), pericarp thickness (PT, mm), fruit length (FL, cm), fruit diameter (FD, cm), single fruit weight (SFW, gr) and Fruit yield per plant (FY, gr). For each trait measured, the means were calculated for hybrids (n= 36) groups and were subjected to preliminary analysis of variance in accordance with the model for hybrid families in the randomized block design. Since the means for individual traits differed significantly among hybrids, the analysis of variance for an incomplete diallel design using Griffing's fixed model in the fourthmethod. Statistical analysis was carried out using algorithms developed by Garretsen and Keuls (1978), and Mądry and Ubysz Borucka (1982).

3. Results

Parental had highly significant ($P \leq 0.01$) general combining ability (GCA) for all evaluated traits and specific combining ability (SCA) effects was non-significant for vigor of plant (VoP) and highly significant for other traits. The ratio of MSgca/MSsca was non -significant for single fruit weight (SFW) and pericarp thickness (PT). This ratio was significant ($P \leq 0.01$) for fruit length (FL), fruit diameter (FD) and pedicel length (PeL) and significant ($P \leq 0.05$) for fruit yield per plant (FY). The amount of Baker's ratio for all studied traits was high (more than 0.7).

The general combining ability (GCA) effects of the parents are presented in Table 1. The parent P165and P174-2 showed highly significant positive GCA values while the parent P102-2 showed highly significant negative GCA values for fruit yield and highly significant positive for fruit diameter and pericarp thickness. Highly significant positive value of GCA for vigor was observed in the P209-2 line. Positive GCA value was also found for pedicle length in P103-and 188-3. The P174-2 and 188-3 lines had the highest GCA value for single fruit weight.

Table 1. Combining ability analysis of studied traits

Fruit yield per plant (FY)	single fruit weight (SFW)	fruit diameter (FD)	fruit length (FL)	pericarp thickness (PT)	Pedicle length (PeL)	Vigor of plant (VoP)	df	Source of variation
1020443.86**	12353.35**	0.76**	5.27**	184.41**	1.03**	1.40**	8	GCA
450603.9**	9873.56**	0.56**	2.11**	75.78**	0.26**	0.216^{ns}	36	SCA
145172.9	638.25	0.26	0.56	30.57	0.08	0.230	44	Error
2.26*	1.25ns	1.34**	2.46**	2.43^{ns}	3.93**	6.50**	-	MSGCA/MSSCA
0.82	0.71	0.73	0.83	0.83	0.89	0.93	-	Baker ratio

The SCA of direct crosses are presented in Table 2. The highest negative SCA effects of -521.65 and -502.00 for fruit yield per plant were observed in the following crosses: P102-2×P209-2 and P102-3×P213-1. The following crosses: P102-2×P213-1, P103-1×P209-2 and P174-2×209-2 expressed the highest positive SCA effects of, 601.74, 584.67 and 1516.08 respectively. For fruit length and fruit diameter, significantly nTable 3egative SCA effects were recorded in P102-2×P188-3 and P102-3×P174-2, P102-3×188-3 and P103-1×P188-3. P102-3× P103-1 was the only cross that had a positive SCA effect on single fruit weight. Positive and high SCA effects were observed for fruit diameter and pericarp thickness in the P165×P103-1 and P209-2×213-1. The cross P102-2× P102-3 showed the highest negative significant SCA effect for fruit diameter, while P165× P213-1 cross had the highest negative SCA value for pericarp thickness. For vigor of plant the only cross that had a significant effect was P188-3× P209-2, which was a negative effect. The highest positive SCA effects for pedicle length were generated in the crosses of P173×P102-3 and P188-3×P174-2 while the highest negative of this parameter was found for P102-3×213-2 and P165×P174-2.

4. Discussion

The GCA effect for all traits and the SCA effect for all traits except for vigor of plant were significant (Table 3). Rego *et al*. (2014) reported that effects of GCA and SCA were significant for fruit diameter and weight and pericarp thickness in the pepper *(Capsicum annuum)*.

The ratio of MSgca/MSsca (Table 1) displayed the relative importance of additive gene action. This ratio was significant for most traits except single fruit weight and pericarp thickness; therefore they are predominantly controlled by additive gene effects, so the pedigree method of selection can be used for their improvement. The baker ratio was > 50% for all of the evaluated traits. Our findings agree with earlier reports for fruit length and diameter (Reddy *et al*., 2008; Syukur *et al*., 2010; Rodrigues *et al*., 2012), number of secondary branches (Reddy *et al*. 2008) and stem height (at first bifurcation height) (Rêgo *et al*. 2011) that were found to be controlled by additive gene action.

The selection of parents based on their combining ability, and understanding the genetic control of key traits ensure the efficiency of a breeding program (Nadarajan and Gunasekaran, 2005; Sleper and Poehlman, 2006). The best general combiners with positive effects for of fruit yield were P165 and P174-2 (Table 3) and P174-2 and P188-3 were the best general combiners for single fruit weight. Good combiners for fruit diameter and pericarp thickness were P102-2, while good combiner for pedicle length and fruit length was P188-3.Specific combining ability effects are useful to identify specific crosses with desirable traits (Acquaah, 2009). In this study, the best specific crosses for fruit yield were P103-1×P209-2, P174-2×P209-2, P173×P102-3 and P102-2×P213-1. A high positive SCA for this trait means that the parental forms are useless for breeding purposes.

Table 2. Specific combining ability (SCA) effects of the crosses for studied traits. Fruit yield per plant (FY), Fruit length (FL), Fruit diameter (FD), Pericarp thickness (PT), Vigor of plant (VoP), Pedicle length (Pel), Single fruit weight (SFW).

crosses	FY	FL	FD	PT	VoP	PeL	SFW
165× 173	427.44	0.62	-0.61	2.11	0.13	-0.23	21.50
165× 102-2	-19.30	-0.34	0.30	-0.28	-0.23	0.45*	-23.73
165× 102-3	257.65	0.06	0.83*	4.48	0.29	-0.50*	11.01
165× 103-1	-168.16	-0.50	0.70*	6.14	0.080	0.23	5.46
165× 174-2	102.74	0.34	0.10	3.91	0.31	-0.58**	-35.68*
165× 188-3	-233.36	-0.87*	0.59	1.31	-0.33	0.35	-22.16

165× 209-2	411.61	-0.25	-0.26	-7.44	0.44	0.41*	37.56*
165× 213-1	5.41	1.97**	-0.03	-12.74**	-0.20	0.48*	28.27
173× 102-2	330.48	-0.35	0.21	-4.45	-0.29	0.04	13.22
173× 102-3	592.126*	0.10	0.15	-2.69	0.28	0.58**	-2.07
173× 103-1	241.31	-0.21	0.61	5.79	0.63	-0.18	6.25
173× 174-2	-463.09	-0.01	0.45	-2.67	-0.46	0.50*	-20.53
173× 188-3	163.70	1.25**	-0.38	1.31	0.090	-0.01	20.05
173× 209-2	-289.31	0.11	-0.18	0.61	0.18	-0.49*	5.90
173× 213-1	392.98	-1.22**	-0.02	-3.20	-0.22	0.07	18.93
102-2× 102-3	130.93	2.63**	-1.18**	-3.17	0.18	-0.12	4.84
102-2× 103-1	-414.83	1.14*	0.23	-4.28	-0.092	0.00	-28.06
102-2× 174-2	-99.96	-0.19	0.73*	6.93	0.14	-0.32	-5.74
102-2× 188-3	154.75	-1.02*	0.00	3.63	-0.30	0.11	-39.06*
102-2× 209-2	-521.35*	-1.24*	-0.24	1.84	0.52	0.18	20.20
102-2× 213-1	601.74*	-0.70	-0.19	1.71	0.13	0.25	10.10
102-3× 103-1	71.42	-0.03	-0.58	-2.84	-0.23	0.04	72.84**
102-3× 174-2	-71.58	-1.28*	0.32	1.74	0.20	-0.28	-43.27*
102-3× 188-3	-160.59	-1.33**	0.21	8.71*	-0.43	0.15	-39.48*
102-3× 209-2	201.09	-1.13*	0.35	8.97*	-0.16	0.22	26.62
102-3× 213-1	-502.00*	0.78	-0.14	-1.34	-0.54	-0.70**	2.54
103-1× 174-2	-323.49	0.75**	-0.87*	-12.31**	-0.51	0.46*	-65.58**
103-1× 188-3	362.15	-1.31**	-0.15	8.87*	0.60	-0.11	-35.97*
103-1× 209-2	584.67*	0.28	-0.88*	-2.81	0.38	-0.04	-22.03
103-1× 213-1	-205.22	0.84**	0.40	2.12	-0.18	0.03	-2.29
174-2× 209-2	1516.08**	0.56	0.05	-1.37	-0.17	-0.42*	62.65**
174-2× 213-1	483.58	-0.86*	0.27	4.51	-0.39	-0.36	-19.25
188-3× 174-2	-364.02	0.46	-0.47	-5.54	-0.41	0.71**	-47.79**
188-3× 209-2	-466.64	1.87**	-0.43	-2.32	-0.79*	0.07	-52.15**
188-3× 213-1	161.68	0.23	-0.46	2.31	0.16	-0.15	-12.71
209-2× 213-1	447.72	-1.39**	1.13**	11.22**	-0.15	-0.28	-14.82

Generally, the GCA effects of the inbred lines and SCA effects of their crosses in the current study showed that the crosses between two high general combiners were not always the best their SCA effects. The best specific cross combinations for different traits in this study were the combinations of poor × average, good × poor and poor × poor general combiners. The marked desirable specific combining ability effects in crosses between poor × poor combiners includes, P102-2×P213-1 for fruit yield; P188-3× P209-2 for fruit length; poor × average combiner e.g., P102-3× P103-1 for single fruit weight; poor × good combiner e.g., P188-3 × P174-2 for pedicle length. In fact, in majority of cases, the best specific combinations for various traits were poor × poor, good × poor, average × poor, average × average and vice versa general combiners.

Table 3. General combining ability (GCA) of parents in a half diallel design for studied traits.

Traits / Parents	Vigor (VoP)	Pedicle length (PeL)	pericarp thickness (PT)	fruit length (FL)	fruit diameter (FD)	single fruit weight (SFW)	Fruit yield per plant (FY)
165	-0.109	-0.154*	-2.200	0.113	-0.252**	-21.71**	246.883**
173	0.157	-0.239**	-1.632	-0.468**	-0.099	-34.11**	137.409
102-2	-0.187	0.084	6.05**	-0.703**	0.339**	-2.34	-294.551**
102-3	0.244*	0.038	1.097	-0.396**	0.129	-1.92	20.800
103-1	0.208*	0.300**	1.590	-0.211*	0.084	5.85	45.418
174-2	-0.268**	-0.381**	1.484	0.064	0.092	33.88**	342.018**
188-3	-0.380**	0.188**	-3.279*	0.495**	-0.23**	36.91**	-127.265
209-2	0.345**	0.118	-2.383*	0.303**	-0.048	-17.41**	-192.257*
213-1	-0.011	0459.0	-0.728	0.803**	-0.015	0.853	-178.450*
SE g(i)	0.096	0.059	1.111	0.150	0.102	5.08	76.587
SE (gi-gj)	0.146	0.056	1.685	0.228	0.153	6.20	105.678

This suggested that SCA and GCA effect information should be used in conjunction with the performance of hybrids to predict the possibility of transgressive type possibly made available in segregating generations. In If parental GCA effects and SCA effects of crosses are in same direction, the selection is quick. If crosses indicating high SCA effects involve at least one parent possessing good

GCA effect and high mean performance, they could be exploited for practical breeding. However, in some cases, high SCA effects would not necessarily mean high performance by the hybrid, and the SCA effect estimates seemed to be redundant, as no additional information was obtained by doing so. Therefore, it is suggested that the selection of parents for further breeding program should be based on GCA effects and due consideration should be given to mean value of the cross combinations while selecting crosses for specific combining ability effects (Vekariya *et al.* 2019).

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