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Heterosis and Combining Ability in Complete Diallel Cross of Seven Chili Pepper Genotypes Grown in Ultisol

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ABSTRACT

Ultisol is very promising area for Indonesian chili pepper production. This experiment aimed to determine General Combining Ability (GCA), Specific Combining Ability (SCA), heterosis and heterobeltiosis estimates of seven parental lines; A(KG1), B(KG2), C(KG3), D(KG4), E(KG5/UNIB-C-GTS1), F(KG6), and G(KG7) through full-diallel parental crosses. Experiment was conducted from July to November 2012 and designed in Randomized Complete Block with three replications. Results indicated that parent C(KG 3) had the highest GCA estimates for fruit length and fruit weight per plant. Parent F(KG6) had the highest fruit number per plant. Parents B(KG2), D(KD4) and G(KD7) had the highest GCA estimates for fruit diameter. Cross combinations C(KG3)xF(KG6) had the highest SCA estimates for fruit weight and fruit number per plant, whereas G(KG7)xC(KG3) and D(KG4)xG(KG7) had the highest SCA estimates for fruit length and fruit diameter. Cross combinations G(KG7)xC(KG3) and F(KG6) xC(KG3) had the highest heterosis and heterobeltiosis estimates for fruit weight per plant, whereas D(KG4)xB(KG2) and D(KG4)xE(KG5) had the highest heterosis and heterobeltiosis estimates for fruit number per plant. Cross combinations B(KG2)xE(KG5) and D(KG4)xG(KG7) had the highest heterosis and heterobeltiosis estimates for fruit length and fruit diameter. It is suggested that G(KG7)xC(KG3) and F(KG6) xC(KG3) are the most promising chili pepper hybrids grown in Ultisol.

INTRODUCTION

Chili-pepper (*Capsicum annuum* L.) is a very important vegetable crop for Indonesian with average consumption per capita reaching 2.92 kg year^{-1} (Farid & Subekti, 2012) and its production area is the largest among other Indonesian vegetable productions (Ditjen Horti, 2015). However, Indonesian chili-pepper productivity was only 6.83 t ha^{-1}, it was much lower than Chinese productivity which has reached more than 22 t ha^{-1} (FAO, 2014). This low productivity was presumably due to lack of high-quality seeds available in the market and poor farmers'access to high yielding pepper varieties. Since domestic Indonesian chili-pepper varieties are not widely available, it is generally understood why most farmers replant chili-pepper seeds produced from previous growing seasons.

High yielding chili-pepper varieties are very important in increasing crop productivity to meet consumer demands. Ganefianti, Hidayat, & Syukur (2015) have conducted series of chili pepper breeding programs and used seven potentially high yielding (> 10 t ha^{-1}) chili-pepper pure lines designed for both production and disease-resistant purposes. The performances of those seven pure lines were evaluated through a complete diallel cross to produce the best parental population which was, later, used in developing the hybrid varieties. In addition, diallel cross also provides both heterosis and heterobeltiosis values which are very important to improve chili pepper productivity. Knowledge on combining ability of the lines is essential in a plant breeding program in order to understand the inheritance of the characteristics, including in chili-

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peppers. Excellent chili-pepper hybrids are generally produced from the results of parental cross that have high general combining ability (GCA), specific combining ability (SCA) and heterosis estimates.

Several studies on combining ability and heterosis on chili pepper breeding program have been previously conducted and mainly focussed on characteristics of yield components, yield, disease resistance and yield quality (Daryanto, Sujiprihati, & Syukur, 2010; Herison, Handayaningsih, Fahrurrozi, & Rustikawati, 2014; Sharma, Punetha, & Sharma, 2013; Sitaresmi, Sujiprihati, & Syukur, 2010; Yunianti, Sastrosumarjo, Sujiprihati, Surahman, & Hidayat, 2011). However, information concerning combining ability and heterosis estimates of chili pepper grown in Ultisol have not been widely reported. In Indonesia, Ultisol covered 21 % of Indonesian agricultural lands and accounted almost 40,000,000 ha (Barchia, 2009). This area is very prospective for chili pepper production in Indonesia since Indonesian chili-pepper production generally takes place in highland areas in which dominated by Andosol. It is, therefore, very urgent to find substituted areas at Ultisol to compensate the declining highland production. However, ultisol land was characterized by high acidity, high solubility of Al, Mn and Fe and low nutrient availability, especially P and Mo that might suppress growth and development of chili pepper (Barchia, 2009). High Al and Fe solubility absorb phosphate which brings about low availability of P to plants. Such limitations could be overcome by developing new chili pepper hybrids that grow well and have high productivity.

Therefore, this experiment aimed to determine General Combining Ability (GCA) and Specific Combining Ability (SCA), heterosis and heterobeltiosis estimates of chili pepper genotypes grown in Ultisol.

MATERIALS AND METHODS

The experiment was conducted from July to November 2012 in farmer's land of Karang Suci, Arga Makmur, North Bengkulu. There were 49 plant materials consisting of seven chili pepper genotypes, namely, (A) curly chili pepper (cabai keriting) KG1, (B) curly chili pepper KG2, (C) curly chili pepper KG3, (D) hot chili pepper (cabai rawit) KG4, (E) curly chili pepper KG5, (F) hot chili pepper KG6 and (G) chili pepper KG7, and 42 combinations of full diallel chili pepper crosses. The experiment was designed in a randomized complete block design with three replications. Each genotype was planted in a single row of 12 plants on 1 m x 7 m beds. Experimental plot was fertilized with NPK (150 kg ha^{-1}) and each plant received 20 t ha^{-1} goat manure. At 4, 8 and 12 weeks after transplanting, each was refertilized with NPK (50 kg ha^{-1}). Six sample plants from each genotype were randomly selected. Observation variables were addressed to fruit length (cm), fruit diameter (cm), the number of fruit per plant and fruit weight per plant (gram). Observed fruits were those harvested from the first to the eighth harvest.

Analysis of variance for each crop variable among genotypes was analysed using F test at 95 % level of confidence. Each significant variable was, later, estimated its CGA, SGA, heterosis, and heterobeltiosis. Both GCA and SCA were estimated using Model 1 (Parents, F1 and reciprocals) by Griffing (1956). Meanwhile, the determination of heterosis, and heterobeltiosis following the study by Arif, Sujiprihati, & Syukur (2012).

RESULTS AND DISCUSSIONS

Combining Ability

Contributions of general combining ability (GCA) and specific combining ability (SCA) to genotype variation were highly significant at 5 % level for fruit length, fruit diameter, the number of fruit and fruit weight per plant. Except for the fruit diameter, SCA contributions were not significant (Table 1). It is in line with results reported by Sitaresmi, Sujiprihati, & Syukur (2010), the result indicated that CGA estimates of fruit weight and the number of fruit of chili pepper per plant were significant, but not for SCA. Riyanto, Farid, & Utari (2010) reported that GCA siginificantly contributed to the variations of fruit length, the number of fruit, fruits weight per plant, but not fruit diameter of chili pepper. In addition, SCA significantly affected fruit length, fruit diameter, the number of fruit and fruit weight of chili pepper per plant. Such phenomenon indicated that there were additive and dominance gene actions that play important roles on fruit length, fruit diameter, the number of fruit and fruit weight of chili pepper per plant. According to Riyanto, Farid, & Utari (2010) and Sitaresmi, Sujiprihati, & Syukur (2010), characteristics having significant GCA estimates were controlled by additive gene actions, while characteristics having significant SCA were controlled by dominance gene actions. Bhutia, Seth, Shende, Dutta, & Chattopadhyay (2015) revealed that fresh yields, most of yield components,

vitamines, antioxidants, curly leaf diseases of chili peppers were controlled by non-additive gene actions.

Reciprocal effects significantly influence the fruit length of chili pepper, but not fruit diameter, the number of fruit, and fruit weight per plant (Table 1). It indicated that there was extra chromosomal genes' effect on fruit length of chili peppers, but not on fruit diameter, the number of fruit, and fruit weight per plant. Therefore, fruit length traits are very important to be considered as female parental lines. Research conducted by Riyanto, Farid, & Utari (2010) found significant reciprocal estimates on disease intensity and fruit weight of chili peppers per plant. The estimates of dominance variances on the number of fruit and fruit weight per plant were higher than their additive variances. It implied that there was a probability to produce a high yielding hybrid.

Results also indicated that genotype C had high GCA estimates on fruit length and fruit length per plant, while genotype B had high GCA estimates on fruit diameter (Table 2). In addition, genotypes F, E and A had high GCA estimates on the number of fruit per plant. These results indicated that each genotype had high GCA estimates on particular traits, and there was no single genotype had high GCA estimates in all observed characteristics. Correspondingly, Khalil & Hatem (2014) and Payakhapaab, Boonyakiat, & Nikornpun (2012) reported the same results. According to Iriany, Sujiprihati, Syukur, Koswara, & Yunus (2011), genotypes with high GCA on yield traits will likely produce high yielding hybrids. Riyanto, Farid, & Utari (2010) suggested that high GCA estimates on fruit length, fruit diameter, the number of fruit and fruit weight of G9854, Randu and G3257 genotypes might be employed as parental lines in improving these characteristics. In addition, Perez-Grajales, Gonzalez-Hernandez, Pena-Lomeli, & Sahagun-Castellanos (2009) also found that Landrase 'Puebla' served as the best parents due to its high GCA estimates on yield characteristics and yield components of chili pepper. It is also suggested that genotype C could be used to generate open-pollinated varieties since this genotype has the highest GCA estimates in fruit weight per plant. Similarly, Sitaresmi, Sujiprihati, & Syukur (2010) concluded that IPB C-19 genotype could be developed to become open-pollinated varieties due to its highest GCA estimates in characteristics of fruit weight per plant.

Table 1. Means squares from the diallel analysis of general combining analysis (GCA), specific combining analysis (SCA) and reciprocal effects on fruit length, fruit diameter, the number of fruit, and fruit weight per plant from seven chili pepper genotypes and their hybrids.

Source of variations	df	Means Square			
		Fruit length	Fruit diameter	Fruit number per plant	Fruith weight per plant
GCA	6	109.450**	11.706**	3099.749**	33528.71**
SCA	21	3.033**	0.566 ns	1076.781**	19156.46**
Reciprocal	21	2.027**	0.405 ns	248.132 ns	6373.691 ns
Error	96	0.880	0.305	321.704	4600.034
Additive variances		15.2096	1.5923	291.5040	2101.540
Dominance variances		1.2271	0.1492	430.2180	8293.776
Coefficient of Variances (%)		13.34	14.18	33.20	33.35

Remarks: ns,** = not significant, and significant at P < 0.05, respectively

Table 2. Estimates of general combining ability (GCA) of seven chili pepper genotypes.

Genotypes	Estimates of GCA			
	Fruit length	Fruit diameter	Fruit number per plant	Fruith weight per plant
A	0.1486 ns	-0.7167*	12.7209*	33.2122 ns
B	0.3115 ns	1.4483*	-21.9362*	16.0174 ns
C	5.4272*	-1.0044*	-0.6467 ns	57.4098*
D	-2.3971*	0.698*	-8.0272 ns	-52.0671*
E	0.0679 ns	-0.6229*	13.9447*	17.5491 ns
F	-3.3997*	-0.4022*	16.4353*	-81.3059*
G	-0.1583 ns	0.5999*	-12.4907*	9.1844 ns

Remarks: ns,** = not significant, and significant at T-test < 0.05, respectively

Table 3. Estimates of specific combining ability (SCA) for 42 cross combinations of chili pepper lines.

Lines	Estimates of GCA			
	Fruit length	Fruit diameter	Fruit number per plant	Fruith weight per plant
A x B	1.22*	-0.75*	-23.73*	-38.04 ns
A x C	0.24 ns	0.40 ns	-3.63 ns	14.16 ns
A x D	-0.67 ns	-0.05 ns	25.19*	105.57*
A x E	0.67 ns	0.13 ns	18.41 ns	100.72*
A x F	-0.58 ns	0.02 ns	9.85 ns	14.51 ns
A x G	-0.69 ns	-0.13 ns	-12.06 ns	-75.40*
B x A	1.41*	-0.15 ns	0.61 ns	-38.14 ns
B x C	-0.11 ns	-0.41 ns	-0.12 ns	-18.54 ns
B x D	0.07 ns	-0.13 ns	11.24 ns	34.67 ns
B x E	0.19 ns	-0.21 ns	-5.13 ns	38.29 ns
B x F	0.05 ns	-0.39 ns	28.70*	79.14*
B x G	-0.04 ns	-0.03 ns	13.51 ns	106.23*
C x A	-1.98*	-0.43 ns	-4.74 ns	-43.29 ns
C x B	1.15*	0.46 ns	-10.6 ns	-25.97 ns
C x D	-1.89*	-0.45 ns	6.33 ns	0.37 ns
C x E	1.00 ns	0.12 ns	4.62 ns	15.23 ns
C x F	-2.16*	0.33 ns	29.62*	130.89*
C x G	2.52*	-0.26 ns	-1.10 ns	86.90*
D x A	0.04 ns	-0.25 ns	-23.70*	-136.66*
D x B	-0.34 ns	0.17 ns	-4.91 ns	5.49 ns
D x C	0.84 ns	0.08 ns	-3.58 ns	-27.69 ns
D x E	0.52 ns	0.11 ns	-0.74 ns	-18.13 ns
D x F	1.11 ns	0.17 ns	-28.20*	-74.24*
D x G	0.13 ns	0.84*	25.50*	58.47*
E x A	0.43 ns	0.40 ns	17.13 ns	74.73*
E x B	1.58*	0.79*	1.66 ns	118.98*
E x C	-0.77 ns	0.38 ns	17.55 ns	45.70 ns
E x D	0.21 ns	0.04 ns	26.92*	95.99*
E x F	0.29 ns	0.04 ns	18.13 ns	-10.46 ns
E x G	0.48 ns	-0.88*	24.17*	92.26*
F x A	0.54 ns	0.67 ns	-12.88 ns	-17.58 ns
F x B	0.33 ns	0.48 ns	0.33 ns	-6.82 ns
F x C	0.21 ns	0.01 ns	-2.37 ns	-31.40 ns
F x D	1.05 ns	0.45 ns	3.47 ns	10.16 ns
F x E	0.00 ns	-0.12 ns	-11.58 ns	-30.47 ns
F x G	-1.12 ns	-0.32 ns	-26.82*	-118.88*
G x A	-0.03 ns	0.00ns	1.92 ns	8.70 ns
G x B	-0.64 ns	-1.42*	2.68 ns	-5.87 ns
G x C	-2.47*	-0.02 ns	-4.38 ns	-97.11*
G x D	0.26 ns	0.40 ns	-7.19 ns	-0.78 ns
G x E	-0.31 ns	0.40 ns	-8.24 ns	-17.88 ns
G x F	-1.23*	-0.50 ns	-8.58 ns	12.80 ns

Remarks: ns,** = nonsignificant and significant at T-test < 0.05, respectively

Cross combination of CxG lines had the highest estimate of SCA for fruit length, *i.e*. 2.52, while a combination of DxG had the highest estimate of SCA for fruit diameter, *i.e*. 0.84 (Table 3). Cross combination of CxF had the highest estimate of SCA for the number of fruit and fruit weight per plant, *i.e*. 29.62 and 130.89, respectively. High SCA estimates reflected that its parents had high hybrid combinations with one of its parents. High SCA estimates for fruit length, fruit diameter, and fruit weight of chili pepper per plant have been previously reported by Chaudhary, Kumar, & Solankey, 2013; Hasanuzzaman, Hakim, Fersdous, Islam, & Rahman, 2012; Khalil & Hatem, 2014; Payakhapaab, Boonyakiat, & Nikornpun, 2012; Riyanto, Farid, & Utari, 2010. Meanwhile, Perez-Grajales, Gonzalez-Hernandez, Pena-Lomeli, & Sahagun-Castellanos (2009) reported high SCA estimates for the number

of fruit and fruit weight per plant. High and positive SCA estimates indicated that parent of C had high hybrid combinations with one of other employed parents. Since parent of C had high GCA estimates for fruit length and fruit weight per plant (Table 2), it is not surprising that cross combination of CxF had high SCA for fruit weight and the number of fruit per plant, and the combination of CxG had high SCA on fruit length (Table 3). So did with parents of F which had high GCA estimate for the number of fruit per plant, the cross combination of CxF had high SCA estimate for the number of fruit per plant. Cross combinations with high SCA are usually generated from the cross of parental lines with high GCA x high GCA, high GCA x low GCA, or at least one of its parents has high GCA (Aliu, Fetahu, & Salillari, 2008). Cross combination lines with high SCA could be considered to be developed as hybrid varieties.

Table 4. Mean estimates for fruit length of chili pepper hybrids on P1, P2, F1, heterosis and heterobeltiosis.

Hybrids	P1 (cm)	P2 (cm)	F1 (cm)	Heterosis (%)	Heterobeltiosis (%)
A x B	10.230	10.293	12.115	18.061	17.698
A x C	10.230	21.377	14.435	-8.659	-32.473
A x D	10.230	5.943	8.173	1.072	-20.104
A x E	10.230	8.913	11.202	17.029	9.498
A x F	10.230	5.455	7.372	-6.004	-27.941
A x G	10.230	9.383	9.942	1.377	-2.819
B x A	10.293	10.230	10.907	6.286	5.959
B x C	10.293	21.377	17.642	11.409	-17.472
B x D	10.293	5.943	8.057	-0.760	-21.729
B x E	10.293	8.913	12.285	27.924	19.349
B x F	10.293	5.455	7.867	-0.095	-23.575
B x G	10.293	9.383	10.475	6.471	1.765
C x A	21.377	10.230	16.485	4.313	-22.883
C x B	21.377	10.293	15.795	-0.253	-26.111
C x D	21.377	5.943	12.110	-11.347	-43.349
C x E	21.377	8.913	15.608	3.059	-26.984
C x F	21.377	5.455	10.582	-21.126	-50.499
C x G	21.377	9.383	15.503	0.802	-27.475
D x A	5.944	10.230	8.123	0.453	-20.593
D x B	5.944	10.293	8.523	4.989	-17.196
D x C	5.944	21.377	11.093	-18.780	-48.105
D x E	5.944	8.913	8.582	15.526	-3.721
D x F	5.944	5.455	6.587	15.573	10.825
D x G	5.944	9.383	8.165	6.546	-12.984
E x A	8.913	10.230	11.500	20.146	12.415
E x B	8.913	10.293	9.565	-0.399	-7.076
E x C	8.913	21.377	16.463	8.705	-22.985
E x D	8.913	5.943	8.280	11.465	-7.106
E x F	8.913	5.455	7.538	4.930	-15.426
E x G	8.913	9.383	10.992	20.149	17.140
F x A	5.455	10.230	6.883	-12.230	-32.714
F x B	5.455	10.293	6.925	-12.054	-32.723
F x C	5.455	21.377	9.058	-32.480	-57.625
F x D	5.455	5.943	5.418	-4.928	-8.833
F x E	5.455	8.913	7.415	3.213	-16.810
F x G	5.455	9.383	5.642	-23.958	-39.876
G x A	9.383	10.230	10.715	9.262	4.741
G x B	9.383	10.293	11.057	12.384	7.416
G x C	9.383	21.377	19.275	25.325	-9.832
G x D	9.383	5.943	7.902	3.110	-15.790
G x E	9.383	8.913	10.517	14.957	12.078
G x F	9.383	5.455	7.025	-5.313	-25.133

Table 5. Mean estimates for fruit diameter of chili pepper hybrids on P1, P2, F1, heterosis and heterobeltiosis.

Hybrids	P1 (cm)	P2 (cm)	F1 (cm)	Heterosis (%)	Heterobeltiosis (%)
A x B	6.355	10.718	7.276	-14.768	-32.1157
A x C	6.355	5.161	5.658	-1.738	-10.9683
A x D	6.355	8.172	6.739	-7.213	-17.5297
A x E	6.355	6.567	6.061	-6.194	-7.70812
A x F	6.355	5.863	6.553	7.268	3.118443
A x G	6.355	8.527	6.856	-7.859	-19.5926
B x A	10.718	6.355	7.339	-14.022	-31.5217
B x C	10.718	5.161	7.373	-7.136	-31.2091
B x D	10.718	8.172	9.434	-0.113	-11.9757
B x E	10.718	6.567	7.818	-9.542	-27.0585
B x F	10.718	5.863	8.126	-1.977	-24.177
B x G	10.718	8.527	8.917	-7.329	-16.8027
C x A	5.161	6.355	5.829	1.229	-8.28
C x B	5.161	10.718	7.088	-10.721	-33.8652
C x D	5.161	8.172	6.467	-2.988	-20.8603
C x E	5.161	6.567	6.149	4.870	-6.35533
C x F	5.161	5.863	5.729	3.932	-2.2912
C x G	5.161	8.527	6.841	-0.041	-19.7686
D x A	8.172	6.355	7.669	5.570	-6.16753
D x B	8.172	10.718	9.179	-2.818	-14.3597
D x C	8.172	5.161	6.312	-5.315	-22.7591
D x E	8.172	6.567	7.229	-1.901	-11.5356
D x F	8.172	5.863	7.532	7.331	-7.83178
D x G	8.172	8.527	9.569	14.617	12.23488
E x A	6.567	6.355	6.361	-1.543	-3.13198
E x B	6.567	10.718	7.422	-14.120	-30.7503
E x C	6.567	5.161	5.880	0.280	-10.4543
E x D	6.567	8.172	7.283	-1.168	-10.8748
E x F	6.567	5.863	6.545	5.305	-0.33756
E x G	6.567	8.527	7.189	-4.739	-15.685
F x A	5.863	6.355	5.810	-4.897	-8.57637
F x B	5.863	10.718	7.248	-12.572	-32.3723
F x C	5.863	5.161	6.265	13.660	6.853715
F x D	5.863	8.172	6.955	-0.897	-14.8967
F x E	5.863	5.863	6.668	7.289	1.540609
F x G	5.863	8.527	6.898	-4.120	-19.0942
G x A	8.526	6.355	7.096	-4.629	-16.7739
G x B	8.526	10.718	9.772	1.557	-8.82513
G x C	8.526	5.161	6.979	1.978	-18.1481
G x D	8.526	8.172	8.900	6.560	4.384542
G x E	8.526	6.567	7.153	-5.209	-16.1014
G x F	8.526	5.863	7.557	5.030	-11.3728

Heterosis and Heterobeltiosis Fruit Length

This experiment revealed that mean estimates of fruit length for parents of both P1 and P2 of chili pepper cross combinations ranged from 5.94 to 21.38 cm, while means of F1 ranged from 5.42 to 19.28 cm. In addition, heterosis values ranged from -32.48 % to 27.92 % and heterobeltiosis values ranged from -57.63 % to 19.35 % (Table 4). Cross combinations of BxE had high heterosis and heterobeltiosis estimates for fruit length with the magnitude of 27.93 %, respectively. Other cross combinations that had high heterosis dan heterobeltiosis estimates were AxE (17.03 % and 9.50 %), AxB (18.06 % and 17.70 %), ExG (20.15 % and 17.14 %), DxF (15.57 % and 10.83 %) dan ExA (20.15 % and 12.42 %). The cross combinations of GxC had high heterosis estimates (25.33 %), but low heterobeltiosis estimates. High heterosis estimates for fruit length of chili pepper took place on cross combinations involving genotype of '*cabai rawit*' (D or F) as one of its parents that had been crossed with '*cabai*

keriting' (A, C or E) or 'cabai besar' (B or G). According to Syukur, Sujiprihati, & Yunianti (2012), heterosis illustrates the superior performance of heterozygous hybrid plants over their homozygous parental inbred lines. This phenomenon takes place as a results of accumulation of dominance genes, over-dominance and non-allelic interaction (Syukur, Sujiprihati, & Yunianti, 2012). Research conducted by Daryanto, Sujiprihati, & Syukur (2010) also found high heterosis and heterobeltiosis estimates for fruit length of chili pepper.

Fruit Diameter

Mean estimates for fruit diameter on parents of both P1 and P2 ranged between 5.51–10.72 mm, means estimates of F1 ranged from 5.66–9.77 mm, heterosis and heterobeltiosis estimates ranged from -14.768 % to 14.617 % dan -33.87 % to 12.23 %, respectively (Table 5). There were five cross combinations among 42 cross combinations had high heterosis and heterobeltiosis estimates, i.e. AxF (7.27 % and 3.12 %), DxG (14.62 % and 12.23 %), FxC (13.66 % and 6.85 %), FxE (7.29 % and 1.54 %) and GxD (6.56 % and 438 %). In addition, there were ten cross combinations had high heterosis estimates, *i.e*. CxA (1.23 %), CxE (4.87 %), CxF (3.93 %), DxA (5.57 %), DxF (7.33 %), ExC (0.28 %), ExF (5.31 %), GxB (1.56 %), GxC (1.98 %), GxF (5.03 %) and GxF (5.03 %), but did not have heterobeltiosis. Table 5 also indicated that there were only five out of 42 cross combinations experienced heterobeltiosis (10.20 %) with the highest heterobeltiosis estimates of 12.23 %. Since fruit diameter was affected by additive variance, not dominance variance (Table 1), and low heterobeltiosis estimates (Table 5), it implied that crossing between parents with different fruit diameter will produce hybrid lines with fruit diameter in between both of its parents. Research conducted by Payakhapaab, Boonyakiat, & Nikornpun (2012) revealed that heterobeltiosis estimates for fruit diameter took place on eight out of 18 cross combinations, 8.67 % on a cross combination of CA 1449xCA 683. Khalil & Hatem (2014) found that on fruit diameter variable, there was only one out of 15 cross combinations had heterobeltiosis with the magnitude 5.8 %

The Number of Fruit per Plant

Mean estimates for the number of fruit per plant on parents of both P1 and P2 ranged from 35.18 to 121.41, while on F1 ranged from 61.26 to 177.22. The heterosis estimates for the number of fruit per plant ranged from -16.26 % to 163.74 %, and heterobeltiosis estimates ranged from -41.61 % to 143.91 % (Table 6). There were 31 out of 42 cross combinations had high both heterosis and heterobeltiosis estimates. In addition, there were three cross combinations had heterosis and heterobeltiosis estimates above 70 %, i.e. cross combinations of DxB (163.74 % and 143.91 %), DxE (137.30 % and 84.27 %) and GxE (89.26 % and 76.42 %). Research conducted by Sitaresmi, Sujiprihati, & Syukur (2010) reported that the highest heterosis and heterobeltiosis estimates for the number of fruit per plant occurred on cross combination of IPBC8xIPBC15, *i.e*., 68.76 % and 62.93 %, respectively. Khalil & Hatem (2014) found that the highest heterosis and heterobeltiosis estimates for the number of fruit per plant took place on a cross combination of 3x4, i.e., 44.97 % and 10.15 %, respectively. High heterosis heterosis estimates for the number of fruit per plant have been also reported by Kamble, Mulge, & Madalageri (2009); Reddy, Kumar, & Salimath (2008) and Riyanto, Farid, & Utari (2010).

Fruit Weight Per Plant

Mean estimates for fruit weight per plant on parents of both P1 and P2 ranged from 121.13 to 362.66 g, while on F1 ranged from 239.92 to 707.57. The heterosis estimates for fruit weight per plant ranged from 3.503 % to 164.409 % and heterobeltiosis estimate ranged from -9.60 % to 151.24 % (Table 7). Although all cross combinations experienced heterosis, there were only 36 out of 42 cross combinations went through high heterosis and heterobeltiosis. There were three cross combinations which had both heterosis and heterobeltiosis estimates above 90 %, *i.e*. DxE (139.15 % dan 96.57 %), GxC (164.41 % dan 151.24 %), and GxE (120.32 % dan 107.29 %). High heterosis and heterobeltiosis estimates reflected that those cross combinations had higher fruit number per plant compared to mean and the highest estimates of their parents. This was related to the fact that all seven parental lines had different genetic materials. According to Iriany, Sujiprihati, Syukur, Koswara, & Yunus (2011), high heterosis and heterobeltiosis estimates of cross combinations reflected that those cross combinations came from long genetic distance parental. It appeared that high genetic differentiation among parents was one of the determinating factors in heterosis expressions.

Table 6. Mean estimates for the number of fruit per plant of chili pepper lines on P1, P2, F1, heterosis and heterobeltiosis.

Lines	P1 (the number of fruit per plant)	P2 (the number of fruit per plant)	F1 (the number of fruit per plant)	Heterosis (%)	Heterobeltiosis (%)
A x B	104.905	41.408	71.263	-2.588	-32.069
A x C	104.905	67.040	85.693	-0.325	-18.313
A x D	104.905	35.183	143.875	105.406	37.148
A x E	104.905	63.620	137.917	63.675	31.468
A x F	104.905	121.410	134.320	18.702	10.633
A x G	104.905	54.987	85.638	7.120	-18.366
B x A	41.408	104.905	61.258	-16.264	-41.606
B x C	41.408	67.040	66.697	23.002	-0.512
B x D	41.408	35.183	66.423	73.448	60.411
B x E	41.408	63.620	81.975	56.101	28.851
B x F	41.408	121.410	102.995	26.515	-15.168
B x G	41.408	54.987	70.310	45.879	27.867
C x A	67.040	104.905	134.403	56.333	28.119
C x B	67.040	41.408	88.985	64.106	32.734
C x D	67.040	35.183	111.422	117.997	66.202
C x E	67.040	63.620	113.448	73.654	69.225
C x F	67.040	121.410	157.722	67.388	29.908
C x G	67.040	54.987	82.555	35.306	50.136
D x A	35.183	104.905	121.665	73.698	15.976
D x B	35.183	41.408	101.000	163.736	143.912
D x C	35.183	67.040	103.987	103.450	55.111
D x E	35.183	63.620	117.230	137.300	84.266
D x F	35.183	121.410	99.812	27.479	-17.790
D x G	35.183	54.987	92.190	104.480	67.659
E x A	63.620	104.905	122.065	44.863	16.358
E x B	63.620	41.408	88.360	68.259	38.887
E x C	63.620	67.040	79.805	22.157	19.041
E x D	63.620	35.183	96.158	94.646	51.145
E x F	63.620	121.410	155.277	67.839	27.894
E x G	63.620	54.987	105.680	78.202	66.111
F x A	121.410	104.905	158.307	39.899	30.390
F x B	121.410	41.408	100.973	24.032	-16.833
F x C	121.410	67.040	139.312	47.850	14.745
F x D	121.410	35.183	127.717	63.119	5.195
F x E	121.410	63.620	177.223	91.562	45.971
F x G	121.410	54.987	92.233	4.575	-24.032
G x A	54.987	104.905	85.543	7.002	-18.456
G x B	54.987	41.408	69.873	44.973	27.073
G x C	54.987	67.040	92.793	52.087	38.415
G x D	54.987	35.183	89.500	98.514	62.767
G x E	54.987	63.620	112.238	89.261	76.420
G x F	54.987	121.410	79.970	-9.329	-34.132

In general, cross combinations of CxF had the highest Specific Combining Ability (SCA) estimates for the number of fruit and fruit weight per plant, meanwhile CxG had high heterosis and heterobeltiosis estimates for fruit length. It is also noticed that high SCA estimates were generally followed by high heterosis and heterobeltiosis estimates. According to Hasanuzzaman, Hakim, Fersdous, Islam, & Rahman (2012), promising hybrids are produced from parental crosses that have high estimates of GCA, SCA, heterosis and heterobeltiosis. This experiment revealed that cross combinations with high SCA, heterosis and heterobeltiosis estimates were cross combinations of G(KG7)xC(KG3) with fruit weight per plant as much as 707.57 g, G(KG7)xE(KG5) with fruit weight

per plant as much as 618.37 g. Research conducted by Sharma, Punetha, & Sharma (2013) concluded that F1 from cross of Rani Sel-1xSSP, Rani Sel-1xSel-12-2-1, SSPxSP-316 and PRC-1xCalifornia Wonder had heterosis estimates for fruit weight per plant and quality of bell pepper was higher than those produced by their parents and comparing varieties.

Table 7. Mean estimates for fruit weight per plant of chili pepper lines on P1, P2, F1, heterosis and heterobeltiosis.

Lines	P1 (g)	P2 (g)	F1 (g)	Heterosis (%)	Heterobeltiosis (%)
A x B	362.658	282.026	333.635	3.503	-8.002
A x C	362.658	281.625	343.983	6.780	-5.149
A x D	362.658	121.133	372.818	54.123	2.801
A x E	362.658	188.130	456.273	65.680	25.813
A x F	362.658	196.546	371.256	32.780	2.370
A x G	362.658	253.580	332.208	7.818	-8.396
B x A	282.026	362.658	368.701	14.382	1.666
B x C	282.026	281.625	412.220	46.267	46.163
B x D	282.026	121.133	294.750	46.219	4.511
B x E	282.026	188.130	464.411	97.556	64.669
B x F	282.026	196.546	336.563	40.652	19.337
B x G	282.026	253.580	339.365	26.721	20.330
C x A	281.625	362.658	542.746	68.480	49.657
C x B	281.625	282.026	415.638	47.480	47.375
C x D	281.625	121.133	323.170	60.478	14.751
C x E	281.625	188.130	472.305	101.085	67.707
C x F	281.625	196.546	445.711	86.423	58.264
C x G	281.625	253.580	353.685	32.168	25.587
D x A	121.133	362.658	438.181	81.144	20.824
D x B	121.133	282.026	400.695	98.777	42.077
D x C	121.133	281.625	379.286	88.344	34.677
D x E	121.133	188.130	369.801	139.150	96.567
D x F	121.133	196.546	241.703	52.167	22.975
D x G	121.133	253.580	308.776	64.806	21.767
E x A	188.130	362.658	431.106	56.541	18.874
E x B	188.130	282.026	366.408	55.866	29.919
E x C	188.130	281.625	325.548	38.603	15.596
E x D	188.130	121.133	281.981	82.357	49.886
E x F	188.130	196.546	304.235	58.177	54.790
E x G	188.130	253.580	409.155	85.259	61.351
F x A	196.546	362.658	418.835	49.796	15.490
F x B	196.546	282.026	288.581	20.600	2.324
F x C	196.546	281.625	424.833	77.690	50.850
F x D	196.546	121.133	266.088	67.519	35.381
F x E	196.546	188.130	361.463	87.931	83.907
F x G	196.546	253.580	253.260	12.528	-0.126
G x A	253.580	362.658	327.836	6.399	-9.601
G x B	253.580	282.026	413.280	54.322	46.539
G x C	253.580	281.625	707.566	164.409	151.244
G x D	253.580	121.133	314.390	67.802	23.980
G x E	253.580	188.130	494.041	123.695	94.826
G x F	253.580	196.546	239.923	6.602	-5.385

CONCLUSION

Fruit length, fruit diameter, the number of fruit per plant, and fruit weight per plant were affected by additive and dominance gene actions. The additive variance of fruit length was higher than dominance variance, but an additive variance of the number of fruit and fruit weight per plant was lower than its dominance variance. Cross combinations of G(KG7)xC(KG3) and F(KG6)xC(KG3) are the most two-promising chili pepper hybrids to be developed for high chili pepper productions in Ultisol.

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