

Evaluation of Heterosis and Combining Ability of Yield Components in Chillies

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Abstract

Nine F₁ hybrids were obtained from crossing between three maintainer lines, CA1445, CA1449 and CA1450 and three restorer lines, CA683, CA1447 and CA1448. The hybrids were significantly different in yield and agronomic performance by using DMRT. The F₁ hybrids CA1450 × CA1447 and CA1450 × CA1448 gave the highest yield while different statistically significant from each other in terms of yield levels differed at statistically significant level in this productivity performance when compared with their female parents, male parents and YokSiam variety but not differ statistically significant when compared with JomThong 2 and Jakkrapat varieties. The F₁ hybrid CA1450 × CA1448 showed positive heterosis in terms of fruit weight per plant, the number of fruit per plant, fruit weight, fruit width, fruit length and pericarp thickness while F₁ hybrid CA1450 × CA1447 expressed positive heterosis in fruit weight per plant, the number of fruits per plant, fruit weight, fruit length and pericarp thickness. The general combining ability of the female parent, CA1450, was good for five characteristics. The male parent, CA1447 was good for five characteristics.

Keywords: chilli, male sterile, maintainer, heterosis, heterobeltiosis, combining ability

1. Introduction

Cytoplasmic male sterile (CMS) is a unique attribute important for breeding programs of many crops as this trait impairs the production of viable pollen or male gamete (Kim et al., 2006; Lee et al., 2008). CMS system was applied for producing F₁ chilli hybrid (Duvick, 1959; Min et al., 2009) as this approach could help reduce production cost by 47% compare to the conventional method (Yang et al., 2008). While assuring the hybrid seeds will be free from self-pollination action contamination (Mulyantoro et al., 2009; Wang et al., 2006). The farmers using hybrid seed chilli is consistent and higher output, especially expressive heterosis in chilli hybrid seed that result from heterozygosity (Bosland & Votava, 2000; Kuroda et al., 1998).

2. Materials and Methods

The three maintainer varieties, CA1445, CA1449 and CA1450 were crossed with three restorer cultivars, CA683, CA1447, CA1448 in a testcross method (Kempthorne, 1957; Singh & Chaudhary, 1979). When the fruit matured the seeds were extracted from the fruit and dried. The nine hybrids were compared with the parents and commercial cultivars as checks. A randomized block design with three replications was used. Ten plants were used in each treatment. They were planted in a double row bed, at a spacing of 50 × 50 cm with a plot size of 4.5 m². Fertilizer was applied at the rate 200 kg of 15N-15P-15K/ha. Liquid fertilizer contained 150 g of 15N-0P-0K, 65 g of 13N-0P-42K, 75 g of 0N-52P-34K and 5 g of trace element which consisted of Mg 9.0%, Fe 4.0%, Mn 4.0%, Cu 1.5%, Co 0.05%, Zn 1.5%, B 0.5% and Mo 0.1% were mixed in 100 liters of water. Insecticide such as imidacloprid, fipronil sulfur and methomyl were used at recommended rates once a week. Horticultural characteristics were evaluated at harvesting time. Heterobeltiosis over the better parent for some horticultural characteristics; yield, fruit number per plant, fruit weight and fruit length were calculated (Chen et al., 2003). General and specific combining abilities of three female parents and three male parents were calculated for yield, fruit weight, fruit number per plant, fruit weight, fruit length and fruit width were evaluated (Kempthorne, 1957; Singh & Chaudhary, 1979). Analysis of combining ability was carried out by using R software.

3. Results

3.1 Fruit Yield

The fruit yield of all line $\times$ tester F_1 hybrids, parental and commercial varieties of green chilli were grown for yield and horticultural characteristics comparison. The line $\times$ tester F_1 hybrid CA 1450 $\times$ CA1448 was the highest yielding among the line $\times$ tester F_1 hybrid, followed by F_1 hybrid CA1450 $\times$ CA1447, higher than output levels of the parental and commercial varieties. They showed a range from 2.346 to 6.794 t/rai (Table 1). The results indicated among the various lines tested, the yield per rai, the number of fruits per plant, fruit weight, fruit width and fruit length differed at statistically significant levels. F_1 hybrid CA1450 $\times$ CA1448 produced the highest yield at 6.794 t/rai, followed by F_1 hybrid CA1450 $\times$ CA1447 with 5.913 t/rai (Figure 1a - 1b), higher than output levels of the parental and commercial varieties namely JomThong 2, Jakkrapat and YokSiam which yielded 5.413, 5.026 and 4.169 t/rai, respectively. Specifically, F_1 hybrid CA1449 $\times$ CA1448 obtained the lowest yield at 2.346 t/rai; F_1 hybrids CA1445 $\times$ CA1448 and CA1449 $\times$ CA683 produced the longest fruit length of 19.91 and 19.70 cm respectively; F_1 hybrid CA1450 $\times$ CA1448 got the widest fruit width of 3.27 cm; F_1 hybrids CA1450 $\times$ CA1447 and CA1450 $\times$ CA1448 obtained maximum fruit weights of 51.17 and 50.20 gram, respectively. The levels of yield components of all these hybrid lines were differed from those of commercial varieties at statistically significant level.

Table 1. Yield components and horticultural characteristics of F_1 hybrids, male parents, female parents and commercial varieties, winter 2010

Variety	Plant height (cm)	Plant width (cm)	Yield (t/rai) ^{2/}	Fruit weight per plant (kg/plant)	Number of fruits per plant	Fruit			Pericarp thickness (mm)
						Weight (g)	Width (cm)	Length (cm)	
F ₁ Hybrid									
CA 1445 × CA 683	74.89a-d ^{1/}	79.22ns	4.734cde	0.74cde	41.67 a ^{1/}	20.93 gh	2.16 c	15.84 e	0.22 def
CA 1445 × CA 1447	63.56d-h	80.22	4.677cde	0.73cde	28.17 b	32.93 cd	2.52 b	19.13 ab	0.22 de
CA 1445 × CA 1448	59.89gh	77.33	5.032bcd	0.79bcd	27.13 bc	32.87 cd	2.52 b	19.91 a	0.23 de
CA 1449 × CA 683	74.45a-e	80.78	4.066def	0.64def	24.70 bc	36.90 c	2.73 b	19.70 a	0.24 d
CA 1449 × CA 1447	62.78e-h	77.67	5.059bcd	0.79bcd	22.13 cd	43.70 b	3.18 a	18.22 bcd	0.24 cd
CA 1449 × CA 1448	78.78ab	70.33	2.346h	0.37h	15.03 e	20.53 gh	2.20 c	14.50 fg	0.20 fg
CA 1450 × CA 683	64.78c-h	64.22	3.413fg	0.53fg	14.83 e	28.63 def	2.60 b	14.45 fg	0.22 def
CA 1450 × CA 1447	59.11 gh	77.11	5.913ab	0.93ab	25.53 bc	51.17 a	3.19 a	19.21 ab	0.28 ab
CA 1450 × CA 1448	57.33h	79.78	6.794a	1.06a	25.93 bc	50.20 a	3.27 a	19.23 ab	0.29 a
Male Parent									
CA 683	80.89ab	72.22	2.583 gh	0.41 gh	26.82 bc	16.53 h	2.00 c	14.20 fg	0.19 g
CA 1447	62.11 fgh	76.11	4.126def	0.65def	24.97 bc	47.50 ab	3.16 a	18.92 abc	0.26 bc
CA1448	58.56gh	66.89	4.542cde	0.71 cde	17.83 de	46.77 ab	3.20 a	19.26 ab	0.28 ab
Female Parent									
CA 1445	69.33b-g	79.78	2.735gh	0.43gh	28.33 b	17.93 h	2.12 c	13.65 g	0.21 efg
CA1449	72.45a-f	74.33	3.899ef	0.61 ef	27.87 bc	32.23 d	3.05 a	13.86 g	0.25 cd
CA1450	52.89h	76.22	4.551 cde	0.71 cde	24.32 bc	44.33 b	3.26 a	15.38 ef	0.29 ab
Commercial									
Jakkrapat	76.00abc	73.67	5.026bcd	0.79bcd	25.90 bc	30.23 de	2.15 c	18.74 abc	0.23 de
JomThong 2	81.78a	78.78	5.413 bc	0.85bc	37.48 a	27.67 ef	2.20 c	17.79 cd	0.24 cd
YokSiam	74.22a-e	76.22	4.169def	0.65def	37.23 a	24.83 fg	2.07 c	17.09 d	0.19 g

^{1/} Means within column with different letters differ significantly at $P \leq 0.05$ according to DMRT;

^{2/} 1 rai = 1600 m².

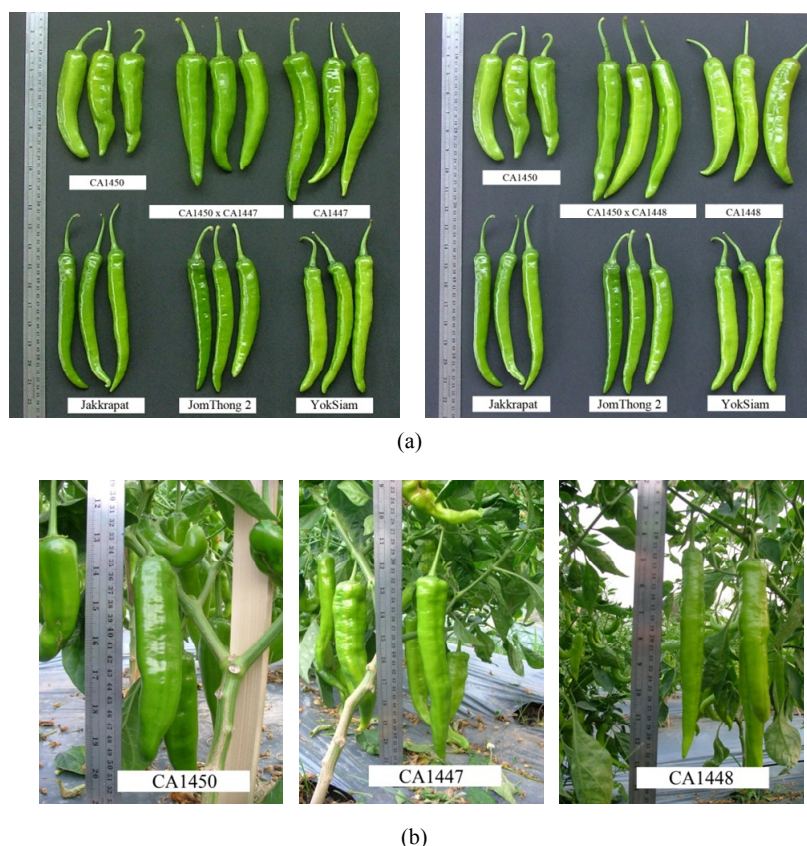


Figure 1. Fruit characteristics of chillies

- (a) F_1 hybrid; varieties CA1450 $\times$ CA1447 and CA1450 $\times$ CA1448, female parent; variety CA1450, male parents; varieties CA1447 and CA1448 and commercial varieties; Jakkrapat, JomThong 2 and YokSiam;
 (b) Female variety CA1450 and male varieties CA1447, CA1448.

3.2 Heterosis of F_1 Hybrids

The analysis of F_1 heterosis over parent (% Hp) revealed F_1 hybrid CA1445 $\times$ CA683 and CA1450 $\times$ CA1448 had positive heterosis over their male and female parents in terms of fruit length, fruit width, fruit weight, fruit weight per plant and the number of fruits per plant, except, however, the F_1 hybrid CA1450 $\times$ CA1448 which showed the heterosis in fruit length over its female parent only (Table 2). The F_1 hybrid CA1449 $\times$ CA683 hybrid showed positive heterosis over the male and female parents in the aspects of fruit length and fruit weight while its fruit width indicated the positive heterosis over the male parent only. The F_1 hybrid CA1450 $\times$ CA1447 expressed its positive heterosis over its male and female parents in terms of fruit length, fruit weight, fruit weight per plant and the number of fruits per plant. It can be concluded that a number of F_1 hybrids from crossing CA1445, CA1449 and CA1450 (B line) with male parents (C line) exhibited positive heterosis in some horticultural characteristic such as number of fruits per plant, fruit weight per plant, fruit weight and fruit length.

3.3 Heterobeltiosis of F_1 Hybrids

Heterobeltiosis of the line $\times$ tester, the F_1 hybrids compared with the better parents (%Hb) showed that there were three F_1 hybrids, CA1445 $\times$ CA683, CA1449 $\times$ CA683 and CA1450 $\times$ CA1448, which showed significant heterobeltiosis of some characteristics (Table 2). The F_1 hybrid CA1445 $\times$ CA683 showed heterobeltiosis in fruit length, fruit width, fruit weight and the number of fruits per plant, 11.55%, 1.88%, 16.73% and 47.06%, respectively. The F_1 hybrid CA1450 $\times$ CA1447 showed heterobeltiosis in fruit weight per plant, fruit weight and the number of fruits per plant, 29.85%, 7.72% and 2.27%, respectively. The F_1 hybrid CA1450 $\times$ CA1448 showed heterobeltiosis in the number of fruits per plant and fruit weight per plant, 6.59 and 49.25%, respectively. All these horticultural characteristics were different at statistically significant level (Table 2) and were major contributing factors for the highest yields of these three F_1 hybrids among all hybrids tested.

Table 2. Heterosis and heterobeltiosis in horticultural characteristics of F₁ hybrids, winter 2010

F ₁ Hybrid	Fruit weight (g)		Fruit width (cm)		Fruit length (cm)		Pericarp thickness (mm)	
	%H	%Hb	%H	%Hb	%H	%Hb	%H	%Hb
CA 1445 × CA 683	21.47 **	16.73 **	4.85 **	1.88 **	13.78 **	11.55 **	15.73 **	10.75 **
CA 1445 × CA 1447	0.66	-30.67 **	-4.61 **	-20.25 **	17.49 **	1.11 *	-5.94 **	-18.25 **
CA 1445 × CA 1448	1.60	-29.72 **	-5.51 **	-21.44 **	20.99 **	3.36 **	-3.96 **	-18.66 **
CA 1449 × CA 683	51.33 **	14.48 **	7.92 **	-10.60 **	40.36 **	38.68 **	10.34 **	-5.08 **
CA 1449 × CA 1447	9.62 **	-8.00 *	2.52 **	0.74 **	11.12 **	-3.73 **	-6.56 **	-9.52 **
CA 1449 × CA 1448	-48.02 **	-56.09 **	-29.64 **	-31.32 **	-12.43 **	-24.70 **	-29.37 **	-33.58 **
CA 1450 × CA 683	-5.91 *	-35.41 **	-1.14 **	-20.22 **	-2.34 **	-6.09 **	-7.62 **	-25.36 **
CA 1450 × CA 1447	11.43 **	7.72 **	-0.67 **	-2.25 **	11.97 **	1.50	2.27 **	-2.17 **
CA 1450 × CA 1448	10.21 *	7.34	1.13 **	0.20	11.00 **	-0.17	0.74 **	-0.72 **

H=Heterosis; Hb=Heterobeltiosis;

*, ** significant difference at $P \leq 0.05$ and $P \leq 0.01$ levels, respectively.Table 2. Heterosis and heterobeltiosis in horticultural characteristics of F₁ hybrids, winter 2010 (continue)

F ₁ Hybrid	Plant height (cm)		Plant width (cm)		Fruit weight per plant (kg/plant)		Yield (t/rai)		Number of fruits per plant	
	%H	%Hb	%H	%Hb	%H	%Hb	%H	%Hb	%H	%Hb
CA 1445 × CA 683	-0.30	-7.42	4.24	-0.69	78.03 **	73.03 **	77.94 **	72.96 **	51.09 **	47.06 **
CA 1445 × CA 1447	-3.29	-8.33	2.93	0.56	36.28 **	13.34 **	36.28 **	13.33 **	5.69	-0.59
CA 1445 × CA 1448	-6.35 *	-13.62 **	5.45	-3.06	38.28 **	10.80 **	38.19 **	10.71 **	17.56 **	-4.24
CA 1449 × CA 683	-2.90	-7.97	10.24	8.67	25.37 **	4.21 **	25.45 **	4.27 **	-9.67 **	-11.37 **
CA 1449 × CA 1447	-6.69	-13.35 *	3.25	2.05	26.10 **	22.65 **	26.00 **	22.54 **	-16.22 **	-20.58 **
CA 1449 × CA 1448	20.27 *	8.74	-0.39	-5.38	-44.40 **	-48.33 **	-44.41 **	-48.35 **	-34.20 **	-46.06 **
CA 1450 × CA 683	-3.16	-19.92 **	-13.47	-15.74	-4.33 **	-25.02 **	-4.39 **	-25.05 **	-41.99 **	-44.69 **
CA 1450 × CA 1447	2.81	-4.82	1.24	1.17	36.23 **	29.85 **	36.23 **	29.89 **	3.60 **	2.27 *
CA 1450 × CA 1448	2.89	-2.09	11.49 *	4.67	49.43 **	49.25 **	49.41 **	49.30 **	23.02 **	6.59 *

H=Heterosis; Hb=Heterobeltiosis;

*, ** significant difference at $P \leq 0.05$ and $P \leq 0.01$ levels, respectively.

3.4 General Combining Ability and Specific Combining Ability

The general combining ability effects calculated for each parent are present in Table 3. Among the 6 parents, the highest and significant general combining ability effect for green fruit yield per plant was observed in CA1450 followed by CA1447. The female parent CA1450 was found to be good general combiner for the characteristics fruit weight per plant, yield, fruit weight, fruit width and pericarp thickness. The female parent CA1445 showed significant positive general combining ability effects for the number of fruits per plant. The male parent CA1447 showed significant positive combining ability for fruit weight per plant, yield, fruit weight, fruit width and fruit length. The female parent CA1449 and male parent CA683 exhibited significant positive general combining ability effects for plant height. The cross having desired significant specific combining ability effects are present in Table 3. The F₁ hybrid CA1445 × CA683 showed significant specific combining ability effect for the number of fruits per plant. This cross involved the parent of positive general combiners. The F₁ hybrid CA1449 × CA683 exhibited significant specific combining ability effect for fruit weight per plant, yield, fruit weight, fruit width, fruit length and pericarp thickness. The F₁ hybrid CA1450 × CA1448 showed significant specific combining

ability effect for fruit weight per plant, yield, the number of fruits per plant, fruit weight, fruit width, fruit length and pericarp thickness. The F_1 hybrid CA1449 $\times$ CA1447 showed significant specific combining ability effect for fruit weight per plant, yield and fruit width. The F_1 hybrid CA1450 $\times$ CA1448 had maximum specific combining ability effect for yield and fruit weight per plant. Two F_1 hybrid, CA1449 $\times$ CA683 and CA1450 $\times$ CA1448, exhibited high specific combining ability effects for fruit weight per plant, yield, fruit weight, fruit width, fruit length and pericarp thickness. Analysis of variance of horticultural characteristics is shown in Table 4.

4. Discussion and Conclusion

The F_1 hybrids CA1450 $\times$ CA1448 and CA1450 $\times$ CA1447 obtained maximum yield at 6.794 and 5.913 t/rai levels, respectively, higher than the performance of other hybrid, male parent, female parent and commercial varieties at statistically significant different levels. The F_1 hybrid CA1450 $\times$ CA1448 showed positive heterosis in terms of fruit weight per plant, the number of fruit per plant, fruit weight, fruit width, fruit length and pericarp thickness while F_1 hybrid CA1450 $\times$ CA1447 expressed positive heterosis in fruit weight per plant, the number of fruits per plant, fruit weight, fruit length and pericarp thickness. The line $\times$ tester F_1 hybrids, CA1445 $\times$ CA683, showed significant heterobeltiosis for fruit weight per plant, the number of fruits per plant, fruit weight, fruit width, fruit length and pericarp thickness, respectively, in consonance with the trials of Geleta & Labuschagne, 2004; Shrestha et al., 2011; Sousa & Maluf, 2003; Patel et al., 2010, as high heterosis hybrids are associated with parents having good characteristics (Pérez-Grajales et al., 2009). Although there was no parental varieties which showed a good appearance in all but some parents varieties show a high general combining ability value in some characteristics. These are useful in breeding program to improve the fruit yield and qualities of commercial varieties. Zou et al. (2007) for example used combining ability concept for the analysis in breed improvement program to obtain high yield Chilli varieties. The female parent, CA1450 showed positive general combining abilities in fruit weight per plant, yield, fruit weight, fruit width, and pericarp thickness, while that of CA1447 appeared positive in fruit weight per plant, yield, fruit weight, fruit width and fruit length. The F_1 hybrid CA1450 $\times$ CA1448 showed significant specific combining ability effect for fruit weight per plant, yield, the number of fruits per plant, fruit weight, fruit width, fruit length and pericarp thickness indicating the relationship with additive and non-additive effect which have influence on the horticultural expression of the hybrids (Rego et al., 2009; Haung et al., 2009; Zewdie et al., 2001; Legesse, 2000).

Table 3. General combining abilities and specific combining abilities in horticultural characteristics of male parents, female parents and F_1 hybrids chillies, winter 2010

Variety/Lines	Plant height (cm)	Plant width (cm)	Fruit weight (kg / plant)	Yield (t/rai)	Number of fruits per plant
<i>General combining ability</i>					
<i>Lines</i>					
CA 1445	-0.06	2.63	0.023	0.144	7.31 **
CA 1449	5.83 **	-0.04	-0.132 **	-0.846 **	-4.39 **
CA 1450	-5.77 *	-2.59	0.110 **	0.702 **	-2.92 **
<i>Testers</i>					
CA 683	5.20 *	-1.56	-0.094 **	-0.599 **	2.05 *
CA 1447	-4.36 *	2.04	0.085 **	0.545 **	0.26
CA 1448	-0.84	-0.48	0.008	0.054	-2.32 *
<i>Specific combining ability</i>					
CA 1445 $\times$ CA 683	3.58	1.85	0.081	0.519	7.29 **
CA 1445 $\times$ CA 1447	1.80	-0.74	-0.107 *	-0.682 *	-4.42 *
CA 1445 $\times$ CA 1448	-5.38	-1.11	0.026	0.163	-2.87
CA 1449 $\times$ CA 683	-2.75	6.07	0.131 *	0.843 *	2.03
CA 1449 $\times$ CA 1447	-4.87	-0.63	0.108 *	0.688 *	1.25
CA 1449 $\times$ CA 1448	7.62 *	-5.44	-0.239 **	-0.153 **	-3.27
CA 1450 $\times$ CA 683	-0.83	-7.93	-0.213 **	-0.1362 **	-9.32 **
CA 1450 $\times$ CA 1447	3.06	1.37	-0.001	-0.006	3.17
CA 1450 $\times$ CA 1448	-2.23	6.56	0.214 **	0.1368 **	6.15 **

*, ** significant difference at $P \leq 0.05$ and $P \leq 0.01$ levels, respectively.

Table 3. General combining abilities and specific combining abilities in horticultural characteristics of male parents, female parents and F₁ hybrids chillies, winter 2010 (continue)

Variety/Lines	Fruit weight (g)	Fruit width (cm)	Fruit length (cm)	Pericarp thickness (mm)
<i>General combining ability</i>				
<i>Lines</i>				
CA 1445	-6.41 **	-0.308 **	0.497	-0.022 *
CA 1449	-1.61	-0.005	-0.326	-0.022 *
CA 1450	8.02 **	0.313 **	-0.171	0.044 **
<i>Testers</i>				
CA 683	-6.50 **	-0.210 **	-1.136 **	-0.019
CA 1447	7.28 **	0.256 **	1.054 **	0.019
CA 1448	-0.79	-0.046	0.081	0.000
<i>Specific combining ability</i>				
CA 1445 × CA 683	-1.48	-0.026	-1.316 **	0.012
CA 1445 × CA 1447	-3.26 *	-0.136	-0.216	-0.026
CA 1445 × CA 1448	4.74 **	0.163	1.531 **	0.013
CA 1449 × CA 683	9.69 **	0.234 **	3.360 **	0.042 *
CA 1449 × CA 1447	2.71	0.224 **	-0.310	0.011
CA 1449 × CA 1448	-12.39 **	-0.457 **	-3.050 **	-0.053 **
CA 1450 × CA 683	-8.20 **	-0.207 *	-2.044 **	-0.054 **
CA 1450 × CA 1447	0.55	-0.087	0.526	0.014
CA 1450 × CA 1448	7.65 **	0.295 **	1.519 **	0.040 *

*, ** significant difference at $P \leq 0.05$ and $P \leq 0.01$ levels, respectively.

Table 4. Analysis of variance of horticultural characteristics of chillies

Source of variance	d.f.	Mean Square				
		Plant height (cm)	Plant width (cm)	Fruit weight (kg/plant)	Yield (t/rai)	Number of fruits per plant
Replication	2	35.55	80.04	0.010	0.410	22.597
Crosses	8	184.15 **	90.41	0.125 **	5.130 **	189.188 **
Lines	2	302.38	61.40	0.135	5.530	365.410
Testers	2	210.16	30.60	0.072	2.967	43.416
Line × Tester	4	112.02 *	134.83 *	0.147 **	6.011 **	173.963 **
Error	28	39.57	48.75	0.008	0.329	7.938

*, ** significant difference at $P \leq 0.05$ and $P \leq 0.01$ levels, respectively.

Table 4. Analysis of variance of horticultural characteristics of chillies (continue)

Source of variance	d.f.	Mean Square			
		Fruit weight (g)	Fruit width (cm)	Fruit length (cm)	Pericarp thickness (mm)
Replication	2	1.31	0.000	1.110	0.000
Crosses	8	385.24 **	0.530 **	14.978 **	0.008 **
Lines	2	485.44	0.868	1.719	0.013
Testers	2	431.27	0.504	10.836	0.003
Line × Tester	4	312.12 **	0.373 **	23.679 **	0.008 **
Error	28	7.26	0.019	0.559	0.001

*, ** significant difference at $P \leq 0.05$ and $P \leq 0.01$ levels, respectively.

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References

- Bosland, P. W. & Votava, E. J. (2000). *Peppers: Vegetable and Spice Capsicums*. Wallingford: CABI Publishing.
- Chen, X., Sorajjapinun, W., Reiwthongchum, S., & Srinives, P. (2003). Identification of parental mungbean lines for production of hybrid varieties. *Chiang Mai University Journal*, 2(2), 97-105.
- Duvick, D. N. (1959). The use of cytoplasmic male-sterility in hybrid seed production. *Economic Botany*, 13, 167-195. <http://dx.doi.org/10.1007/BF02860581>
- Geleta, L. F., & Labuschagne, M. T. (2004). Hybrid performance for yield and other characteristics in peppers (*Capsicum annuum* L.). *Journal of Agricultural Science*, 142, 411-419. <http://dx.doi.org/10.1017/S002185960400440X>
- Huang, Z., Laosuan, P., Machikowa, T., & Chen, Z. (2009). Combining ability for seed yield and other characters in rapeseed. *Suranaree Journal of Science and Technology*, 17(1), 39-47.
- Kempthorne, O. (1957). *The design and analysis of experiments* (p. 631). Robert E. Krieger Publ. Co. Inc. New York.
- Kim, D. S., Kim, D. H., Yoo, J. H., & Kim, B. D. (2006). Cleaved amplified polymorphic sequence and amplified fragment length polymorphism markers linked to the fertility restorer gene in chili pepper (*Capsicum annuum* L.). *Molecular Cells*, 21(1), 135-140.
- Kuroda, S., Kato, H., & Ikeda, I. (1998). Heterosis and combining ability for callus growth rate in rice. *Crop Science*, 33, 933-936.
- Lee, J., Yoon, J. B., & Park, H. G. (2008). A CAPS marker associated with the partial restoration of cytoplasmic male sterility in chili pepper (*Capsicum annuum* L.). *Molecular Breeding*, 21(1), 95-104. <http://dx.doi.org/10.1007/s11032-007-9111-0>
- Legesse, G. (2000). Combining ability study for green fruit yield and its components in hot pepper (*Capsicum annuum* L.). *Acta Agronomica Hungarica*, 48(4), 373-380. <http://dx.doi.org/10.1556/AAgr.48.2000.4.7>
- Min, W. K., Kim, S., Sung, S. K., Kim, B. D., & Lee, S. (2009). Allelic discrimination of the *Restorer-of-fertility* gene and its inheritance in peppers (*Capsicum annuum* L.). *Theoretical and Applied Genetics*, 119(7), 1289-1299. <http://dx.doi.org/10.1007/s00122-009-1134-y>
- Mulyantoro, Chen, S. Y., Wahyono, A., & Ku, H. M. (2009). Modified complementation test of male sterility mutants in pepper (*Capsicum annuum* L.): preliminary study to convert male sterility system from GMS to CMS. *Euphytica*, 169(3), 353-361. <http://dx.doi.org/10.1007/s10681-009-9968-6>
- Patel, M. P., Patel, A. R., Patel, J. B., & Patel, J. A. (2010). Heterosis for green fruit yield and its components in chilli (*Capsicum annuum* var. longicum (D.G) Sendt) over environments. *Journal of Plant Breeding*, 1(6), 1443-1453. Retrieved from http://journaldatabase.org/articles/heterosis_for_green_fruit_yield_its.html
- Pérez-Grajales, M., González-Hernández, V. A., Peña-Lomelí, A. & Sahagún-Castellanos, J. (2009). Combining ability and heterosis for fruit yield and quality in manzano hot pepper (*Capsicum pubescens* R & P) landraces. *Revista Chapingo. Serie Horticultura*, 15(1), 103-109
- Rego, E. R., Rego, M. M., Finger, F. L., Cruz, C. D., & Casali, V. W. D. (2009). A diallel study of yield components and fruit quality in chilli pepper (*Capsicum annuum* L.). *Euphytica*, 168(2), 275-287. <http://dx.doi.org/10.1007/s10681-009-9947-y>
- Shrestha, S. L., Luitel, B. P., & Kang, W. H. (2011). Heterosis and heterobeltiosis studies in sweet pepper (*Capsicum annuum* L.). *Horticulture, Environment, and Biotechnology*, 52(3), 278-283. <http://dx.doi.org/10.1007/s13580-011-0106-8>
- Singh, R. K., & B. D. Chaudhary. (1979). *Biometrical methods in quantitative genetic analysis*. Kalyani Publishers, Ludhiana, New Delhi.
- Sousa, J. A. D., & Maluf, W. R. (2003). Dialle analyses and estimation of genetic parameters of hot pepper (*Capsicum chinense* Jacq.). *Scientia Agricola*, 60(1), 113-105. <http://dx.doi.org/10.1590/S0103-90162003000100016>

- Wang, L. H., Zhang, B. X., Daubeze, A. M., Huang, S. W., Guo, J. Z., Mao, S. L., ... Du, Y. C. (2006). Genetics of fertility restoration in cytoplasmic male sterile pepper. *Agricultural Sciences in China*, 5(3), 188-195. [http://dx.doi.org/10.1016/S1671-2927\(06\)60037-0](http://dx.doi.org/10.1016/S1671-2927(06)60037-0)
- Yang, C. J., Chen, B. J., Liu, J. G., & Li, S. (2008). Study on the superiority of hybrid breeding by male sterility in hot pepper. *Journal of China Capsicum*, 1, 36-38.
- Zewdie, Y., Bosland, W., & Steiner, R. (2001). Combining ability and heterosis for capsaicinoids in *Capsicum pubescens*. *Hort Science*, 36(7), 1315-1317. Retrieved from <http://hortsci.ashspublications.org/content/36/7/1315.full.pdf+html>
- Zou, X. X., Ma, Y. Q., Liu, R. Y., Zhang, Z. Q., Cheng, W. C., Dai, X. Z., ... & Zhou, Q. C. (2007). Combining ability analyses of net photosynthesis rate in pepper (*Capsicum annuum* L.). *Agricultural Sciences in China*, 6(2), 159-166. [http://dx.doi.org/10.1016/S1671-2927\(07\)60030-3](http://dx.doi.org/10.1016/S1671-2927(07)60030-3)