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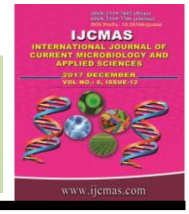

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Influence of Cyto-Nuclear Interactions on Heterosis and Combining Ability for Yield Contributing Traits in Indian mustard (*Brassica juncea* L.)

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A B S T R A C T

In the present study, influence of cyto-nuclear interactions using *Ogu* CMS cytoplasm has been studied by comparing the estimates of GCA, SCA and manifestation of heterosis in euplasmic vis-à-vis in alloplasmic set of crosses. Experimental material consisted of 30 euplasmic hybrids generated by crossing 10 lines viz. PRL-2008-5, PBR-357, Maya, PRKS-28, Rohini, Sej-2, Vaibhav, EJ-22, PYR-2009-5 and PYR-2009-13 and three testers viz. IC-414317, IC-414322 and PR-2006-14. Besides, same set of lines converted into O*gu* CMS background was used to develop 30 alloplasmic hybrids by crossing with three restorers (same set of testers carrying restorer gene). GCA status of parental lines in euplasmic and alloplasmic sets of crosses revealed that nicking ability of lines may or may not be influenced by the genetic and cytoplasmic background for different characters. The effect of cyto-nuclear interactions was clearly evidenced by higher frequency of crosses displaying desirable heterotic crosses in euplasmic set than in alloplasmic set for all the characters except plant height, seeds per siliqua and oil content. The effect was more pronounce for days to 50% flowering, siliquae on main raceme, primary branches, secondary branches and siliqua length for which crosses with desirable heterosis were very less in alloplasmic crosses. One cross *i.e.* Maya × PR-2006-14 did not show any directional change in heterosis over MP as well as BP. This revealed that combining ability and heterosis of parental lines with native cytoplasm may or may not remain intact after their conversion into CMS background. Thus, it can be inferred that assessment of combining ability and heterosis of lines converted into CMS background will have to be re-examined for identification of potential crosses for commercialization of CMS based hybrids. There also exists possibility of finding crosses with negligible or no effect of cyto-nuclear interactions due to re-establishment of harmonious interaction.

Introduction

Development and commercialization of hybrids is the most promising strategy for enhancing productivity in *B. juncea* L., the third most important oilseed crop of the World. Commercialization of the hybrids delayed due to lack of efficient pollination control system. However, development of F_1 hybrids were stimulated by the development of a large number of CMS sources during the last few decades viz., *nap*, *polima*, *ogura*, *tournefortii*, *oxyrrhina*, *siifolia*, *catholica*, *sinapis*, *trachystoma*, *moricandia and lyratus* (Banga *et al.*, 2015). Hybrids based on *polima* or *ogura* and/or transgenic barnase-barstar system have been commercialized on a large scale in *B. napus* in Canada, China and

Europe. In India, hybrids based on *ogura*, *INS 126* or *mori* CMS systems have been commercialized in *B. juncea*. However, the average heterosis for seed yield over the better parent continues to be below 15%.

CMS, a maternally inherited inability to produce fertile pollen, is encoded in the mitochondrial genome and can be developed following cytoplasmic substitutions due to nuclear-mitochondrial incompatibility (alloplasmy). Also CMS lines could be developed following backcrossing either sexually synthesized allopolyploids or somatic hybrids between wild and crop species. Alloplasmic CMS plants, in general, are similar to euplasmic plants in development and morphology. However, many of them exhibited developmental and floral abnormalities as a consequence of altered nucleo-cytoplasmic interactions which have been corrected subsequently by somatic hybridization followed by backcrossing. Fertility restorers for *moricandia, ogura, catholica, erucoides* and *lyratus* CMS systems could be introgressed from cytoplasm donor wild species (Banga and Banga, 2009; Prakash *et al.*, 2009).

The mitochondria is principle organelle which performs a pivotal role in energy metabolism of cells and any alteration in gene expression of mitochondria could affect growth and yield contributing traits besides inducing male sterility. Further, it is also known that effect of sterility inducing cytoplasm can be counteracted in hybrids by fertility restorer genes present in the nucleus by correcting the mitochondrial gene expression through transcriptional or post transcriptional processing or through appropriate modification of the downstream metabolic pathways (Hanson and Bentolila, 2004). This study was aimed at assessing the effects of *Ogu* CMS system on heterosis over mid parent for yield and yield contributing traits by comparing euplasmic hybrids with alloplasmic hybrids. In the present study, influence of cyto-nuclear interactions has been studied by comparing the estimates of GCA, SCA and manifestation of heterosis in euplasmic vis-à-vis in alloplasmic set of crosses.

Materials and Methods

The experimental material for present study comprised of 2 sets of hybrids each of which consists 30 F_1′s (B×R) derived from crosses of 10 diverse lines of Indian mustard includes PRL-2008-5, PBR-357, Maya, PRKS-28, Rohini, Sej-2, Vaibhav, EJ-22, PYR-2009-5 and PYR-2009-13 used as females and 3 testers viz. IC-414317, IC-414322 and PR-2006-14 used as males. The other set of 30 F1's (A×R) was generated from crossing *Ogu* based CMS conversion lines in BC_3 generation of conversion viz. PRL-2008-5 A, PBR-357 A, Maya A, PR-20 A, Rohini A, Sej-2 A, Vaibhav A, EJ-22 A, PYR-2009-5 A and PYR-2009-13 A used as females and 3 restorers as testers viz. IC-414317 R, IC-414322 R and PR-2006-14 R. All crosses were made by carefully by hand emasculation and pollination to avoid any mixing. The euplasmic crosses (Set I) and alloplasmic crosses (Set II) with 13 parents (10 lines and 3 testers) was evaluated in a Compact Family Block Design with three replications during rabi 2016-17. Each plot comprised of 1 row of 3 meter long. The row to row distance was 30 cm and plant to plant distance of 10 cm was maintained by thinning after 20-25 days of sowing. Single row of Indian mustard strain Divya was sown on either side of block as guard row. Recommended agronomic practices were followed from sowing to final harvest of the produce. Five competitive plants from parents and F_1′s (single cross) were randomly selected from each plot and tagged at the time of vegetative stage for recording of observations. All the observations on various characters were recorded on them. The percent difference between the means of two sets for different characters and adverse effect of above 10 % was observed as biological penalty due to Ogu cytoplasm. The difference in significance and direction in estimates of GCA, SCA and heterosis were used to identify influence of ogu cytoplasm over different characters.

Results and Discussion

Results of analysis of variance indicated that mean squares due to families were highly significant for all the characters under study and within family variance were also significant for all attributes barring siliqua density (Table 1). A cursory view of GCA status of parental lines in euplasmic and alloplasmic sets of crosses revealed that nicking ability of lines may or may not be influenced by the genetic and cytoplasmic background for different characters (Table 2). For instance, GCA status (either good or poor) of nine lines was consistent in euplasmic as well as in alloplasmic sets for seed yield; six lines for plant height; five lines each for five characters namely, days to flowering, number of secondary branches, number of seeds per siliqua, 1000 seed weight and oil content; 4 lines each for length of main raceme, number of primary branches and siliqua length; 2 lines each for siliquae on main raceme and days to maturity; and only one line for siliqua density. On the contrary, there was complete change (Good to Poor or Poor to Good) in the GCA status of different lines for 3 or more characters. For example, PBR-357 exhibited changed GCA status for 9 characters viz., days to flowering, days to maturity, length of main raceme, siliquae on main raceme, siliqua density, number of primary branches, number of secondary branches, siliqua length and number of seeds per siliqua in either direction. Similarly, Maya showed altered GCA status for five characters - days to maturity, length of main raceme, siliquae on main raceme, number of seeds per siliqua and oil content; and PR-20 for only three characters *i.e*. siliquae on main raceme, number of secondary branches and siliqua length.

Like GCA effects, estimates of SCA also reflected a similar pattern of either consistency or alteration in status of SCA for different characters in majority of the crosses. It was interesting to note that four crosses viz., Rohini × IC 414322, Sej-2 × PR 2006-14, EJ 22 × PR 2006-14 and PYR 2009-5 × PR 2006-14 showed consistency in building up of SCA effects for all the characters studied in both the set of crosses. Latter three crosses had PR 2006-14 as a common pollen parent. This observation leads us to infer that there exists possibility of finding parents/crosses with consistency in their combining ability in both native as well as *ogu* cytoplasmic background in *B. juncea*.

A noteworthy observation was that two phenological traits-days to 50% flowering and days to maturity; two developmental traits (primary and secondary branches); and three siliqua traits-siliqua density, siliqua length and number of seeds per siliqua- showed consistency in the direction of their SCA estimates, of course with change in their magnitude in the two sets of crosses.

Visible influence of cyto-nuclear interaction was observed in 26 crosses for other characters. A perusal of SCA effects exhibited that 7, 13 and 10 F_1's each manifested shift in status of SCA effects in euplasmic set from that of alloplasmic set for plant height, 1000 seed weight and oil content, respectively. The cross EJ-22 × IC-414322 showed change in direction of SCA effect for as many as 4 characters; PYR-2009-13 × IC-414317 and PYR-2009-5 × IC-414322 for 3 characters each.

Table.1 ANOVA for compact family block design for different characters of Indian mustard

Source of Variations / Mean Squares	Replication	Family	Error (a)	Progeny	Error (b)
Degree of Freedom	**2**	**1**	**2**	**84**	**168**
Days to 50% flowering	42.59	2093.93**	10.61	52.28**	3.56
Days to maturity	48.18	1509.20**	6.88	38.59**	3.60
Plant height (cm)	8.47	1714.80**	16.83	442.87**	22.48
Length of main raceme (cm)	16.76	824.47**	12.59	169.48**	13.34
Siliquae on main raceme	8.94	859.49**	4.19	28.42**	3.96
Siliqua density	0.001	0.12**	0.001	0.01	0.001
Number of primary branches	1.90	7.07**	0.15	0.81**	0.34
Number of secondary branches	4.71	1.81**	0.68	16.68**	1.90
Siliqua length (cm)	0.032	7.41**	0.86	0.46**	0.17
Number of seeds per siliqua	7.18	50.87**	1.96	4.58**	1.44
Seed yield per plant (g)	3.49	42.43**	2.87	16.01**	1.05
1000 seed weight (g)	0.02	0.57**	0.002	1.78**	0.001
Oil content (%)	-0.09	2.07**	0.12	3.45**	0.006

Table.2 Influence of *Ogu* CMS cytoplasmic background on GCA status of lines

S. No.	Lines	Change in GCA status of lines from euplasmic to alloplasmic	
		Good to Poor	**Poor to Good**
1	PRL-2008-5	TW, OC	DM, SMR, SD, NSS,
2	PBR-357	SMR, LMR, SD, NPB, NSB, SL, NSS	DF, DM
3	MAYA	DM, NSS, OC	LMR, SMR
4	PR-20	SL	SMR, NSB
5	ROHINI	NSS, NSB, PH	OC, SD, DF, DM, LMR, SMR
6	SEJ-2	DM, SD, SL	DF, NSB, NSS, TW
7	VAIBHAV	-	SD, NPB, NSB, SL
8	EJ-22	OC, DF, DM, LMR, SMR	NSS, TW, PH
9	PYR-2009-5	DF, DM, LMR, NSB, NSS, TW	PH, SD, NPB, SL
10	PYR-2009-13	TW, OC, DF, DM, LMR, SMR	SY, SD, PH

Note: DF-Days to 50 % flowering, DM-Days to maturity, PH-Plant height (cm), LMR-Length of main raceme (cm), SMR- Siliqua on main raceme, SD-Siliqua density, NPB- Number of primary branches, NSB- Number of secondary branches, NSS-Number of seeds per siliqua, SL-Siliqua length (cm), SY-Seed yield per plant (g), 1000 seed weight (g) and OC-Oil content (%).

Table.3 Percentage of heterotic crosses for different characters in euplasmic and alloplasmic sets in Indian mustard

S. No.	Characters	Percentage of crosses with significant heterosis over MP		Percentage of crosses with desirable heterosis over MP	
		Euplasmic Set	Alloplasmic Set	Euplasmic Set	Alloplasmic set
1	Days to 50 % flowering	56.67	80.00	23.33	3.33
2	Days to Maturity	36.67	76.67	10.00	0.00
3	Plant height (cm)	36.67	76.67	10.00	46.67
4	Length of main raceme (cm)	83.33	83.33	60.00	43.33
5	Siliquae on main raceme	73.33	90.00	43.33	13.33
6	Siliqua density	90.00	96.67	40.00	3.33
7	Number of primary branches	96.67	96.67	70.00	33.33
8	Number of secondary branches	93.33	80.00	100.00	80.00
9	Siliqua length (cm)	93.33	63.33	93.33	26.67
10	Number of seeds per siliqua	90.00	96.67	83.33	93.33
11	Seed yield per plant (g)	96.67	93.33	86.67	66.67
12	1000-seed weight (g)	100.00	100.00	66.67	63.33
13	Oil Content (%)	96.67	96.67	3.00	3.00

Note: For days to 50% flowering, days to maturity and plant height significant negative heterosis and for other characters significant positive heterosis was considered desirable.

Table.4 Mid-parent and better parent heterosis for different characters in Indian mustard

Crosses	Days to 50 % flowering			
	Euplasmic		Alloplasmic	
	Over MP	Over BP	Over MP	Over BP
PRL-2008-5×IC-414317	-19.24**	-28.89**	-2.84*	1.91
PRL-2008-5×IC-414322	9.84**	1.17	19.37**	0.64
PRL-2008-5×PR-2006-14	-6.37*	-18.33**	0.00	0.00
PBR-357×IC-414317	11.82**	-2.78	11.82**	4.58**
PBR-357×IC-414322	-4.82*	-13.45**	-0.97	3.27**
PBR-357×PR-2006-14	6.45*	-8.33**	15.48**	2.61*
Maya×IC-414317	-2.52	-16.67**	9.43**	1.27
Maya×IC-414322	6.96**	-1.17	18.35**	0.00
Maya×PR-2006-14	-2.86	-16.39**	4.13**	-0.63
PR-20×IC-414317	2.18	5.128**	17.76**	0.00
PR-20×IC-414322	7.84**	10.26**	2.19	0.00
PR-20×PR-2006-14	8.81**	10.20**	18.24**	0.00
Rohini×IC-414317	-0.63	-15.59**	8.86**	2.56
Rohini×IC-414322	14.01**	4.68**	19.75**	1.28
Rohini×PR-2006-14	2.88	-12.02**	1.60	0.64
Sej-2×IC-414317	-1.88	-6.55**	18.13**	0.00
Sej-2×Ic-414322	4.40*	-1.19	5.03**	0.00
Sej-2×PR-2006-14	-4.73*	-10.12**	0.95	0.00
Vaibhav×Ic-414317	1.25	-12.90**	0.00	0.00
Vaibhav×IC-414322	25.16**	16.37**	15.72**	0.00
Vaibhav×PR-2006-14	10.41**	-4.37*	18.61**	0.00
EJ-22×IC-414317	-4.00*	-1.27	16.92**	0.00
EJ-22×IC-414322	-17.65**	-15.83**	20.74**	0.00
EJ-22×PR-2006-14	-0.62	1.26	19.26**	0.00
PYR-2009-5×IC-414317	1.89	-12.90**	25.16**	1.27
PYR-2009-5×IC-414322	-1.90	-9.36**	17.09**	0.00
PYR-2009-5×PR-2006-14	-13.65**	-25.68**	7.94**	0.00
PYR-2009-13×IC-414317	1.88	3.16	17.50**	0.00
PYR-2009-13×IC-414322	-0.63	-0.01	7.55**	0.00
PYR-2009-13×PR-2006-14	-2.21	-1.91	16.09**	0.00
CD 1%	3.84	4.44	2.97	3.01
CD 5%	2.93	3.38	2.26	2.61
Mean Heterosis (%)	1.07	-6.09	11.66	0.65
Range of heterosis: From	-19.24	-28.89	-2.84	-0.63
To	25.16	16.37	25.16	4.58
No. of crosses with +ve heterosis	10	5	23	3
No. of crosses with -ve heterosis	7	16	1	0

Table.4 Contd..........

Crosses	Days to maturity			
	Euplasmic		Alloplasmic	
	Over MP	Over BP	Over MP	Over BP
PRL-2008-5×IC414317	-0.54	0.00	-1.63	-1.09
PRL-2008-5×IC414322	4.63**	4.63**	7.90**	7.90**
PRL-2008-5×PR-2006-14	-1.90	-1.64	-0.82	-0.54
PBR-357×IC414317	6.31**	6.74**	4.16**	4.58**
PBR-357×IC414322	-2.56	-1.64	-0.95	0
PBR-357×PR-2006-14	-0.94	-0.27	4.17**	4.88**
Maya×IC414317	-0.82	0.01	4.62**	5.48**
Maya×IC414322	3.55*	3.84*	8.47**	8.77**
Maya×PR-2006-14	-0.27	0.28	3.27**	3.84**
PR-20×IC414317	2.16	2.16	7.01**	7.01**
PR-20×IC414322	4.34**	4.91**	1.9	2.45
PR-20×PR-2006-14	2.97*	3.25	7.30**	7.59**
Rohini×IC414317	-1.22	-0.55	3.12*	3.83**
Rohini×IC414322	6.14**	6.28	8.60**	8.74**
Rohini×PR-2006-14	-0.41	0.00	1.77	2.19
Sej-2×IC414317	0.14	0.27	7.69**	7.84**
Sej-2×IC414322	1.76	1.35	3.39**	2.97*
Sej-2×PR-2006-14	-2.84	-2.71	0.14	0.27
Vaibhav×IC414317	2.56	2.70	-0.68	-0.54
Vaibhav×IC414322	8.55**	8.11**	7.19**	6.76**
Vaibhav×PR-2006-14	3.92**	4.07*	7.71**	7.86**
EJ-22×IC414317	-3.18*	-1.62	4.78**	6.47**
EJ-22×IC414322	-4.27**	-2.18	6.93**	9.26**
EJ-22×PR-2006-14	-2.39	-0.54	5.85**	7.86**
PYR-2009-5×IC414317	0.68	1.37	9.63**	10.38**
PYR-2009-5×IC414322	-0.68	-0.55	6.41**	6.56**
PYR-2009-5×PR-2006-14	-4.22**	-3.83*	3.13*	3.55*
PYR-2009-13×IC414317	0.54	0.81	6.49**	6.78**
PYR-2009-13×IC414322	0.27	0.55	2.99*	2.71
PYR-2009-13×PR-2006-14	1.63	1.63	7.32**	7.32**
CD 1%	3.74	4.32	3.15	3.64
CD 5%	2.85	3.29	2.4	2.77
Mean Heterosis (%)	0.80	1.25	4.60	5.06
Range of heterosis From	-4.27	-3.83	-1.63	-1.09
To	8.55	8.11	9.63	10.38
No. of crosses with +ve heterosis	8	6	23	22
No. of crosses with –ve heterosis	3	1	0	0

Table.4 Contd..........

Crosses	Plant height (cm)			
	Euplasmic		Alloplasmic	
	Over MP	Over BP	Over MP	Over BP
PRL-2008-5×IC414317	-0.35	1.72	3.06*	5.20**
PRL-2008-5×IC414322	-0.56	4.54	-5.17**	-0.31
PRL-2008-5×PR-2006-14	18.15**	18.61**	5.15**	5.56**
PBR-357×IC414317	7.20	10.98*	-7.61**	-4.35**
PBR-357×IC414322	-3.88	-3.34	1.23	1.81
PBR-357×PR-2006-14	13.30**	19.32**	-7.62**	-2.71
Maya×IC414317	-0.72	5.12	17.72**	24.74**
Maya×IC414322	14.23**	24.69**	5.92**	15.71**
Maya×PR-2006-14	9.94*	14.42**	18.92**	23.86**
PR-20×IC414317	-10.82*	-8.12	-2.09	0.87
PR-20×IC414322	-10.27*	-4.76	-9.53**	-3.98**
PR-20×PR-2006-14	-3.38	-2.11	-3.38*	-2.11
Rohini×IC414317	3.45	6.98	15.32**	19.25**
Rohini×IC414322	-5.53	0.64	-10.74**	-4.91**
Rohini×PR-2006-14	-0.16	1.53	-0.63	1.04
Sej-2×IC414317	-4.69	-0.69	-10.74**	-7.00**
Sej-2×IC414322	-13.68**	-7.32	0.11	7.49**
Sej-2×PR-2006-14	-2.86	-0.49	-16.92**	-14.89**
Vaibhav×IC414317	-6.71	0.45	6.24**	14.39**
Vaibhav×IC414322	-3.23	7.47	-8.61**	1.49
Vaibhav×PR-2006-14	-4.90	0.62	0.5	6.34**
EJ-22×IC414317	9.41*	9.53	-12.18**	-12.28**
EJ-22×IC414322	-1.93	0.83	-0.69	2.1
EJ-22×PR-2006-14	10.52*	12.49*	-5.79**	-7.42**
PYR-2009-5×IC414317	4.28	5.36	6.18**	7.28**
PYR-2009-5×IC414322	-0.75	3.25	-19.27**	-16.02**
PYR-2009-5×PR-2006-14	17.04**	17.77**	3.70**	4.35**
PYR-2009-13×IC414317	6.70	9.58	-4.39**	-1.82
PYR-2009-13×IC414322	-4.04	1.58	1.50	7.36**
PYR-2009-13×PR-2006-14	9.39*	10.56*	-18.84**	-18.04**
CD 1%	11.67	13.47	3.6	4.15
CD 5%	8.88	10.25	2.74	3.16
Mean Heterosis (%)	1.51	5.37	-1.95	1.77
Range of heterosis From	-13.68	-8.12	-19.27	-18.04
To	18.15	24.69	18.92	24.74
No. of crosses with +ve heterosis	8	9	9	12
No. of crosses with -ve heterosis	3	0	14	9

Table.4 Contd..........

Crosses	Length of main raceme (cm)			
	Euplasmic		Alloplasmic	
	Over MP	Over BP	Over MP	Over BP
PRL-2008-5×IC-414317	11.50**	9.08*	6.15**	3.85*
PRL-2008-5×IC-414322	2.05	-3.51	1.47	-4.06**
PRL-2008-5×PR-2006-14	28.62**	27.61**	4.26**	3.44*
PBR-357×IC-414317	16.54**	12.72**	-9.78**	-12.73**
PBR-357×IC-414322	-7.17*	-11.25**	-2.02	-6.32**
PBR-357×PR-2006-14	9.78**	7.67*	3.14*	1.16
Maya×IC-414317	7.13*	0.62	32.50**	24.44**
Maya×IC-414322	13.77**	-0.53	-3.12*	-15.29**
Maya×PR-2006-14	22.27**	13.32**	21.94**	13.02**
PR-20×IC-414317	10.53**	6.08	6.77**	2.48
PR-20×IC-414322	-10.13**	-19.84**	2.08	-8.96**
PR-20×PR-2006-14	-0.43	-5.72	4.34**	-1.21
Rohini×IC-414317	30.41**	28.67**	41.89**	39.99**
Rohini×IC-414322	11.43**	1.94	-6.44**	-14.41**
Rohini×PR-2006-14	-2.36	-5.01	0.52	-2.21
Sej-2×IC-414317	-15.17**	-19.27**	-4.50**	-9.12**
Sej-2×IC-414322	-33.45**	-35.32**	-0.18	-2.98
Sej-2×PR-2006-14	-4.25	-7.64*	-16.22**	-19.18**
Vaibhav×IC-414317	-14.18**	-19.86**	13.03**	5.54**
Vaibhav×IC-414322	-9.75**	-10.54**	-22.26**	-22.94**
Vaibhav×PR-2006-14	-8.89**	-13.78**	-11.72**	-16.46**
EJ-22×IC-414317	13.09**	6.32	-20.46**	-25.23**
EJ-22×IC-414322	-2.16	-3.71	-3.57*	-5.09**
EJ-22×PR-2006-14	18.13**	12.56**	-11.24**	-15.43**
PYR-2009-5×IC-414317	17.67**	16.72**	8.18**	7.30**
PYR-2009-5×IC-414322	14.39**	6.75	-28.70**	-33.46**
PYR-2009-5×PR-2006-14	34.15**	33.34**	15.93**	15.23**
PYR-2009-13×IC-414317	25.63**	13.20	10.99**	0.01
PYR-2009-13×IC-414322	13.58**	-4.39	16.29**	-2.10
PYR-2009-13×PR-2006-14	32.02**	17.47	-34.24**	-41.49**
CD 1%	8.67	10.01	3.65	4.21
CD 5%	6.60	7.62	2.78	3.21
Mean Heterosis (%)	7.49	1.79	0.50	-4.74
Range of heterosis From	-33.45	-35.32	-34.24	-41.49
To	34.15	33.34	41.89	39.99
No. of crosses with +ve heterosis	18	9	13	9
No. of crosses with -ve heterosis	7	8	12	15

Table.4 Contd……….

Crosses	Siliquae on main raceme			
	Euplasmic		Alloplasmic	
	Over MP	Over BP	Over MP	Over BP
PRL-2008-5×IC-414317	-18.96**	-22.27**	-22.67**	-25.83**
PRL-2008-5×IC-414322	12.59**	9.36**	-8.60**	-11.22**
PRL-2008-5×PR-2006-14	4.70**	-5.73**	-13.13**	-21.77**
PBR-357×IC-414317	24.94**	12.61**	-24.48**	-31.93**
PBR-357×IC-414322	-0.27	-3.90	-15.37**	-18.45**
PBR-357×PR-2006-14	42.17**	36.22**	-13.12**	-16.76**
Maya×IC-414317	-17.64**	-26.46**	-18.83**	-27.52**
Maya×IC-414322	26.71**	20.87**	-17.06**	-20.88**
Maya×PR-2006-14	-8.02**	-10.97**	1.08	-2.17
PR-20×IC-414317	-5.36**	-18.48**	-18.53**	-29.83**
PR-20×IC-414322	-11.11**	-18.45**	-7.67**	-15.29**
PR-20×PR-2006-14	12.96**	11.98**	1.67	0.79
Rohini×IC-414317	4.43*	-10.93**	12.57**	-3.98**
Rohini×IC-414322	0.54	-8.74**	-6.95**	-15.54**
Rohini×PR-2006-14	12.82**	10.56**	-6.72**	-8.59**
Sej-2×IC-414317	-23.69**	-32.35**	-27.49**	-35.71**
Sej-2×IC-414322	-2.05	-7.28**	-8.22**	-13.12**
Sej-2×PR-2006-14	-16.99**	-19.01**	-33.70**	-35.32**
Vaibhav×IC-414317	-11.64**	-21.85**	4.51**	-7.56**
Vaibhav×IC-414322	-9.52**	-14.58**	-22.37**	-26.71**
Vaibhav×PR-2006-14	-3.35	-5.46**	1.11	-1.1
EJ-22×IC-414317	0.46	-8.40**	-33.63**	-39.48**
EJ-22×IC-414322	-0.01	-2.43	-15.92**	-17.96**
EJ-22×PR-2006-14	27.75**	20.91**	-25.61**	-29.60**
PYR-2009-5×IC-414317	-3.60*	-7.85**	-22.63**	-26.04**
PYR-2009-5×IC-414322	17.26**	14.30**	-34.75**	-36.40**
PYR-2009-5×PR-2006-14	14.181**	3.14	13.77**	2.77*
PYR-2009-13×IC-414317	-1.56	-21.417**	-20.53**	-36.56**
PYR-2009-13×IC-414322	6.897**	-9.713**	11.50**	-5.83**
PYR-2009-13×PR-2006-14	67.69**	51.87**	-29.95**	-36.56**
CD 1%	4.45	5.14	2.55	2.95
CD 5%	3.38	3.91	1.94	2.24
Mean Heterosis (%)	4.74	-2.82	-13.39	-19.80
Range of heterosis From	-23.69	-32.35	-34.75	-39.48
To	67.69	51.87	13.77	2.77
No. of crosses with +ve heterosis	13	9	4	1
No. of crosses with -ve heterosis	9	18	23	26

Table.4 Contd..........

Crosses	Siliqua Density			
	Euplasmic		Alloplasmic	
	Over MP	Over BP	Over MP	Over BP
PRL-2008-5×IC-414317	-28.73**	-33.33**	-28.00**	-32.65**
PRL-2008-5×IC-414322	10.17**	1.56*	-11.02**	-17.97**
PRL-2008-5×PR-2006-14	-18.10**	-25.78**	-17.24**	-25.00**
PBR-357×IC-414317	7.09**	-7.48**	-16.54**	-27.89**
PBR-357×IC-414322	7.91**	7.41**	-13.49**	-13.89**
PBR-357×PR-2006-14	31.75**	29.91**	-15.64**	-16.82**
Maya×IC-414317	-22.02**	-26.53**	-39.35**	-42.86**
Maya×IC-414322	10.08**	0.77	-15.97**	-23.08**
Maya×PR-2006-14	-25.64**	-33.08**	-18.80**	-26.92**
PR-20×IC-414317	-13.85**	-23.81**	-23.08**	-31.97**
PR-20×IC-414322	-2.26**	-4.43**	-8.60**	-10.62**
PR-20×PR-2006-14	14.29**	9.74**	-3.23**	-7.08**
Rohini×IC-414317	-20.95**	-31.97**	-24.11**	-34.69**
Rohini×IC-414322	-11.22**	-12.04**	-0.94	-1.85**
Rohini×PR-2006-14	15.24**	14.15**	-8.57**	-9.43**
Sej-2×IC-414317	-12.10**	-25.85**	-25.00**	-36.74**
Sej-2×IC-414322	47.37**	42.59**	-9.09**	-12.04**
Sej-2×PR-2006-14	-13.17**	-14.42**	-20.98**	-22.12**
Vaibhav×IC-414317	0.82	-16.33**	-9.84**	-25.17**
Vaibhav×IC-414322	-0.49	-5.56**	-1.46**	-6.48**
Vaibhav×PR-2006-14	5.47**	1.92*	14.43**	10.58**
EJ-22×IC-414317	-12.25**	-24.49**	-17.79**	-29.25**
EJ-22×IC-414322	0.94	0.00	-14.02**	-14.82**
EJ-22×PR-2006-14	8.571**	7.55**	-15.24**	-16.04**
PYR-2009-5×IC-414317	-18.41**	-23.13**	-29.24**	-33.33**
PYR-2009-5×IC-414322	1.68*	-6.92**	-9.24**	-16.92**
PYR-2009-5×PR-2006-14	-14.53**	-23.08**	-1.71**	-11.54**
PYR-2009-13×IC-414317	-20.78**	-31.29**	-27.84**	-37.42**
PYR-2009-13×IC-414322	-7.41**	-7.407**	-4.63**	-4.63**
PYR-2009-13×PR-2006-14	26.41**	24.07**	5.66**	3.70**
CD 1%	1.71	1.98	1.46	1.68
CD 5%	1.30	1.51	1.11	1.28
Mean Heterosis (%)	-1.80	-7.91	-13.68	-19.16
Range of heterosis From	-28.73	-33.33	14.43	10.58
To	47.37	42.59	14.43	10.58
No. of crosses with +ve heterosis	12	9	1	1
No. of crosses with -ve heterosis	15	19	28	29

Table.4 Contd..........

Crosses	Number of primary branches per plant			
	Euplasmic		Alloplasmic	
	Over MP	Over BP	Over MP	Over BP
PRL-2008-5×IC-414317	13.21**	0.00	0.60	-11.13**
PRL-2008-5×IC-414322	3.78**	1.48**	12.41**	9.91**
PRL-2008-5×PR-2006-14	11.59**	5.15**	-12.90**	-17.92**
PBR-357×IC-414317	4.52**	-10.60**	-11.69**	-24.47**
PBR-357×IC-414322	63.23**	60.78**	4.67**	3.09**
PBR-357×PR-2006-14	16.06**	5.62**	4.31**	-5.08**
Maya×IC-414317	3.57**	-2.20**	-4.70**	-10.00**
Maya×IC-414322	9.62**	0.00	-6.83**	-15.00**
Maya×PR-2006-14	0.57	-0.68	-13.86**	-14.93**
PR-20×IC-414317	6.39**	-7.80**	-15.39**	-26.67**
PR-20×IC-414322	12.14**	12.09**	-10.69**	-10.73**
PR-20×PR-2006-14	-9.75**	-16.69**	5.58**	-2.54**
Rohini×IC-414317	23.08**	6.67**	-7.69**	-20.00**
Rohini×IC-414322	6.14**	6.09**	18.33**	18.27**
Rohini×PR-2006-14	4.08**	-3.923**	-8.33**	-15.39**
Sej-2×IC-414317	-12.85**	-24.47**	-1.23**	-14.40**
Sej-2×IC-414322	13.69**	13.64**	3.14**	3.09**
Sej-2×PR-2006-14	8.33**	0.00	-13.83**	-20.46**
Vaibhav×IC-414317	3.57**	-3.33**	-2.36**	-8.87**
Vaibhav×IC-414322	5.63**	-2.54**	-16.63**	-23.08**
Vaibhav×PR-2006-14	-20.46**	-20.46**	2.54**	2.54**
EJ-22×IC-414317	4.64**	-15.13**	-6.86**	-24.47**
EJ-22×IC-414322	17.52**	8.64**	14.76**	6.10**
EJ-22×PR-2006-14	-4.43**	-17.92**	-13.39**	-25.62**
PYR-2009-5×IC-414317	-23.37**	-26.87**	14.08**	8.87**
PYR-2009-5×IC-414322	-3.01**	-12.40**	-10.64**	-19.30**
PYR-2009-5×PR-2006-14	18.66**	15.92**	5.15**	2.72**
PYR-2009-13×IC-414317	13.39**	3.33**	-14.63**	-22.20**
PYR-2009-13×IC-414322	-2.79**	-8.11**	-11.36**	-16.21**
PYR-2009-13×PR-2006-14	-6.87**	-9.23**	-26.36**	-28.23**
CD 1%	1.10	1.27	1.05	1.21
CD 5%	0.84	0.96	0.8	0.92
Mean Heterosis (%)	6.00	-1.43	-4.13	-10.74
Range of heterosis From	-23.37	-26.87	18.33	18.27
To	63.23	60.78	18.33	18.27
No. of crosses with +ve heterosis	21	11	10	8
No. of crosses with -ve heterosis	8	15	19	22

Table.4 Contd..........

Crosses	Number of secondary branches per plant			
	Euplasmic		Alloplasmic	
	Over MP	Over BP	Over MP	Over BP
PRL-2008-5×IC-414317	-3.91**	-11.10**	30.94**	21.14**
PRL-2008-5×IC-414322	55.07**	44.43**	59.96**	48.98**
PRL-2008-5×PR-2006-14	16.93**	10.46**	6.18**	0.31
PBR-357×IC-414317	19.48**	-4.40**	22.23**	-2.2
PBR-357×IC-414322	82.90**	66.27**	46.65**	33.32**
PBR-357×PR-2006-14	40.00**	13.95**	68.55**	37.18**
Maya×IC-414317	11.56**	5.37**	-3.51**	-8.87**
Maya×IC-414322	30.17**	18.79**	60.30**	46.29**
Maya×PR-2006-14	18.09**	13.95**	12.06**	8.13**
PR-20×IC-414317	27.25**	2.53*	22.78**	-1.07
PR-20×IC-414322	50.37**	37.86**	61.97**	48.50**
PR-20×PR-2006-14	34.74**	10.46**	38.99**	13.95**
Rohini×IC-414317	1.60	-12.20**	68.51**	45.62**
Rohini×IC-414322	59.67**	59.09**	56.66**	56.09**
Rohini×PR-2006-14	87.41**	65.09**	-7.62**	-18.63**
Sej-2×IC-414317	-6.66**	-21.67**	45.72**	22.27**
Sej-2×IC-414322	-22.06**	-25.00**	85.83**	78.82**
Sej-2×PR-2006-14	18.34**	1.15	8.84**	-6.98**
Vaibhav×IC-414317	0.57	-0.53	34.86**	33.38**
Vaibhav×IC-414322	25.97**	10.23**	7.81**	-5.66**
Vaibhav×PR-2006-14	5.72**	4.53**	16.10**	14.80**
EJ-22×IC-414317	1.99*	-12.17**	32.93**	14.47**
EJ-22×IC-414322	24.92**	23.95**	37.43**	36.36**
EJ-22×PR-2006-14	25.81**	10.43**	-16.55**	-26.75**
PYR-2009-5×IC-414317	-21.98**	-28.79**	30.67**	19.27**
PYR-2009-5×IC-414322	30.98**	5.15**	-18.84**	-34.85**
PYR-2009-5×PR-2006-14	5.85**	-5.31**	-41.54**	-47.70**
PYR-2009-13×IC-414317	28.88**	6.70**	19.49**	-1.07
PYR-2009-13×IC-414322	81.57**	71.96**	47.16**	39.36**
PYR-2009-13×PR-2006-14	33.76**	12.77**	-40.67**	-49.98**
CD 1%	2.31	2.66	2.7	3.12
CD 5%	1.76	2.03	2.06	2.37
Mean Heterosis (%)	25.50	12.46	26.46	13.82
Range of heterosis From	-22.06	-28.79	-41.54	-49.98
To	87.41	71.96	85.83	78.82
No. of crosses with +ve heterosis	24	20	24	17
No. of crosses with -ve heterosis	4	8	6	8

Table.4 Contd..........

Crosses	Siliqua length (cm)			
	Euplasmic		Alloplasmic	
	Over MP	Over BP	Over MP	Over BP
PRL-2008-5×IC-414317	-16.13**	-22.16**	-11.91**	-18.23**
PRL-2008-5×IC-414322	-12.35**	-20.37**	-23.79**	-30.76**
PRL-2008-5×PR-2006-14	-12.68**	-17.31**	-21.82**	-25.97**
PBR-357×IC-414317	11.07**	10.96**	-1.52**	-1.61**
PBR-357×IC-414322	5.68**	3.16**	3.34**	0.87**
PBR-357×PR-2006-14	7.18**	5.04**	-15.48**	-17.17**
Maya×IC-414317	2.22**	-0.89*	-8.62**	-11.39**
Maya×IC-414322	10.08**	4.37**	-9.95**	-14.62**
Maya×PR-2006-14	-11.35**	-12.22**	-6.30**	-7.22**
PR-20×IC-414317	14.08**	8.90**	-8.22**	-12.40**
PR-20×IC-414322	6.04**	3.53**	3.65**	1.20**
PR-20×PR-2006-14	11.59**	4.39**	-12.08**	-17.75**
Rohini×IC-414317	1.71**	1.20**	-12.30**	-12.74**
Rohini×IC-414322	-3.95**	-6.60**	-10.88**	-13.34**
Rohini×PR-2006-14	-8.27**	-9.75**	-17.98**	-19.30**
Sej-2×IC-414317	19.03**	8.96**	12.85**	3.30**
Sej-2×IC-414322	20.80**	12.99**	11.97**	4.73**
Sej-2×PR-2006-14	20.41**	8.13**	-11.43**	-20.47**
Vaibhav×IC-414317	0.57	-4.58**	-5.33**	-10.18**
Vaibhav×IC-414322	-4.22**	-7.06**	-4.80**	-7.63**
Vaibhav×PR-2006-14	9.82**	2.13**	4.13**	-3.16**
EJ-22×IC-414317	3.54**	-0.54	0.53	-3.44**
EJ-22×IC-414322	15.92**	13.91**	-0.54	-2.26**
EJ-22×PR-2006-14	10.63**	4.13**	-1.72**	-7.49**
PYR-2009-5×IC-414317	11.86**	6.13**	8.88**	3.30**
PYR-2009-5×IC-414322	1.82**	-1.20**	1.89**	-1.13**
PYR-2009-5×PR-2006-14	-9.75**	-16.08**	2.74**	-4.45**
PYR-2009-13×IC-414317	1.62**	0.00	-7.66**	-9.13**
PYR-2009-13×IC-414322	0.51	-3.33**	-2.82**	-6.52**
PYR-2009-13×PR-2006-14	-9.15**	-9.62**	-18.95**	-19.37**
CD 1%	0.80	0.92	0.74	0.85
CD 5%	0.61	0.70	0.56	0.65
Mean Heterosis (%)	3.28	-1.13	-5.47	-9.48
Range of heterosis From	-16.13	-22.16	-23.79	-30.76
To	20.80	13.91	12.85	4.73
No. of crosses with +ve heterosis	19	15	8	5
No. of crosses with -ve heterosis	9	13	20	25

Table.4 Contd..........

Crosses	Number of seeds per siliqua			
	Euplasmic		Alloplasmic	
	Over MP	Over BP	Over MP	Over BP
PRL-2008-5×IC-414317	12.41**	2.50*	10.12**	0.400
PRL-2008-5×IC-414322	7.32**	2.80**	20.95**	15.87**
PRL-2008-5×PR-2006-14	10.81**	-0.80	4.51**	-6.44**
PBR-357×IC-414317	12.62**	6.93**	8.78**	3.28**
PBR-357×IC-414322	9.35**	9.34**	8.43**	8.41**
PBR-357×PR-2006-14	0.79	-6.12**	2.17*	-4.84**
Maya×IC-414317	26.01**	15.96**	5.93**	-2.52*
Maya×IC-414322	24.62**	20.55**	13.98**	10.26**
Maya×PR-2006-14	2.45**	-7.45**	7.83**	-2.59**
PR-20×IC-414317	-4.50**	-10.92**	8.99**	1.66
PR-20×IC-414322	12.36**	10.26**	25.70**	23.35**
PR-20×PR-2006-14	2.66**	-6.03**	3.53**	-5.23**
Rohini×IC-414317	10.03**	-3.38**	14.83**	0.83
Rohini×IC-414322	10.68**	1.88	21.79**	12.11**
Rohini×PR-2006-14	21.97**	5.25**	2.82**	-11.28**
Sej-2×IC-414317	-2.35**	-12.60**	21.59**	8.82**
Sej-2×IC-414322	6.46**	0.00	53.20**	43.90**
Sej-2×PR-2006-14	13.31**	-0.39	3.67**	-8.86**
Vaibhav×IC-414317	4.65**	-5.90**	9.34**	-1.69
Vaibhav×IC-414322	19.78**	13.06**	19.78**	13.06**
Vaibhav×PR-2006-14	-1.37	-12.90**	21.45**	7.26**
EJ-22×IC-414317	4.14**	-2.87**	14.43**	6.73**
EJ-22×IC-414322	4.77**	2.80**	23.80**	21.48**
EJ-22×PR-2006-14	6.45**	-2.57**	28.66**	17.76**
PYR-2009-5×IC-414317	10.82**	5.70**	25.97**	20.14**
PYR-2009-5×IC-414322	17.76**	17.22**	0.46	0.00
PYR-2009-5×PR-2006-14	4.49**	-2.25*	16.38**	8.88**
PYR-2009-13×IC-414317	1.84*	-6.30**	24.19**	14.27**
PYR-2009-13×IC-414322	13.04**	9.34**	17.86**	13.99**
PYR-2009-13×PR-2006-14	-0.88	-10.48**	-2.68**	-12.10**
CD 1%	2.17	2.51	2.21	2.55
CD 5%	1.65	1.91	1.68	1.94
Mean Heterosis (%)	8.75	1.09	14.61	6.56
Range of heterosis From	-4.50	-12.90	-2.68	-12.10
To	26.01	20.55	53.20	43.90
No. of crosses with +ve heterosis	25	13	28	17
No. of crosses with -ve heterosis	2	14	1	8

Table.4 Contd..........

Crosses	Seed yield per plant (g)			
	Euplasmic		Alloplasmic	
	Over MP	Over BP	Over MP	Over BP
PRL-2008-5×IC-414317	54.82**	40.06**	46.20**	32.25**
PRL-2008-5×IC-414322	22.21**	-2.43**	-2.88**	-22.46**
PRL-2008-5×PR-2006-14	26.89**	18.27**	27.02**	18.40**
PBR-357×IC-414317	74.70**	42.89**	121.48**	81.16**
PBR-357×IC-414322	28.73**	-5.46**	92.98**	41.73**
PBR-357×PR-2006-14	115.22**	80.68**	63.68**	37.41**
Maya×IC-414317	196.70**	134.10**	169.23**	112.43**
Maya×IC-414322	116.98**	54.73**	63.84**	16.84**
Maya×PR-2006-14	84.66**	49.32**	79.92**	45.49**
PR-20×IC-414317	72.55**	27.17**	-5.49**	-30.35**
PR-20×IC-414322	13.71**	-23.27**	5.50**	-28.82**
PR-20×PR-2006-14	57.38**	18.52**	52.05**	14.51**
Rohini×IC-414317	78.20**	47.40**	70.02**	40.64**
Rohini×IC-414322	43.76**	6.56**	-13.40**	-35.81**
Rohini×PR-2006-14	-12.79**	-25.93**	-30.16**	-40.68**
Sej-2×IC-414317	37.27**	7.51*	25.90**	-1.39
Sej-2×IC-414322	14.25**	-19.01**	0.06	-29.07**
Sej-2×PR-2006-14	15.39**	-7.41**	12.08**	-10.06**
Vaibhav×IC-414317	41.24**	25.32**	32.90**	17.92**
Vaibhav×IC-414322	6.99**	-15.94**	0.98	-20.67**
Vaibhav×PR-2006-14	18.78**	8.52**	-8.92**	-16.79**
EJ-22×IC-414317	63.52**	48.21**	38.71**	25.72**
EJ-22×IC-414322	-0.85	-20.72**	25.48**	0.34
EJ-22×PR-2006-14	25.31**	17.04**	-24.32**	-29.32**
PYR-2009-5×IC-414317	16.97**	15.95**	46.65**	45.38**
PYR-2009-5×IC-414322	24.57**	7.42**	-38.66**	-47.10**
PYR-2009-5×PR-2006-14	-1.87**	-4.18**	-24.58**	-26.35**
PYR-2009-13×IC-414317	60.81**	56.54**	38.32**	34.65**
PYR-2009-13×IC-414322	38.99**	23.62**	12.73**	0.26
PYR-2009-13×PR-2006-14	-15.29**	-20.09**	24.17**	17.13**
CD 1%	1.83	2.11	1.61	1.85
CD 5%	1.39	1.61	1.22	1.41
Mean Heterosis (%)	43.99	19.51	30.05	8.11
Range of heterosis From	-15.29	-25.93	-38.66	-47.10
To	196.70	134.10	169.23	112.43
No. of crosses with +ve heterosis	26	19	20	15
No. of crosses with -ve heterosis	4	11	8	12

Table.4 Contd..........

Crosses	1000 seed weight (g)			
	Euplasmic		Alloplasmic	
	Over MP	Over BP	Over MP	Over BP
PRL-2008-5×IC-414317	35.79**	24.32**	43.91**	31.76**
PRL-2008-5×IC-414322	41.26**	17.84**	-18.68**	-32.16**
PRL-2008-5×PR-2006-14	5.84**	-8.33**	23.71**	7.14**
PBR-357×IC-414317	-12.57**	-30.92**	5.29**	-16.80**
PBR-357×IC-414322	1.60**	-12.55**	-1.60**	-15.29**
PBR-357×PR-2006-14	-12.06**	-27.06**	-19.15**	-32.94**
Maya×IC-414317	15.04**	-2.13**	5.29**	-10.43**
Maya×IC-414322	-13.92**	-19.43**	-9.87**	-15.64**
Maya×PR-2006-14	-0.62**	-10.74**	-11.35**	-20.38**
PR-20×IC-414317	43.66**	31.16**	25.32**	14.42**
PR-20×IC-414322	-2.62**	-3.89**	-20.42**	-21.47**
PR-20×PR-2006-14	6.67**	3.35**	7.15**	3.81**
Rohini×IC-414317	21.69**	16.89**	17.47**	12.84**
Rohini×IC-414322	6.76**	-7.07**	32.99**	15.76**
Rohini×PR-2006-14	-13.25**	-21.43**	-0.77**	-10.12**
Sej-2×IC-414317	8.52**	-6.37**	7.77**	-7.03**
Sej-2×IC-414322	-63.14**	-64.95**	-7.73**	-12.26**
Sej-2×PR-2006-14	-11.29**	-19.12**	-8.07**	-16.18**
Vaibhav×IC-414317	4.67**	-4.17**	35.06**	23.65**
Vaibhav×IC-414322	-53.42**	-61.14**	18.57**	-1.09**
Vaibhav×PR-2006-14	8.59**	-5.95**	-7.22**	-19.64**
EJ-22×IC-414317	-11.04**	-15.50**	26.72**	20.37**
EJ-22×IC-414322	6.84**	1.18**	-1.39**	-6.61**
EJ-22×PR-2006-14	10.78**	9.62**	7.07**	5.95**
PYR-2009-5×IC-414317	103.72**	47.97**	86.98**	35.81**
PYR-2009-5×IC-414322	34.66**	-8.15**	29.08**	-11.96**
PYR-2009-5×PR-2006-14	16.17**	-18.75**	29.36**	-9.52**
PYR-2009-13×IC-414317	99.02**	59.46**	51.79**	21.62**
PYR-2009-13×IC-414322	42.65**	5.89**	22.39**	-9.15**
PYR-2009-13×PR-2006-14	31.43**	0.60**	31.43**	0.60**
CD 1%	0.08	0.09	0.06	0.07
CD 5%	0.06	0.07	0.04	0.05
Mean Heterosis (%)	11.71	-4.31	13.37	-2.50
Range of heterosis From	-63.14	-64.95	-20.42	-32.94
To	103.72	59.46	86.98	35.81
No. of crosses with +ve heterosis	20	11	19	12
No. of crosses with -ve heterosis	10	19	11	18

Table.4 Contd..........

Crosses	Oil content (%)			
	Euplasmic		Alloplasmic	
	Over MP	Over BP	Over MP	Over BP
PRL-2008-5×IC-414317	-0.82**	-3.17**	-2.32**	-4.63**
PRL-2008-5×IC-414322	2.12**	0.22**	-0.61**	-2.46**
PRL-2008-5×PR-2006-14	0.06	-0.89**	-0.81**	-1.75**
PBR-357×IC-414317	-1.51**	-2.97**	-0.29**	-1.77**
PBR-357×IC-414322	1.20**	0.22**	1.30**	0.32**
PBR-357×PR-2006-14	2.302**	2.26**	2.21**	2.17**
Maya×IC-414317	-1.37**	-2.58**	-2.06**	-3.27**
Maya×IC-414322	1.56**	0.84**	-1.84**	-2.53**
Maya×PR-2006-14	-0.31**	-0.53**	-0.47**	-0.69**
PR-20×IC-414317	-2.97**	-4.76**	-2.89**	-4.69**
PR-20×IC-414322	-0.55**	-1.89**	-0.68**	-2.01**
PR-20×PR-2006-14	0.49**	0.07	0.63**	0.20**
Rohini×IC-414317	-4.15**	-6.47**	1.45**	-1.01**
Rohini×IC-414322	-0.28**	-2.18**	0.63**	-1.29**
Rohini×PR-2006-14	1.09**	0.08*	1.57**	0.55**
Sej-2×IC-414317	-3.84**	-7.02**	-1.88**	-5.13**
Sej-2×IC-414322	0.65**	-2.18**	1.47**	-1.39**
Sej-2×PR-2006-14	1.05**	-0.89**	2.19**	0.22**
Vaibhav×IC-414317	-0.36**	-2.17**	-2.95**	-4.72**
Vaibhav×IC-414322	-1.09**	-2.38**	-0.82**	-2.11**
Vaibhav×PR-2006-14	-19.40**	-19.71**	-0.16*	-0.54**
EJ-22×IC-414317	-0.26**	-2.69**	-3.71**	-6.07**
EJ-22×IC-414322	-1.42**	-3.33**	-0.1	-2.04**
EJ-22×PR-2006-14	0.49**	-0.54**	1.18**	0.14
PYR-2009-5×IC-414317	-1.75**	-2.10**	-2.88**	-3.23**
PYR-2009-5×IC-414322	-3.50**	-3.67**	-1.49**	-1.66**
PYR-2009-5×PR-2006-14	-4.69**	-5.74**	-1.57**	-2.65**
PYR-2009-13×IC-414317	-3.78**	-3.81**	-3.70**	-3.73**
PYR-2009-13×IC-414322	-2.94**	-3.49**	-4.15**	-4.70**
PYR-2009-13×PR-2006-14	-2.30**	-3.75**	-2.13**	-3.58**
CD 1%	0.08	0.09	0.17	0.2
CD 5%	0.06	0.07	0.13	0.15
Mean Heterosis (%)	-1.54	-2.84	-0.83	-2.13
Range of heterosis From	-19.40	-19.71	-4.15	-6.07
To	2.30	2.26	2.21	2.17
No. of crosses with +ve heterosis	9	5	9	5
No. of crosses with -ve heterosis	20	24	20	24

When the percentage of crosses showing heterosis over MP was compared for different characters under study between both the sets, the effect of cyto-nuclear interactions was clearly visible (Table 3). It was observed that frequency of crosses exhibiting heterosis was higher in euplasmic crosses for three characters (number of secondary branches, siliqua length & seed yield per plant), in alloplasmic crosses for six characters (days to 50 % flowering, days to maturity, plant height, siliquae on main raceme, siliqua density & number of seeds per siliqua) while crosses manifesting significant heterosis for four characters (length of main raceme, number of primary branches, 1000 seed weight & oil content) were equally frequent in euplasmic as well as in alloplasmic crosses. The wide differences in frequency of crosses manifesting heterosis in euplasmic and alloplasmic sets indicated some effect of cyto-nuclear interaction for 9 characters.

However, the effect of cyto-nuclear interaction was clearly evidenced by higher frequency of crosses displaying desirable heterotic crosses in euplasmic set than in alloplasmic set for all the characters except plant height, seeds per siliqua and oil content. The effect was more pronounce for days to 50% flowering, siliquae on main raceme, primary branches, secondary branches and siliqua length for which crosses with desirable heterosis were very less in alloplasmic crosses.

A cursory view of estimated heterosis over mid-parent as well as over better parent (Table 4) showed a shift in direction of significant heterosis in the two sets of crosses, which varied with cross as well as with character. Such a change in mid-parent heterosis in either direction was observed for 16 crosses for number of primary branches; 11 for siliqua length; 10 for number of secondary branches; 9 for siliqua on main raceme while for rest of the characters 5 or less number of crosses were exhibited a such a shift. Similarly, better parent heterosis was also affected in same way in number of crosses for the characters under study. For heterobeltiosis, number of crosses affected were 12 for number of secondary branches, 10 for siliqua length, 8 for number of seeds per siliqua, 7 each for the siliqua density, number of primary branches, seed yield per plant and 1000 seed weight, and 6 for siliquae on main raceme while three or less number of crosses exhibited such changes for rest of the characters. One cross *i.e.* Maya × PR-2006-14 did not show any directional change in both the types of heterosis.

This revealed that combining ability and heterosis of parental lines with native cytoplasm may or may not remain intact after their conversion into CMS background. Thus, it can be inferred that assessment of combining ability and heterosis of lines converted into CMS background will have to be re-examined for identification of potential crosses for commercialisation of CMS based hybrids. There also exists possibility of finding crosses with negligible or no effect of cyto-nuclear interactions due to re-establishment of harmonious interaction.

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