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Exploitation of Heterosis for Seed Yield and its Contributing Traits in CMS Based Hybrids of Indian Mustard [*Brassica juncea* (L.) Czern and Coss]

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Abstract

In the present study, line× tester analysis was carried out at Castor-Mustard Research Station, S. D. Agricultural University, Sardarkrushinagar, Gujarat, India during *rabi* 2018–19 (October 2018 to February 2019) in order to estimate all three types of heterosis (relative heterosis, heterobeltiosis and economic heterosis) for identification of superior cross combinations of Indian mustard [*Brassica juncea* (L.) Czern&Coss]. Thirty-five hybrids along with five CMS lines, seven testers and check GDM 4 were evaluated for ten different traits. The F_1 generation of all the crosses exhibited fertility restoration with pollen fertility except F_1 crosses with Vardan, Rohini and SKM 319 fertile line (0%). The remaining crosses exhibited pollen fertility ranging from 68.26% (Krantі×SKM 303) to 85.17% (Krantі×Mori 'R' 1-18). The analysis of variance for parents, hybrids and parents vs. hybrids revealed that mean sum of squares of parents were highly significant for majority of the characters except days to maturity. Whereas, hybrids differed highly significant for all the characters. Comparison of mean squares due to parents vs. hybrids was found significant for almost all the characters except number of seeds siliqua^{-1} and oil content. This indicates that considerable amount of genetic variability present among the parents and hybrids for all the characters studied. On the basis of per se performance, three hybrids viz., Krantі×Mori 'R' 1-18, SKM 9928×PusaAgrani and SKM 9928×Mori 'R' 1-18 were foundpromising for seed yield plant^{-1} over the standard check GDM 4.With respect to heterosis, one of the hybrid Krantі×Mori 'R' 1-18 (17.85 %)manifested significant and positive standard heterosis for seed yield plant^{-1}.

Keywords: Heterosis and Mori CMS, Indian mustard

1. Introduction

Indian mustard (*Brassica juncea* L.) is an important *rabi* season (October to March) oilseed crop in India which is popularly known as rai, raya or laha. The genus *Brassica*, belongs to brassicaceae family. Indian mustard is a natural amphidiploid (2n=36) of *Brassica campestris* (2n=20) and *Brassica nigra* (2n=16) (Nagaharu, 1935). *Brassica juncea* is a crop of Asiatic origin with its major centre of diversity in China from where it was introduced in India (Vaughan, 1977). It is the second important oilseed crop at national level and contributes nearly 27% of edible oil pool of the country (Singh et al., 2013). It is a naturally autogamous species

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in which out crossing varies from 5–30% depending upon environmental conditions and frequency of pollinating insects (Shrimali et al., 2016). Mustard seed contains about 38 to 46% oil.It is mainly grown for oil-seed usage in India. In Northern India, mustard oil is mainly utilized for human consumption (Vaghela et al., 2011). Mustard oil has isothiocyanates as the most important content contained responsible for its flavour and pungency (Park et al., 2018). In addition to its use as edible oil, mustard oil has a spectrum of industrial utilities such as paintand printing ink additives, greases and lubricants, resins and polymers, plastics, cosmetics and also in the pharmaceutical industries (Gupta, 2016). Globally, India is the second largest rapeseed–mustard-cultivating country after China and third in production next to China and Canada (Kumari et al., 2019). It was cultivated in an area of 6.85 million hectares in India with an annual production of 9.12 million tonnes and productivity of 1331 kg ha^{-1} (Anonymous, 2019-20). Major rapeseed-mustard growing states are Rajasthan, Uttar Pradesh, Madhya Pradesh, Punjab, Gujarat, Haryana, Assam, Bihar and West Bengal.

Seed yield a very complex trait, possesses many components which finally result in a highly plastic yield structure (Diepenbrock, 2000). Heterosis has an important role in all the plant breeding programmes; it would be very helpful to know the relationship between heterosis for seed yield and its components (Azizia, 2011). In oilseed *Brassicas* heterosis was first reported in brown sarson by Singh and Mehta (1954). Subsequently many studies have reported the extent of heterosis for seed yield. Significant level of heterosis was reported in *B. juncea* (13 to 91%) by Verma et al. (2011), Yadava et al. (2012) and Meena et al. (2015). Exploitable level of standard heterosis depends on an effective male sterility and fertility system which is the most important prerequisites for the development of commercially viable hybrids. Restoration ability in CMS line is an important factor for the exploitation of hybrid in the breeding programme. Alloplasmic *B. juncea* and *B. napus* have been obtained based on *B. oxyrrhina*, *Trachystomaballi*, *Moricandia arvensis*, *Diplotaxissiifolia*and *Sinapis alba* cytoplasm (Raoand Shivanna*.,* 1996; Prakash et al., 2001). Fertility restorers have been identified in the *Trachystoma* and *Moricandia* based CMS lines of *B. juncea* (Prakash and Kirti, 1997). Among the different sterile cytoplasms, *Moricandia arvensis (mori)* and *Diplotaxis erucoides (eru)* cytoplasms are proved to be stable and with almost no adverse effects in *B. juncea* backgrounds (Kaur et al., 2004, Chamola et al., 2013). The *mori* CMS system is available in *B. juncea* with small non-dehiscent anthers and excellent nectarines. Restorers are available and female fertility is about 95% for this cms system. The *mori* CMS system was developed by Prakash et al. (1998) and subsequently rectified by Kirti et al. (1998). Alloplasmic lines having cytoplasm from *Diplotaxis erucoides (eru)* and *Diplotaxis berthautii (ber)* were developed by Malik et al. (1999) and later improved by Bhat et al. (2006, 2008). Heterosis has been extensively explored and utilized for boosting various quality traits in *Brassica* because of an effective and economic pollination control system for production of F_1 hybrid seeds on a large scale. With these facts, in the present study, restoration ability and level of standard heterosis were estimated for the hybrids developed using L×T mating design.

2. Materials and Methods

2.1. Plant material and experimental details

The study was conducted during *rabi* 2018–19 (October 2018 to February 2019) at Castor-Mustard Research Station, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat, India. Sardarkrushinagar is situated at semi-arid region of North Gujarat. Geographically, it is situated at 24°.31' N latitude and 72°.32' E longitude with an altitude of 154.52 meters above the mean sea level. The experimental material for the present study includes five *Mori* based CMS lines (SKM 301, SKM 9928, GM 1, Kranti and GM 2) as female parent and seven *Mori* based restorer lines (Vardan, Rohini, SKM 319, SKM 303, Pusa Agrani, PCR 7 and Mori 'R' 1-18) as male parent to generate 35 alloplasmichybrids.At the same time, male sterile lines (A lines) werecrossed with its maintainer lines (B line) to get seeds of female parents for evaluationin the next season and the testers or restorer lines (male parents) were selfed to getpure seeds. Female line is CMS, so hand emasculation is not necessary While hybridization was carried out by manual hand pollination. During *rabi* 2018–19, a set of 48 genotypes comprising of twelve parents and their 35 F_1 hybrids along with standard check GDM 4 were sown in Randomized Complete Block Design with three replications. The soil of the experimental field was sandy loam with pH 7.5. Each entry was sown in 3 m row length with 45×15 cm^2 spacing. The recommended agronomical practices and plant protection measures were adopted to raise healthy crop.

2.2. Assessment of pollen fertility in F_1 generation

In the field, pollen fertility was tested as number of siliquae set on selfing per bag and % siliquae set on selfing. In the laboratory,pollen fertility/sterility of F_1 crosses was tested with 2% acetocarmine. All the hybrids have been tested for their pollen fertility status (Alexander, 1969) at the initial flowering stage of randomly selected plant. The round and well stained pollen grains were counted as fertile, while shrivelled hyaline pollen grains were scored as sterile. The mean for all the microscopic fields were worked out and the proportions of fertile pollens were expressed in % for individual plants. Based on the number of stained and unstained pollen grains, the fertility status was computed as follows:

Pollen fertility (%)=((Number of round and stained pollen (fertile pollen)/Total number of pollen grains examined))×100

2.3. Traits measurement

The observations were recorded on five randomly selected plants from each replicationfor all the traits viz., plant height

(cm), total number of branches plant^{-1}, total number of siliquae plant^{-1}, siliqua length (cm), number of seeds siliqua^{-1}, seed yield plant^{-1} (g), 1000 seed weight (g) and oil content (%) except days to flowering and days to maturity which were recorded on plot basis. The oil content of each samples was estimated in % by using Nuclear Magnetic Resonance (NMR) Technique (Tiwari et al., 1974).

2.4. Statistical analysis

The analysis of variance was carried out for ten characters as per the procedure described by Panse and Sukhatame (1967). The estimate of heterosis was calculated using the procedure of Turner (1953), heterobeltiosis by Fonesca and Patterson (1968) and economic heterosis by Meredith and Bridges (1972).

3. Results and Discussion

The present study was conducted using five cytoplasmic male sterile (CMS) lines and seven diverse male fertile lines to generate 35 F_1 hybrids in Indian mustard. For the experimental materials, selfing of one inflorescence of each F_1 plant was also carried out to examine ability or inability of the plant to produce selfed seeds for field confirmation. The pollen fertility was observed for all the F_1 crosses and standard check GDM 4 (Figure 1 and Figure 2) under light microscope and on the basis of its staining properties, pollen grains which were round, deep to light red colour consider as fertile pollen and shrivelled, hyaline, transparent or light yellow colour consider as sterile pollen. There were visual differences observed in all the F_1 crosses and standard check for the pollen fertility which are presented in Table 1.

The crosses made by CMS lines and male fertile lines SKM 303, Pusa Agrani, PCR 7 and Mori 'R' 1-18 exhibited pollen fertility which ranged from 68.26% to 85.17%, whereas standard check GDM 4 had 91.36% pollen fertility, while the crosses carried out by crossing CMS lines and male fertile lines Vardan, Rohini and SKM 319 had 0% pollen fertility, i.e., totally sterile pollen (Table 1). These results were further confirmed by ability to produce seed set upon self-fertilization. The crosses made by CMS lines and male fertile lines SKM 303, PusaAgrani, PCR 7 and Mori 'R' 1-18 exhibited % siliquae set by self-pollination, which was ranging from 66.99% to 83.82%, where as standard check GDM 4 had 89.76% siliquae set, while the crosses carried out by crossing CMS lines and male fertile lines Vardan, Rohini and SKM 319 had 0% siliquae set (Table 2). It

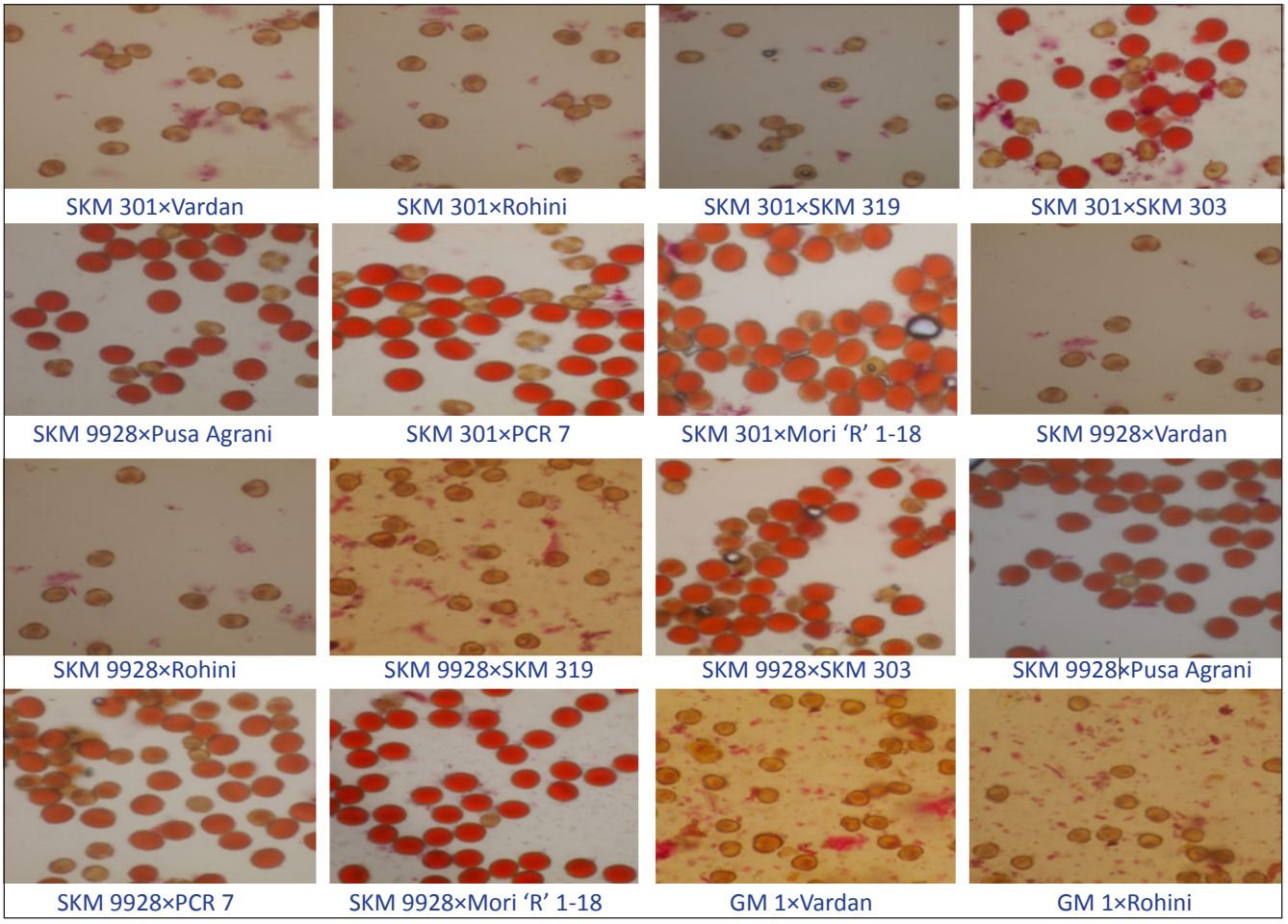

Figure 1: Pollen grain stainability of hybrids

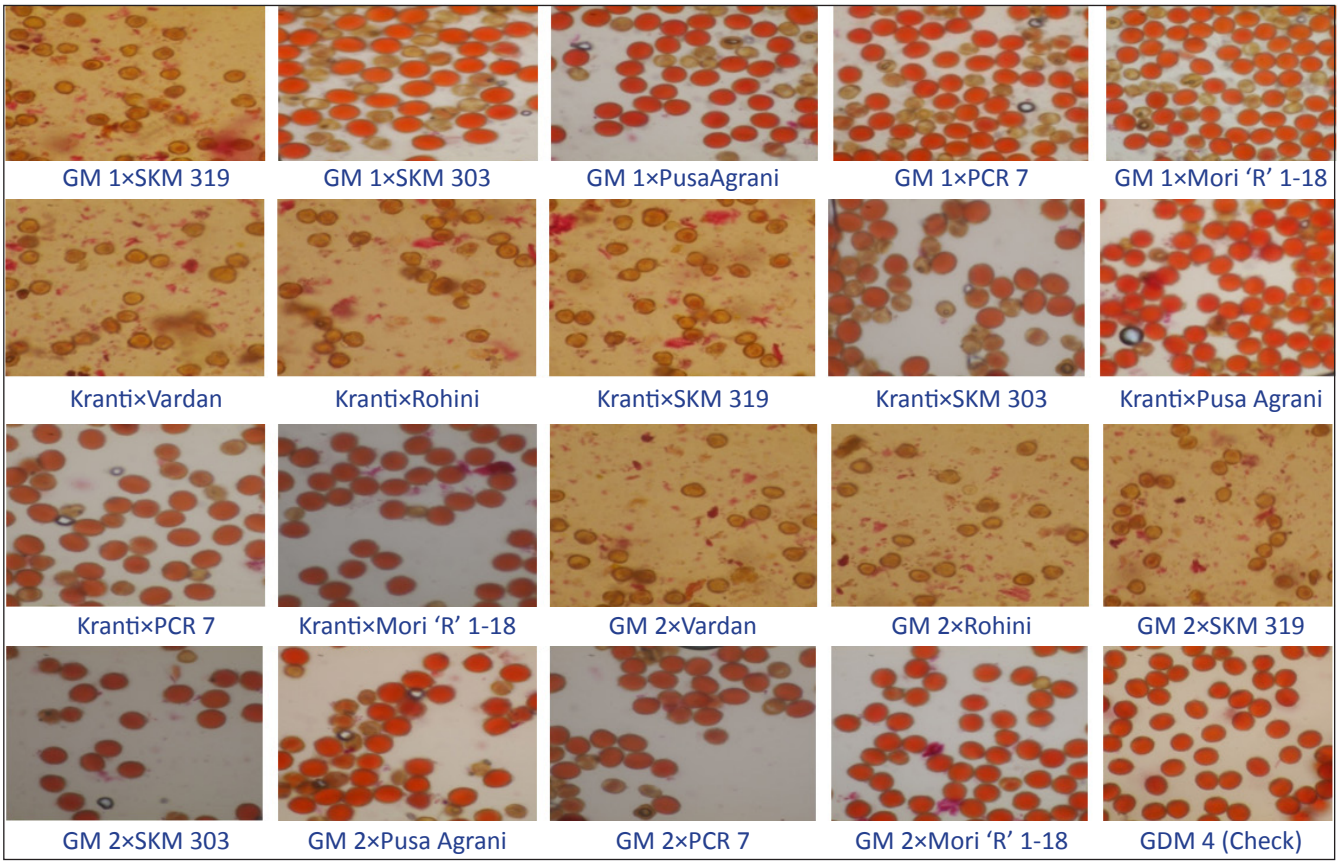

Figure 2: Pollen grain stainability of hybrids

Table 1: Pollen fertility status of F_1 hybrids and standard check (GDM 4) in Indian mustard

Sl. No.	Genotypes	R I		R II		R III		Total		TPO	Plant Fertility	Pollen Fertility (%)
		Sterile	Fertile	Sterile	Fertile	Sterile	Fertile	Sterile	Fertile			
1.	SKM 301×Vardan	46	0	58	0	53	0	157	0	157	S	0
2.	SKM 301×Rohini	54	0	38	0	39	0	131	0	131	S	0
3.	SKM 301×SKM 319	33	0	42	0	46	0	121	0	121	S	0
4.	SKM 301×SKM 303	23	57	19	52	21	55	63	164	227	F	72.24
5.	SKM 301×Pusa Agrani	10	33	15	46	18	55	43	134	177	F	75.70
6.	SKM 301×PCR 7	12	34	22	56	21	62	55	152	207	F	73.42
7.	SKM 301×Mori 'R' 1-18	19	60	20	68	22	72	61	200	261	F	76.62
8.	SKM 9928×Vardan	51	0	56	0	44	0	151	0	151	S	0
9.	SKM 9928×Rohini	40	0	52	0	62	0	154	0	154	S	0
10.	SKM 9928×SKM 319	45	0	48	0	59	0	152	0	152	S	0
11.	SKM 9928×SKM 303	24	57	31	72	20	48	75	177	252	F	70.23
12.	SKM 9928×Pusa Agrani	19	53	18	54	22	65	59	172	231	F	74.45
13.	SKM 9928×PCR 7	20	49	26	62	26	69	72	180	252	F	71.42
14.	SKM 9928×Mori 'R' 1-18	14	64	21	78	13	71	48	213	261	F	81.61
15.	GM 1×Vardan	53	0	56	0	48	0	157	0	157	S	0
16.	GM 1×Rohini	48	0	64	0	58	0	170	0	170	S	0

Table 1: Continue...

Sl. No.	Genotypes	R I		R II		R III		Total		TPO	Plant Fertility	Pollen Fertility (%)
		Sterile	Fertile	Sterile	Fertile	Sterile	Fertile	Sterile	Fertile			
17.	GM 1×SKM 319	59	0	52	0	48	0	159	0	159	S	0
18.	GM 1×SKM 303	28	66	20	42	24	56	72	164	236	F	69.49
19.	GM 1×Pusa Agrani	17	43	19	52	22	64	58	159	217	F	73.27
20.	GM 1×PCR 7	28	74	29	65	24	58	81	197	278	F	70.86
21.	GM 1×Mori 'R' 1-18	24	69	22	64	24	62	70	195	265	F	73.58
22.	Kranti×Vardan	48	0	61	0	64	0	173	0	173	S	0
23.	Kranti×Rohini	47	0	66	0	58	0	171	0	171	S	0
24.	Kranti×SKM 319	54	0	49	0	56	0	159	0	159	S	0
25.	Kranti×SKM 303	16	38	24	48	26	56	66	142	208	F	68.26
26.	Kranti×PusaAgrani	34	76	26	66	22	62	82	204	286	F	71.32
27.	Kranti×PCR 7	16	49	22	56	18	54	56	159	215	F	73.95
28.	Kranti×Mori 'R' 1-18	16	76	10	70	13	78	39	224	263	F	85.17
29.	GM 2×Vardan	45	0	64	0	58	0	167	0	167	S	0
30.	GM 2×Rohini	51	0	68	0	62	0	181	0	181	S	0
31.	GM 2×SKM 319	59	0	62	0	66	0	187	0	187	S	0
32.	GM 2×SKM 303	26	55	25	66	19	48	70	169	239	F	70.71
33.	GM 2×Pusa Agrani	14	38	18	46	21	54	53	138	191	F	72.25
34.	GM 2×PCR 7	13	35	18	48	22	58	53	141	194	F	72.68
35.	GM 2×Mori 'R' 1-18	19	69	14	58	22	72	55	199	254	F	78.34
36.	GDM 4 (Standard Check)	4	58	6	65	9	78	19	201	220	F	91.36

S : Sterile, F : Fertile; TPO: Total pollen observed

suggested that the male fertile line Vardan, Rohini and SKM 319 lacks the fertility restorer gene *(Rf)* and has no ability to restore fertility upon crossing with cytoplasmic male sterile possessing *Moricandia* background. The results are supported by Kumar et al. (2014a). The CMS line crossed with pollen fertility restorer line plants (F_1's) exhibited in Kranti×SKM 303 (68.26%) to Kranti×Mori 'R' 1-18 (85.17%) and Kranti×SKM 303 (66.99%) to Kranti×Mori 'R' 1-18 (83.82%) pollen fertility and % siliquae set, respectively which subsequently increases in selfed progeny. Similar results were also obtained by Banga et al. (2003).

The aim of estimation of heterosis was to mark the best combination of parents giving high degree of useful heterosis for seed yield and its contributing characters for its future use in the breeding programme. In the present investigation, out ofthirty fivecrosses, fifteen crosses were sterile in both pollen fertility (0%) and siliquae set % (0%) study so, these fifteen sterile crosses were not considered for the estimation of heterosis and not discussed onward in heterosis studies. Heterosis was measured as % increase or decrease of F_1 over the mid parental value (relative heterosis), better parent (heterobeltiosis) and over standard check GDM 4 (standard heterosis) for all the characters under study. The analysis of variance for parents, hybrids and parents vs. hybrids revealed that mean sum of squares of parents were highly significant for majority of the characters except days to maturity. Whereas, hybrids differed highly significant for all the characters. Comparison of mean squares due to parents vs. hybrids was found significant for almost all the characters except number of seeds siliqua^{-1} and oil content (Table 3). This indicates that considerable amount of genetic variability present among the parents and hybrids for all the characters studied. Similar results were also recorded for all the charactersexcept seed yield plant^{-1} by Synrem et al. (2015), while for all the characters by Chaurasiya et al. (2018).

Overall performance of the hybrids with respect to relative heterosis for yield components revealed that ten hybrids, SKM 9928×SKM 303(63.31%), SKM 9928×Pusa Agrani (126.29%), SKM 9928×PCR 7 (75.85%), SKM 9928×Mori 'R' 1-18 (102.68%), GM 1×Pusa Agrani (65.54%), GM 1×PCR 7 (58.01%), GM 1×Mori 'R' 1-18 (62.58%), Kranti×Mori 'R' 1-18 (34.18%), GM 2×Pusa Agrani (37.30%) and GM 2×Mori 'R' 1-18 (58.84%) exhibited highly significant desirable heterosis for seed yield plant^{-1}; one hybrid for days to maturity, one hybrid for plant height, twelve hybrids for number of branches plant^{-1}, ten hybrids for total number of siliquae plant^{-1}, four hybrids for

Table 2: Number of siliquae set and % siliquae set upon selfing in F_1 hybrids and standard check (GDM 4) in Indian mustard

Sl. No.	Genotypes	R I		R II		R III		Total flower bud kept	Total siliquae set	% Siliquae set
		Flower bud kept	Siliquae set	Flower bud kept	Siliquae set	Flower bud kept	Siliquae set			
1.	SKM 301×Vardan	35	0	32	0	41	0	108	0	0
2.	SKM 301×Rohini	38	0	36	0	38	0	112	0	0
3.	SKM 301×SKM 319	28	0	27	0	42	0	97	0	0
4.	SKM 301×SKM 303	44	31	39	28	29	20	112	79	70.53
5.	SKM 301×PusaAgrani	38	29	29	21	40	30	107	80	74.76
6.	SKM 301×PCR 7	36	26	32	23	35	25	103	74	71.84
7.	SKM 301×Mori ‘R’ 1-18	34	25	35	26	40	30	109	81	74.31
8.	SKM 9928×Vardan	38	0	42	0	27	0	107	0	0
9.	SKM 9928×Rohini	42	0	35	0	34	0	111	0	0
10.	SKM 9928×SKM 319	29	0	28	0	32	0	89	0	0
11.	SKM 9928×SKM 303	32	22	36	24	41	28	109	74	67.88
12.	SKM 9928×PusaAgrani	41	30	43	32	29	21	113	83	73.45
13.	SKM 9928×PCR 7	46	32	34	24	27	19	107	75	70.09
14.	SKM 9928×Mori ‘R’ 1-18	41	33	38	29	44	36	123	98	79.67
15.	GM 1×Vardan	28	0	31	0	38	0	97	0	0
16.	GM 1×Rohini	27	0	26	0	39	0	92	0	0
17.	GM 1×SKM 319	38	0	28	0	29	0	95	0	0
18.	GM 1×SKM 303	39	26	48	32	35	24	122	82	67.21
19.	GM 1×PusaAgrani	41	29	32	23	30	22	103	74	71.84
20.	GM 1×PCR 7	44	30	44	30	42	29	130	89	68.46
21.	GM 1×Mori ‘R’ 1-18	46	34	29	21	33	23	108	78	72.22
22.	Kranti×Vardan	32	0	40	0	41	0	113	0	0
23.	Kranti×Rohini	31	0	45	0	29	0	105	0	0
24.	Kranti×SKM 319	28	0	28	0	31	0	87	0	0
25.	Kranti×SKM 303	35	24	26	17	42	28	103	69	66.99
26.	Kranti×PusaAgrani	36	24	36	25	28	20	100	69	69.00
27.	Kranti×PCR 7	27	20	31	22	31	22	89	64	71.91
28.	Kranti×Mori ‘R’ 1-18	46	37	42	36	48	41	136	114	83.82
29.	GM 2×Vardan	32	0	31	0	35	0	98	0	0
30.	GM 2×Rohini	41	0	35	0	29	0	105	0	0
31.	GM 2×SKM 319	39	0	41	0	30	0	110	0	0
32.	GM 2×SKM 303	38	25	28	20	32	22	98	67	68.36
33.	GM 2×PusaAgrani	40	28	32	22	35	25	107	75	70.09
34.	GM 2×PCR 7	44	31	30	21	36	25	110	77	70.00
35.	GM 2×Mori ‘R’ 1-18	42	32	46	37	38	29	126	98	77.77
36.	GDM 4 (Standard Check)	46	42	42	38	39	34	127	114	89.76

Table 3: Analysis of variance (Mean sum of square) for parents and hybrids for seed yield and its component characters in Indian mustard

Source of variation	d.f.	Days to flowering	Days to maturity	Plant height	Total no. of branches plant^{-1}	Total no. of siliquae plant^{-1}	Siliqua length	No.of seeds siliqua^{-1}	Seed yield plant^{-1}	1000 seed weight	Oil content
Replications	2	5.70	5.53	159.55	2.82	682.62	0.01	0.91	7.88	0.03	0.16
Treatments	28	26.37**	9.03**	1183.18**	89.10**	18588.98**	1.05**	6.06**	149.51**	1.27**	1.99**
Parents	8	26.16**	5.06	1394.75**	134.16**	27191.57**	0.89**	5.77**	222.79**	1.30**	3.65**
Females	4	3.93	2.23	408.27*	255.72**	50620.40**	1.31**	7.40**	384.16**	2.47**	5.03**
Males	3	18.53**	5.64	2438.89**	0.35	318.85	0.001	0.80	3.27	0.14**	0.93**
Females vs. Males	1	138.02**	14.67*	2208.27**	49.32**	14094.40**	1.84**	14.15**	235.83**	0.10*	6.29**
Parents vs. Hybrids	1	154.21**	16.54*	9646.79**	252.02**	46103.84**	0.40**	0.83	426.74**	1.76**	0.002
Hybrids	19	19.72**	10.30**	648.65**	61.56**	13518.69**	1.15**	6.46**	104.06**	1.22**	1.40**
Error	56	2.25	2.73	153.02	3.04	912.14	0.039	1.23	8.90	0.018	0.14

siliqua length; four hybrids for number of seeds siliqua^{-1}, ten hybrids for 1000 seed weight and seven hybrids for oil content. None of hybrids was obtained for days to flowering which exhibited significant negative relative heterosis (Table 4, 5 and 6). The result also showed that hybrids, SKM 9928×SKM 303 and SKM 9928×Pusa Agrani which showed significant heterosis for seed yield plant^{-1} also possessed desirable heterotic effects for one or more important yield contributing characters like

Table 4: Estimates of heterosis in % in F_1 hybrids over mid parent, better parent and standard check GDM 4 for days to flowering, days to maturity and plant height in Indian mustard

Sl. No.	Hybrids	Days to flowering			Days to maturity			Plant height (cm)		
		MP	BP	SC	MP	BP	SC	MP	BP	SC
1.	SKM 301×SKM 303	7.82**	11.97**	11.02**	-0.42	0.85	2.31	40.14**	41.44**	18.41**
2.	SKM 301×PusaAgrani	5.10*	14.53**	13.56**	2.68*	4.60**	4.90**	25.95**	39.55**	18.99**
3.	SKM 301×PCR 7	4.56	7.69*	6.78*	1.12	2.27	4.03**	-0.10	19.32**	1.74
4.	SKM 301×Mori R' 1-18	7.56**	9.40**	8.47**	-0.70	-0.28	2.88*	26.65**	26.94**	7.75
5.	SKM 9928×SKM 303	19.34**	23.93**	22.88**	2.54*	3.41**	4.90**	27.92**	29.40**	8.33
6.	SKM 9928×PusaAgrani	11.37**	21.37**	20.34**	2.55*	4.02**	4.32**	21.19**	33.94**	14.73*
7.	SKM 9928×PCR 7	11.20**	14.53**	13.56**	2.39*	3.12**	4.90**	-1.23	17.65*	0.78
8.	SKM 9928×Mori 'R' 1-18	9.24**	11.11**	10.17**	0.84	0.84	4.03**	27.95**	28.54**	9.11
9.	GM 1×SKM 303	10.92**	17.86**	11.86**	2.26*	2.84*	4.32**	41.87**	46.78**	14.92*
10.	GM 1×PusaAgrani	0.00	11.61**	5.93	0.00	1.15	1.44	21.62**	41.34**	10.66
11.	GM 1×PCR 7	3.39	8.93**	3.39	-0.42	0.00	1.73	4.24	30.94**	2.52
12.	GM 1×Mori 'R' 1-18	2.15	6.25	0.85	-0.28	0.00	2.59*	31.59**	37.13**	7.36
13.	Kranti×SKM 303	19.15**	28.44**	18.64**	4.82**	5.11**	6.63**	18.25**	22.22**	2.33
14.	Kranti×PusaAgrani	0.40	13.76**	5.08	1.42	2.30	2.59*	14.66**	23.86**	10.66
15.	Kranti×PCR 7	9.01**	16.51**	7.63*	2.12*	2.27	4.03**	-11.19*	3.25	-7.75
16.	Kranti×Mori 'R' 1-18	6.09*	11.93**	3.39	0.00	0.56	2.59*	14.35*	17.35*	-0.39
17.	GM 2×SKM 303	-0.42	5.31	0.85	-0.42	0.28	1.73	-1.93	5.79	-11.43

Table 4: Continue...

Sl. No.	Hybrids	Days to flowering			Days to maturity			Plant height (cm)		
		MP	BP	SC	MP	BP	SC	MP	BP	SC
18.	GM 2×PusaAgrani	-1.20	9.73**	5.08	0.99	2.30	2.59*	-7.63	-4.40	-7.36
19.	GM 2×PCR 7	4.64	9.73**	5.08	-1.41	-0.85	0.86	-7.11	3.20	0.00
20.	GM 2×Mori 'R' 1-18	0.85	4.42	0.00	-2.66*	-2.52*	0.29	9.17	16.89*	-0.78
SEm±		1.06	1.22	1.22	1.17	1.35	1.35	8.75	10.10	10.10
Range		-1.20 to +19.34	+4.42to +28.44	0.00to +22.88	-2.66 to +4.82	-2.52 to +5.11	0.29 to 6.63	-11.19 to +41.87	-4.40 to +46.78	-11.43 to +18.99
Significant Heterosis		11	17	11	8	7	14	13	16	4
Number of +ve significant		11	17	11	7	6	14	12	16	4
Number of -ve significant		0	0	0	1	1	0	1	0	0

*: $p \leq 0.05$, **: $p \leq 0.01$

Table 5: Estimates of heterosis in % in F_1 hybrids over mid parent, better parent and standard check GDM 4 for total number of branches plant^{-1}, total number of siliquae plant^{-1}, siliqua length and numbers of seeds siliqua^{-1} in Indian mustard

Sl. No.	Hybrids	Total number of branches plant^{-1}			Total number of siliquae plant^{-1}			Siliqua length (cm)		
		MP	BP	SC	MP	BP	SC	MP	BP	SC
1.	SKM 301×SKM 303	-14.91**	-31.53**	-30.38**	-17.66**	-31.50**	-28.16**	5.42	-10.00**	-4.83
2.	SKM 301×PusaAgrani	-21.73**	-38.12**	-37.08**	-18.35**	-34.21**	-31.01**	-10.30**	-23.09**	-18.67**
3.	SKM 301×PCR 7	10.22	-12.47*	-11.00*	7.42	-13.06*	-8.82	-7.43*	-20.74**	-16.19**
4.	SKM 301×Mori R' 1-18	11.96*	-10.82*	-9.33	8.63	-11.41*	-7.09	2.53	-12.47**	-7.44*
5.	SKM 9928×SKM 303	25.75**	13.13	-29.90**	17.00*	7.28	-25.31**	51.71**	50.79**	12.79**
6.	SKM 9928×PusaAgrani	93.83**	78.14**	5.26	77.55**	69.12**	8.46	45.33**	43.70**	8.62*
7.	SKM 9928×PCR 7	81.18**	65.60**	-0.96	63.99**	55.36**	0.79	0.44	-0.52	-25.07**
8.	SKM 9928×Mori 'R' 1-18	79.52**	63.49**	-1.44	63.86**	53.79**	1.78	26.60**	25.83**	-5.87
9.	GM 1×SKM 303	13.12	-3.47	-40.19**	9.47	-4.93	-33.81**	3.66	3.66	-22.45**
10.	GM 1×PusaAgrani	21.86**	6.07	-37.32**	10.86	-0.22	-36.01**	-2.26	-2.76	-26.50**
11.	GM 1×PCR 7	27.94**	10.80	-33.73**	24.13**	11.15	-27.89**	5.22	4.85	-21.02**
12.	GM 1×Mori 'R' 1-18	45.75**	25.79**	-24.16**	35.76**	20.51*	-20.25**	-1.75	-1.75	-26.50**
13.	Kranti×SKM 303	-6.80	-27.27**	-19.62**	-5.88	-24.61**	-12.80*	0.16	-7.66*	-18.15**
14.	Kranti×Pusa Agrani	-19.89**	-38.53**	-32.06**	-19.14**	-37.15**	-27.31**	-2.23	-9.43*	-19.71**
15.	Kranti×PCR 7	-10.11	-30.74**	-23.44**	-8.03	-28.22**	-16.99**	1.91	-5.74	-16.45**
16.	Kranti×Mori 'R' 1-18	23.53**	-4.55	5.50	25.69**	-1.20	14.27*	-2.72	-10.31**	-20.50**
17.	GM 2×SKM 303	3.59	-10.81	-44.74**	5.66	-5.15	-33.96**	-18.65**	-23.14**	-35.38**
18.	GM 2×PusaAgrani	40.09**	23.08*	-27.27**	31.66**	22.66*	-21.33**	14.15**	8.39*	-8.88**
19.	GM 2×PCR 7	30.43**	14.00	-31.82**	26.03**	16.80	-24.23**	-6.47	-11.34**	-25.46**
20.	GM 2×Mori 'R' 1-18	94.08**	69.05**	1.91	79.50**	64.84**	9.09	-8.79*	-13.82**	-27.55**
SEm+		1.23	1.42	1.42	21.36	24.66	24.66	0.14	0.16	0.16
Significant Heterosis		15	13	14	13	13	14	8	14	18
Number of +ve significant		12	6	0	10	6	1	4	4	2
Number of -ve significant		3	7	14	3	7	13	4	10	16

*: $p \leq 0.05$, **: $p \leq 0.01$

Table 5: Continue...

Sl. No.	Hybrids	Number of seeds siliqua^{-1}		
		MP	BP	SC
1.	SKM 301×SKM 303	7.98	-6.12	2.22
2.	SKM 301×PusaAgrani	-11.63*	-22.45**	-15.56*
3.	SKM 301×PCR 7	-17.12**	-24.90**	-18.22**
4.	SKM 301×Mori R' 1-18	11.72*	-0.82	8.00
5.	SKM 9928×SKM 303	33.88**	31.38**	9.78
6.	SKM 9928×PusaAgrani	21.18**	20.21**	0.44
7.	SKM 9928×PCR 7	-1.29	-4.02	-15.11*
8.	SKM 9928×Mori 'R' 1-18	22.75**	22.11**	3.11
9.	GM 1×SKM 303	1.62	-0.53	-16.44**
10.	GM 1×PusaAgrani	8.02	6.88	-10.22
11.	GM 1×PCR 7	1.03	-1.51	-12.89*
12.	GM 1×Mori 'R' 1-18	-3.96	-4.21	-19.11**
13.	Kranti×SKM 303	0.25	-8.26	-11.11
14.	Kranti×Pusa Agrani	4.22	-3.67	-6.67
15.	Kranti×PCR 7	-6.47	-10.55	-13.33*
16.	Kranti×Mori 'R' 1-18	-3.92	-10.09	-12.89*
17.	GM 2×SKM 303	-16.24**	-22.54**	-26.67**
18.	GM 2×PusaAgrani	11.06	3.76	-1.78
19.	GM 2×PCR 7	-6.80	-9.86	-14.67*
20.	GM 2×Mori 'R' 1-18	-5.21	-10.33	-15.11*
SEm±		0.78	0.91	0.91
Significant Heterosis		7	6	11
Number of +ve significant		4	3	0
Number of -ve significant		3	3	11

*: $p \leq 0.05$, **: $p \leq 0.01$

number of branches plant^{-1}, total number of siliquae plant^{-1}, siliqua length, number of seeds siliqua^{-1}, 1000-seed weight and oil content.The similar results were also reported by Arher et al. (2009), Gami et al. (2011) and Synrem et al. (2015).

The highly significant heterobeltiosis for seed yield plant^{-1} was recorded by the eight hybrids i.e., SKM 9928×SKM 303 (46.59%), SKM 9928×Pusa Agrani (115.42%), SKM 9928×PCR 7 (57.87%), SKM 9928×Mori 'R' 1-18 (83.85%), GM 1×Pusa Agrani (43.83%), GM 1×PCR 7 (30.30%), GM 1×Mori 'R' 1-18 (35.31%) and GM 2×Mori 'R' 1-18 (46.54%). Several hybrids registered significant heterobeltiosis in desirable direction for various characters under study viz., days to maturity (one hybrid), total number of branches plant^{-1} (five hybrids), total number of siliquaeplant^{-1} (six hybrids), siliqua length (four hybrids), number of seeds siliqua^{-1}(three hybrids), 1000 seed weight (eight hybrids) and oil content(five hybrids). None of hybrids exhibited significant negative heterobeltiosis for days to flowering and plant height.The best two hybrids, SKM 9928 ×Pusa Agrani (115.42%) and SKM 9928×PCR 7(57.87%) exhibited significant heterobeltiosis for seed yield plant^{-1}also manifested significant heterobeltiosis for one or more important yield characters like number of branches plant^{-1}, total number of siliquae plant^{-1}, 1000 seed weight and oil content (Table 4, 5 and 6). Significant heterobeltiosis for seed yield plant^{-1}, 1000 seed weightand oil content was also reported by Chodhary et al (2020).

The variety, GDM 4 released for general cultivation in Gujarat, therefore used as standard variety in order to obtain information regarding superiority of new hybrids over best cultivated variety. None of the hybrids however manifested significant desirable standard heterosis for days to flowering, days to maturity, plant height, number of branches plant^{-1} and number of seeds siliqua^{-1}. In this study, only one hybrid Kranti×Mori 'R' 1-18 showed positive and significant heterosis

Table 6: Estimates of heterosis in % in F_1 hybrids over mid parent, better parent and standard check GDM 4 for seed yield plant^{-1}, 1000 seed weight and oil content in Indian mustard

Sl. No.	Hybrids	Seed yield plant^{-1} (g)			1000 seed weight (g)			Oil content (%)		
		MP	BP	SC	MP	BP	SC	MP	BP	SC
1.	SKM 301×SKM 303	8.00	-15.23	-14.91	20.91**	12.94**	6.86**	1.44	0.57	-1.36
2.	SKM 301×Pusa Agrani	-38.67**	-53.96**	-53.79**	-13.43**	-15.40**	-27.20**	2.71**	2.53**	-1.16
3.	SKM 301×PCR 7	-4.73	-25.23**	-24.95**	5.49**	0.13	-8.46**	2.84**	2.34**	-1.34
4.	SKM 301×Mori R' 1-18	11.91	-12.90	-12.57	-5.64**	-8.69**	-19.81**	-0.78	-1.83*	-3.32**
5.	SKM 9928×SKM 303	63.31**	46.59**	-16.15*	3.27	-2.19	-7.45**	3.26**	2.06*	0.10
6.	SKM 9928×Pusa Agrani	126.29**	115.42**	8.41	7.83**	6.94**	-7.98**	3.01**	2.87**	-1.19
7.	SKM 9928×PCR 7	75.85**	57.87**	-9.72	10.51**	6.40**	-2.72	2.07**	1.89*	-2.39**
8.	SKM 9928×Mori 'R' 1-18	102.68**	83.85**	2.72	1.44	-0.40	-12.54**	1.72*	0.33	-1.19
9.	GM 1×SKM 303	-0.95	-18.33	-53.29**	-9.91**	-18.19**	-22.59**	0.30	-0.96	-0.36
10.	GM 1×Pusa Agrani	65.54**	43.83**	-27.62**	41.76**	34.50**	15.73**	-3.40**	-5.59**	-5.01**
11.	GM 1×PCR 7	58.01**	30.30*	-25.49**	27.56**	17.66**	7.57**	-2.22**	-4.72**	-4.14**

Table 6: Continue...

Sl. No.	Hybrids	Seed yield plant^{-1} (g)			1000 seed weight (g)			Oil content (%)		
		MP	BP	SC	MP	BP	SC	MP	BP	SC
12.	GM 1×Mori 'R' 1-18	62.58**	35.31*	-24.40**	28.48**	20.74**	6.03**	-1.56*	-2.61**	-2.01*
13.	Kranti×SKM 303	-9.02	-32.79**	-19.49*	-2.73	-5.48**	-5.20*	-2.35**	-3.87**	-2.68**
14.	Kranti×Pusa Agrani	-3.84	-31.72**	-18.21*	18.31**	9.91**	10.23**	-0.59	-3.13**	-1.94*
15.	Kranti×PCR 7	-8.27	-32.24**	-18.83*	7.83**	3.07	3.37	1.45*	-1.45	-0.23
16.	Kranti×Mori 'R' 1-18	34.18**	-1.62	17.85*	15.62**	8.43**	8.75**	-4.32**	-5.63**	-4.46**
17.	GM 2×SKM 303	-15.19	-20.90	-47.71**	-6.61**	-15.38**	-1.42	-0.84	-3.66**	0.19
18.	GM 2×Pusa Agrani	37.30**	20.92	-20.07*	-7.45**	-19.54**	-6.27**	1.35	-2.51**	1.38
19.	GM 2×PCR 7	15.55	7.76	-28.77**	-3.81*	-14.16**	0.00	-0.92	-4.98**	-1.19
20.	GM 2×Mori 'R' 1-18	58.84**	46.54**	-3.13	-5.93**	-17.51**	-3.90	0.69	-1.97*	1.94*
SEm±		2.11	2.44	2.44	0.10	0.11	0.11	0.26	0.30	0.30
Range		-38.67 to +126.29	-53.96 to +115.42	-53.79 to +17.85	-13.43 to +41.76	-19.54 to +34.50	-27.20 to +15.73	-4.32 to +3.26	-5.63 to +2.87	-5.01 to +1.94
Significant Heterosis		11	13	14	17	16	15	12	16	9
Number of +ve significant		10	8	1	10	8	6	7	5	1
Number of -ve significant		1	5	13	7	8	9	5	11	8

*: $p \leq 0.05$, **: $p \leq 0.01$

over standard check GDM 4 for seed yield plant^{-1}. The top three hybrids which evinced promising standard heterosis were GM 1×Pusa Agrani, Kranti×Pusa Agrani and Kranti×Mori 'R' 1-18 for 1000 seed weight and for oil content, the superior hybrid was GM 2×Mori 'R' 1-18. The best hybrids for siliqua length over the standard check GDM 4 were SKM 9928×SKM 303and SKM 9928×PusaAgrani. The superior hybrid over standard check GDM 4 for total number of siliquae plant^{-1} was Kranti×Mori 'R' 1-18 (Table 4, 5 and 6). The present findings were in close agreement with the findings of Patel et al. (2010), Verma et al. (2011), Kumar et al. (2014b) and Synrem et al. (2015).

4. Conclusion

Hybrid Kranti×Mori 'R' 1-18 was identified as best heterotic combination for total number of siliquae plant^{-1}, seed yield plant^{-1} and 1000 seed weight. Hybrids, SKM 301×SKM 303, SKM 9928×Pusa Agrani and Kranti×Mori 'R' 1-18 had good genetic architecture and needed large scale testing to develop a superior hybrid with high and stable seed yield in *Brassica juncea* L.

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