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Original Research Paper

Heterosis for seed yield related traits in *Brassica napus* L. hybrids – preliminary studies

M. Sakibur Alam[1], M. S. Raihan[1], M. M. Haque[2], A. K. M. Aminul Islam[1]✉

[1]Department of Genetics and Plant Breeding, [2]Department of Agronomy Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur 1706

✉aminulgpb@bsmrau.edu.bd

An experiment was conducted to evaluate 14 selected hybrids of *Brassica napus* L. with their 10 pollen parents and two standard varieties (BARI Sarisha-13, 18) as a control for seed yield related traits. The experiment was laid out in Randomized Complete Block Design with three replications. The analysis of variance showed significant variability among the genotypes for studied traits. It was also evident for the estimates of heterosis over pollen parent and standard checks, several hybrids exhibited heterosis in desirable directions for most of the yield related traits. The highest level of heterosis (or heterosis effect) (70.64%) over pollen parent was observed in the hybrid 248A × 001(3) for number of siliques (or pods) per plant. Besides, the highest pollen parent heterosis (58.24%) in positive direction was found for thousand seed weight (g) in hybrid 248A × 30(2). The estimates of standard heterosis for the experimental hybrids revealed that the hybrid 206A × 004(1) and 248A × 004(1) exhibited the highest negative heterosis (-13.95% and -11.62%, respectively) for days to flowering and seeds per silique, and the hybrid 248A × 001(3) for plant height (-22.08%). For number of siliques per plant, the hybrids 248A × 017(1) (114.41%) and 206A × 001(2) (106.11%) exhibited the highest significant standard heterosis over both controls. The hybrids 248A × 30(2) produced the heaviest seed (48.45%) and 206A × 017(1) and 206A × 001(2) produced the highest seed yield per plant (90.20% and 89.40%, respectively) which was exhibited from their significant positive heterosis (48.45%). In conclusion, the hybrids could be selected as promising hybrid combinations and forwarded for CMS based hybrid variety development of *Brassica napus*.

Keywords: rapeseed, hybrid, CMS line, pollen parent, check variety, standard heterosis

Introduction

The youngest species of *Brassicaceae* family, *B. napus,* is commonly used as an oil crop and has several common names – rapeseed, oilseed rape, colza and canola (Raboanatahiry *et al.,* 2021). Rapeseed is an allotetraploid species (AACC genome, 2n = 4x = 38 chromosomes), ancestrally originated from an interspecific hybridization between two extant diploid progenitors, *B. rapa* (AA genome, 2n = 2x = 20 chromosomes) and *B. oleracea* (CC genome, 2n = 2x = 18 chromosomes) (Chalhoub *et al.,* 2014, Song *et al.,* 2020). Rapeseed is of significant economic interest worldwide, providing high-quality oil with excellent health-promoting properties. Rapeseed-mustard occupied third position after oil palm (*Elaeis guineensis* Jacq.) and soybean (*Glycine max* L.) (Dina *et al.,* 2019) among the sources of edible oils in the world. Thus, its cultivation has risen significantly in most parts of the world over the last few decades (Filipova *et al.,* 2017). In Bangladesh, rapeseed occupies the first position both in terms of area (1.1 million hectares) and production (1.42 million Metric ton) among the oilseeds crop (USDA, 2024). Rapeseed production worldwide has increased by about 3.3 times between 1994 and 2018, while cultivated areas have almost doubled (Fridrihsone *et al.,* 2020).

Cultivation of low yielding local varieties and late sowing are the major causes for poor yield of rapeseed in Bangladesh (Malek *et al.,* 2012, Sarkar *et al.,* 2021, Yesmin *et al.,* 2022). Major cropping pattern in Bangladesh is T Aman-Fallow-Boro rice (*Oryza sativa* L.) which occupies more than 45% area (Khatun *et al.,* 2019). Usually, farmers keep their land fallow rather than cultivation of rapeseed-mustard after harvest of T Aman to avoid the risk of delaying cultivation of Boro rice. The turn-around date between T Aman and Boro is about 80-85 days. This stipulated date may be utilized through cultivation of short duration high yielding varieties of rapeseed-mustard in between T Aman and Boro rice (Talukder *et al.,* 2020); will increase cropping intensity simultaneously accelerating the oil seed production in Bangladesh. Therefore, development of short duration high yielding rapeseed-mustard variety is essential to fulfill the edible oil demand in Bangladesh (Islam *et al.,* 2020a; Islam *et al.,* 2020b). There are many rapeseed varieties are available in Bangladesh such as BINA Sarisha-3, BINA Sarisha-4, BARI Sarisha-7, BARI Sarisha-8, BARI Sarisha-13, Safal, Agrani, etc., but no hybrid variety (Helal *et al.,* 2022). The exploitation of genetic variation present in the breeding material is very important to obtain high yielding and early maturing varieties. The utilization of hybridization, leading to hybrid vigor, or heterosis, is a successful strategy in increasing yield and vigor for many field crops including rapeseed (Wang *et al.,* 2021). Another powerful tool is heterosis which provides infor-

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mation about valuable hybrid combination. Line × Tester is very helpful in the breeding program because it helps to estimate the different genetic variation among the population (Anum *et al.,* 2019; Saroj et al., 2021). The production of rapeseed can be boosted at commercial level by using hybrid variety (Anum *et al.,* 2019). Therefore, the present study was undertaken to develop experimental hybrids of rapeseed through CMS Lines × Restorer cross and asses their performance (heterosis) for seed yield related traits, and utilize the best one as hybrid variety in commercial production.

Materials and Methods

Experimental site and climate

The research work was conducted at the experimental farm, Department of Genetics and Plant Breeding, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur. Experimental farm consists with silt loam soil texture having soil pH 5.5. The area was situated under sub-tropical climate zone having scanty of rain from October to April and plenty from May to September. The average daily temperature was 26.92°C (max) and 17.33°C (min), rainfall was 8.52 mm per month and relative humidity was 85.63% during the experimental period.

Experimental materials

Two CMS lines (248A and 206A) of rapeseed were used in this research and these lines are the introgressed lines of Ogura CMS system which is one of the important methods of hybrid seed production in cruciferous crops. Fourteen experimental hybrids were developed by controlled pollination and hand pollination between CMS lines and the selected restorers i.e. 248A × BNR-001(3), 248A × BNR-004(1), 248A × BNR-017(1), 248A × BNR-27(2), 248A × BNR-30(2), 248A × BNR-37 (1), 206A × BNR-001(2), 206A × BNR-004(1), 206A × BNR-017(1), 206A × BNR-027(2), 206A × BNR-037(1), 206A × BNR-037(2), 206A × BNR-37(3), 206A × BNR-030(1) with 10 pollen parents (restorers) i.e. BNR-001(3), BNR-004(1), BNR-017(1), BNR-27(2), BNR-30(2), BNR-37(1), BNR-001(2), BNR-037(2), BNR-37(3), BNR-030(1). Experimental hybrids along with 10 restorer lines and two standard check varieties (BARI Sarisha 13 and BARI Sarisha 18, as there is no released hybrid variety of rapeseed in Bangladesh) were used as experimental materials to evaluated the heterotic performance of the hybrids.

Experimental design, seed sowing and crop management

The experiment was laid out in a randomized complete block design with three replications. Each plot has three rows and the spacing between rows was 30 cm having plant spacing of 15 cm within the row, the individual plot size was 4.20 m^2 (1.05 m × 4.0 m). Soil fertility was ensured by applying additional quantities of urea, triple super phosphate (TSP), muriate of potash (MoP), gypsum, zinc sulphate, boron at the rate of 250 $kg \cdot ha^{-1}$, 170 $kg \cdot ha^{-1}$, 85 $kg \cdot ha^{-1}$, 150 $kg \cdot ha^{-1}$, 5 $kg \cdot ha^{-1}$, 10 $kg \cdot ha^{-1}$, respectively (Miah *et al.,* 2015). Total TSP, MoP, zinc sulphate and cow dung (10 $t \cdot ha^{-1}$) was applied during the final land preparation. Total urea was applied in three installments, at 15, 30 and 50 days after sowing (DAS). Seeds of 26 genotypes (14 hybrids, 10 pollen parents and two standard cultivars) of rapeseed were sown in different row in the experimental field. Intercultural operations were done as and when necessary for proper growth and development of the crop plants (Khaleque 1985, Saha *et al*., 2011).

Data collection and statistical analysis

Twenty randomly selected competitive plants from each replication were used for recording data on DFF: days to 50% flowering, DTM: days to maturity, PHT: plant height (cm), PBP: primary branches per plant (nos.), SPP: siliques per plant (nos.), SLT: silique length (cm), SPS: seeds per silique (nos.), TSW: thousand seed weight (g), and SYP: seed yield per plant (g). Simple analysis of variance (ANOVA), mean, standard error (SE), coefficient of variation (CV) was done from the replicated data of different characters by using computer software STAR (Statistical Tools for Agricultural Research) and Statistix 10.0 according to Panse and Sukhatme (1957). Hybrid performances were done through estimation of heterosis (Singh and Chaudhary, 1985) as percent increase or decrease over the pollen parent and standard check (standard heterosis).

Heterosis over pollen parent (H1) (%)

$$\frac{\overline{F_1} - \overline{PP}}{\overline{PP}} \times 100$$

Where, $\overline{F_1}$ = Mean performance of hybrid,

$\overline{PP}$ = Mean performance of pollen parent

Standard heterosis (SH) (%)

$$\frac{\overline{F_1} - \overline{SC}}{\overline{SC}} \times 100$$

Where, $\overline{F_1}$ = Mean performance of hybrid,

$\overline{SC}$ = Mean variance of standard cultivars (BARI Sarisha 13 or BARI Sarisha 18).

Results and Discussion

Analysis of variance (ANOVA)

Analysis of variance was carried out for nine yield related characters of selected hybrids and ten pollen parent and two standard varieties of rapeseed. The results revealed highly significant genetic variability among 14 experimental hybrids, 10 pollen parents and two standard variety of rapeseed (Tab. 1).

Mean performance of hybrids and their pollen parents

Days to 50% flowering ranged from 37 to 52 days in hybrid population. Khan *et al.,* (2023) reported that the days of 50% flowering ranged from 30 to 32 days in rapeseed. The highest value for days to 50% flowering was observed in the hybrid combination 206A × 37(3) (52 days) followed by 206A × 037(2) (51 days). The minimum days to 50% flowering was observed in the hybrid combination 206A × 004(1) (37 days) and BARI Sarisha -13 (37 days) (Tab. 2).

Table 1

Analysis of variance (ANOVA) for yield and yield related characteristics in 26 genotypes of *Brassica n*apus L.

SV	DF	DFF	DTM	PHT	PBP	SPP	SPS	SLT	TSW	SYP
Replication	2	0.01	154.39	81.44	0.1	480.39	11.57	0.70	0.005	0.87
Genotype	26	42.34***	280.82***	391.15***	0.36***	867.32***	601.26***	1.60**	0.01***	0.87****
Error	52	0.12	0.68	52.35	0.07	253.99	93.06	0.60	0.002	0.23

SV: Sources of variation; DF: Degrees of freedom; DFF: Days to 50% flowering (days); DTM: Days to maturity (days); PHT: Plant height (cm); PBP: Number of primary branches per plant; SPP: Number of siliques per plant; SPS: Number of seeds per siliques; SLT: Silique length (cm); TSW: Thousand seed weight (g); SYP: Seed yield per plant (g).

Table 2

Mean performance of 16 *Brassica napus* L. hybrids for yield and yield related characters

Genotypes	DFF	DTM	PHT	PBP	SPP	SPS	SLT	TSW	SYP
248A × 001(3)	40.00	88.00	113.89	3.86	107.76	108.40	8.03	4.10	4.50
248A × 004(1)	38.00	88.00	121.82	3.24	93.58	117.22	8.50	3.60	4.38
248A × 017(1)	41.00	89.00	123.25	3.51	125.65	112.87	8.40	4.00	3.90
248A × 27(2)	39.00	89.00	129.07	3.69	81.71	122.21	7.90	4.50	4.22
248A × 30(2)	39.00	89.00	134.13	3.32	67.04	104.77	7.80	4.80	3.17
248A × 37(1)	41.00	90.00	137.28	3.65	93.61	124.49	8.40	4.60	4.36
206A × 001(2)	41.00	90.00	134.42	3.65	120.79	104.83	9.10	3.30	4.70
206A × 004(1)	37.00	90.00	127.33	3.68	101.39	105.70	7.47	4.00	4.14
206A × 017(1)	43.00	92.00	133.69	3.53	87.26	113.94	8.40	4.70	4.73
206A × 027(2)	43.00	92.00	132.36	3.39	66.90	115.20	9.73	4.60	3.38
206A × 37(1)	40.50	92.00	138.75	3.42	70.44	113.47	8.63	4.10	3.82
206A × 037(2)	51.00	99.00	119.68	3.49	73.60	99.21	8.80	4.30	3.81
206A × 37(3)	52.00	99.00	122.39	3.43	82.79	99.23	8.33	3.30	3.31
206A × 030(1)	41.00	92.00	145.89	3.29	73.54	106.00	8.50	3.80	2.76
BARI-13	37.00	82.00	146.17	4.00	93.47	93.47	8.03	3.20	2.48
BARI-18	43.00	85.00	107.13	5.02	58.61	58.61	8.90	3.60	3.74
Mean	41.66	90.38	129.20	3.64	87.39	110.53	8.43	4.00	3.84
CV (%)	1.11	3.23	5.22	9.11	19.02	9.00	5.38	7.34	12.93
LSD (5%)	0.33	13.84	4.87	0.24	12.00	7.17	0.32	0.02	0.35

DFF: Days to 50% flowering (days); DTM: Days to maturity (days); PHT: Plant height (cm); PBP: Number of primary branches per plant; SPP: Number of siliques per plant; SPS: Number of seeds per siliques; SLT: Silique length (cm); TSW: Thousand seed weight (g); SYP: Seed yield per plant (g).

In case of pollen parents, days to 50% flowering ranged from 37 to 49 days (Tab. 3). The tallest plant was observed in the hybrid 206A × 030(1) (145.89 cm) followed by 206A × 37(1) (138.75 cm) and 248A × 37(1) (137.28 cm). The shortest plant was observed in BARI Sarisha-18 (107.13 cm) followed by 248A × 001(3) (113.89 cm), 206A × 037(2) (119.68 cm) and 248A × 004(1) (121.82 cm) (Tab. 2). The minimum plant height was observed in the pollen parent BNR -001(3) (122.15 cm) followed by BNR-017(1) (125.14 cm) and BNR-037(2) (127.88 cm)

(Tab. 3). Plant height should be lower for *Brassica napus* to avoid lodging. Anum *et al.,* (2019) reported varying plant height in rapeseed from 142 cm to 251 cm. The experimental hybrid produces varying number of primary branches per plant that was ranged from 3.24 to 5.02 (Tab. 2). Maximum number of primary branches per plant was observed in BARI Sarisha-18 (5.02) followed by BARI Sarisha-13 (4.00), 248A × 001(3) (3.86), 248A × 27(2) (3.69), 206A × 004(1) (3.68), and minimum in 248A × 004(1) (3.24). The maximum number of primary branches per plant was observed in the pollen parent BNR-017(1) (4.01) followed by BNR-37(3) (3.79) (Tab. 3).

Table 3

Mean performance of 10 pollen parent of *Brassica napus* L. for yield and yield related characters

Genotypes	DFF	DTM	PHT	PBP	SPP	SPS	SLT	TSW	SYP
BNR-001(3)	41.00	84.00	122.15	3.38	63.15	106.34	8.23	4.20	3.45
BNR-004(1)	42.00	84.00	139.72	3.77	84.88	83.10	7.90	2.80	3.87
BNR-017(1)	39.00	76.00	125.14	4.01	90.18	100.15	7.27	3.30	3.65
BNR-27(2)	41.00	85.00	130.50	3.61	68.61	83.43	9.33	3.40	3.45
BNR-30(2)	43.00	88.00	153.07	3.39	90.71	80.04	8.97	3.00	3.56
BNR-37(1)	42.00	88.00	151.64	3.77	104.64	94.06	9.83	3.50	3.73
BNR-001(2)	49.00	81.00	134.90	3.77	81.63	102.60	8.07	3.40	3.94
BNR-037(2)	37.00	75.00	127.88	3.64	82.53	83.29	10.37	3.00	3.89
BNR-37(3)	40.00	84.00	130.75	3.79	69.96	100.60	9.10	3.20	3.24
BNR-030(1)	43.00	88.00	153.07	3.39	90.71	80.04	8.97	3.00	3.56
Mean	41.64	83.45	136.30	3.65	81.42	90.64	8.85	3.30	3.62
CV (%)	7.32	5.43	9.38	6.62	19.28	10.32	12.51	19.01	12.06
LSD (5%)	0.21	2.37	6.305	0.122	14.978	8.863	1.035	0.051	0.421

DFF: Days to 50% flowering (days); DTM: Days to maturity (days); PHT: Plant height (cm); PBP: Number of primary branches per plant; SPP: Number of siliques per plant; SPS: Number of seeds per siliques; SLT: Silique length (cm); TSW: Thousand seed weight (g); SYP: Seed yield per plant (g).

Fatima *et al.* (2022) reported maximum number of branches per plant (6.5) in the genotype ZM -M-6 of winter rapeseed. Days to maturity of rapeseed hybrids ranged from 82 to 99 days. The earliest hybrids were 248A × 001(3) and 248A × 004(1) took 88.0 day for maturity and the latest was the hybrid 206A × 037(2) and 206A × 37(3) (99 days). The minimum days to maturity was taken by BARI Sarisha-13 (82 days) and BARI Sarisha-18 (85 days) (Tab. 2). The pollen parent BNR-037(2) (75 days) followed by BNR-017(1) (76 days) were found most earliest for days to maturity (Tab. 3).

Number of siliques per plant ranged from 58.61 to 125.65 among the hybrids. The highest number of siliques per plant was observed in the hybrid combination 248A × 017(1) (125.65) followed by 206A × 001(2) (120.79) and 248A × 001(3) (107.76). Maximum number of siliques per plant (235) was reported by Anum *et al.* (2019) reported maximum number of silique per plant (256) in a hybrid ZM-R-21 × Hyola-401 of winter rapeseed. In the present study, minimum number of siliques per plant (58.61) was observed in BARI Sarisha-18 (Tab. 2) and maximum in the pollen parent BNR-37(1) (104.64) followed by pollen parent BNR-030(1) (90.71), BNR-30(2) (90.71) and BNR-017(1) (90.18). Number of seed per five siliques was counted for hybrids and pollen parents. The SPS ranged from 58.61 to 124.49 in hybrid and from 80.04 to 106.34 in paternal components (Tab. 2 and Tab. 3). The highest number of seeds per five siliques was observed in the hybrid 248A × 37(1) (124.50) followed by 248A × 27(2) (122.21). The minimum number of seeds per siliques was observed in the standard varieties BARI Sarisha-18 (58.61) followed by BARI Sarisha-13 (93.47), and two hybrids 206A × 037(2) (99.21) 206A × 37(3) (99.23) (Tab. 2). The highest number of seeds per siliques was observed in the pollen parent BNR-001(3) (106.34) followed by pollen parent BNR-001(2) (102.60), BNR-37(3) (100.60) and BNR-017(1) (100.15), respectively. Silique length ranged from 7.47 to 9.73 cm among the hybrids and 7.27 to 10.37 cm in pollen parents (Tab. 2 and Tab. 3). The longest siliques were observed in the hybrid 206A × 027(2) (9.73 cm) followed by 206A × 001 (2) (9.10 cm). The shortest siliques were observed in the hybrid 206A × 004(1) (7.47 cm) followed by 248A × 30(2) (7.8 cm), 248A × 27(2) (7.9 cm) (Tab. 2). The shortest siliques were observed in the pollen parent BNR-017(1) (7.27 cm) followed by BNR-004(1) (7.9 cm) and the longest in BNR-037(2) (10.37) (Tab. 3).

Thousand seed weight ranged from 3.20 g to 4.80 g in the hybrid genotypes where the heaviest or bold seed was observed in the hybrid 248A × 30(2) (4.80 g) followed by 206A × 017(1) (4.70 g). On the contrary, the lightest seed weight was observed in BARI Sarisha-13 (3.20 g) followed by 206A × 001(2) (3.30 g), 206A × 37(3) (3.30 g) and 248A × 004(1) (3.60 g) (Tab. 2). The bold seed was observed in the pollen parent BNR-001(3) (4.20 g) followed by pollen parent BNR-37(1) (3.50), BNR-27(2) (3.40 g) and BNR-017(1) (3.30) (Tab. 3). Liu *et al.,* (2022) reported that thousand seed weight ranged from 3.70 g to 4.0 g. The hybrid 206A × 017(1) produces the highest seed yield per plant (4.73 g) followed by 206A × 001(2) (4.70 g) and the lowest seed yield per plant was produced by BARI Sarisha-13 (2.48 g). Similar results were also revealed by the hybrids 206A × 030(1) (2.76 g) and 248A × 30(2) (3.17 g) (Tab. 2). In case of pollen parent, seed yield per plant was ranged from 3.24 g to 3.94 g where the highest seed yield per plant was exhibited by the pollen parent BNR-001(2) (3.94g). Azim *et al.,* (2024) found the highest seed yield per plant (4.81 g) in hybrid combination NAP-0724-2 × BD7118 of *Brassica napus*.

Correlation among yield related traits in restorer lines and hybrids

Correlation coefficient among nine traits (days to 50% flowering, days to maturity (days), plant height, number of primary branches, number of siliques per plant, number of seeds per five siliques silique length, thousand seed weight, seed yield per plant) of 10 parental genotypes and 14 hybrids were estimated and are presented in Table 4. Some characters showed non-significant correlations and some characters showed significant correlation among them. Magnitude and directions of correlation values among traits had differences. Days to maturity showed significant negative correlation with days to 50% flowering (-0.945**) and significant positive correlation with seeds per silique (0.505**) and thousand seed weight (0.631**). Days to 50% flowering also showed significant negative correlation with seeds per silique (-0.516**) and thousand seed weight (-0.609**). Laghari *et al.*, (2020) noticed significant negative correlation of days to 75% flowering with silique per plant. Number of primary branches per plant showed significant positive correlation with number of silique per plant (0.522**). Seed yield per plant had significant positive correlations with number of seeds per plant (0.461*) and thousand seed weight (0.239**). Meena *et al.*, (2017) also reported significant positive correlation of seed yield per plant with thousand seed weight in Indian mustard (*Brassica juncea* (L.) Czern.). Negative and nonsignificant correlation of seed yield per plant with plant height (Laghari *et al.*, 2020). Significant and positive correlation between seeds per silique and seed yield per plant (Guang *et al.*, 2011), and silique per plant and seed yield per plant (Abideen *et al.*, 2013, Tariq *et al.*, 2020) in rapeseed.

Table 4

Correlation coefficient for nine yield related traits in 10 restorers, 14 hybrids and two standard check

Traits	DTM	DFF	PHT	PBP	SPP	SPS	SLT	TSW	SYP
DTM	1.00								
DFF	-0.945**	1.00							
PHT	-0.313	0.341	1.00						
PBP	-0.092	-0.012	-0.376	1.00					
SPP	0.116	-0.163	0.141	-0.078	1.00				
SPS	0.505**	-0.516**	-0.062	0.522**	0.235	1.00			
SLT	-0.251	0.299	0.184	-0.063	-0.111	-0.313	1.00		
TSW	0.631**	-0.609**	-0.275	-0.221	-0.166	0.671	-0.223	1.00	
SYP	0.197	-0.204	-0.309	0.035	0.461*	0.322	-0.046	0.239*	1.00

DTM: Days to maturity (days); DFF: Days to 50% flowering (days); PHT: Plant height (cm); PBP: Number of primary branches per plant; SPP: Number of siliques per plant; SPS: Number of seeds per siliques; SLT: Silique length (cm); TSW: Thousand seed weight (g); SYP: Seed yield per plant (g).

Heterosis over pollen parent

Heterosis over pollen parent ranged from -16.33% to 37.84% for days to 50% flowering. The desired negative and significant heterosis was observed in the cross 206A × 001(2) (-16.33%) followed by 206A × 004(1) (-11.90%) and 248A × 004(1) (-9.52%) indicating their suitability as early hybrid (Tab. 5). Surin *et al.* (2018) and Barupal *et al.* (2017) found the highest negative heterosis (-7.93% and -20.83%, respectively) for days to flowering. The lowest significant but positive heterosis was observed in the hybrids 248A × 30(2) (1.14%) for days to maturity followed by 206A × 030(1) (4.55%), 206A × 37(1) (4.55%), 248A × 27(2) (4.71%), 248A × 004(1) and 248A × 001(3) (4.76%), respectively revealing the fact that they might be potential candidates as short duration rapeseed hybrids (Tab. 5). Kaur *et al.* (2019) in *Brassica juncea* and Liton *et al.* (2017) in *Brassica rapa* reported the highest negative heterosis -5.58% and -4.71%, respectively for days to maturity in mustard.

Heterosis over pollen parent ranged from -12.81% to 6.84%, and only five hybrids 248A × 004(1), 248A × 30(2), 248A × 37(1), 206A × 004(1) and 206A × 037(1) exhibited significant results while the rest of the nine hybrids had non-significant heterosis for plant height. However, negative heterosis is desirable for plant height and consequent significant negative heterosis ranged from -8.50% to -12.81% whereas the hybrid 248A × 004(1) showed the highest significant negative heterosis (-12.81%). Thus, the hybrid 248A × 004(1) might be the best hybrid with the shortest plant height (Tab. 5). The highest negative heterosis (-43.88% and -14.34%, respectively) was observed by Channa *et al.* (2018) and Liton *et al.* (2017) for plant height in mustard. Four hybrids 248A × 004(1), 248A × 001(3), 248A × 017(1) and 206A × 017(1) exhibited significant heterosis for number of primary branches per plant (Tab. 5). However, the highest negative heterosis was observed in the hybrid 248A × 004(1) (-14.15%) followed by 248A × 017(1) (-12.38%) and 206A × 017(1) (-12.04%). Whereas the highest positive significant heterosis was revealed by 248A × 001(3) (14.30%) (Tab. 5). Nassimi *et al.* (2006) and Liton *et al.* (2017) found the highest positive heterosis 50% and 16.67%, respectively for number of primary branches per plant.

The magnitude of significant heterosis ranged from -32.68% to 70.64% for number of siliques per plant. Out of 14 hybrids, three crosses 248A × 001(3), 248A × 017(1), and 206A × 001(2) revealed significant positive heterosis and one cross 206A × 37(1) showed negative significant heterosis. The highest positive heterosis was observed in the hybrid 248A × 001(3) (70.64%) (Tab. 5). All hybrids except 206A × 37(3) revealed positive heterosis for number of seeds per silique while nine out of 14 explored significant positive heterosis that ranged from 19.10% to 46.49%. Where the highest positive heterosis was observed for 248A × 27(2) (46.49%) followed by 248A×004(1) (41.07%) and 206A × 027(2) (38.08%) signifying their potentiality for developing varieties with the highest number of seeds per silique (Tab. 5). Radoev *et al.,* (2008) and Surin *et al.,* (2018) found the highest positive heterosis 12.7% and 15.81%, respectively.

Both positive and negative magnitudes of heterosis were exhibited predominantly when heterosis was calculated for pod length. All the hybrids showed non-significant heterosis over pollen parent except three hybrids 248A × 27(2), 248A × 37(1), and 206A × 037(2) for pod length (Tab. 5). How-

Table 5

Percentage of heterosis over pollen parent for nine characters in *Brassica napus* L. hybrids

Genotypes	DFF	DTM	PHT	PBP	SPP	SPS	SLT	TSW	SYP
248A × 001(3)	-2.44 **	4.76 **	-6.77 ns	14.30 *	70.64 **	1.94 ns	-2.43 ns	-3.15 ns	30.21 *
248A × 004(1)	-9.52 **	4.76 **	-12.81 **	-14.15 **	10.26 ns	41.07 **	7.59 ns	27.38 *	13.19 ns
248A × 017(1)	5.13 **	17.11 **	-1.51 ns	-12.38 *	39.34 *	12.70 ns	15.60 ns	23.23 *	6.86 ns
248A × 27(2)	-4.88 **	4.71 **	-1.09 ns	2.40 ns	19.09 ns	46.49 **	-15.36 *	31.37 **	22.22 ns
248A × 30(2)	-9.30 *	1.14 **	-12.38 **	-2.16 ns	-26.09 ns	30.90 **	-13.01 ns	58.24 **	-10.96 ns
248A × 37(1)	-2.38 **	2.27 **	-9.47 *	-3.09 ns	-10.54 ns	32.36 **	-14.58 *	31.73 **	17.07 ns
206A × 001(2)	-16.33 **	11.11 **	-5.61 ns	-3.09 ns	47.98 **	2.17 ns	12.81 ns	-3.92 ns	19.37 ns
206A × 004(1)	-11.90 **	7.14 **	-8.87 *	-2.39 ns	19.45 ns	27.20 **	-5.49 ns	41.67 **	7.16 ns
206A × 017(1)	10.26 **	21.05 **	6.84 ns	-12.04 *	-3.23 ns	13.76 ns	15.60 ns	42.42 **	29.52 **
206A × 027(2)	4.88 **	8.24 **	1.43 ns	-6.01 ns	-2.48 ns	38.08 **	4.29 ns	33.33 **	-2.03 ns
206A × 37(1)	-3.57 **	4.55 **	-8.50 *	-9.37 ns	-32.68 *	20.64 *	-12.20 ns	18.27 ns	2.32 ns
206A × 037(2)	37.84 **	32.00 **	-6.41 ns	4.30 ns	-10.82 ns	19.10 *	-15.11 *	42.70 **	-2.06 ns
206A × 37(3)	30.00 **	17.86 **	-6.39 ns	-9.33 ns	18.34 ns	-1.37 ns	-8.42 ns	2.06 ns	2.26 ns
206A × 030(1)	-4.65 **	4.55 **	-4.69 ns	-2.95 ns	-18.92 ns	32.43 **	-5.20 ns	24.18 *	-22.57 *

DFF: Days to 50% flowering (days); DTM: Days to maturity (days); PHT: Plant height (cm); PBP: Number of primary branches per plant; SPP: Number of siliques per plant; SPS: Number of seeds per siliques; SLT: Silique length (cm); TSW: Thousand seed weight (g); SYP: Seed yield per plant (g).

ever, significant positive heterosis was preferable for pod size and unfortunately magnitude of all significant heterosis were negative. The highest negative heterosis was observed in the cross 248A × 27(2) (-15.36%) followed by 206A × 037(2) (-15.11%) and 248A × 37(1) (-14.58%) (Tab. 5). Kaur *et al.* (2019) and Liton *et al.* (2017) found the highest negative heterosis (-12.86% and 17.80%, respectively) for pod length in mustard.

Positive heterosis is desirable for thousand seed weight and the estimates of heterosis revealed that all the hybrids except two 248A × 001(3) and 206A × 001(2) showed positive heterosis. The significant positive heterosis ranged between 23.23% and 58.24%, and the hybrid 248A × 30(2) showed the highest (58.24%) positive heterosis (Tab. 5). The magnitude of significant heterosis over pollen parent ranged from -22.57% to 30.21% for seed yield per plant. Positive heterosis is desirable for seed yield per plant and it was found in two hybrids 248A × 001(3) (30.21%) followed by 206A × 017(1) (29.52%) (Tab. 5). Surin *et al.* (2018) and Radoev *et al.* (2008) also found the highest positive heterosis (109.08% and 13.0%, respectively) for seed yield per plant in mustard.

Heterosis over standard varieties

Significant standard heterosis was observed for almost all hybrids for days to 50% flowering. The highest positive heterosis over standard variety (BARI Sarisha-13) was found in the hybrid 206A × 37(3) (40.54%) followed by 206A×037(2) (37.84%) and the highest negative was observed in 248A × 004(1) (-11.63%) over BARI Sarisha-13 (Tab. 6). The magnitude of significant negative heterosis over standard variety (BARI Sarisha-18) varied from -13.95% to -4.65% (Tab. 6). The highest negative heterosis over BARI Sarisha-18 was obtained from the cross 206A × 004(1) (-13.95%). Bharti *et al.* (2018) and Liton *et al.* (2017) found the highest negative heterosis (-9.79% and -18.05%, respectively) over standard. The cross 206A × 037(2) and 206A × 37(3) showed the highest (20.73%) heterosis over standard variety (BARI Sarisha-13) followed by 206A × 030(1), 206A × 017(1), 206A × 027(2) and 206A × 037(1) (12.20%) for days to maturity (Tab. 6). On the other hand, significant positive heterosis were observed in all hybrids over BARI Sarisha-18. The cross 206A × 037(2) and 206A ×3 7(3) showed the highest (16.47%) heterosis over BARI Sarisha-18 (Tab. 5). Kaur *et al.,* (2019) and Surin *et al.,* (2018) found highest negative heterosis (-8.58% and -5.98%, respectively) over BARI Sarisha-18. Negative heterosis is desirable for days to 50% flowering and days to maturity to develop short duration hybrid variety of *Brassica napus*.

Negative heterosis was exhibited for all the hybrids over BARI Sarisha-13 which was ranged from -22.08% to -8.04% for plant height (Tab. 6). The hybrid 248A × 001(3) showed the highest negative heterosis (-22.08%) over BARI Sarisha-13 followed by 206A × 037(2) (-18.12%), 248A × 004(1) (-16.66%) and 206A × 37(3) (-16.27%). In contrary, significant positive heterosis over BARI Sarisha-18 was revealed from all the hybrids except 248A × 001(3) which was non-significant. Negative heterosis is desirable for plant height which helps to develop shorter plants leading to tolerant against lodging (Karim *et al*., 2018). Channa *et al.* (2018) and Surin *et al.* (2018) found the highest negative heterosis (-86.48% and -30.20%, respectively) over standard variety. Six hybrids out of 14 had significant heterosis over standard checks and rest of the eight had non-significant heterosis for number of primary branches per plant (Tab. 6). The highest significant negative heterosis over BARI Sarisha-13 was found for the hybrid 2 48A × 004(1) (-19.08%) followed by hybrids 206A × 030(1) (-17.67%) and 248A × 30(2) (-17%). Significant negative heterosis was observed for all the hybrids over both the varieties BARI Sarisha-13 and BARI Sarisha-18. Significant negative heterosis over BARI Sarisha-18 ranged from -35.70% to -23.25%. The hybrid 248A × 004(1) showed the highest negative heterosis (-35.70%) over BARI Sarisha-18 followed by 206A × 030(1) (-34.57%), 248A × 30(2) (-34.04%), and 206A × 027(2) (-32.65%) (Tab. 6). Bharti *et al.* (2018) and Surin *et al.* (2018) found the highest positive heterosis (25.74% and 34.78%, respectively) over standard check in mustard.

Non-significant negative heterosis over BARI Sarisha-13 was recorded in majority of the hybrids except 248A × 017(1) (34.44%) for number of siliques per plant. On the other hand, significant positive heterosis over BARI Sarisha-18 was ranged from 48.90% to 114.41% (Tab. 6). The highest significant positive heterosis over BARI Sarisha-18 was observed in the hybrid 248A × 017(1) (114.41%) followed by 206A × 001(2) (106.11%) (Tab. 6). Positive heterosis is desirable for number of siliques per plant. Therefore, the hybrids '248A × 017(1)' and '206A × 001(2)' could be selected as the most promising for number of siliques per plant. Radoev *et al.* (2008) and Kaur *et al.* (2019) also reported significant positive heterosis (7.9% and 183.94%, respectively) over standard check in rapeseed mustard. Significant standard heterosis ranged from 19.9% to 37.81% for number of seeds per five siliques over BARI Sarisha-13 (Tab. 6). Eight hybrids out of 14 exhibited significant positive level of heterosis effect and rest of the six exhibited non-significant heterosis. The highest positive heterosis was observed in the hybrid 248A × 37(1) (37.81%) followed by 248A × 27(2) (35.29%) and 248A × 004(1) (29.76%). Significant negative heterosis was observed in all hybrids over BARI Sarisha-18 for number of seeds per five siliques. Kaur *et al.* (2019) and Surin *et al.*

Table 6

Percentage of heterosis over standard varieties (BARI-13 and BARI-18) for nine characters in *Brassica napus* L. hybrids

Genotypes	DFF		DTM		PHT		PBP		SPP		SPS		SLT		TSW		SYP	
	BARI-13	BARI-18	BARI-13	BARI-18	BARI-13	BARI-18	BARI-13	BARI-18	BARI-13	BARI-18	BARI-13	BARI-18	BARI-13	BARI-18	BARI-13	BARI-18	BARI-13	BARI-18
248A × 001(3)	8.11**	-6.98**	7.32**	3.53**	-22.08**	6.31 ns	-3.42 ns	-23.25**	15.30 ns	83.88**	19.99*	-16.99*	0.00 ns	-9.74*	26.80**	14.95*	81.07*	20.23 ns
248A × 004(1)	-11.63**	-11.63**	7.32**	3.53**	-16.66**	13.72*	-19.08**	-35.70**	0.12 ns	59.68*	29.76**	-10.23 ns	5.81 ns	-4.49 ns	10.31ns	0.00 ns	76.24**	17.02 ns
248A × 017(1)	10.81**	-4.65**	8.54**	4.71**	-15.68**	15.05**	-12.08 ns	-30.13**	34.44*	114.41**	24.94**	-13.56*	4.56 ns	-5.62 ns	25.77**	14.02*	56.91**	4.19 ns
248A × 27(2)	5.41**	-9.30**	8.54**	4.71**	-11.69**	20.49**	-7.67 ns	-26.62**	-12.58 ns	39.42 ns	35.29**	-6.41 ns	-1.66 ns	-11.24*	38.14**	25.23**	69.80**	12.75 ns
248A × 30(2)	5.41**	-9.30**	8.54**	4.71**	-8.24*	25.20**	-17.00*	-34.04*	-28.27 ns	14.40 ns	15.98 ns	-19.76**	-2.90 ns	-12.36**	48.45**	34.58**	27.65 ns	-15.24 ns
248A × 37(1)	10.81**	-4.65**	9.76**	5.88**	-6.08 ns	28.14**	-8.67 ns	-27.42**	0.15 ns	59.73*	37.81**	-4.66 ns	4.56 ns	-5.62 ns	41.24**	28.04**	75.84**	16.76 ns
206A × 001(2)	10.81**	-4.65**	9.76**	5.88**	-8.04*	25.47**	-8.67 ns	-27.42**	29.23 ns	106.11 **	16.04 ns	-19.72**	13.28**	2.25 ns	1.03ns	-8.41 ns	89.40**	25.76*
206A × 004(1)	0.00 ns	-13.95**	9.76**	5.88**	-12.88**	18.86**	-8.00 ns	-26.89**	8.47 ns	73.00**	17.01 ns	-19.05**	-7.05 ns	-16.10**	22.68**	11.21 ns	66.85**	10.78 ns
206A × 017(1)	16.22**	0.00 ns	12.20**	8.24**	-8.53*	24.80**	-11.75 ns	-29.87**	-6.64 ns	48.90*	26.12**	-12.75*	4.56 ns	-5.62 ns	45.36**	31.78**	90.20**	26.29*
206A × 027(2)	16.22**	0.00 ns	12.20**	8.24**	-9.44*	23.56**	-15.25*	-32.65**	-28.42 ns	14.16 ns	27.52**	-11.78 ns	21.16**	9.36*	40.21**	27.10**	36.11*	-9.63 ns
206A × 037(1)	9.46**	-5.81**	12.20**	8.24**	-5.07 ns	29.52**	-14.58*	-32.12**	-24.63 ns	20.20 ns	25.60**	-13.11*	7.47 ns	-3.00 ns	26.80**	14.95*	53.69**	2.05 ns
206A × 037(2)	37.84**	18.60**	20.73**	16.47**	-18.12**	11.72*	-12.83 ns	-30.73**	-21.26 ns	25.58 ns	9.82 ns	-24.03**	9.54*	-1.12 ns	30.93**	18.69**	53.29**	1.78 ns
206A × 37(3)	40.54**	20.93**	20.73**	16.47**	-16.27**	14.25**	-14.17*	-31.79**	-11.42 ns	41.27 ns	9.84 ns	-24.01**	3.73 ns	-6.37 ns	2.06 ns	-7.48 ns	33.42*	-11.41 ns
206A × 030(1)	10.81**	-4.65**	12.20**	8.24**	-0.19 ns	36.18**	-17.67*	-34.57**	-21.32 ns	25.49 ns	17.34 ns	-18.82**	5.81 ns	-4.49 ns	16.49*	5.61 ns	11.01 ns	-26.29*

DFF: Days to 50% flowering (days); DTM: Days to maturity (days); PHT: Plant height (cm); PBP: Number of primary branches per plant; SPP: Number of siliques per plant; SPS: Number of seeds per five siliques; SLT: Silique length (cm); TSW: Thousand seed weight (g); SYP: Seed yield per plant (g).

(2018) found the highest positive heterosis (40.74% and 15.32%, respectively) over standard check in mustard. The highest significant positive heterosis (21.16%) over BARI Sarisha-13 was obtained from the hybrid 206A × 027(2) followed by 206A × 001(2) giving the value of 13.28% for silique length and only one hybrid 206A × 027(2) exhibited significant positive heterosis (9.36%) over BARI Sarisha-18.

Estimates of standard heterosis over BARI Sarisha-13 revealed positive heterosis in all hybrids for thousand seed weight except three hybrids and significant positive heterosis over BARI Sarisha-13 ranged from 16.49% to 48.45%. The highest significant heterosis was obtained from the hybrid 248A × 30(2) (48.45%) followed by 206A × 017(1) (45.36%), 206A × 027(2) (40.21%) over BARI Sarisha-13 (Tab. 6). The highest level of heterosis effect was obtained from the hybrid 248A × 30(2) (34.58%) followed by 206A × 017(1) (31.78%) over the BARI Sarisha-18 for thousand seed weight. Positive heterosis effect is considered to be desirable for thousand seed weight and the hybrid with the highest value will produce bold seeds. Thus, the hybrids 248A × 30(2), 206A × 017(1) and 206A×027(2) might be considered as promising for the bold seed (Tab. 6). Channa *et al.* (2018) and Bharti *et al.* (2018) also reported significant positive heterosis (17.40% and 22.02%, respectively) over standard varieties for thousand seed weight. Two hybrids 248A × 30(2) and 206A × 030(1) out of 14 showed non-significant and rest 12 hybrids had positive significant heterosis effect over control variety BARI Sarisha-13 for seed yield per plant. The highest standard heterosis was observed in the hybrid 206A × 017(1) (90.20%) followed by 206A × 001(2) (89.40%), and 248A × 001(3) (81.07%) (Tab. 6). Significant heterosis over the variety BARI Sarisha-18 ranged from -26.29% to 26.29% for seed yield per plant. The highest positive standard heterosis for this trait was obtained for the hybrid 206A × 017(1) (26.29%) followed by 206A × 001(2) (25.76%) and the highest negative standard heterosis over BARI Sarisha-18 was obtained from the hybrid 206A × 030(1) (-26.29%). Positive heterosis was considered to be desirable for seed weight per plant.

Conclusions

The present research was conducted to estimates heterosis over two standard varieties (BARI Sarisha-13 and BARI Sarisha-18) and pollen parent for 14 experimental hybrids for days to flowering, days to maturity, plant height, length of silique, seeds per siliques, thousand seed weight and seed yield per plant. Considering these yield related traits and the estimates of standard heterosis the experimental hybrids 248A × 004(1) for days to flowering and seeds per silique, 248A × 017(1) for plant height and number of siliques per plant, 206A × 001(2), 206A × 001(2) and 206A × 017(1) for thousand seed weight and seed yield per plant were found promising and could be utilized in the CMS based hybrid variety development breeding program in *Brassica napus*.

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Conflicts of interest

Author declares that there is no conflict of interest in publication of the manuscript.

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