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Estimation of Heterosis for Yield and Its Attributes in *Brassica rapa* L.

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Authors' contributions

This work was carried out in collaboration between all authors. Author MMUAL designed the study, collected the data, performed the statistical analysis and wrote the first draft of the manuscript. Authors MSRB and NZ supervised and monitored the study. Author MHR managed all literature searches and performed internal review of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Six parents of *Brassica rapa* (L) viz. SAU Sarisha-1, SAU Sarisha-2, SAU Sarisha-3, BARI Sarisha-6, BARI Sarisha-15, and Tori-7 were crossed in a half diallel fashion. The resultant fifteen hybrids along with six parents were evaluated in randomized complete block design with three replications with the aim of evaluating the performance of hybrids over their parents. The study was conducted at the Research field of Sher-e-Bangla Agricultural University, Bangladesh during Rabi 2010-2011. Results indicated that, all the parameters except 1000-seed weight and seed yield/plant were significantly differed among the parents indicated existing variation in the parents. The best

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performance was observed from the parents BARI Sarisha-15 and Tori-7. The growth as well as yield and yield attributes of all hybrids were also significantly differed. The highest seed yield was obtained from the hybrid CC6 (11.55 g/plant) followed by CC15 (9.75 g/plant) with a moderate days to flowering. The most heterotic hybrids for seed yield per plant were CC14, which produced significantly positive heterosis over mid-parent (35.99%) and better-parent (17.09%) in our study. However, the parent BARI Sarisha-6, BARI Sarisha-15, and Tori-7 can be used in any breeding program and the hybrids CC14 can be selected for further study towards a variety development.

Keywords: Brassica rapa; heterosis; half diallel; yield attributes.

1. INTRODUCTION

Brassica is grown worldwide for a variety of use. Some of them are important sources of vegetable and condiments, edible and industrial oils, and fodder and forage [1]. In addition to that *Brassica* is also used in production of biodiesel due to having high levels of glucosinolate compounds [2]. The genus *Brassica* has been divided into three groups viz. rapeseed, mustard and cole. The rapeseed group includes the diploid *Brassica rapa* L.turnip rape (AA, 2n=20) and amphidiploid *Brassica napus* L. rape (AACC, 2n=38) while the mustard group includes species viz.*Brassica juncea* Czern and Coss; *Brassica nigra* Koch and *Brassica carinata* Braun [3]. Rapeseed and mustard is an important oil seed crop of Bangladesh belong to this *Brassica* group. It is produced the highest amount of edible oil among the oilseed crops in Bangladesh and the third largest oilseed crops in the world after the soybean and palm [4,5]. The seeds of rapeseed and mustard not only contain oil (42%) and protein (25%) but also the sources of fat, soluble vitamins A, D, E and K [6].

Oil seed crop covers more than 2.75% area of the total cultivable land in Bangladesh whereas rapeseed and mustard covers almost 77.51% of that area [7]. Despite the production of oilseed crops, the huge shortage of the edible oil becomes a chronic problem for the nation. Bangladesh requires 0.29 million tons of oil equivalent to 0.8 million tons of oilseeds whereas the production is only about 0.254 million tons, which covers only 40% of the domestic requirement [8]. As a result Bangladesh spends huge amount of foreign currency every year to fulfill the domestic requirement indicating need to increase the production of oilseed crop. The average yield of rapeseed and mustard (1.104 t/ha) in Bangladesh [7] is low compared to the average of Europe (2.658 t/ha), South America (1.739 t/ha), North America (1.436 t/ha) and Asia (1.188 t/ha) [9] stressing need to develop high yielding variety. This huge production gap can be reduced by breeding short durated and high yielding cultivars [10]. For the development of high yielding genotypes, it would be desirable to identify the superior parents, promising cross combinations and logically adopted breeding methodology as pre-requisites [11].

Diallel analysis is one of the efficient, convenient and often used biometrical tools that provide the estimation of genetic parameters from the study of F_1 generation with or without reciprocals [12,13]. The most important aspects for hybridization are the choice of parents and the selection of the best genotypes from hybrid progenies. Heterotic investigations can provide basis for the exploitation of valuable cross combinations from the breeding program [14] and for this reason, the achievement of heterosis has become a major objective for the breeders of canola [15] and the related species. Because exploitation of heterosis can be contributory in increasing seed yield. Therefore, the present study has been undertaken with the aim of estimation of heterosis for different yield contributing characters of rapeseed (*Brassica rapa* L), and to identify the potential parents and promising cross combinations in developing high yielding varieties (HYV).

2. MATERIALS AND METHODS

2.1 Plant Materials

Six parents and their fifteens intra-specific hybrids were used in the study (Table 1). Three parents (SAU Sarisha-1, SAU Sarisha-2 and SAU Sarisha-3) were developed by the Sher-e-Bangla Agricultural University (SAU) and the rest of the three (BARI Sarisha-6, BARI Sarisha-15 and Tori-7) were developed by the Bangladesh Agricultural Research Institute (BARI). The parents were crossed in a half diallel fashion (Table 2) to develop F_1's during October 2009 to February 2010 at the experimental farm of SAU Dhaka, Bangladesh.

Table 1. Plant materials used in the study

Parents	Sources	Important characteristics
SAU Sarisha-1	SAU	Plant height 80-90 cm, primary branches/plant 5-8, Number of pods /plant 150, Number of seeds / pod 25, 1000-seed weight 2.5-3.0 gm
SAU Sarisha-2	SAU	Plant height 115-125 cm, primary branches 6-9, flowering start after 30 days of sowing, pods /plant 250, seeds / pod 20, pod length 5.5-6.0 cm, 1000-seed weight 2.5-3.0 gm and oil content 41-43%
SAU Sarisha-3	SAU	Plant height 110-115 cm, Number of pods /plant 115, Number of seeds / pod 20, pod length 6.0-6.5 cm, higher pod length and short duration variety
BARI Sarisha-6	BARI	Plant height 100-117 cm, primary branches /plant 4-7, Number of seeds /pod 10-15, oil content 44-45% and shattering tolerance
BARI Sarisha-15	BARI	Plant height 90-100 cm, primary branches/plant 5-8, pods /plant 70-80, seeds /pod 20-22, 1000-seed weight 3.25-3.50 g, short duration variety 80-85 days
Tori-7	BARI	Plant height 60-70 cm, primary branches /plant 5-6, pods/plant 50-60, seeds / pod 10-12 and 1000-seed weight 2.6-2.7 g.

2.2 Experimental Site

Field experiment was conducted at the research farm of the Department of Genetics and Plant Breeding, SAU, Dhaka, Bangladesh, during the period from October 2010 to February 2011. The soil of the experimental site is clay loam and medium high with moderate fertility level [16]. The position of the experimental site is in subtropical climatic zone characterized by the wet-humid summer and dry winter. Winter season is generally characterized by the scanty rainfall and moderate temperature with short day length (Khatun et al. Bangladesh Metrological Department, Unpublished result).

2.3 Land Preparation and Fertilizer Application

The land was ploughed well and cleaned from previous crop stubbles. The fertilizer doses and application procedure were followed according to BARI Krishi Projukti Hatboi [17]. Cowdung was applied at the rate of 8-10 t/ha during final land preparation. Chemical fertilizers were applied at the rate of 280-180-90-150-5 kg/ha of urea, triple super phosphate (TSP), muriate of potash (MP), gypsum and zinc sulphate, respectively. The total amount of TSP, MP, gypsum, zinc sulphate and half of urea were applied during final land preparation. The remaining half of urea was applied as top dressing at flower initiation stage.

2.4 Experimental Design and Layout

The seeds of fifteen F_1's and six parents were sown in randomized complete block (RCB) design with three replications. Seeds were sown in line with the spacing of 40 cm x 10 cm and at a soil depth of 2.5-3.5 cm on 30 October 2010 by hand. The seeds were covered with soil carefully after sowing so that no clods were on the seeds. Seed germination was observed after 3-4 days of sowing.

2.5 Intercultural Operation

A single post sowing sprinkler irrigation was done to maintain proper moisture condition of the soil for germination. Thinning and first weeding were done at 15 days after sowing (DAS). Urea top dressing, second weeding and necessary thinning were done at 25 DAS. A good drainage system was maintained surrounding the experimental plot for immediate release of rainwater. Necessary intercultural operations were done during the crop period to ensure normal growth and development of the plants.

2.6 Data Collection

Days to 50% flowering was counted when near about 50 percent plants had at least an open flower. Days to maturity was counted from sowing to pod maturity of 80% plants of each row. At the maturity stage i.e. when 80% of the pod turns brown to straw colour and plants were dead, plant growth parameters like plant height, primary branches per plant originated from the main stem and secondary branches per plant originated from the primary branches were measured from randomly selected 10 plants. Prior to harvesting, the previously selected 10 plants were uprooted for yield attributes viz. number of pods per plant, length of pod, number of seeds per pod, weight of 1000-seeds, and seed yield per plant. Seeds from uprooted plants were collected and sun dried 3-4 days to get proper moisture content of 12% for optimum seed weight.

2.7 Data Analysis

Statistical analyses were done to calculate the analyses of variance (ANOVA) and other parameters of the genotypes for the characters tested [18]. The amount of heterosis in the F_1's was analysed using the equations (1) and (2).

$$\text{Heterosis over better parent (\%)} = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100 \quad (1)$$

Here, $\overline{F}_1$ =Mean of F_1 individuals

$\overline{BP}$ = Mean of the better parent values

$$\text{Heterosis over mid parent (\%)} = \frac{\overline{F_1} - \overline{MP}}{\overline{MP}} \times 100 \quad (2)$$

Here, $\overline{F}_1$ =Mean of F_1 individuals

$\overline{MP}$ = Mean of the mid parent values

Critical difference values were used for the testing of the significance of heterotic effects. CD values were compared with the values came from (F_1-*BP*) and (F_1-*MP*) to test significance of respective heterotic effects by the equation (3).

$$\text{Critical differences (CD)} = tx \sqrt{\frac{2\ EMS}{r}} \quad (3)$$

Here, EMS = Error Mean Sum of square
r = Number of replication
t = Tabulated t value at error df

3. RESULTS AND DISCUSSION

3.1 Days to 50% Flowering

Days to 50% flowering ranged from 35 to 48 days was observed for parent SAU Sarisha-2 and SAU Sarisha-3 took the lowest (39 days) time for flowering whereas the parent Tori-7 took the highest (48 days) duration for flowering (Table 3). In case of hybrids, CC5 flowered by 35 days, which was about 8 days earlier than both of its parents. On the other hand, 13 hybrids showed significant heterotic values over mid-parent, in which 11 were negative. Among them, CC14 showed the highest (-13.14%) negative heterosis followed by CC9 (-11.94%) and CC15 (-10.55%) (Table 4a). Conversely, all hybrids showed significant differences for heterosis over better-parent in which 14 showed negative values ranged from -1.53 to -18.05%. The hybrid CC12 represented the highest (-18.05%) negative values followed by CC14 (-15.60%), CC15 (-13.38%) and CC6 (-13.33%). This finding supported by Kumar et al. [19] and Singh et al. [20] in where they found significant heterotic values for the days to first flowering over mid-parent and better-parent. Significant negative heterosis is desirable for the selection of hybrid in a short duration. Therefore, the hybrid CC12 can be used to develop early flowering recombinant inbred lines if other traits have considerable improvement. Additionally, the hybrids produced significant negative heterosis over both mid-parent and better-parent here might be useful for developing early flowering varieties.

3.2 Days to 80% Maturity

The parent SAU Sarisha-3 matured within the shortest period of time (92 days) whereas the parent SAU Sarisha-2 took the longest duration (104 days) for its maturation (Table 3). These results were supported by Helal et al. [21]. On the same way, the hybrid CC10 matured within the lowest (80 days) duration, which was about two weeks earlier than it’s both parents. Three out of 15 hybrids were produced significantly different heterosis over mid-parent including positive and negative values (Table 4a). Only a hybrid CC15 (-4.71%) showed significant negative heterosis over mid-parent whereas CC9 (-5.36%) followed by CC12 (-6.90%) showed significant negative heterosis over better-parent. In good agreement with our results, Kumar et al. [19], Singh et al. [20] and Nasrin et al. [22] found both positive and negative heterosis for the days to maturity over mid- and better-parent. In this experiment, we found some of the hybrids performed slightly lower than the parents. This could be due to the environmental factors which may play a role in the performance of a hybrid. However, the cross combinations presented significant negative heterosis over mid- and better-parent, might be useful for developing short duration variety.

Table 2. Cross combinations in developing F_1's by a half diallel fashion

Parents	SAU Sarisha-1	SAU Sarisha-2	SAU Sarisha-3	BARI Sarisha-6	BARI Sarisha-15	Tori-7
SAU Sarisha-1	-	SAU Sarisha-1 X SAU Sarisha-2 (CC1)	SAU Sarisha-1 X SAU Sarisha-3 (CC2)	SAU Sarisha-1 X BARI Sarisha-6 (CC3)	SAU Sarisha-1 X BARI Sarisha-15 (CC4)	SAU Sarisha-1 X Tori-7 (CC5)
SAU Sarisha-2		-	SAU Sarisha-2 X SAU Sarisha-3 (CC6)	SAU Sarisha-2 X BARI Sarisha-6 (CC7)	SAU Sarisha-2 X BARI Sarisha-15 (CC8)	SAU Sarisha-2 X Tori-7 (CC9)
SAU Sarisha-3			-	SAU Sarisha-3 X BARI Sarisha-6 (CC10)	SAU Sarisha-3 X BARI Sarisha-15 (CC11)	SAU Sarisha-3 X Tori-7 (CC12)
BARI Sarisha-6				-	BARI Sarisha-6 X BARI Sarisha-15 (CC13)	BARI Sarisha-6 X Tori-7 (CC14)
BARI Sarisha-15					-	BARI Sarisha-15 X Tori-7 (CC15)
Tori-7						-

Table 3. Mean values of parents (P) and their hybrids for measured characteristics

Treatments	Days to 50% flowering	Days to 80% maturity	Primary branches / plant	Secondary branches / plant	Plant height (cm)	Number of pods / plant	Pod length (cm)	Seeds/ pod	1000-seed weight (g)	Seed yield/ plant (g)
Parents										
SAU Sarisha-1	42.33d	95.67e	8.20b	5.47ab	116.20a	255.63a	5.09a	12.73cd	6.00a	8.14a
SAU Sarisha-2	39.67e	104.00a	8.20b	8.67a	106.10a	281.50a	4.22a	10.80d	5.33a	7.88a
SAU Sarisha-3	39.33e	92.00f	6.60b	4.23abc	108.53a	182.03ab	5.32a	13.70bcd	5.33a	7.24a
BARI Sarisha-6	47.67b	102.00c	6.60b	0.00c	116.00a	118.77b	5.26a	20.60a	6.00a	7.08a
BARI Sarisha-15	46.33c	100.00d	10.27a	3.10bc	107.83a	203.33ab	4.92a	17.21ab	5.33a	9.55a
Tori-7	48.33a	103.00b	7.63b	6.77ab	108.37a	222.60ab	5.27a	15.50bc	5.67a	9.81a
Grand mean	43.50	99.33	7.92	4.70	110.51	210.64	5.01	15.09	5.61	8.28
CV	0.68	0.47	11.46	4.70	5.63	30.51	12.25	15.82	10.12	22.52
Crosses										
CC1	48.00a	104.00a	7.33abcd	3.43fgh	99.53b	167.27efgh	4.77bc	15.43b	5.00c	5.92cd
CC2	38.67f	104.00a	5.67d	11.53a	100.00ab	214.00cdef	5.10ab	14.00bc	5.90ab	5.81cd
CC3	47.00b	101.00ab	8.63ab	2.00gh	107.90ab	168.30efgh	4.79bc	13.37bc	6.33a	7.96bc
CC4	47.00b	98bc	7.97abc	2.20gh	101.10ab	114.00h	5.43a	19.70a	5.33bc	6.19cd
CC5	35.00h	100abc	6.73bcd	10.10abc	99.00b	246.90bcde	4.83bc	12.47c	5.33bc	8.14bc

Treatments	Days to 50% flowering	Days to 80% maturity	Primary branches / plant	Secondary branches / plant	Plant height (cm)	Number of pods / plant	Pod length (cm)	Seeds/ pod	1000-seed weight (g)	Seed yield/ plant (g)
CC6	38.00g	98bc	8.97ab	8.27abcd	114.73a	344.30a	4.48cd	12.43c	5.67abc	11.55a
CC7	41.00d	100abc	8.40abc	2.30gh	100.83ab	159.83fgh	4.70bc	12.50c	5.67abc	6.51bcd
CC8	40.00e	103ab	9.17a	1.20h	97.47b	123.10gh	5.38a	20.30a	5.00c	6.21cd
CC9	38.00g	101ab	6.33cd	8.10bcd	105.73ab	257.20bc	4.01ef	6.53e	5.67abc	6.25cd
CC10	40.00e	80d	6.20cd	3.93efgh	104.63ab	209.10cdef	4.49cd	9.93d	6.00ab	6.90bcd
CC11	42.00c	95c	7.10abcd	4.53efg	101.03ab	200.00c-g	3.76f	9.00d	5.67abc	4.20d
CC12	46.67b	98bc	7.67abcd	7.10cde	106.43ab	256.77bc	4.20def	8.50de	5.67abc	6.74bcd
CC13	41.00d	104a	8.43abc	2.13gh	104.37ab	172.37d-h	4.46cde	13.33bc	6.00ab	8.12bc
CC14	42.00c	99abc	6.90abcd	5.77def	103.40ab	250.17bcd	4.05def	8.47de	6.00ab	7.30bcd
CC15	42.00c	102ab	8.33abc	11.17ab	112.07ab	310.27ab	4.00f	7.97de	6.00ab	9.75ab
Grand mean	41.75	99.13	7.59	5.58	103.88	212.90	4.56	12.26	5.68	7.17
CV	0.51	3.17	18.03	5.58	8.60	22.52	5.95	11.80	8.54	27.88

Note: Similar letter in a same column considered as non-significant at 5% level of probability

Table 4a. Mid-parent (MP) and better-parent (BP) heterosis for growth and its attributing traits in *Brassica rapa* L.

Cross combination	Days to 50% flowering		Days to 80% maturity		Primary branches / plant		Secondary branches/plant		Plant height	
	MP (%)	BP (%)	MP (%)	BP (%)	MP (%)	BP (%)	MP (%)	BP (%)	MP (%)	BP (%)
CC1	3.76**	2.22**	4.35	2.44	-10.57**	-10.57**	-51.42**	-60.38**	-10.45**	-14.34**
CC2	7.50**	-1.53**	7.13**	4.64	8.11**	-2.44	47.77**	31.10**	-4.60	-7.75**
CC3	0.00	-3.55**	1.85	-0.80	16.67**	5.28*	-39.02**	-69.51**	-7.06**	-6.98**
CC4	-4.03**	-7.75**	0.82	-1.61	-13.72**	-22.40**	-48.64**	-59.76**	-9.75**	-12.99**
CC5	-4.55**	-5.26**	1.20	-3.45	-12.84**	-15.85**	-5.72	-14.78**	-7.91**	-11.02**
CC6	-4.10**	-13.33**	0.42	-3.66	-18.92**	-26.83**	79.84**	33.85**	-6.82**	-7.86**
CC7	-2.90**	-4.96**	-2.42	-3.20	13.51**	2.44	-46.92**	-73.46**	-9.20**	-13.07**
CC8	-1.81**	-4.23**	-0.20	-0.80	-0.72	-10.71**	-79.60**	-86.15**	-8.88**	-9.61**
CC9	-11.94**	-12.59**	-2.56	-5.36*	-20.00**	-22.76**	4.97	-6.54	-1.40	-2.43
CC10	-0.80*	-12.06**	0.84	-4.00	-6.06**	-6.06*	85.83**	-7.09	-6.80**	-9.80**
CC11	0.40	-11.27**	4.84*	0.00	-15.81**	-30.84**	23.64**	7.17	-6.61*	-6.91**
CC12	-9.92**	-18.05**	-0.21	-6.90**	-5.39*	-11.79**	83.64**	49.26**	-8.71**	-8.78**
CC13	-3.18**	-3.52**	1.00	0.80	0.00	-17.86**	37.63**	-31.18**	-6.75**	-10.03**

Cross combination	Days to 50% flowering		Days to 80% maturity		Primary branches / plant		Secondary branches/plant		Plant height	
	MP (%)	BP (%)	MP (%)	BP (%)	MP (%)	BP (%)	MP (%)	BP (%)	MP (%)	BP (%)
CC14	-13.14**	-15.60**	-4.11	-2.00	33.02**	24.02**	161.08**	30.54**	3.05	-0.34
CC15	-10.55**	-13.38**	-4.71*	-2.41	-6.89**	-18.83**	126.35**	65.02**	3.67	3.41
Maximum	7.50	2.22	4.84	4.64	33.02	24.02	161.08	65.02	3.67	3.41
Minimum	-13.14	-18.05	-4.71	-6.90	-20.00	-30.84	-79.60	-86.15	-10.45	-14.34

***p<0.01, *p<0.05*

Table 4b. Mid-parent (MP) and better parent (BP) heterosis for yield and its attributing traits in *Brassica rapa* L.

Cross combination	Number of pod/plant		Pod length		Seeds/pod		1000-seed weight		Seed yield/plant	
	MP (%)	BP (%)	MP (%)	BP (%)	MP (%)	BP (%)	MP (%)	BP (%)	MP (%)	BP (%)
CC1	-37.72**	-40.58**	2.51	-6.29**	31.16**	21.20**	-11.76**	-16.67**	-26.04**	-27.23**
CC2	18.31**	1.28	-19.69**	-21.43**	-34.93**	-37.23**	0.00	-5.56**	-16.67**	-21.29**
CC3	-10.10**	-34.16**	-7.38**	-8.87**	-19.80**	-35.11**	5.56**	5.56**	4.53	-2.25
CC4	-50.32**	-43.93**	8.39**	6.61**	31.57**	14.45**	-5.88**	-11.11**	-29.97**	-35.13**
CC5	4.62	-2.14	-21.81**	-23.15**	-40.02**	-45.38**	2.86	0.00	-18.66**	-25.59**
CC6	-6.80*	-23.27**	7.65**	-3.51*	22.45**	9.49**	6.25**	6.25**	-21.92**	-25.10**
CC7	-20.14**	-43.22**	-0.88	-10.71**	-20.38**	-39.32**	0.00	-5.56**	-12.92**	-17.31**
CC8	-49.22**	-39.46**	17.80**	9.34**	44.93**	17.93**	-6.25**	-6.25**	-28.68**	-34.92**
CC9	2.04	-8.63**	-15.39**	-23.85**	-50.32**	-57.85**	3.03	0.00	-29.33**	-36.29**
CC10	39.03**	14.87**	-15.19**	-15.66**	-42.08**	-51.78**	5.88**	0.00	-3.68	-4.70
CC11	3.80	-1.64	-26.59**	-29.32**	-41.77**	-47.71**	6.25**	6.25**	-49.99**	-56.04**
CC12	22.04**	10.92**	-8.78**	-9.21**	-14.61**	-19.57**	-3.03	-5.88**	-4.54	-17.06**
CC13	7.03	-15.23**	-12.47**	-15.27**	-29.48**	-35.28**	5.88**	0.00	-2.35	-14.94**
CC14	110.55**	61.44**	-12.82**	-12.90**	-29.64**	-38.35**	-8.57**	-11.11**	35.99**	17.09**
CC15	45.69**	52.59**	-21.58**	-24.16**	-51.29**	-53.72**	9.09**	5.88**	0.71	-0.65
Maximum	110.55	61.44	17.80	9.34	44.93	21.20	9.09	6.25	35.99	17.09
Minimum	-50.32	-43.93	-26.59	-29.32	-51.29	-57.85	-11.76	-16.67	-49.99	-56.04

***p<0.01, *p<0*

3.3 Primary Branches

No significant difference was observed for primary branches per plant among the parents except BARI Sarisha-15. Number of primary branches ranged from 10.27 to 5.67 was found in this study (Table 3). The parent BARI Sarisha-15 produced the maximum number (10.27) of primary branches per plant. Among the hybrids, the highest number of primary branches (9.17) was found in CC8 which was higher than the parent SAU Sarisha-2 but lower than another parent BARI Sarisha-15. Similar result was reported by Mamun et al. [23] where they showed BARI Sarisha-15 produced higher number (7.45) of branches per plant in comparison with other varieties. Only four hybrids showed significant positive heterosis over mid-parent which ranged from 8.11% (CC2) to 33.02% (CC14). In case of better-parent heterosis, the hybrids CC14 showed the highest (24.02%) positive value followed by CC3 (5.28 %). Turi et al. [24] and Gupta et al. [25] reported positive significant mid- and better-parent heterosis which strengthens the findings of the current study. Thakur and Segwall [26] and Yadav et al. [27] also found both positive and negative heterosis over better-parent for primary branches in rapeseed (*Brassica napus* L.). In this experiment, the hybrid CC14 showed the highest heterosis over mid- and better-parent but the parents of the hybrid showed moderate performance indicating an unexpected outcome of the study. This could be due varietal characteristic itself and/or environmental effect. Our finding was close to Sana et al. [28] where they speculated that the higher number of branches per plant is the result of the genetic makeup of the crop and the environmental circumstances, which may play a remarkable role towards the final seed yield of the crop. However, non-significant positive heterosis over mid-parent [29] and better-parent [29,30] were also reported in some other studies.

3.4 Secondary Branches

For secondary branches, both parents and crosses showed significant variation ranged from 0 to 11.53 per plant (Table 3). In case of parent, SAU Sarisha-2 produced higher number (8.67) of secondary branches and no secondary branch was found in BARI Sarisha-6. A study by Mamun et al. [23] found identical result of our findings. The maximum secondary branches (11.53) produced by the hybrid CC2 followed by the hybrid CC15 (11.17) which was almost double than the average value of the parents (Table 3). The hybrid CC15 produced the highest yield (9.75 g/plant) compared to other hybrids. It could be due to production of higher number of secondary branches. Sana et al. [28] reported that the yield contributing characters like branches per plant is an important trait which helps to produce more pods and ultimately assist in producing more yields which reflects in the present study. There were 13 hybrids showed statistically significant mid-parent heterosis, in which eight of them with positive values ranged from 23.64 to 161.08% (Table 4a). The highest significant positive mid-parent heterosis was found in CC14 (161.08%) followed by CC15 (126.35%) and CC12 (83.64%). On the same way, five hybrids showed significant positive better-parent heterosis ranged between 30.54% and 65.02% (Table 4a). The hybrid CC15 exhibited the highest (65.02%) heterosis over better-parent followed by CC12 (49.26%) and CC6 (33.85%). Likewise, Pradhan et al. [31] found positive heterosis for secondary branches and they also recorded highest heterobeltiosis for this character, in line with our findings. Yadav et al. [27] observed a long range of heterosis over better-parent which was in between 9.6% and125.1% for the secondary branches. In our study, the hybrids CC14 and CC15 produced significantly higher heterosis could be considered for further study to develop a heterotic *Brassica* hybrid.

3.5 Plant Height

The tallest plants were recorded in SAU Sarisha-1 (116.20 cm) followed by BARI Sarisha-6 (116 cm) where as SAU Sarisha-2 had the shortest plants (106.10 cm) followed by BARI Sarisha-15 and Tori-7 (Table 3). The parents did not show significant variation for this trait. On the other hand, the plant height of the crosses was significantly varied ranged from 97.47 to114.73 cm (Table 3). The hybrid CC6 produced the tallest (114.73 cm) plants among the 15 hybrids whereas shortest plants produced by the hybrid CC8 (97.47 cm) followed by CC5 (99.00 cm) (Table 3). The hybrids were approximately 6-8 cm shorter than their parents. Out of 15 crosses, 11 hybrids showed significant heterosis over mid-parent and12 over better-parent for the character (Table 4a). The significant heterosis over mid-parent ranged from -10.45 to 3.67% which were represented by the hybrids CC15 (-10.45%) and CC1 (3.67%). In case of better parent heterosis, the significant values were ranged from -14.34 to 3.41%. The highest significant better-parent heterosis was obtained from CC1 (-14.34%) and the lowest better-parent heterosis was produced by CC15 (3.41%) but it was statistically insignificant. Sabaghnia et al. [32] reported positive heterosis in plant height for the hybrids while studying rapeseed. Yadav et al. [27] observed 27.7% heterosis over better-parent for plant height in a hybrid. Both of the studies were a good disagreement with our findings because most of the values for both mid- and better-parent heterosis were negative for the trait. It could be due to varietal characteristic itself and/or environmental effect.

3.6 Pods per Plant

Pods per plant were varied significantly from 118.77 (BARI Sarisha-6) to 281.5 (SAU Sarisha-2) for the parents (Table 3). The average values for the number of pods per plant also varied significantly over the crosses. The maximum pods (344.3) produced by the hybrid CC6 whereas the minimum pods (114.0) produced by CC4. A study by Mamun et al. [23] reported that BARI Sharisa-15 produced maximum 73.11 pods per plant under 40 plants/m^2 and Yadava et al. [33] suggested that for ensuring high yield in *B. juncea* the plant type should have 100-125 pods per plant. All of these studies relay our results for pod per plant. The highly significant and positive mid-parent heterosis for pod per plant was found in five hybrids (CC2, CC10, CC12, CC14 and CC15) ranged from 18.31 to 110.55% (Table 4b). The cross combination CC14 represented the highest (110.55%) heterosis over mid-parent whereas the lowest was in CC2 (18.31%). Similarly, four combinations (CC10, CC12, CC14 and CC15) showed significant and positive better-parent heterosis which ranged from 10.92 to 61.44%. In this case, the hybrid CC14 also produced the highest (61.44%) heterotic value followed by CC15 (52.59%). Positive significant mid- and better-parent heterosis was reported in earlier studies in both rapeseed and mustard [25,26,32,34,35]. Results of many of the previous studies seem to be identical to the present study. Therefore, all the four hybrids having significantly positive heterosis would produce more pod per plant and could be selected for further study.

3.7 Pod Length

Length of pods was not shown significant differences among the parents but their hybrids produced significantly different results. Pod length in hybrids varied from 3.76 to 5.43 cm (Table 3). The hybrid CC4 exhibited the highest (5.43 cm) length of pod and that was a bit longer than it's either parent. Thirteen combinations were found to be significant for heterosis over mid-parent but only three of them i.e. CC4 (8.39%), CC6 (7.65%), and CC6 (17.80%) had positive significant heterosis (Table 4b). The hybrids showed both positive and negative statistically significant heterosis over better-parent. The significant positive heterosis over better-parent were found in CC8 (9.34%) and CC4 (6.61%); rest of the hybrids showed significant negative heterosis (Table 4b). The findings of the present study were consistent with the result of Pradhan et al. [31] and Rameah et al. [35] in where they found both positive and negative significant heterosis over mid- and better-parent for the length of pod.

3.8 Seeds per Pod

Significant variations were observed in terms of number of seeds per pod among all the parents and crosses. The maximum number of seeds per pod (20.60) was produced by the parent BARI Sarisha-6 and it was statistically identical to the cross CC6 (20.30) (Table 3). The minimum number of seeds per pod was produced by the variety SAU sarisha-2 (10.80) and it was similar to the crosses CC10, CC11, CC14 and CC15. Jahan and Zakaria [36] found the lowest number of seeds per pod (18.0) from improved Tori. Our mean value a bit lower than that of 18 seeds per pod, it could be due to varietal characteristic itself and/or environmental effect. Four hybrids showed significant positive heterosis over mid-parent viz. CC8 (44.93%), CC4 (31.57%), CC6 (22.45%), and CC1 (31.16%). Rest of the hybrids showed significant negative heterosis over mid-parent (Table 4b). Interestingly, same four hybrids showed significantly positive heterosis over better-parent but values was slightly lower than the mid-parent. Both positive and negative heterosis for seeds per pod was reported in earlier studies [27,31,32]. All of the earlier studies support our findings. Thus, four combinations viz. CC8, CC4, CC6 and CC1 having significant positive heterosis over mid-parent as well as better-parent could be considered for further evaluation in developing new parents.

3.9 1000-seed Weight

1000-seed weight significantly varied among the crosses but no significant differences among the parents. The 1000-seed weight values of the hybrids varied between 4.20 g (CC11) and 11.55

g (CC6) (Table 3). Mamun et al. [23] observed that 1000-seeds weight was 3.20 g in BARI Sarisha-15 in a population of 10 plants /m^2. Mondal and Wahab [37] described that weight of 1000-seed varied from variety to variety and species to species. They found 2.50-2.65 g of 1000-seed weight for the improved Tori, a *B. campestris* variety. All of these findings were consistent with our lowest value. For heterosis, six hybrids out of 15 were showed significant positive heterosis over mid-parent. They were CC11 (6.25%), CC13 (5.88%), CC15 (9.09%), CC10 (5.88%), CC3 (5.56%) and CC6 (6.25%) (Table 4b). Identical results over mid-parent heterosis were reported by Mahto and Haider [38] and Yadav et al. [27]. Similarly, four hybrids CC3, CC6, CC11, and CC15 showed significant positive heterosis over better-parent (Table 4b). This is an agreement with the findings of the study of Sabaghnia et al. [32]. However, both positive and negative heterosis over mid- and better-parent for the seed weight was also reported in some other studies [25,35,39].

3.10 Seed Yield per Plant

Production of higher yield by different varieties might be due to the contribution of cumulative favorable effects of the crop characteristics viz., number of branches per plant, pods per plant and seeds per pod [21,40,41]. The seed yield of *B. rapa* hybrids differed significantly but parents didn't differ significantly in our study. The highest seed yield were obtained from the hybrid CC6 (11.55 g/plant) and the lowest from CC11 (4.20 g/plant) (Table 3). These results have an agreement with Helal et al. [21] where they found BARI Sarisha-14, BARI Sarisha-15, and Improved Tori produced higher yield compare to other varieties. The crosses produced lower average seed yield (7.17 g) than the parents (8.28 g). Mamun et al. [23] reported that BARI Sarisha-15 produced higher yield under 100 plants/m^2. The hybrids CC15 produced reasonable seed yield (9.75 g/plant) but took maximum days to mature (Table 3). Only a single hybrid CC14 (35.99%) produced significantly positive heterosis over mid- and better-parent heterosis in our study (Table 4b). Rest of the hybrids showed significant negative heterosis over mid- and better-parent. Earlier investigations reported positive significant heterosis over mid-parent [25,29,38,42,43,44,45] and better-parent [25,33,44,45,46] and also negative significant heterosis over mid-parent [47] and better-parent [41,44,47] which is in conformity with the present study. Sing et al. [48] also found the highest heterosis (206.14%) and heterobeltiosis (240.56%) for seed yield per plant in a cross. Significant heterosis for yield and its component traits in oilseed *Brassica* have been reported by several workers [24,49,50,51]. However, the hybrid CC14 produced the highest heterosis over mid- and better-parent for seed yield indicating the contribution of cumulative favorable effects of the crop characteristics such as primary branches per plant, secondary branches per plant, and pods per plant (Table 4a & 4b). Thus, the hybrids CC14 which carry significant positive value for both mid- and better-parent heterosis could be selected for further study.

4. CONCLUSION

It was observed that all the hybrids developed from the six parents by a half-diallel fashion did not perform well for some of the important characters. The crosses were scored on the basis of heterotic values to find out the desirable hybrids. The hybrids CC1 out of fifteen crosses showed desirable negative heterosis for the characters of shorter plant height. The hybrids CC12, CC15 and CC14 were the best for early flowering and the hybrids CC12 and CC15 were the best for the early maturity. The hybrids CC14, CC3, CC15, CC12 and CC1 were found to be the best for primary branches per plant, secondary branches per plant and pods per plant. Most of the crosses showed significant negative heterosis for length of pod and seeds per pod. The hybrids CC8 and CC4 were the best for pod length and the crosses CC8, CC4, CC6 and CC1 were the best for seeds per pod. The hybrids CC11, CC15, CC3 and CC6 were the best for 1000-seed weight whereas the hybrid CC14 was found to be the best for seed yield. However, estimation of heterosis over mid-parent (relative heterosis) may be useful in identifying the true heterotic hybrids. Since higher yields in F_1 may be due to fixable (additive) and/or non-fixable (non-additive) gene action, the total effect partition of F_1 progeny into general and specific combining ability effects interprets the causes of heterosis. Therefore, future study in combining ability and gene action using the same materials should be conducted to predict the overall performance of the parents and hybrids.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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