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Determination of Combining Ability in Ethiopian Mustard (*Brassica carinata*) Parents According to Line x Tester Analysis

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ABSTRACT

This research was conducted to determine the parents and hybrids with superior general and specific combining ability in 20 F_1 hybrids, including five female lines and four male testers. In the study, five advanced lines were used as female parents and four registered varieties were used as male parents to cross, resulting in 20 F_1 hybrids according to line × tester mating design during the 2021-2022 growing season. The 20 crosses and nine parents were evaluated in a randomized complete block design with three replications during 2022-2023 growing season. The results showed that the BC10 and BC22 lines had the highest general combining ability in terms of seed yield, while the Awassa tester had the highest general combining ability in terms of pod number per plant and seed yield. However, BC10 × Saryan, BC13 × Awassa and BC21 × Awassa hybrid combinations showed the highest specific combining ability in seed yield. It was stated that both additive and non-additive gene effects were efficacious for yield and several key yield components in the hybrid progenies. The promising hybrid combinations BC10 × Saryan (48.72**), BC21 × Awassa (126.74**) and BC13 × Awassa (127.83**) exhibited positive significant heterosis for seed yield.

1. INTRODUCTION

Brassica genotypes have become the primary source of vegetable oil due to advancements in breeding techniques worldwide. These genotypes, which are grown mainly in arid and semi-arid regions, offer a combination of strong growth and development characteristics (effective use of nutrients, resistance to diseases and pests, earliness, tolerance to heat and cold) and the opportunity to be used as food, feed and biofuel (Gan et al., 2008). Ethiopian mustard (*Brassica carinata*), known for its suitability in Mediterranean-type semi-arid climates, is not commonly used as food due to its high erucic acid content; however, it is increasingly utilized worldwide for biodiesel production. Ethiopian mustard exhibits acceptable yield values in low-fertility soils and can serve as an alternative to rapeseed in terms of disease and pest resistance (Cardone et al., 2003; Bozzini et al., 2007; Zanetti et al., 2009). When the properties of the oil obtained from Ethiopian mustard were examined, it was reported that there was no problem in using it for biodiesel production and that it met the requirements of European biodiesel standards (Cardone et al., 2003; Bouaid et al., 2005). Due to its tolerance to biotic and abiotic stress factors in semi-arid conditions, the interest of researchers, especially in Canada, Spain, and India, in this plant has increased in recent years (Rakow, 1995). To create good genetic variability in *Brassica* species for breeding purposes, it is essential to generate various hybrid combinations and select the breeding method based on the genetic structures of the hybrid progenies. For this purpose, the line × tester model proposed by Singh and Chaudhary (1977) is considered a good breeding method.

The line × tester (L×T) mating design has emerged as a fundamental tool in quantitative genetics and plant breeding, particularly for evaluating the general combining ability (GCA) of parental genotypes and identifying hybrids with superior specific combining ability (SCA) effects (Ceyhan & Avcı, 2005; Rashid et al., 2007; Ceyhan et al., 2008; Kose, 2017). This method facilitates the partitioning of genetic variance into additive and non-additive components, thereby providing a comprehensive understanding of the inheritance patterns of complex agronomic traits. The L×T analysis not only helps determine the breeding value of parental lines based on their average performance in hybrid combinations (GCA) but also identifies specific hybrid combinations that exhibit superior performance due to favorable gene interactions (SCA). As such, it offers dual utility: guiding the selection of elite parental genotypes and identifying promising hybrid combinations for commercial exploitation (Istipliler et al., 2015). In recent years, the widespread adoption of this technique has been driven by its ability to generate reliable data on gene action, heritability estimates, and genetic interactions, all of which are crucial for formulating effective breeding strategies (Ceyhan et al., 2008, 2014a, 2014b; Ceyhan & Ceyhan, 2021). In the case of *Brassica* species, where yield potential and adaptability are often constrained by narrow genetic bases and complex environmental interactions, precise knowledge of parental combining ability becomes indispensable. The L×T approach aids in the rational design of hybridization schemes by elucidating the relative contributions of additive (fixable) and dominance (non-fixable) gene effects. Numerous studies have consistently reported significant GCA and SCA effects for yield and its component traits, such as plant height, number of pods per plant, seed yield per plant, and thousand-seed weight, highlighting the involvement of both additive and non-additive gene actions in trait expression (Sincik et al., 2014; Kapadia et al., 2020; Ahmad et al., 2022; Chaudhari et al., 2023). These findings emphasize that both types of gene effects should be considered simultaneously when developing new cultivars. The integration of GCA and SCA data into breeding decisions enables a more precise prediction of hybrid performance, thereby accelerating the development of high-yielding, stable, and widely adaptable genotypes. Consequently, the L×T analysis stands as a cornerstone in modern plant breeding programs aiming to exploit heterosis and optimize genetic gains across diverse agro-ecological environments. In this study, planned for this purpose, the combination abilities and hybrid performances of the hybrid populations created by crossbreeding between 5 maternal and 4 paternal genotypes in a line × tester crossing design, which were previously developed through breeding studies, were investigated in terms of agronomic traits.

2. MATERIALS AND METHODS

The research was conducted at the experimental area of Department of Field Crops, Faculty of Agriculture, Bursa Uludag University in Bursa, Türkiye during the 2021-2022 and 2022-2023 growing seasons. The soils of the experimental area are alkaline-clay, rich in phosphorus and potassium, but poor in organic matter (1.83 %), and moderately calcareous with no salinity problem (Aksoy et al., 2001). The long-term total rainfall during the vegetation period, from September to June, in the experimental area was 664.1 mm. The average temperature was 13.4 °C, and the relative humidity was 73.8%. Climatic data for the 2022-2023 vegetation period indicated a growing season precipitation of 444.5 mm, an average temperature of 13.9 °C, and a relative humidity of 72.6%.

In this study, five Ethiopian mustard advanced lines (BC10, BC13, BC15, BC22 and BC23) developed through selection breeding by Bursa Uludag University, Faculty of Agriculture, Department of Field Crops were used as female parents (lines) and four registered varieties (Awassa, Dodolla, Saryan and Winteralaska) were used as male parents (testers). The nine parents were crossed to produce 20 F_1 hybrids according to line × tester mating design developed by Kempthorne (1957) during 2021-2022 growing season. The 20 crosses and 9 parents were evaluated in a randomized complete block design with three replications during the 2022-2023 growing season. Each plot, consisted of four rows, 5 m in length, with 45 cm inter-row and 10 cm intra-row spacings (Sincik et al., 2011). Recommended cultural practices were followed to raise a good crop.

The plant height, number of branches per plant, number of pods per plant, number of seeds per pod, seed yield, and thousand-seed weight of the parents and hybrids were measured.

Statistical analysis

The field experiment was laid out in a randomized complete block design with three replications. Variance analysis was performed as described by Steel & Torrie (1980) on all data obtained from the field experiment using JMP-7 software. The data were subjected to analysis of variance (ANOVA) as described by Steel & Torrie (1980). In addition, analysis of variance for combining ability estimates of GCA and SCA variances according to the line × tester method was performed using the method suggested by Singh and Chaudhary (1977). Analysis of combining ability was performed using TARPOPGEN software (Ege University, Izmir, Turkey) as outlined by Ozcan & Acıkgoz (1999). As the percentage increase or decrease in the mean of the hybrid combinations compared to their better parent and mid-parents, heterosis was calculated. Least Significant Difference (LSD) tests at the 0.05 and 0.01 significance levels were used to compare means and assess heterotic effects. The t-test was employed to evaluate the significance of general combining ability (GCA) and specific combining ability (SCA) effects at $p < 0.05$ and $p < 0.01$.

3. RESULTS AND DISCUSSION

The variance analysis results (mean of squares) of the traits studied in this research are given in Table 1. In the study, genotypes, parents and hybrids, as well as hybrids against parents, were found to be significant at a 1% probability level in terms of plant height, number of pods per plant, number of seeds per pod, seed yield, and thousand-seed weight (Table 1). This situation indicated significant variation among lines, testers and hybrids; therefore, it is possible to compute the general and specific combining abilities in the populations of parents and hybrids, respectively. Parents versus hybrids' mean squares, which indicate average heterosis, were significant for all traits except the number of branches per plant. The lines showed significance at a 5% probability level for the number of seeds per pod and at a 1% probability level for seed yield. It is observed that testers are essential at a 1% probability level in terms of the number of pods per plant and at a 5% probability level in terms of seed yield.

On the other hand, the line × tester interaction showed significance at a 1% probability level for plant height, number of pods per plant, seed yield and thousand-seed weight, and at a 5% probability level for the number of seeds per pod. These results revealed that non-additive gene effects were effective for plant height and thousand-seed weight, while both additive and non-additive gene effects were observed for pod number per plant, seed number per pod, and seed yield. For seed yield and yield related traits in *Brassica* species, significant mean squares were reported by different researchers (Kapadia et al. 2020; Ahmad et al. 2022; Chaudhari et al. 2023) depending on genotypes, parents, parents vs hybrids, lines, testers, and line × tester interaction.

The highest plant height values were obtained from the BC15 (216.2 cm) and BC23 (209.1 cm) lines as well as the Saryan tester (206.9 cm).The hybrid combination with the highest plant height is the BC21 x Winteralaska combination at 197.6 cm. The BC23 x Winteralaska combination had the lowest plant height with 143.3 cm (Table 2). The highest values in terms of number of branches per plant were determined in the BC10 line with 13.3 pcs and in the BC15 x Winteralaska hybrid combination with 13.2 pcs. The BC10 line yielded the highest number of pod number per plant, with 573.6 pcs, followed by the Saryan genotype with 597.0 pcs and the BC21 x Awassa hybrid combination with 589.7 pcs. The highest seed number per pod values were obtained from the BC10 x Awassa hybrid combination (15.6 pcs) and from the BC10 x Winteralaska combination (15.7 pcs). The lowest number of seeds per pod was obtained from the Saryan tester with 9.3 seeds. The highest seed yield value of 5070.1 kg ha^{-1} was obtained from the BC21 x Awassa hybrid combination, and the lowest seed yield value of 1049.3 kg ha^{-1} was obtained from the BC23 x Dodolla hybrid combination. In terms of thousand-seed weight, the highest value was observed in the BC23 x Awassa hybrid combination, at 5.9 g, and the lowest value was observed in the BC15 x Saryan hybrid combination, at 3.9 g. Consistent with the results obtained in this study, Licata et al. (2017), Verma et al. (2018), Mulvaney et al. (2019) and Verocai et al. (2024) found between the plant height 108.0-207.7 cm, the number of branches per plant 12.1-17.5 pcs, the number of pod per plant 232.2-640.0 pcs, the number of seed per pod 13.7-18.2 pcs, the seed yield 854.0-7283.0 kg ha^{-1} and the thousand-seed weight 2.13-5.00 g in different Ethiopian mustard genotypes.

Table 1. Mean squares for seed yield and yield components used in the study.

Source of variation	DF	Plant height	Number of branches per plant	Pod number per plant	Seed number per pod	Seed yield	Thousand-seed weight
Replication	2	5.4	107.4	15.3	2.2*	1734.8	0.2
Genotypes	28	704.6**	142.3	54129.4**	5.5**	350109.5**	0.8**
Parents (P)	8	1193.2**	458.2**	60995.3**	4.8**	284990.8**	0.5**
P vs H	1	2963.1**	225.4	55278.0**	77.5**	309545.5**	1.5**
Hybrids (H)	19	380.0**	5.0	51178.0**	2.1**	379662.9**	0.9**
Lines (L)	4	702.2	4.6	60580.7	5.2*	820067.3**	1.4
Testers (T)	3	46.4	10.6	135571.4**	1.9	764041.9*	0.2
L × T	12	356.0**	3.7	26945.4**	1.1*	136766.6**	0.9**
Error	56	43.4	113.3	1545.0	0.5	9028.9	0.1

DF: Degrees of freedom, * : Significant at p=0.05, **:Significant at p=0.01

Sprague & Tatum (1942) defined general combining ability (GCA) as the average performance of a line or tester. The general combining ability effects of the lines and testers used in this research, as well as the specific combining ability effects are shown in Table 3. An overall appraisal of GCA effects indicated that BC10 and BC22 female lines were good combiners for seed yield. However, BC10 also showed a positive GCA effect in terms of seed number per pod, indicating that it is a good general combiner. The BC15 and BC23 female lines, as well as Saryan tester, were determined to be unsuitable parents because they had a reducing effect on the seed yield in the hybrid combinations. In the testers, Awassa had significant GCA effects in a positive direction for pod number per plant and seed yield. In contrast, Saryan had a significant negative GCA effect for these traits. The estimates of GCA effects among lines and testers showed wide variation in the level of significance for various characters. When GCA effects are significant, additive or additive x additive gene effects are responsible for the inheritance of that particular trait. Research results indicate that the focus should be on improving the combining abilities of yield-enhancing characteristics that directly contribute to general combining ability (GCA) for seed yield, as combiners that excel in seed yield are often less effective for other yield-enhancing traits. Singh et al. (2005), Rameeh (2012), Meena et al. (2015) and Synrem et al. (2015) reported similar results while working with different materials.

The hybrid combinations BC13 × Winteralaska, BC21 x Dodolla and BC23 × Winteralaska which exhibited statistically significant negative SCA effects on plant height, were identified as promising cross combinations for hybrids with smaller heights (Table 4). Nassimi et al. (2006) stated that especially in *Brassica* genotypes grown for seed yield, very tall plants are susceptible to lodging. Therefore, the selected plants should be medium and short, and accordingly, negative GCA and SCA effects for plant height become essential. The SCA effects of the hybrid combinations in the study in terms of the number of branches per plant varied between -1.77 to 1.88 and were found to be statistically insignificant. Out of 20 crosses, 12 hybrid combinations exhibited significant SCA effects on the number of pods per plant.

The hybrid combinations, including BC13 × Winteralaska, BC15 × Awassa, BC15 × Winteralaska, BC21 × Winteralaska, BC23 × Dodolla, and BC23 × Saryan, exhibited significant positive SCA effects for pods per plant, indicating they were good combinations for increasing this trait. BC13 × Saryan and BC23 × Dodolla hybrid combinations exhibited positive SCA effects, significant at the 5% probability level. Highly significant and positive SCA effects were observed for seed yield in 7 hybrid combinations (BC10 × Saryan, BC13 × Awassa, BC21 × Awassa, BC23 × Winteralaska, BC15 × Dodolla, BC13 × Winteralaska and BC23 × Dodolla) and thousand-seed weight in 5 hybrid combinations (BC23 × Awassa, BC13 × Saryan, BC15 × Dodolla, BC13 × Winteralaska and BC10 × Dodolla). The hybrid combinations BC21 × Awassa, BC13 × Awassa, and BC10 × Saryan, which exhibited a positive and statistically significant SCA effect in terms of seed yield, also stood out due to their high average seed yields. Yadava et al. (2012), Tomar et al. (2018), Ahmad et al. (2022), Singh et al. (2022) and Chaudhari et al. (2022) obtained similar results.

Table 2. Mean values of lines, testers and hybrids with respect to studied traits.

Parents	Plant height (cm)	Number of branches per plant (pcs)	Pod number per plant (pcs)	Seed number per pod (pcs)	Seed yield (kg ha^{-1})	Thousand-seed weight (g)
Lines						
BC-10	206.4 ab*	13.3 a	573.6 ab	13.8 b-f	4310.1 b	4.3 ı-m
BC-13	186.7 d-f	9.2 d-g	190.5 lm	12.3 h-j	1680.3 jk	4.0 lm
BC-15	216.2 a	12.7 ab	379.2 fg	12.8 f-j	1544.7 j-l	4.5 g-k
BC-22	178.3 d-k	7.8 gh	368.5 f-h	12.4 h-j	2272.4 e-g	4.6 g-j
BC-23	209.1 a	6.6 h	313.2 h-j	11.7 jk	1180.2 lm	4.2 j-m
Testers						
Awassa (A)	168.2 j-l	8.3 f-h	255.7 ı-k	10.8 k	2200.9 f-ı	4.7 e-ı
Dodolla (D)	168.6 ı-l	9.9 c-g	277.2 ı-k	12.1 ıj	2672.5 c-f	5.3 b-d
Saryan (S)	206.9 ab	8.5 f-h	597.0 a	9.3 l	1144.1 lm	4.4 g-l
Winteralaska (W)	167.7 j-l	8.2 f-h	252.1 j-l	11.7 jk	2442.0 d-g	5.2 b-d
Hybrids						
BC 10 × A	176.6 f-k	9.0 e-g	514.3 b-e	15.6 a	3993.7 b	4.0 k-m
BC 10 × D	183.5 d-g	11.6 a-c	563.9 a-c	14.2 b-d	2252.3 e-h	5.1 c-e
BC 10 × S	186.3 d-f	9.0 e-g	348.6 f-h	14.7 ab	4056.2 b	5.1 c-f
BC 10 × W	179.5 d-h	8.9 e-g	347.5 f-h	15.7 a	3160.4 c	4.9 d-g
BC 13 × A	184.5 d-g	10.2 c-f	466.0 de	14.3 bc	4420.1 b	4.2 j-m
BC 13 × D	174.7 g-k	9.7 c-g	454.1 e	13.0 d-ı	1400.6 k-m	4.6 g-j
BC 13 × S	188.4 cd	8.7 f-h	247.8 kl	14.6 ab	1400.2 k-m	5.5 a-c
BC 13 × W	167.7 kl	10.4 c-f	516.2 b-e	13.9 b-f	2704.4 c-e	5.6 ab
BC 15 × A	178.5 d-j	11.0 b-e	515.3 b-e	13.5 b-h	2720.3 c-e	4.4 h-l
BC 15 × D	179.9 d-h	11.5 a-c	386.6 f	12.9 e-j	1776.0 h-k	4.7 e-ı
BC 15 × S	179.1 d-ı	7.9 gh	180.7 m	13.8 b-f	1742.1 ı-k	3.9 m
BC 15 × W	187.8 c-e	13.2 a	454.0 e	13.8 b-f	1310.8 k-m	4.2 j-m
BC 21 × A	172.5 h-l	11.2 a-d	589.7 a	13.7 b-g	5070.1 a	5.1 b-e
BC 21 × D	171.0 h-l	10.3 c-f	519.3 b-d	13.1 c-ı	2913.7 cd	4.4 g-l
BC 21 × S	179.4 d-h	9.0 e-g	317.0 g-ı	12.9 e-j	2923.1 cd	5.3 b-d
BC 21 × W	197.6 bc	10.9 b-e	566.7 a-c	13.8 b-f	2904.8 cd	5.6 ab
BC 23 × A	170.3 h-l	9.3 d-g	218.4 k-m	14.1 b-e	1760.5 h-k	5.9 a
BC 23 × D	177.5 e-k	10.2 c-f	505.1 c-e	14.5 ab	1049.3 m	5.1 c-f
BC 23 × S	163.3 l	9.3 d-g	273.7 ı-k	12.5 g-j	1448.7 k-m	4.6 f-j
BC 23 × W	143.3 m	8.7 f-h	233.2 k-m	14.0 b-f	2012.4 g-j	4.9 d-h
LSD 0.05	10.7	1.07	63.9	1.22	489.1	0.47

* Means in the same column followed by the same letter were not significantly different at the 0.05 level in the Least Significant Difference (LSD) test.

Heterosis and heterobeltiosis values of hybrid combinations are given in Table 5 and 6. Significant heterosis was observed in all traits for various hybrid combinations. Except for BC13 × Awassa and BC21 × Winteralaska, all hybrid combinations showed negative heterosis for plant height. Additionally, all crosses except for BC13 × Awassa and BC21 × Winteralaska exhibited negative and significant heterobeltiosis for the same traits. Eleven hybrids showed positive and significant heterosis and eight hybrid combinations exhibited positive heterobeltiosis for number of branches per plant. Out of 20 hybrid combinations, 12 hybrid showed positive significant heterosis and eight hybrids exhibited positive significant heterobeltiosis for pod number per plant.

Table 3. General combining abilities (GCA) effects on yield and yield components.

Parents	Plant height	Number of branches per plant	Pod number per plant	Seed number per pod	Seed yield	Thousand-seed weight
Lines						
BC-10	4.61	-0.37	32.45	1.11**	79.78**	-0.07
BC-13	1.65	-0.25	10.28	0.01	-8.63	0.11
BC-15	4.13	0.89	-26.71	-0.42	-68.05**	-0.56
BC-22	3.13	0.35	87.36	-0.54*	88.61**	0.26
BC-23	-13.53	-0.62	-103.38	-0.15	-91.71**	0.25
Testers						
Awassa (A)	-0.53	0.14	49.83**	0.31	102.65**	-0.12
Dodolla (D)	0.23	0.65	74.83**	-0.39	-62.21**	-0.07
Saryan (S)	2.26	-1.22	-137.36**	-0.22	-25.48**	0.01
Winteralaska (W)	-1.96	0.41	12.70	0.31	-14.95	0.18

* : Significant at p=0.05, **:Significant at p=0.01

Table 4. Specific combining abilities (SCA) effects on yield and yield components

Hybrids	Plant height	Number of branches per plant	Pod number per plant	Seed number per pod	Seed yield	Thousand-seed weight
BC 10 ×× A	-4.35	-0.77	21.08	0.24	-39.65*	-0.61**
BC 10 × D	1.78	1.31	45.41	-0.45	-49.11**	0.39*
BC 10 × S	2.55	0.59	42.28	0.12	94.15**	0.27
BC 10 × W	0.01	-1.14	-108.78**	0.34	-5.38	-0.05
BC 13 × A	6.41	0.30	-4.75	0.04	91.43**	-0.66**
BC 13 × D	-4.41	-0.70	-41.75	-0.55	-45.70**	-0.32
BC 13 × S	7.22	0.17	-35.88	0.87*	-82.76**	0.52**
BC 13 × W	-9.22*	0.23	82.38**	-0.36	37.03*	0.46**
BC 15 × A	-2.13	-0.04	81.25**	-0.31	-19.15	0.24
BC 15 × D	-1.90	-0.05	-72.41**	-0.21	51.05**	0.48**
BC 15 × S	-4.26	-1.77	-66.21**	0.54	10.65	-0.43*
BC 15 × W	8.29*	1.88	57.38*	-0.01	-42.55*	-0.29
BC 21 × A	-7.13	0.73	41.50	0.03	59.18**	0.15
BC 21 × D	-9.23*	-0.71	-53.83*	0.10	8.38	-0.60**
BC 21 × S	-2.92	-0.13	-43.63	-0.26	-27.35	0.14
BC 21 × W	19.29**	0.12	55.96*	0.13	-40.21*	0.31
BC 23 × A	7.20	-0.22	-139.08**	0.00	-91.81**	0.89**
BC 23 × D	13.76	0.16	122.58**	1.11*	35.38*	0.03
BC 23 × S	-2.59	1.14	103.45**	-1.02*	5.31	-0.51**
BC 23 × W	-18.37**	-1.09	-86.95**	-0.09	51.11**	-0.41*

* : Significant at p=0.05, **:Significant at p=0.01

The analysis of data on seed number per pod revealed that all hybrid combinations exhibited positive, significant heterosis. For the number of seeds per pod, all hybrids except BC15 × Dodolla gave significant and positive heterobeltiosis values. Seed yield estimates of heterosis revealed that out of 20 hybrid combinations, 12 showed positive and significant heterosis. Additionally, nine hybrids exhibited positive and significant heterobeltiosis for seed yield. Out of 20 hybrid combinations, 12 hybrids exhibited significant and positive heterosis for thousand-seed weight. Thousand-seed weight estimates of heterobeltiosis revealed that out of 20 hybrid combinations, eight hybrids exhibited positive and significant heterobeltiosis. The promising hybrid combinations BC10 × Saryan (48.72**), BC21 × Awassa (126.74**) and BC13 × Awassa (127.83**) exhibited significant positive heterosis for seed yield (Table 6). These results are in agreement with those of Singh et al. (2003), Rai & Verma (2005), Dholu et al. (2014), Surin et al. (2018), Kapadia et al. (2020) and Chaudhari et al. (2023) regarding heterosis and heterobeltiosis.

Table 5. The heterosis and heterobeltiosis values of hybrids for yield and quality characters observed.

Hybrids	Plant height		Number of branches per plant		Pod number per plant	
	Heterosis	Heterobeltiosis	Heterosis	Heterobeltiosis	Heterosis	Heterobeltiosis
BC 10 × A	-5.72**	-0.14**	-16.89**	-0.32**	24.02**	-0.10**
BC 10 × D	-2.14*	-0.11**	-0.25	-0.12**	32.54**	-0.01
BC 10 × S	-9.85**	-0.09**	-17.65**	-0.32**	-40.44**	-0.41**
BC 10 × W	-4.03**	-0.13**	-17.43**	-0.33**	-15.83**	-0.39**
BC 13 × A	3.99**	-0.01	16.37**	0.10**	108.90**	0.82**
BC 13 × D	-1.66	-0.06**	1.41	-0.02	94.17**	0.63**
BC 13 × S	-4.27**	-0.08**	-1.86	-0.05	-37.05**	-0.58**
BC 13 × W	-5.37**	-0.10**	19.33**	0.13**	133.25**	1.04**
BC 15 × A	-7.12**	-0.17**	4.61	-0.13**	62.32**	-0.13**
BC 15 × D	-6.49**	-0.16**	1.63	-0.09**	17.78**	0.01
BC 15 × S	-15.33**	-0.17**	-25.57**	-0.37**	-62.97**	-0.69**
BC 15 × W	-2.16*	-0.13**	26.13**	0.03	43.83**	0.19**
BC 21 × A	-0.43	-0.03**	39.24**	0.34**	88.93**	0.60**
BC 21 × D	-1.41	-0.04**	16.18**	0.03	60.82**	0.40**
BC 21 × S	-6.85**	-0.13**	10.22*	0.05	-34.33**	-0.46**
BC 21 × W	14.20**	0.10**	35.99**	0.32**	82.63**	0.53**
BC 23 × A	-9.72**	-0.18**	24.58**	0.11**	-23.22**	-0.30**
BC 23 × D	-6.01**	-0.15**	23.41**	0.02	71.11**	0.61**
BC 23 × S	-21.47**	-0.21**	22.93**	0.09**	-39.85**	-0.54**
BC 23 × W	-23.92**	-0.31**	17.32**	0.05	-17.49**	-0.25**

* : Significant at p=0.05, **:Significant at p=0.01

Table 6. The heterosis (Ht) and heterobeltiosis (Hb)values of hybrids for yield and quality characters observed.

Hybrids	Seed number per pod		Seed yield		Thousand-seed weight	
	Heterosis	Heterobeltiosis	Heterosis	Heterobeltiosis	Heterosis	Heterobeltiosis
BC 10 × A	26.52**	0.12**	22.68**	-0.07**	-9.77**	-0.13**
BC 10 × D	9.52**	0.02*	-35.49**	-0.47**	6.54**	-0.03**
BC 10 × S	27.10**	0.06**	48.72**	-0.05**	16.43**	0.14**
BC 10 × W	22.84**	0.13**	-6.39**	-0.26**	3.46*	-0.05**
BC 13 × A	23.48**	0.15**	127.83**	1.00**	-3.44*	-0.10**
BC 13 × D	6.42**	0.05**	-35.66**	-0.47**	-1.39	-0.13**
BC 13 × S	34.99**	0.18**	-0.86**	-0.16**	30.73**	0.23**
BC 13 × W	15.54**	0.12**	31.19**	0.10**	21.99**	0.07**
BC 15 × A	14.26**	0.05**	45.29**	0.23**	-3.69*	-0.05**
BC 15 × D	3.61*	0.01	-15.74**	-0.33**	-3.76**	-0.11**
BC 15 × S	25.15**	0.08**	29.62**	0.12*	-12.94**	-0.13**
BC 15 × W	12.51**	0.07**	-34.26**	-0.46**	-13.66**	-0.19**
BC 21 × A	18.20**	0.10**	126.74**	1.23**	10.96**	0.09**
BC 21 × D	6.93**	0.05**	17.85**	0.09**	-10.17**	-0.16**
BC 21 × S	18.89**	0.04**	71.13**	0.28**	16.99**	0.15**
BC 21 × W	14.62**	0.11**	23.20**	0.18**	14.54**	0.07**
BC 23 × A	25.00**	0.20**	4.14	-0.20**	32.58**	0.25**
BC 23 × D	21.69**	0.19**	-45.51**	-0.60**	7.03**	-0.04**
BC 23 × S	19.16**	0.06**	24.64**	0.22**	6.92**	0.03**
BC 23 × W	19.35**	0.19**	11.13**	-0.17**	3.92**	-0.06**

* : Significant at p=0.05, **:Significant at p=0.01

4. CONCLUSION

Analysis of variance was performed to test the differences between parents and hybrids for the traits examined in the study. The results revealed that the mean squares due to genotypes were highly significant for all the characters except for number of branches per plant. This indicated that sufficient genetic variability was present in the material for most of the characters under study. In this study, promising parent lines and hybrids were determined based on seed yield and several key yield components. It was concluded that BC10 and BC22 female parents when crossed with an Awassa male parent are considered good general combiners for developing seed yield in Ethiopian mustard hybrids. Three hybrid combinations with the highest seed yields; BC21 × Awassa, BC13 × Awassa, and BC10 × Saryan respectively, exhibited the highest positive and significant SCA effects in terms of these traits. Additionally, these three hybrid combinations demonstrated high heterotic performance in terms of seed yield and several key yield components.

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