International Journal of Botany Studies
ISSN: 2455-541X; Impact Factor: RJIF 5.12
Received: 07-02-2019; Accepted: 09-03-2019
www.botanyjournals.com
Volume 4; Issue 3; May 2019; Page No. 157-165

Genotypic association studies of yield traits and their inheritance pattern in oilseed rape (*Brassica napus* L.): A review

Syed Ahtisham Masood[1], Haseeb UR Rehman[2], Muhammad Yasin[3], Shahbaz Ahmad[4], Said Salman[5], Qurban Ali[6*]
[1] Cotton Research Station Khanpur, Rahim Yar Khan, Pakistan
[2] Department of Agronomy, Faculty of Agricultural Science and Technology, Bahauddin Zakariya University Multan, Pakistan
[3] Department of Plant Breeding & Genetics, University of Agriculture Faisalabad, Pakistan
[4] Institute of Agricultural Sciences, University of the Punjab Lahore, Lahore, Pakistan
[5] Department of Plant Breeding and Genetics, Gomal University, Dera Ismail Khan, Pakistan
[6] Institute of Molecualr Biology and Biotechnology, University of Lahore, Lahore, Pakistan

Abstract
Realizing the significance of edible oil in the Pakistan and role of brassica species in indigenous oilseed production, the current research review was directed to determine the role of combining ability (GCA and SCA) and heritability for the improvement of seed yield and various yield contributing characters in segregating generations of *Brassica napus* (Gobhi sarson). Study of pattern of combining ability of selected rapeseed (*Brassica napus* L.) genotypes in line × tester method helps to identify superior candidates (parental genotypes) to produce promising hybrid cross combinations.

Keywords: gene action, trait association, heritability, line × tester, oil content

Introduction

Oilseed rape (*Brassica napus* L.) is the 3rd chief reservoir of vegetable oil in the world (USDA, 2016a) [80], contributing the food and livestock feed industries, and remains to be an essential biofuel feedstock (USDA, 2016b) [81]. Even, the production has gradually upgraded through modern and orthodox plant breeding strategies. Heterosis breeding has vibrant role in boosting up the oilseed rape for higher oil content and seed yield. Range of hybrid vigor for spring oilseed rape is 20-50 %, while, in winter rapeseed that ranges higher; 20-80%. Further, in *Brassica napus* L. hybrid vigor for seed yield reaches up to 120 % (Azizinia, 2011) [16]. Price of hybrid varieties in Pakistan is higher and farmers are poor as compared to other countries. Hence, high yielding hybrid cultivars with low rates are needed to increase production. Seed yield of oilseed rape is a quantitative character often having low heritability, and is mainly subjective to diverse ecological conditions (Aghao *et al*., 2010; Aher *et al*., 2008; Ahmad *et al*., 2008; Ahsan *et al*., 2013; Akbar *et al*., 2008) [5, 6, 7, 8, 9]. In agricultural crops genetic variability is known to be critical to bring genetic improvement of economically sound characters and seed yield (Ali *et al*., 2010; Ali *et al*., 2016; Amiri *et al*., 2009; Arifullah *et al*., 2012; Aaliya *et al*., 2016; Abbas *et al*., 2016a, b) [13, 67, 1-3, 12, 27, 62, 14, 15, 1]. Crossing intra and inter *Brassica* species is a suitable means to unfold genetic variants and advance the novel varieties (Cthbert *et al*., 2011; Dar *et al*., 2012; Rashid *et al*., 2016a, b) [20, 62-63].

Magnitude of general (GCA) and specific (SCA) combining ability effects are central indicators of inbred's potential in different hybrid combinations; henceforth, in developing open-pollinated and hybrid varieties. An account of combining ability is essential for parent-plants selection, knowing the nature of gene actions, introgression and maximizing biological yield. The GCA effects are due to the additive section of the total variance, while that for SCA covers the non-additive (dominance and epistatic) share of the total variance (Dia *et al*., 2016; Diepenbrock, 2000; Rehman *et al*., 2017) [22-23, 24, 65]. Even, choice of breeding method and promising lines can be laid upon careful study of combining ability effects (Etedali *et al*., 2011; Gautam and Chauhan 2016) [25, 26]. Practical benefits of this technique have increased its use for choice of parental types. Recent studies on combining abilities have revealed significant GCA and SCA effects for biological characters, indicating that the contribution of both additive and non-additive mode of gene action are important in the inheritance of elite traits (Ghani *et al*., 2016; Gupta *et al*., 2010) [27, 28]. Pattern of variations in yield performance indicated that yield varies with the genetic makeup of cultivars and climatic adversities, emphasizing on exploration of the genetic information of desirable parental combination before selections. Hence, as the diverse genetic materials reveal diverse genetic parameters, the intents of the present research review were to scrutinize the combining ability patterns of selected oilseed rape (*Brassica napus* L.) genotypes and study their impact on genetic parameters of yield and yield related component traits.

Literature

Nair *et al*. (2005) [41] in a research selected the better parents and their combination on the basis of combing abilities estimates. Excluding days to maturity all characters exhibited significant variance for lines and testers. Two crosses were reported to be promising for yield and yield contributing traits. Tahira *et al*. (2005) [76] evaluated F_1 generation of ten Brassica cultivars for estimation of heterosis and heterobeltiosis. Effects were significant for all the traits. Crosses of KS-75 with COON-II, CON-III, Shiralee and Rainbow gave significant heterosis for No. of braches/plant, height, 1000-grain weight (g), No. of seeds/siliquae and seed yield/plant (g). Heterosis was high for oil content for KS-75 × Ac. Excel. Hence, such parents and their can be selected for further improvement of oilseed crops in Pakistan. Taklewold and Becker (2005) [77] studied *B. carinata* combing ability using nine inbred parents and 36 F_1 hybrids acquired by half dialle mating; GCA effects were predominant in all characters excluding secondary branches/plant and No. siliquaes/plant, siliquae length (cm), No. of seeds/siliquaw and oil contents. Brar *et al.* (2006) [17] studied the inheritance pattern in *Brassica campestris* L. Analysis revealed that seed yield/plant, plant height, no. of silique/plant and primary branches/plant were controlled by non-additive genetic factors. Khan *et al.* (2006) [35, 79] assessed the heterosis over better parent and mid parent. They found that seed yield gave maximum heterobeltosis 40.86% - 191.49%. NRCG-58 × SGS-16 and NRCG-29 × ISN-530 were crosses that had maximum heterosis for seed yield. No parents or cross had good GCA/SCA for all characters under observation. Crosses like NRCG-58 × NRCG32, NRCG-58 × SGS-16, and NRCG-32 × ISN-530, ISN-530 × NRCG-57 exhibited high performance with superior SCA effects for seed yield/plant and yield contributing traits. Thus, these can be used for further breeding programme.

Nassimi *et al.* (2006a) [44] conducted an experiment to estimate combining ability in *Brassica napus* L. lines. Hybrids and parents were sown to estimate combining ability for yield and yield related traits. Significant differences were present for all yield traits. GCA effects for no. of seeds/plant were highly significant but pod length (cm) and no. of pods/plant gave significant differences, seed yield/plant and 1000 grain weight (g) were non-significant in nature. All traits showed significant SCA and GCA effects. No. of pods/plant and no. seeds/pod were controlled by additive gene action. Therefore, GCA effects were greater than SCA for above mentioned traits. NUR 1, NUR 3 and NUR 4 had greater GCA so can be used for improvement of *Brassica napus* L. NRU2 × NRU1, NRU3 × NRU1, NRU5 × NRU3, NRU7 × NRU5 and NRU4 × NRU7 were hybrids having supreme SCA effects. So, these can be exploited for improvement of Brassica as an oilseed crops. Nassimi *et al.* (2006b) [45] estimated gene action and combining ability of eight *Brassica napus* L. genotypes by diallel analysis. Results depicted that GCA was highly significant for primary branches, days to 50% flowering, siliquae/raceme while, non-significant for maturity and plant height. SCA effects were highly significant for all the characters. GCA over SCA ratios indicated that additive genetic effects mainly controlled the expression of these characters. Raziuddin *et al.* (2006) [45] performed diallel experiment using eight *Brassica napus* L. genotypes. Combining ability test showed that GCA was significant for number of pods per raceme, days taken to 50% flowering and number of primary branches per plant while for plant height and days to maturity, the GCA was non-significant.

Turi *et al.* (2006) suggested in *Brassica juncea* L. viz. NUM 9 × NUM 113, NUM 103 × NUM 113, NUM 123 × NUM 117, NUM 123 × NUM 113 and NUM 123 × NUM 124 were the best hybrids for; days taken to 50% flower emergence, days taken to physiological maturity and no. of primary branches/plant. Also, parents NUM 103, NUM 113, NUM 117, and NUM 123 were better when used in different hybrid combinations. They also recommended their further use in breeding programs. Noshin *et al.* (2007) [48] conducted diallel experiment on brown mustard, *Brassica juncea* L. to determine general and specific combining abilities on the basis of inheritance pattern for no. of primary branches, length of the main raceme, siliquae in the main raceme and seed yield/plant. The results indicated that variance due to GCA and SCA was significant for all the traits except SCA for seed yield/plant. Mean square of GCA was higher than mean square of SCA indicating that all these traits were controlled by additive type of gene action.

Pathak *et al.* (2007) [53] reported heterosis and combining ability in *Brassica oleracea* L. var. capitata and found 40.14 %, 5.41%, 20.69%, 67.26%, 18.60%, 19.90%, 33.45% and 6.34 % heterosis over better parent and 39.40% , 5.41%, 16.33%, 52.02% , 11.22% , 19.07%, 33.45% and 3.45 % heterosis over the top parent for marketable yield, days to marketable maturity, net weight of head, head size index, no. of non-wrapper leaves, heading (%), leaf size index and vitamin C, respectively. Golden Acre and Pride of Asia exhibited the best GCA for marketable yield and majority of component traits. The hybrids; Golden Acre × Pride of India, Golden Acre × Pride of Asia and Pride of India × Pride of Asia exhibited the best specific combining ability and superior heterosis for marketable yield. Qian *et al.* (2007) [54, 56] studied semi-winter rapeseed for estimating potential for hybrid breeding, to evaluate the genetic impact, to estimate GCA, SCA and heterosis for different crosses in spring and semi-winter rapeseed lines. These (testers) were crossed in line × tester pattern by using 4 male sterile lines and 13 Chinese rapeseed winter lines to develop 52 hybrids. All these crosses, their parents and commercial hybrids of rapeseeds were evaluated for different quantitative and qualitative traits. These were grown in different environment in Canada and Germany. In this environmental condition Chinese parental lines were not adopted. But hybrids had higher heterosis for seed yield. Hybrid performance was increased by additive gene action. GCA mean squares were greater than SCA mean square. So the parent lines have a great potential to improve the brassica in spring rapeseed hybrid breeding programmes.

Singh *et al.* (2007) [73] estimated the heterosis for days taken to maturity, days taken to flowering, plant height, yield and oil contents. Heterosis for days taken to flowering ranged 4.5%-6.8%, days taken to maturity 1.5-2.5%, height 15.4-3.3% and heterosis for yield ranged 4.5-27.1%. Aher *et al.* (2008) [6] studied the extent of heterosis in Indian mustard and moderate heterosis was seen for seed yield/plant, no. of siliquae/plant and no. of secondary branches and in the remaining traits low magnitude of heterosis was observed. The highest standard heterosis for seed yield was noticed in RSK-87 × GM- 2 (42.95%) followed by SKM-95-85 × GM-2 (40.11%) and RSK-87 × Varuna (37.67%). Ahmad *et al.* (2008) [7] evaluated locally developed and improved from *Brassica napus* L., variety; “HS-98”. Dunkled, Rainbow and Oscar were used as check that were commercially cultivated varieties of *Brasssica napus* L. Data were taken for different important agronomic traits like 1000 seed weight , siliquaes/plant, length of siliquae, pedicle length and siliquae width. Siliqua/plant, 1000 seed weight and length of siliquae showed significant behavior. No. of silique/plant was 156 and length recorded from plants was 6.7 cm. This illustrated significant behavior. Protein contents (25.1 %) in HS-98 were higher from all the checks.

Akber *et al.* (2008) used combining ability analysis for the evaluation of *Brassica napus* L. crosses. Data were recorded from F_1 generation of *Brassica napus* on plant height, no. of primary branches, silique length, no. of siliques/plant, no. of seeds/silique, 1000-grain weight and seed yield/plant. Mean squares were highly significant for all characters except 1000-grain weight. RBN-96040 had shown good GCA for all traits that were under study. KS-75 was not a good general combiner for plant height and primary branches. RBN-96040 × RBN-96038 was a cross that had the highest specific combining ability followed by a cross RBN-96038 × DGL/SHIRALEE that showed good SCA also for seed yield per plant. Lohia (2008) studied the pattern of inheritance for different morphological traits. The recorded data on 21 hybrids were tested for combining ability. The results showed that both additive and non-additive genes controlled the traits i.e. length of main raceme, days taken to 50% flowering, secondary branches/plant, 1000-seed weight, oil contents and seed yield/plant. Singh *et al.* (2008) [72] selected genotypes of *Brassica juncea* to analyze the combining ability for yield and yield contributing traits. They analyzed additive as well as non-additive gene action for days taken to 50% flowering, days taken to maturity, siliques/plant, secondary branches/plant, oil contents and seed yield/plant.

Amiri-oghan *et al.* (2009) [14] evaluated the *Brassica napus (*L.) for days to flowering, days to maturity and yield. It was clear from the analysis that additive and non-additive gene action controlled all the traits under observation. Ratio of general combining ability and specific combining ability for days taken to flowering, maturity and yield were 0.91, 0.95 and 0.83 respectively, therefore additive gene action was important for all these traits. Regent and Tower were the best parents for early maturity while Ceres and D. R. were suitable for high yielding. Han-zhong *et al*. (2009) [30] selected the 11 lines of the rapeseed (*Brassica napus* L) and crossed these lines to check the heterosis of the oil contents in these lines. From these crosses the lines and crosses with the high oil content were also identified. From the results it was clear that for oil content positive mid-parent heterosis was present in the 30 crosses and 7 crosses showed the over-parent heterosis. Range of the mid-parent heterosis was 0.43% to 9.86% and the range of the over-parent heterosis was 0.46 to 8.67. When the lines with the low oil content and the lines with the high oil content were crossed then the heterosis was negative. When, crosses were made between the lines with the low oil content then positive mid-parent heterosis was reported. Hence, the parents to be used in the breeding programmes should have the high oil contents.

Huang *et al*. (2009) [31] evaluated the rapeseed for combining ability test for yield and oil related traits. He crossed the five genetically male sterile lines with nine inbred testers. The results showed significant difference among the hybrids. The ratio between sum of squares due to GCA to sum of squares of hybrids were 0.70 for seed yield, 0.80 for oil contents, 0.88 for days to flowering and 0.82 for days to maturity. Additive and non-additive effects were present but additive effect was more responsible for these traits. Nigam and Alka (2009) [47] studied forty five hybrids of *Brassica napus* L. for the pattern of inheritance in governing different quantitative characters. The general and specific combining abilities (GCA & SCA) were also determined. It was observed that GCA and SCA variance were important and indicated additive and non-additive gene action were pivotal in directing these characters. Sixteen hybrids exhibited good general combining ability for seed yield, controlled by non-additive gene actions. Qian *et al*. (2009) [55] determined the specific and general combining ability effects by crossing; fourteen Chinese semi-winter rapeseed with four European winter rapeseed varieties. Variance due to GCA was higher than the SCA indicating additive gene effects to be more prevalent to monitor the seed yield, oil contents and protein contents. The objective of experiment was also to determine the heterosis based on parental genetic distance estimated from marker assisted data and general combining ability for hybrid performance. These hybrids showed the higher value of heterosis for seed yield. The results demonstrated that Chinese semi-winter rapeseed germplasm has increased yield in winter rapeseed.

Solanki *et al.* (2009) [74] estimated the general combining ability and specific combining ability effects for eleven parents and their fifty five crosses by using four different environments. The parents, RN-539, BPR-6166 and GM-2 were acknowledged as good combiners, while GM-1 × BPR-6166, GM-2 × JM-1 and BIO-902 × TM-40 showed good SCA effects for yield linked traits. However, hybrid GM-1 x BPR-6166 had significant SCA effects. So, the best parents and hybrids can be used for further breeding. Aghao *et al*. (2010) [5] analyzed *Brassica juncea* for estimation of GCA and SCA of the parents and their hybrids. Seeta, Laxmi and Varuna were genotypes that were used in experiment for identification of good general combiner on the basis of their performance. Varuna × Seeta was recognized as the best combination. Therefore, this cross can be advanced by appropriate breeding method. Ali *et al*. (2010) [13, 67] conducted research to evaluate the genetic control of some important agronomic and quality contributing characters. Analysis of variance directed highly significant differences among the parents and their hybrids for all the characters above studied. Days taken to flowering, days taken to maturity, no. of primary branches/plant, no. of secondary branches/ plant, number of siliquaes/plant, no. of seeds/siliquae, and seed yield/plant under study indicated that they were exclusively controlled by partial-dominance (gene action) but plant height and 1000-seed weight gave complete dominance (gene action). Thus, it is clear that additive properties have main role in the variation of the traits.

Gupta *et al*. (2010) [28] conducted an experiment to estimate the heterosis for yield associated traits and oil content in 36 F_1 hybrids; derived from parental genotypes. F_1 hybrids along with their parents were sown in lattice design. GCA and SCA, both were highly significant. Even, genetic variance due to SCA was greater than the variance due to GCA. Heterotic effects for mid-parent and better parent heterosis were positive and significant for all the characters observed. Opera and Talaye were parental genotypes, having best GCA effects that can be used as parents for better hybrid combination with good SCA for oil yield and yield related components. Sabaghnia *et al*. (2010) [66-67] evaluated the 36 rapeseed lines to study the heterosis for different yield contributing traits, oil yield and oil percentage in the hybrids and in their parents. It was cleared from the results that mean square due to GCA and SCA both were highly significant. Variance due to GCA was greater than the variance due to SCA showing that non-additive gene action was dominant. Opera and Talaye were the parental genotypes that presented the best GCA. So, its exploitation as one of the parents can create outstanding hybrid combinations having appreciable SCA effects. Hybrids like Orient × Zarfam, Opera × Talaye and Orient × Talaye showed the excellent performance for the determination of the GCA and SCA for oil yield. These results could be good indicator for recognition as the most favorable genotypes to be exploited either as F_1 hybrids or as a source population for more research for the improvement of the rapeseed crop.

Azizinia (2011) [16] conducted a research to evaluate top rapeseed genotypes. Results showed that variances for all the traits were significant except for seed yield/plant. Significant general combining ability (GCA) and specific combining ability (SCA) were exhibited for seed yield/plant (g), seed weight (g) and oil contents (%). Oil contents had significant reciprocal effects and yield and its related traits had significant positive effects. Cuthbert *et al.* (2011) [19] conducted an experiment to conclude if high parent or commercial heterosis for some seed quality characters produces hybrids with low erusic acid rapeseed hybrids. Better parent heterosis was 9% that was observed in the results and commercial heterosis was recorded up to 14% in the hybrids. Protein and glucosinolate showed the low parent heterosis. Commercial heterosis was only shown for the erusic acid concentration. Several hybrids exhibited no heterosis for some seed quality characters. Etedali *et al.* (2011) [25] performed experiment on five inbred lines of rapeseed to determine their combining abilities for three in vitro traits i.e. percentage of callus induction, callus diameter and callus fresh weight. Variance due to SCA was superior to variance due to GCA, suggesting the dominance kind of gene action for these studied characters. Dominant gene action was suggested by high broad sense and low narrow sense heritability in controlling these traits.

Parmar *et al.* (2011) [49] analyzed the combining ability of the Indian mustard (*Brassica juncea* L.) by using five testers (males) and ten lines (females) and crossed them in line × tester scheme. SKM-0149, GM-3 and RSK-28 were proved as the best general combiner in the crosses. Crosses; SKM-0149 × RSK-28, NDR-8501 × NUDH-YJ-3 and RH-819 × RSK-28 presented the best specific combining ability effects for yield and some yield contributing traits. So, these crosses could be used in further breeding for improved characters. Rameeh (2011a) [60] examined combing ability and heterosis for yield using line × tester analysis; (6 × 2). Results disclosed significant differences in yield traits. GCA was more significant for seed yield and no. of siliquae/plant but SCA was significant for siliquae/plant as well as seed yield/plant. It was concluded that more yield related traits were controlled by additive genetic effect and less by non-addictive genetic effect. Shweta *et al.* (2011) [69] carried out a study to estimate GCA and SCA of parent and crosses. Maya showed the highest general combining ability variance followed by Vardan for days taken to maturity, oil content and seed yield/plant. Vardan × RK 06-3 and Maya × RK 06-6 had the highest specific combining ability based on SCA effects.

Arifullah *et al.* (2012) [15] crossed eight genotypes in all possible combinations. All the traits showed significant GCA except siliquae length and plant height. BRS-2 and KJ-119 exhibited best general combining ability for yield and yield components. BRS-2 × UCD-8 had positive SCA for yield. Canola raya × UCD-8 was a good cross combination for no. of seeds/silique. Dar *et al.* (2012) [20] estimated the heterosis of *Brassica rapa* (L.) hybrids for yield and yield related traits. CR-1485 × CR-1607 was a promising cross with more better and mid parent heterosis for no. of primary branches/plant and 1000-seed weight. CR-1630 × CR-2871, CR-2638 × KOS-1 and CR-1485 × CR-1607 exhibited significant heterosis for oil content, days taken to maturity, no. of siliquaes/plant, respectively. So, these good cross combinations could be used to improve the yield and yield contributing traits of brown sarson. Maurya *et al.* (2012) [39] performed combining ability analysis for yield and yield related traits of 45 hybrids produced from 10 parental lines through diallel mating. Parents 819, RH-3904 and Varuna showed good combining ability for seed yield and oil content (%). 1000 seed weight and oil content (%) were controlled by additive gene action. RH-819 and Varuna were the best combiners for earliness. Varuna × RH-819 was a good specific combination for no. of primary branches, days taken to 50% flowering and yield/plant.

Patel *et al.* (2012) [50] conducted a study to evaluate 45 hybrids and their parents for combining ability and heterosis. Parent, RK-9501 and cross; RK-9501 × GM 2 were suitable for seed yield. GM-1 × GM-3 was a cross that had significant mid-parent heterosis and GM 3 × SKM-139 had better parent heterosis for seed yield. GM-1, RK-9501, SKM-139, GM-2 and GM-3 showed the best general combining ability (GCA) for yield and yield contributing traits. Mode of gene action was non-additive for seed yield/plant so, hybrid breeding would be suitable for further improvement. Abideen *et al.* (2013) [4] carried out experiments on the *Brassica napus* L. to check the variability and correlation. RCBD was used to evaluate the genotypes in the three replications. Most of the traits showed the significant difference among the genotypes that were under study. Primary branches/plant and pods/plant showed the non-significant differences. In the genotype pods/plant and protein content (%) showed the positive correlations and was significant. If objective is to improve the yield of oil then genotype number-1 can be used in the breeding programmes. To improve the seed yield and seeds/pod the genotype-7 showed the best result.

Ahsan *et al.* (2013) [8] conducted an experiment to evaluate the *Brassica napus* lines for combining ability and heterosis by using line × tetser crossing scheme. Mean squares were significant for yield and yield components that indicated significant variation was present in both parents and their crosses. GCA/SCA ratio was high which indicated that genetic effects were additive in nature for all the traits only excluding seed yield/plant. GCA and SCA effects were significant and positive. For hybrids, seed yield was significant over better parent which was the indication that these crosses were appropriate for improving genotypes by combination method. Nasim *et al.* (2013) [42] evaluated 10 genotypes of rapeseed (*Brassica napus* L) for heritability, genetic variability and studied the correlation of different traits. Results showed that variability is present in the / seeds/pod showed the better heritability. There was association for length of the pods with the width of pods and also for 1000-seed weight. For selection in the further research, length of the pods (cm), height of the plants (cm) and seeds/pod can be used as selection criteria.

Patel *et al.* (2013) [51] evaluated 45 hybrids for combining ability. They concluded that the days taken to 50% flowering, days to maturity, harvest index and biological yield had non-additive nature of gene action. Parents GM-1, RK-9501 and GM-2 gave good general combining ability as compared to other parents used in study. Crosses GM-1 × GM-3, RK-9501 × GM-2 and GM-3 × SKM-139 were the best combination for yield and yield contributing traits when compared to other crosses. Ali *et al.* (2014) [10] carried out study on *Brassica napus* L. to investigate the pattern of inheritance for yield and yield contributing traits. Four genotypes G2, G4, G6 and G9 were used for making the crosses in diallel pattern. Plant height, no. of branches/plant, seeds/pod, pods/plant, seed weight/plant and 1000-seed weight showed significant differences. Additive-dominance model was adequate for primary branches/plant, pods/plant, seeds/pod while, on the other hand remaining traits were partially adequate. Genetic parameters estimation showed significant and higher magnitude of dominance effects for all the studied traits. Over dominance, gene action was present in plant height, pods/plant, no. of primary branches and seed weight/plant.

Dholu *et al.* (2014) [21] estimated the combining ability of *Brassica juncea.* Ratios of GCA/SCA directed that gene action were non-additive in nature for days taken to 50% flowering, seeds/siliquae, plant height and seed weight. IC-560696 and GM-2 was the best general combiner for yield and yield contributing traits. Laxmi × IC-560696, Laxmi × Vardan and IC-491446 × GM-2 were good cross combinations for yield and aphids resistance. So these were promising genotypes and hybrids to improve the Indian mustard. Kang *et al.* (2014) [34] conducted experiment on 16 genotypes of *Brassica napus* L. for estimating the combining ability and heterosis of the hybrids. Genotypes were crossed in the Line × Tester (11×5) method. Data of the 55 hybrids were taken for different traits; no. of branches/plant, no. of secondary branches, no. of seeds/siliquae, seed yield/plant and 1000-seed weight. Lines showed the significant mean sum of squares for all the characters except plant height. Testers had the non-significant mean sum of square for all the traits under study except plants height (cm) and no. of siliquae/plant. Estimated SCA variances were greater than the GCA variances. Heterosis (hybrid vigor) and SCA effects of the seven hybrids were highly significant than other hybrids studied. So, these hybrids can be used for further research and in breeding programs to expand the oil seed crops.

Muhammad *et al.* (2014) [40] designed an experiment in 4 × 4 diallel in *Brassica napus* (Gibhi sarson) for the calculation of heritability and combining ability variance. They determined that main raceme length and plant height (cm) were highly heritable traits that can be used in future breeding programs. Additionally, additive and non-additive effects could be exploited efficiently for breeding plans for the mentioned traits. Sincik *et al.* (2014) [70] performed an experiment to estimate magnitude and nature of gene action in *Brassica rapa* for yield and yield related traits. Parents and 20 F_1 hybrids were sown using RCBD with three replications. Mean squares of GCA, SCA and RCA (relative combining ability) were significant. Lenox showed the best general combining ability (GCA) for height (cm). Hybrid vigor over mid and better parent was positive and significant. GCA effects were positive as exhibited by all the genotypes used in study. Promising genotypes will be incorporated for further breeding programmes. Ali *et al.* (2015a) [11, 68] estimated the heterosis in *Brassica juncea* L. from 56 crosses and parents in this study. Oil % was significant for 34 crosses out of 56. Heterobeltiosis was significant and positive for 26 crosses. Significant and negative heterosis was recorded for glucosinolates content in 26 crosses. Protein content indicated significant heterosis in 32 crosses out of 56.

Chaudhari *et al*. (2015) [18] used 36 hybrids of *Brassica rapa* along with one standard check to estimate the heterosis and combining ability for yield and quality contributing traits. For yield and yield related traits parents; PS-66 and GS-1 were proved as the best general combiner out of nine parents used in the study. SSK-9203, AA-14 and SPAN were parents that showed good general combining ability for erucic acid and oil contents. Crosses GS-1 × YSB 4-2005, GS-1 × YSB-2001 and PS-66 × YSB-2001 performed exceptionally on the basis of standard heterosis and combining ability. Nausheen *et al.* (2015) [46] carried out an experiment by using *B. carinata* lines for assessing heterosis and heterobeltiosis for different quality and quantity traits. Traits like no. of primary branches/plant, seed yield/plant, raceme length and oil content presented significant variation in parents and their hybrids. Cross C-93 × C-90 gave maximum value of heterosis for seed yield/ plant. Cross C-88 × C-97 had maximum positive heterosis for oil contents in the seed. From the results it is concluded that these parental lines can be further exploited to improve performance in quantitative and qualitative traits. Patel *et al*. (2015) [18] used 7 lines and 5 testers of Indian mustard for studying the gene action, combining ability and heterosis. Reportedly, non-additive gene action was present for traits like plant height (cm), days taken to flowering, no. of branch/plant, no. of siliquaes/plant, seed yield, lenoleic acid, lenolenic acid and oil content. The highest positive heterosis was recorded for CJ 3761 × GM 3 and the maximum heterobeltosis was revealed by hybrid CJ 3761 × GM-3. ZEM-1 was a parent that showed good general combining ability (GCA) for oil contents and no. of branches/plant. So, these parents and hybrids would be used in the breeding programmes for developing of the high yielding and better quality genotypes.

Shehzad *et al*. (2015a) [68] done an experiment on the *Brassica Napus* L. lines to evaluate the effects of heterosis and heritability by using Line × Tester crossing scheme. All the lines and testers gave the significant mean sum of square for combining ability. Duncled that was used as line had the good general combining ability for oil, erusic acid, protein, glucosinolate and oleic acid than other lines and Durree-NIFA that was used as the tester for protein, linoleic acid and erusic acid. Legend × ZN-R-1 gave the higher oil (52.4%) contents than all other crosses and Punjab sarson × Dunkled had the higher protein (26.5%). Punjab Sarson × Dunkled had the lower amount of the glucosinolate (19.3μmol/g), Erusic acid (2.3%) and also linoleic acid (5.4%). Selection of good hybrids and parents would be pivotal in improving the nutrition of the rapeseed in future.

Gautam and Chauhan (2016) [26] used 20 lines (female) and 3 testers (male) in *Brassica juncea* L. to make hybrids by using line × tester analysis. Experiment was conducted to compute GCA, SCA, heritability (narrow sense) and heterosis for height of plants (cm), yield and yield related traits. In line × tester, variance was significant for traits like pods/plant and seed yield indicating non-additive gene action. Average heterosis for all traits under study was significant because mean squares for parent vs crosses were significant. Heritability (narrow sense) for all the traits was high except no. of seeds/pod. Negative SCA effects were observed in all crosses for plant height that was the indication that at least one of parent had significant negative GCA effects for plant height (cm). Almost, for all the traits except pods/plant high parent heterosis was greater than SCA effects that help in selection of better cross combination for further breeding programmes.

Ghani *et al*. (2016) [27] studied ten genotypes of *Brassica napus (*L.) by using Line × Tester crossing scheme for the estimation of combining ability. F_1 hybrids and parents showed significant differences for yield per plant and also for oil contents (%). DH-6 and CA-4 were special genotypes that had maximum yield per plant and oil contents, respectively in study. CA-4 and CA-5 were reported genotypes (testers) that exhibited best yield/plant based on general combining ability. Ishaq and Raziuddin (2016) [33] determined the combining ability in *Brassica napus* L. Data were recorded for different traits i.e. days taken to flowering, plant height (cm), maturity (days), no. of primary branches and length of main raceme. Significant GCA, SCA and variances were reported for traits under consideration. AUP-7, AUP-2, AUP-14 and AUP-9 presented the best general combing ability for early maturity, plant height (cm), no. of primary branches/plant and length of main raceme, respectively. AUP-17 × AUP-18, AUP-14 × AUP-20, AUP-7 × AUP-14, AUP-14 × AUP-20 and AUP-8 × AUP-9 were cross combinations that exhibited significant specific combining ability for plant height (cm), no. of primary branches/plant, days taken to flowering, length of main raceme and days taken to maturity, respectively. Further, days taken to flowering had additive gene action while all other traits were controlled by non-additive gene action.

Rameeh (2016) [61] evaluated 20 F_1 hybrids of rapeseed. These 20 hybrids were made by crossing 5 female (lines) and 4 male (testers). The lines incorporated were moderate maturing and testers were early maturing. Main purpose of this study was to investigate genetic makeup of hybrids, GCA of parents and SCA of crosses. Lines and testers mean squares were significant and gene action was additive in nature. Interaction showed significant effect that gave guarantee of presence of non-additive gene action or dominance effects. No. of branches/plant and length of pods (cm) showed narrow sense heritability that was indication of additive gene action for traits. GCA effects for seed yield and no. of pods on main raceme had positive correlation. Number of pods on main raceme can be used as selection criteria for improving the yields character. L41 × bFoma2, Zafar × R42 and L22B × R38 were crosses with significant GCA that was also positive in nature. Seed yield recorded by these crosses were 3400, 3311.3 and 2904.2 kg/ha, respectively. So these can be used for improvement of yield of brassica; oilseed crops. Tian *et al*. (2017) [78] performed an experiment to estimate the combining ability and heterosis. They used nine lines of Chinese rapeseed (*Brassica napus* L.) in their experiment. They used SSR and SRAP molecular markers for prediction of heterosis and combining ability. Three better cross hybrids, 8D12998E001 (HCK, 23.56%), 8C18998C272 (23.31%), and 8C34398D129 (20.08%), were recognized as supreme performers assessed across four environments. Apparently, they may be promoted for adoption and commercialization in China.

Conclusion

Combing ability and gene action play important role in deciding which traits to combine. Eventually, the heterosis (hybrid vigor) can be used to boost up the yield of oilseed crops for higher seed yield and oil content.

References

1. Aaliya K, Qamar Z, Nasir IA, Ali Q, Munim AF. Transformation, evaluation of gtgene and multivariate genetic analysis for morpho-physiological and yield attributing traits in Zea mays. Genetika. 2016; 48(1):423-443.
2. Abbas GH, Shahid MR, Mahmood A, Ali Q. Characterization of plant spacing best fit for economic yield, fiber quality, whitefly and CLCuV disease management on upland cotton. Nature and Science. 2016; 14(5):12-16.
3. Abbas HG, Mahmood A, Ali Q. Zero tillage: a potential technology to improve cotton yield. Genetika. 2016; (0534-0012):48(2).
4. Abideen SNU, Nadeem F, Abideen SA. Genetic variability and correlation studies in *Brassica napus* L. genotypes. Int. J. Innov. Appl. 2013; 2(4):574-581.
5. Aghao RR, Nair B, Kalamkar V, Bainade RR. Diallel analysis for yield and yield contributing characters in Indian mustard [*Brassica juncea* (L.) Czern & Coss]. J. Oilseed Brassica. 2010; 1(2):75-78.
6. Aher CD, Shelke LT, Chinchane VN, Bogaonkar SB, Gaikwad AR. Heterosis for yield and yield components in Indian mustard (*Brassica juncea* Czern and Coss]. Int. J. Pl. Sci. 2008; 4(1):30-32.
7. Ahmad H, Islam M, Khan IA, Ali H, Hidayatur-Rehman, Inamullah. Evaluation of advance rapeseed line HS-98 for yield attributes and biochemical characters. Pak. J. Bot. 2008; 40(3):1099-1101.
8. Ahsan MZ, Khan FA, Kang SA, Rasheed K. Combining Ability and Heteroses Analysis for Seed Yield and Yield Components in *Brassica napus* L. J. Biol. Agric. Health. 2013; 3(9):31-37.
9. Akbar M, Tahira BM, Hussain M. Combining ability studies in *Brassica napus* L. International Journal of Agriculture and Biology. 2008; 10:205-208.
10. Ali M, Khalil IA, Khan NU, Khan U, Rehman MU, Afridi GG. Genetic analysis of yield and yield related attributes in *Brassica napus*. Pure Appl. Bio. 2014; 3(4):175-187.
11. Ali N, Bakht J, Naveed K, Liaquat M, Khan SA, Saeed M, Ali S, Hussain I, Khan SM, Salim M. Heterosis studies for some fatty acids composition of indian mustard (*Brassica juncea* L.). J. Anim. Pl. Sci. 2015; 25(3):587-592.
12. Ali Q, Ahsan M, Kanwal N, Ali F, Ali A, Ahmed W, Saleem M. Screening for drought tolerance: comparison of maize hybrids under water deficit condition. Advancements in Life Sciences. 2016; 3(2):51-58.
13. Ali Q, Abbas HG, Farooq J, Nadeem Tahir H, Arshad S. Genetic analysis of some morphological traits of *Brassica napus* (Canola). Electron. J. Pl. Breed. 2010; 1(5):1309-1319.
14. Amiri Oghan H, Fotokianb MH, Javidfar F Alizadeh B. Genetic analysis of grain yield, days to flowering and

maturity in oilseed rape (*Brassica napus* L.) using diallel crosses. Int. J. Pl. Prod. 2009; 2:19-26.
15. Arifullah M, Munir M, Mahmood A, Ajmal SK, Shabbir G. Combining ability analysis of some yield attributes in indian mustard (*Brassica juncea* L.). Pak. J. Agric. Res. 2012; 25(2):104-109.
16. Azizinia S. Combining ability analysis for yield component parameters in winter rapeseed genotypes (*Brassica napus* L.). J. Oilseed Brassica. 2011; 2(2):67-75.
17. Brar KS, Yadav MS, Mittal VP, Singh P. Combining ability studies for seed yield, its component characters and oil contents in Toria. Crop Impr. 2006; 33(2):185-189.
18. Chaudhari NH, Patel RN, Gami RA, Shah SK. Study of combining ability and heterosis for seed yield and seed quality traits in rapeseed [*Brassica rapa* L.] quality. The Bioscan. 2015; 10(4):1985-1989.
19. Cuthbert RD, Crow G, Mcvetty PBE. Assessment of seed quality performance and heterosis for seed quality traits in hybrid high erucic acid rapeseed (HEAR). Can. J. Plant Sci. 2011; 91(5):837-846.
20. Dar ZA, Wani SA, Gulzaffar, Habib M, Sofi NR, Ahmed I, Ahmed ZA, Khan MH. Heterosis studies in brown sarson (*Brassica rapa* L.). Electron. J. Plant Breed. 2012; 3(1):676-681.
21. Dholu VK, Sasidharan N, Suthar K, Bhusan B, Patel JN. Heterosis and combining ability analysis in Indian mustard [*Brassica juncea* (L.) Czern & Coss.] Int. J. Agric. Sci. 2014; 10 (1):1102-10.
22. Dia M, Wehner TC, Arellano C. Analysis of genotype × environment interaction (G × E) using SAS programming. Agron, J, 2016, 108(4).
23. Dia M, Wehner TC, Hassell R, Price DS, Boyhan GE, Olson S, King S, Davis AR, Tolla GE. Values of locations for representing mega-environments and for discriminating yield of watermelon in the U.S. Crop Sci. 2016; 56(4):1726-1735.
24. Diepenbrock W. Yield analysis of winter oilseed rape (*Brassica napus* L.): A review. Field crops research. 2000; 67:35-49.
25. Etedali G, Moghaddam M, Vaheda M, Khossroshahlib A, Motallebi-Azra, Valizaheda M, Kazemiania S. Gene action and heterosis for callus induction and growth from mature embryo culture of rapeseed (*Brassica napus* L). Int. Res. J. Agric. Sci. Soil. Sci. 2011; 1(9):402-407.
26. Gautam SC, Chauhan MP. Combining ability of plant height and yield components in Indian mustard (*Brassica juncea* L. Czern & Coss.) under salt affected soil using Line × Tester Analysis. J. Agric. Res. 2016; 3(2):93-100.
27. Ghani G, Teixeira A, Khalil IA, Adnan M, Rahman ZU, Ali M. Biplot analysis of seed yield and oil content combining ability in rapeseed (*Brassica napus* L.). Australas. J. Crop Sci. 2016; 10(9):1238-1243.
28. Gupta P, Chaudhary HB, Lal S. Heterosis and combining ability analysis for yield and its components in Indian mustard (*Brassica juncea* L. Czern & Coss). Front. Agric. China. 2010; 4(3):299-307.
29. Habekotte B. Evaluation of seed yield determining factors of winter oilseed rape (*Brassica napus* L.) by means of crop growth modeling. Field crops research. 1997; 54:137-151.
30. Han-zhong W, Gui-hua L, Xin-fa W, Jing L, Qing Y, Wei H. Heterosis and breeding of high oil content in rapeseed (*Brassica napus* L). 16th Australian Research Assembly on *Brassica*. Ballarat, Victoria, 2009.
31. Huang Z, Laosuwan P, Machikowa T, Chen Z. Combining ability for seed yield and other characters in rapeseed. J. Sci. Technol. 2009; 17(1):39-47.
32. Inamullah H, Ahmad F, Mohammad S, Hassan G, Gul R. Evaluation of the heterotic and heterobeltiotic potential of wheat genotypes for improved yield. Pak. J. Bot. 2006; 38(4):1159-1168.
33. Ishaq M, Raziuddin. Research Article Combining Ability Analysis for Maturity and Plant Architecture Traits in Intra-Specific Crosses of Rapeseed (*Brassica napus* L.). Sarhad J. Agric. 2016; 32(3):168-176.
34. Kang SA, Khan FA, Javed MA. Heterosis and combining ability studies for exploitation of hybrid genotype of *Brassica napus* L. J. Agric. Res. 2014; 52(3):303-316.
35. Khan MN, Wani SA, Shah SA. Heterosis and combining ability in gobi sarson (*Brassica napus* L.). Int. J. Agric. Sci. 2006; 2(2):510-514.
36. Lohia RS. Combining ability analysis in Indian mustard. (*Brassica juncea*). Pl. Arch. 2008; 8(1):395-398.
37. Mahmood T, Ali M, Iqbal S, Anwar M. Genetic variability and heritability estimates in summer mustard (*Brassica juncea*). Asian J. Pl. Sci. 2003; 2(1):77-7.
38. Malik SI, Malik HN, Minhas NM, Munir M. General and specific combining ability studies in maize. Int. J. Agric. Bio. 2004; 6:856-859.
39. Maurya N, Singh AK, Singh SK. Analysis of combining ability in Indian mustard (*Brassica juncea* L). Ind. J. Pl. Sci. 2012; 1(2):116-123.
40. Muhammad A, Muhammad A, Raza H, Rahman AU, Ali I. Combining Ability and heritability studies for important traits in F2 of *Brassica napus*. American-Eurasian J. Agric. Environ. Sci. 2014; 14(01):509-515.
41. Nair B, Kalamkar V, Bansood S. Combining ability analysis in Brassica (*Brassica juncea* L.). J. Soils Crops. 2005; 15(2):415-418.
42. Nasim A, Farhatullah, Iqbal S, Shah S, Azam SM. Genetic variability and correlation studies for morpho-physiological traits in *Brassica napus* L. Pak. J. Bot. 2013; 45(4):1229-1234.
43. Nassimi AW, Raziuddin Sardar A, Naushad A. Study on heterosis in agronomic characters of rapeseed (*Brassica napus* L.) using diallel. J. Agron. 2006; 5:505-508.
44. Nassimi AW, Raziuddin, Ali N, Bakht J. Analysis of combining ability in *Brassica napus* L. lines for yield associated traits. Pak. J. Biol. Sci. 2006a; 9(12):2333-2337.
45. Nassimi AW, Raziuddin, Ali S, Hussain G, Ali N. Combining ability analysis for maturity and other traits in rapeseed (*Brassica napus* L). J. Agron. 2006b; 5(3):523-526.
46. Nausheen, Farhatullah, Khalil IH, Amanullah. Heterosis and heterobeltiotic studies of F1 hybrids. Pak. J. Bot. 2015; 47(5):1831-1837.
47. Nigam R, Alka. Combining ability analysis for yield and its components in Indian mustard (*Brassica juncea*). Int. J. Pl. Sci. 2009; 4(1):109-111.
48. Noshin MM, Iqbal, Hassan G, Ahmad R, Khan S.

Combining ability analysis for yield and its Components in Brown mustard. Sarhad J. Agric. 2007; 23(3):617-622.
49. Parmar AS, Jaiminiand SN, Ram B. Combining ability analysis for seed yield and its components over environments in Indian mustard (*Brassica juncea* L.). J. Oilseed Brassica. 2011; 2(2):61-66.
50. Patel AM, Prajapati DB, Patel DG, Pulses M. Heterosis and combining ability studies in indian mustard (*Brassica juncea* L.). Ind. J. Sci. Res. Tech. 2012; 1(1):38-40.
51. Patel AM, Arha MD, Khule AA. Combining ability analysis for seed yield and its attributes in Indian mustard [*Brassica juncea* (L.) Czern and Coss]. Asian J. Bio Sci. 2013; 8(1):12-15.
52. Patel R, Solanki SD, Gami RA, Prajapati KP, Patel PT, Bhadauria HS. Genetic study for seed yield and seed quality traits in Indian mustard [*Brassica juncea* (L.) Czern & coss]. Electron. J. Pl. Breed. 2015; 6(3):672-679.
53. Pathak S, Kumar J, Sagar V, Verma S. Heterosis and combining ability for marketable yield and component traits in cabbage (*Brassica oleracea* var. capitata). Ind. J. Agric. Sci. 2007; 77(2):97-100.
54. Qian W, Sass O, Meng J, Frauen CJM. Heterotic patterns in rapeseed (*Brassica napus* L.): I. crosses between spring and Chinese semi-winter lines. Theor. Appl. Genet. 2007; 115:27-34.
55. Qian W, Li Q, Noack J, Sass O, Meng J, Frauen M, Jung C. Heterotic patterns in rapeseed (*Brassica napus* L.): II. Crosses between European winter and Chinese semi-winter lines. Pl. Breed. 2009; 128:466-470.
56. Qian W, Sass O, Meng J, Li M, Frauen M, Jung C. Heterotic patterns in rapeseed (*Brassica napus* L.): I. crosses between spring and Chinese semi-winter lines. Theor. Appl. Genetics. 2007; 115:27-34.
57. Rameeh V. Combining ability and factor analysis in F2 diallel crosses of rapeseed varieties. Pl. breed. seed sci. 2010; 62:73-83.
58. Rameeh V. Heritability and other genetic parameters assessment for flowering associated stress indices in oil seed rape varieties. Int. J. Pl. Breed. Genet. 2011; 5(3):268-276.
59. Rameeh V, Cherati A, Abbaszadeh F. Salinity effects on yield, yield components and nutrient ions in rapeseed genotypes. J. Agric. Sci. 2012; 57(1):19-29.
60. Rameeh V. Line × tester analysis for seed yield and yield components in spring and winter type varieties of oilseed rape. J. Cereals and Oilseeds. 2011a; 2(5):66-70.
61. Rameeh V. Line × tester analysis in rapeseed : Identification of superior parents and combinations for seed yield and its components. Open Agric. 2016; 1:74-78.
62. Rashid BHT, Yousaf I, Rasheed Z, Ali Q, Javed F, Husnain T. Roadmap to sustainable cotton production. Life Science Journal. 2016; 13(11):41-48.
63. Rashid B, Kousar S, Yousaf M, Ali Q, Fatima F, Parveen S, Husnain T. Biotechnology: Future Tools for Stable Insect Pest and Weed Control in Cotton. Cotton Genomics and Genetics, 2016, 7.
64. Raziuddin D, Nassimi AW, Ali N, Ali S, Bakht J. Combining ability analysis for maturity and other traits in rapeseed (*Brassica napus* L). Agron. J. 2006; 5(3):523-526.
65. Rehman I, Aftab B, Bilal Sarwar, Rashid M, Ali B, Majid Q, Husnain MU. gene expression in response to cotton leaf curl virus infection in Gossypium hirsutum under variable environmental conditions. Genetika.; 2017; (0534-0012):49(3).
66. Sabaghnia N, Dehghani H, Alizadeh B, Mohghaddam M. Diallel analysis of oil content and some agronomic traits in rapeseed (*Brassica napus* L.) based on the additive dominance genetic model. Aust. J. Crop Sci. 2010; 4:609-616.
67. Sabaghnia N, Dehghani H, Alizadeh B, Mohghaddam M. Heterosis and combining ability analysis for oil yield and its components in rapeseed. Aust. J. Crop Sci. 2010; 4(6):390-397.
68. Shehzad A, Sadaqat HA, Ali M, Ashraf MF. Combining ability analysis and genetic-effects studies for some important quality characters in *Brassica napus* L . Tur. J. Agric. F. Sci. Tech. 2015; 3(10):790-795.
69. Shweta Ranjeet, Singh P. Diallel analysis for yield and yield components in Indian mustard [*Brassica juncea* (L.) Czern and Coss.]. Prog. Agric. 2011; 11(1):127-132.
70. Sincik M, Sozen E, Falk KC, Goksoy AT, Acikgoz E. Heterosis and combining ability in a diallel cross of turnip rape genotypes. Tur. J. F. Crop. 2014; 19(2):228-234.
71. Singh M, Singh L, Srivastava SBL. Combining ability analysis in Indian mustard (*Brassica juncea* L. Czern and Coss). J. Oilseed Brassica. 2010; 1(1):23-27.
72. Singh M, Singh G, Kumar V, Dhaka A. Combining ability analysis for some metric traits related to seed yield in Indian mustard [*Brassica juncea* (L.) Czern and Coss]. Prog. Agric. 2008; 8(1):57-60.
73. Singh M, Dixit RK, Vijendra V. Studies on heterosis in relation to seed yield in Indian mustard (*Brassica juncea* L.). ISOR, National Seminar, 2007, 106.
74. Solanki SD, Joshi VC, Haibatpure SH, Pathak HC. Combining ability studies in Indian mustard [*Brassica juncea* (L.) Czern & Coss] over environments. J. Oilseeds Res. 2009; 26(Special Issue):593-596.
75. Steel RGD, Torrie JH, Dickey DA. Principles and Procedures of Statistics: A Biometrical Approach. McGraw-Hill. New York. USA, 1997.
76. Tahira, Mahmood T, Ali M, Rauf S. Hybrid vigour of some quantitative characters in *Brassica napus*. J. Agric. Res. 2005; 43(2):85-93.
77. Taklewold A, Becker HC. Heterosis and combining ability in a diallel cross of Ethiopian mustard inbred lines. Crop Sci. 2005; 45:2629-2635.
78. Tian HY, Channa SA, Hu SW. Relationships between genetic distance, combining ability and heterosis in rapeseed (*Brassica napus* L.). Euphytica. 2017; 213(1):1-11.
79. Turi NA, Raziuddin Farhatulla, Khan NU, Hassan G, Bakhat J, Khan S, Shafi M. Combining ability for yield related traits in *Brassica juncea*. Pak. J. Bot. 2006; 43(2):1241-1248.
80. USDA. Oilseeds: World markets and trade. USDA-FAS September 2016-2016a. Avialable at: http://usda.mannlib.cornell.edu/usda/fas/oilseed-trade//2010s/2016/oilseed-trade-09-12-2016.pdf
81. USDA. Oilseeds and Products Annual. GAIN Report AU1603, 2016b. Avialable at:

https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Oilseeds%20and%20Products%20Annual_Vienna_EU-28_4-1-2016.pdf

82. Variath MT, Wu JG, Li YX, Chen GL, Shi CH. Genetic analysis for oil and protein contents of rapeseed (*Brassica napus* L.) at different developmental times. Euphytica. 2009; 166:145-153.
83. Wang JS, Wang XF, Zhang YF, Zhang Z, Tian JH, Li DR. Study on heterosis among subspecies or varieties in *B. campestris* L. Proceedings of the 12th International Rapeseed Congress Wuhan, (TRCW'07), China: Sci, Press, USA, 2007, 108-110.
84. Wang X, Hua W, Liu G, Liu J, Yang Q, Wang H. Genetic analysis on oil content in rapeseed (*Brassica napus* L.). Euphytica. 2010; 173:17-24.
85. Yadav YP, Prakash R, Singh R, Singh RK, Yadav JS. Genetics of yield and its component characters in Indian mustard (*Brassica juncea* (L.) Czern and Coss) under rainfed conditions. J. oilseeds res. 2005; 22:255-258.
86. Zhang G, Zhu W. Genetic analysis of agronomic and seed quality traits of synthetic oilseed Brassica napus produced from interspecific hybridization of *B. campetris* and *B. Oleracesea*. J. genet. 2006; 85:45-51.
87. Zhang H, Zhen C, Wu JG. Analysis of genetic effects for heterosis of erucic acid and glucosinolate contents in rapeseed (*Brassica napus* L). Agric. Sci. China. 2011; 10(9):1525-1531.