CHAPTER-II
REVIEW OF LITERATURE

The present investigation was undertaken to study heterosis and combining ability in durum wheat (*Triticum durum* L.). The literature pertaining to the heterosis, combining ability and gene action analysis for grain yield and its components in durum wheat is reviewed under the following subheads.

2.1 Heterosis

2.2 Combining ability and gene action

2.1 Heterosis:

The application of heterosis in wheat involves the identification of parental combination showing high specific combining ability. The scope for exploitation of hybrid vigour and the breeding methodology to be adopted in any crop greatly depend on the direction and magnitude of heterosis. If the commercial production of hybrid wheat is attainable, those specific combinations of parents which express the desired degree of heterosis will have to be determined.

Heterosis or hybrid vigour was first reported in plants by Koelreuter (1763) and noted that vigour in crosses increased with the increase in dissimilarity of parents. The term "heterosis" as now widely used, was coined by Shull (1914). It refers to the phenomenon in which the F₁ hybrid obtained by crossing two dissimilar individuals shows the increased or decreased vigour over the better or mid-parental value. Later on Fonseca and Patterson (1968) used a new term "heterobeltiosis" to describe improvement of heterozygotes in relation to better parent.

Genetically, “heterosis” refers to the superiority of hybrid in one or more characters over its parents. The heterosis over average of parents is termed as mid parent heterosis, over better parent it is referred as heterobeltiosis, while over standard check variety is referred as standard or economic heterosis which has practical value in commercial point of view. The genetic causes of heterosis are dominance, non-allelic interaction or epistasis and over dominance (Mather and Jinks, 1971).

Hassan *et al.* (1996) conducted a study in three different locations to estimate a pooled heterosis in $6 \times 6$ diallel set in wheat. They reported significant and positive pooled
better parent heterosis for grain yield per plant (19.93%) grains per spike (16.08%), plant height (9.86%), spike length (10.21%) and 1000-grain weight (31.72%).

The studies on heterosis for yield and yield components, in 10 crosses of bread wheat attempted by Khan and Khan (1996) revealed the maximum heterosis over mid parental value (31.91%) for number of tillers per plant, followed by grain yield per plant (19.41%), 1000-grain weight (17.32%), grains per spike (11.37%) and plant height (5.23%). Maximum heterobeltiosis was recorded for grain yield per plant (19.08%) followed by tillers per plant (15.82%) and grains per spike (10.27%).

Ten diverse parents of wheat were crossed to produce 45 F1s by Sharma and Menon (1996). It reported highly significant positive heterosis for grain yield (39.7 to 89.1 %) in 23 crosses. However, the magnitude of heterosis was found non-significant for the yield components.

Morgan (1998) estimated heterosis for grain yield and its components from the crosses of seven modern varieties used as female parents and either two old or two modern varieties, which were used as male parents. The results showed that the hybrid derived from modern male parents exhibited greater heterosis for grain yield and mean grain weight than those from old parents. Positive heterosis for mean grain weight resulted in heavier seeds and was the most important yield components in determining heterosis in grain yield. Heterosis for number of grains per ear was small while number of ears per meter square showed negative heterosis.

Prasad et al. (1998) evaluated a set of diallel involving ten parents of to investigate the extent of heterosis for grain yield and its components in wheat. The maximum heterosis over better parent for grain yield per plant was 59.7 %, while the maximum heterosis over standard parents was 27.3 %. Three crosses viz; KS 19 × KS 34, KS 34 × HD 2402 and HUW 206 × KS 19 exhibited significant heterosis over better parent for grain yield per plant, flag leaf area and biological yield per plant. Heterosis for number of grains per ear and 100-grain weight was generally independently associated with heterosis for grain yield per plant.

Seven diverse varieties of wheat along with their hybrid combinations were studied by Deshpande and Nayeeem (1999). Significant heterosis over better parent was observed for grain yield. Hindi 62 × Ajantha exhibited significant heterosis over mid and better parent (Hindi 62) for grain yield per plant.
Munir et al. (1999) studied seven F₁ wheat (Triticum aestivum L.) hybrids for heterotic performance. The highest heterotic and heterobeltiotic negative values by days to 50% heading and grain weight for main spike were recorded for the cross Lu-26 × Mutant 1.

Rajora (1999) evaluated 12 lines, 5 testers and resulting 60 crosses to derive information on heterosis for grain yield and its components in bread wheat and observed positive and significant heterobeltiosis in 26 crosses for grain yield plant, 17 crosses for grains per spike, 23 crosses for 1000-grain weight and 13 crosses for harvest index.

Bloch et al. (2001) evaluated a set of 4 × 4 diallel cross for important agronomic traits of spring wheat and observed the highest heterobeltiosis of 62.02% in cross combination of Jauhar 78 × Pavon for grain yield per plant. Whereas, its reciprocal cross Pavon × Jauhar 78 displayed maximum heterosis for number of tillers per plant and grains per spike.

Ijaz et al. (2002) studied heterosis for grain yield and yield components in 10 crosses of bread wheat and observed that grain yield per plant showed the highest heterosis over mid-parent (31.56%) followed by number of grains per spike (15.56%), spike length (7.42%), number of spikelets per spike (7.29%), 1000-grain weight. The maximum heterobeltiosis was recorded for grain yield per plant (27.11%) and the number of spikelets per spike (6.59%).

Nehvi et al. (2002) observed heterosis in bread wheat involving 10 lines and 3 morpho-physiologically diverse testers. Heterosis in general was more pronounced over mid parent than over better parent. Significant heterosis was observed for development, grain-yield and drought-related traits. The cross S 56 × HD 2380 exhibited the highest significant heterosis over both the parents for grain yield per plant. The parents CPAN 1796, HD 2380 and F₆-F₈ were observed to give desirable heterosis for most of the traits.

Salgotra et al. (2002) examined heterosis for grain yield and nine other traits in the F₁ hybrids between 13 winter wheat and four diverse testers of spring wheat. Two crosses IWWSN 6-110 × HPW 42 and IWWSN 6-134 × HS 240 showed significant economic heterosis for grain yield, grains per spike and harvest index.

Sharma et al. (2002) estimated heterosis in durum wheat in which heterosis over mid-parent and better parent using a 10 × 10 diallel set for grain yield and yield related components. Marked heterosis for grain yield (upto 68.8% over BP) and its important
components was observed. NP 401 × Raj 911, Corcorit 71 × JNK 4W-184, Corcorit 71 × A 9-30-1, Fleming ‘s’ × A 9-30-1, NP 401 × Fleming ‘s’, Fleming ‘s’ × Strock ‘s’ and HD 4530 × Strock ‘s’ were found the most promising crosses for grain yield and some other desirable traits. The study revealed good scope for commercial exploitation of heterosis as well as isolation of pure lines from the progenies of heterotic F₁s for improvement of yield levels.

Joshi et al. (2003) observed hybrid vigour over environments in a ten parents diallel cross in common wheat. The magnitudes of heterosis over mid-parent and better-parent, were calculated using a 10 × 10 diallel set of common bread wheat for quantitative and qualitative traits under varying environmental conditions, i.e. early sown (25 october), normal sown (20 november) and late sown (20 december). Twenty-nine crosses showed significant and positive heterobeltiosis for grain yield in all three environments. Under early, normal and late sowing environments, maximum heterobeltiosis for grain yield was 13.30 % (Sonalika × WH 157), 44.30 % (CPAN 3004 × Durgapura 65), and 36.37 % (Sonalika × HD 2285), respectively. The cross CPAN 3004 × Raj 1972 exhibited significant and positive heterobeltiosis for grain yield in all the environments.

Oetter et al. (2003) estimated hetrosis for eight agronomic traits using six females and four males and their 24 hybrids in line × tester analysis. They revealed that in comparison with mid-parent values, hybrids averaged a 10.1 % higher grain yield per plant, 8.4 % more kernels per spike, 6.8 % higher 1000-kernel weight and 4.4 % greater plant height.

Rathod (2003) estimated heterosis and inbreeding depression on genetic architecture of grain yield and its components using generation mean analysis in six crosses of wheat. He observed that the most of the crosses exhibited significant heterosis and heterobeltiosis for number of tillers per plant, plant height, flag leaf area, length of main spike, number of spikelets and grains per spike, grain yield per plant and harvest index. In case of days to flowering and grain protein content, a poor heterobeltiosis was observed in all the six crosses.

A study was conducted by Singh et al. (2004) to estimate the heterosis over mid and better parent in a 10 × 10 diallel set in bread wheat under three different environments. Marked heterobeltiosis for grain yield and its important components was observed. A total of 20 crosses showed significant heterobeltiosis for grain yield per plant over all the three
environments. The maximum heterobeltiosis for grain yield per plant was 50.94% (Raj 3765 × HD 2285), 121.08% (PDW 373 × HD 2329) and 93.96% (PDW 373 × HD 2329) under early, normal and late sowing, respectively. The crosses which showed heterosis for grain yield were not heterotic for all the characters. Heterosis for grain yield per spike followed by tillers per plant and 1000-grain weight was independently associated with heterosis for grain yield per plant in early and normal planting.

Tariq et al. (2004) evaluated 10 spring wheat cultivars and their 30 F1S to estimate mid-parent heterosis for grain yield and yield related traits. The mid parent heterosis ranged from -10.9% to 16.5% for spike length, -13.7% to 7.9% for spikelets per spike, -33.6% to 17.1% for kernels per spike, -21.7% to 61.6% for 1000-kernel weight and -55.7% to 156.8% for grain yield per plant.

Akbar et al. (2005) estimated heterosis and heterobeltiosis for various quantitative traits in 4 × 4 wheat diallel crosses involving four bread wheat genotypes (SH 02, V 00125, V 00055 and Uqab 2000). The results exhibited highly significant differences among genotypes comparing parents and their crosses for all traits studied except for 1000-grain weight and harvest index. The cross V 00055 × V 00125 exhibited highly significant and maximum heterosis and heterobeltiosis for grain yield, spikes per plant, biomass per plant and 1000-grain weight followed by crosses SH 02 × Uqab 2000 and V 00055 × SH 02 for grain yield. Both these cross combinations were recommended to be considered for finding out transgressive segregants in late segregating generations to develop a potential wheat variety.

Chowdhry et al. (2005) made 20 crosses of bread wheat involving varieties/lines viz., 8763, 8779, 8784, Inqlab 91 and Iqbal 2000. The maximum significant heterobeltiosis was recorded for grain yield per plant (33.45%), flag leaf area (28.75%), tillers per plant (12.91%) and spike length (15.77%). The crosses 8779 of Iqbal 2000, 8779 x 8763 and 8784 x Inqlab 91 may be considered for selection as hybrid or pure line wheat varieties after achieving desired homozygosity.

Hassan et al. (2005) studied heterosis for grain yield and associated traits in an eight-parent diallel of wheat. The significant positive mid-parent and better parent heterosis were recorded, respectively, in 11 and 9 hybrids for number of fertile tillers per plant; 32 and 28 for grain yield per plant; 10 and 5 for number of grains spike; 26 and 14 for grain weight per spike and 38 and 28 for 1000-grain weight. Better-parent heterosis was to 85%
for grain yield per plant; 38.2% for grain weight per spike and 1000-grain weight and 29.4% for number of fertile tillers per plant and 17.9% for number of grains per spike.

Forty-five F₁ combinations from along with their parents were evaluated for the estimation of the extent of heterosis over mid-parental values by Bhatt et al. (2006). Five crosses showed significant heterosis for grain yield per plant. The negative heterosis for plant height was observed in the cross K 9527 × K 9107 (-12.23%). Highly significant heterosis for tillers per plant was observed in K 9107 × K 9006 (14.98%) and for spike length in K 8965 × K 7903 (8.61%).

Innamullah et al. (2006) studied heterotic and heterobeltiotic performance of 28 F₁s obtained through crossing of eight commercial varieties, for days to heading, days to maturity, tillers per plant, flag leaf area, plant height, spike length, grains per spike, 1000 grains weight, harvest index and yield per plant. The highest heterotic and heterobeltiotic effects was recorded in GZ × Der (-5.35 and -4.98%) for days to heading, Tat × SQ (-2.16 and -1.21%) for days to maturity, GZ × Tat (14.92 and 7.46%) for tillers per plant, SQ × ICP (17.14 and 14.01%) for flag leaf area, Tat × Sar (-3.29 and -2.89%) for plant height, SQ × Der (19.11 and 16.21%) for spike length, Sar × Der (23.14 and 17.60%) for grains per spike, Tkb × Der (28.42 and 28.0%) for 1000 grain weight, SQ × ICP (24.69 and 21.68%) for harvest index and Tat × SQ (56.25 and 26.87%) for yield per plant, respectively. The result revealed that the hybrid combinations Tat × SQ and SQ × ICP could be recommended for improved yield and enhanced biological production of wheat, respectively.

Vanpariya et al. (2006a) evaluated fourteen parents (ten lines and four testers) and 40 F₁S for line × tester analysis in bread wheat. They found higher magnitude of heterosis for grain yield per plant, effective tillers per plant, length of main spike, spikelets per spike, number of grains per spike, grain yield per spike and harvest index; moderate for peduncle length of main spike and 100-grain weight, and low for days to heading, plant height and days to maturity. The crosses PBW 316 × Lok 1, DWR 202 × GW 496, K 8565 × Lok 1, DL 803 3 × GW 173 and GW 326 × GW 190 exhibited exploitable heterosis for grain yield and most of its component traits.

Singh et al. (2007) estimated heterosis for yield and associated traits in bread wheat. Heterosis over better parent ranged from -48.01% to 90.20% for grain yield per plant; -1.89% to 2.43% for days to maturity; -2.45% to 59.05% for plant height; -24.03% to
0.78 % for spike length; -13.89 % to 8.70 % for effective tillers per plant; -51.22 % to 2.50 % for grains per spike; -35.12 % to 118.79 % for harvest index and 4.50 % to 32.56 % for 1000-grain weight.

In order to study the selection of combination, with strong heterosis and use of their parents, the heterosis, combining ability and genetic distance were studied with 56 hybrids from 8 × 7 incomplete diallel cross and their parents by LI Xiao-yan et al. (2008). The results showed: (1) the heterosis over mid-parent was positive in 5 characters, its order was grain weight per plant, kernel number per head, head number per plant, 1000-kernel weight and plant height. The crosses had positive heterosis over high-parent and over check in grain weight per plant, kernel number per head and head number per plant (2) the crosses with strong heterosis were with the results of the heterosis of their yield components, which supplied and accumulated each other.

Rasul et al. (2008) estimated heterosis over mid and better parents for yield and some important yield related traits in 10 crosses of bread wheat. Grain yield per plant revealed maximum heterosis over mid parent (31.65%) followed by number of grains per spike (15.50%), spike length (7.42%), number of spikelets per spike (7.29%), 1000-grain weight (5.79%), and number of tillers per plant (-2.14%). The maximum heterobeltiosis was recorded for grain yield per plant (27.11%) and number of spikelets per spike (6.69%).

Sjemenarstvo et al. (2008) used ten winter wheat genotype (Banica, Kuna, Magdalen, Lipa, 232489-ZgMI, Edita, OSK 10/96, Zg 10262, Mihelca and Concordia) to produce 13 F₁ progenies. Heterosis and heterobeltiosis was estimated for five quantitative traits (1000-grain weight, grain weight per spike, number of grains per spike, spike length, and number of spikelets per spike). Positive heterosis and heterobeltiosis in the F₁ generation (average for all cross combinations) was recorded for grain weight per spike (13.45%, 4.94%) and 1000-grain weight (12.86%, 5.50%), whereas negative heterosis and heterobeltiosis was registered for number of grains per spike (-2.42%, -7.57%). Significant and positive heterosis for grain weight per spike (48.60%) and 1000-grain weight (42.44%) was recorded in cross Edita × Magdalen. Positive heterosis for most of the traits was also observed in two cross combinations (Mihelca × Kuna and Magdalen × Edita).

Akinci et al. (2009) estimated heterosis and combining ability effects for heading time, 1000-kernel weight and plant yield of 6 durum wheat parents and their 15 half diallel crosses. Two local populations (Beyaziye and Bagacak) and four cultivars (Kunduru 1149,
Cakmak-79, Diyarbakir-81, and Duraking) of durum wheat were used as parents in the studies. Heterosis percent for high parent and mid-parent were -2.16 % and -0.74 % for heading date; -1.64 % and 3.78 % for 1000 kernel weight; -2.24 % and 5.24 % for plant yield, respectively. The highest heterosis percentage for mid-parent was determined at the hybrids of ‘Kunduru 1149 × Diyarbakir-81’ (1.10 %) for heading date; ‘Kunduru 1149 × Cakmak-79’ (12.86 %) for 1000-kernel weight and ‘Beyaziye × Duraking’ (37.67 %) combination for plant yield.

Kamani (2009) estimated heterosis and heterobeltiosis in 48 F₁₈ using line (16 lines) × tester (3 testers) analysis in bread wheat. He observed high estimates of heterosis for grain yield per plant, biological yield per plant and number of tillers per plant. Moderate values were noticed for length of main spike, plant height and number of spikelets per spike. Days to 50% flowering, days to maturity, number of grains per spike, 1000-grain weight and harvest index showed low estimates of heterosis. The crosses RWP 2002-2 × GW 366, HUW 234 × LOK 1, RWP 2002-2 × PBW 373, HD 2864 × GW 366, RWP 2002-2 × LOK 1, HUW 234 × PBW 373, GW 173 × GW 366, HUW 234 × GW 366 and HD 2864 × LOK 1 manifested significant and desirable heterobeltiosis for grain yield per plant.

Ashutosh kumar et al. (2011) studied 7 × 7 diallel set of wheat. Significant heterosis over economic parent and mid parent was observed for days to 75 % flowering, number of tillers per plant, plant height, number of spikelets per main spike, number of grains per spike, 1000-grain weight and grain yield per plant. Economic heterosis was estimated over widely adopted and high yielding variety GW 373. Out of 21 crosses, 9 exhibited significant and positive heterosis over economic parent for grain yield per plant. These include K 9162 × GW 373, K 9351 × K 9107, K 9162 × K 9107, GW 373 × K 99107, K 65 × K 9351, K 65 × K 9107, K 65 × K 68, K 9351 × GW 373, K 65 × K 9162 and K 9351 × K 9162.

Bilgin et al. (2011) studied the heterotic and heterobeltiotic performance of 22 bread wheat hybrids. The maximum heterosis and heterobeltiosis were recorded in Syrena × Bezostaja and Sana × Bezostaja (-5.05 and -14.01%) for plant height; Krasnunia × Sana and Syrena × Krasnunia (25.93 and 9.40%) for spike length; Sadovo 1 × Bezostaja (26.96 and 26.56%) for grains per spike; Pehlivan × Krasnunia (25.00 and 22.28%) for grain weight per spike; Bezostaja × Sana and Bezostaja × Sadovo 1 (8.62% and 5.45%) for 1000-grain weight; Sadovo 1 × Bezostaja (9.28 and 9.14%) for harvest index and Pehlivan × Krasnunia (27.85 and 24.10%) for grain yield per plant, respectively.
Kalimullah (2011) studied about heterotic and heterobeltiotic performances of 10 F$_1$s obtained from half-diallel crosses of five commercial varieties for plant height, number of tillers per plant, spike length, number of spikelets per spike, flag leaf area and number of grains per spike. The highest negative heterosis and heterobeltiosis were recorded in Daman 98 × Sehar (-7.74%) for plant height. Daman 98 × Zam 04 showed maximum positive heterosis (44.05%) whereas Daman 98 × Shafaq showed maximum positive heterobeltiosis (34.85%) for number of tillers per plant.

Desale and Mehta (2013) studied heterosis in a 10 × 10 diallel set of bread wheat. Significant heterobeltiosis and standard heterosis were observed in HW 5018 × HI 1544 for grain yield per plant and harvest index. The cross RAJ 4136 × UAS 281 showed significant heterobeltiosis for grain yield per plant as well as significant standard heterosis for grain yield per plant and harvest index.

Lal et al. (2013) estimated the heterosis and heterobeltiosis for some quantitative characters in 3 crosses involving 4 parents of bread wheat. For grain yield, heterosis over mid parent ranged from -7.62% (Raj 3765 × PBW 343) to 16.84% (Raj 3765 × Raj 4037), while heterobeltiosis ranged from 8.15% (Raj 3765 × Raj 4083) to 14.69% (Raj 3765 × Raj 4037). The cross Raj 3765 × Raj 4037 was found to be promising for days to heading, days to maturity, plant height and grain yield while the cross Raj 3765 × PBW 343 was heterotic for 1000-grain weight.

Lamalakshmidevi et al. (2013) estimated the magnitude of heterosis for grain yield and seven yield components. Thirty six F$_1$ hybrids were derived from crosses among 12 female lines and 3 testers using line x tester mating design. Highly significant differences were observed among the genotypes for the traits viz. days to 75% heading, plant height, spike length, number of spikelets per spike, days to maturity, number of grains per spike, 1000-grain weight and grain yield per plant. The cross UP 2596 x DBW 17 was recognized as the best heterotic cross for grain yield as it exhibited highly significant positive heterosis over both the standard checks UP 2554 and PBW 343. The cross HW 2019 x UP 2338 exhibited the highest and significant positive heterosis over better parent, mid parent and over both the standard variety for number of grains per spike.

Singh et al. (2013) crossed 15 parents in a line × tester mating design. Manifestation of heterosis was observed over mid parent, better parent and the two standard checks viz., UP 2684 and PBW 343. The generated data registered JUPIBJY/URES × UP 2572 as the
best heterotic hybrid for harvest index against the checks UP 2684 and PBW 343 with the values of 27.39% and 50.54%, respectively. Likewise, HP 1749 × UP 2572 showed maximum heterosis (18.66%) over check PBW 343 for grain yield per plant. The data provide information on heterotic advantage of important yield and associated components viz., days to heading, days to maturity, plant height, spike length, productive tillers per plant, number of spikelets per spike, grain yield per plot, harvest index, number of grains per spike and 1000-grain weight.

Barot et al. (2014) evaluated heterosis for yield and yield contributing traits in wheat using 4 lines and 8 testers. The highest heterosis over standard check variety (GW 496) for grain yield per plant was registered by the cross GW 503 x GW 190 followed by GW 173 x GW 190, GW 11 x GW 190 and GW 503 x GW 322.

Gul et al. (2015) estimated heterosis and heterobeltiosis in F₁ generation developed by crossing different wheat genotypes. Significant differences among F₁ hybrid means and respective mid-parent and better parent values were estimated using T-test. Grain yield per plant exhibited the highest heterosis (122.74 %) followed by grains per spike (46.07 %), 100-grain weight (34.07 %), and spike length (24.29 %). The highest heterobeltiosis was observed for grain yield per plant (111.07 %) followed by 100-grain weight (29.90 %) and grains per spike (24.94 %).

Kumar et al. (2015) studied heterosis over better parent for yield and its contributing traits in a 10 x 10 half diallel mating in wheat to identify the best heterotic cross combination. The highest magnitude of heterosis over better parent was observed in the crosses K 9423 x NW 1014 (49.65) followed by UNNAT-HALNA x HUW 560 (48.90) and K 7903 x HUW 560 (48.34) and therefore recognized as better heterotic crosses for grain yield and six other yield attributes. These individual crosses may be exploited in heterosis breeding programme for the improvement of grain yield and other traits according to the objectives of breeding programme.

Patel et al. (2015) estimated heterosis in F₁ generation, generated by crossing different wheat genotype in partial diallel design. Significant heterosis over better parent and mid parent was observed for almost all traits under studied. The maximum heterosis over better parent and mid parent (153.44 and 163.05%, respectively) was observed for grain yield per plant in the cross LOK 1 x GW 273.
Ahmad et al. (2016) conducted an experiment to estimate the nature and magnitude of heterosis for grain yield, its components and quality traits in a diallel cross of eight genetically diverse wheat genotypes excluding recombinants. Highly significant differences were observed among the genotypes for all the traits studied. Significant heterobeltiosis, average heterosis and standard heterosis was observed in the cross BL 3065 x DBW 16 with a value 39.64, 54.59 and 54.30, respectively over the check variety, UP 2554 and it was adjudged best heterotic cross combination for grain yield per plant. The cross UP 2596 x NAPHAL exhibited significant positive standard heterosis for number of tillers per plant and spikelets per spike over the check.

Rahul (2017) studied heterosis for grain yield and its components in F\textsubscript{1} generation of wheat through Line × Tester analysis. The experiment was conducted with 2 replications and 54 genotypes consisting 10 lines viz., ESWYT150, HRWYT213, HRWYT235, IBWSN1021, FHBNS6418, SAWSN3065, PBW658, KB2013-03, KB2013, VW921 and 4 testers viz., GW273, GW366, RVW 4106, SUJATA and their 40 crosses in randomized block design. The cross ESWYT150 × RVW4106 followed by KB2013-03 × SUJATA and KB2013-03 × RVW4106 was recognized as the best heterotic cross by virtue of high per se performance for grain yield and highly significant positive heterosis over both better and mid parent.

Thomas et al. (2017) studied 10 parents and their 45 F\textsubscript{1}’s in wheat under normal and heat stress condition. Cross combination HD 2733 x HUW 468 (50.24 %) depicted the highest positive significant relative heterosis for grain yield followed by AAI 11 x HUW 468 (47.08%) and K 911 x HUW 468 (43.19%). Similarly, AAI 11 x HUW 468 (36.17%) exhibited highest positive significant heterobeltiosis for grain yield followed by hybrids HD 2733 x HUW 468 (35.76%) and HD 2733 x AAI 16 (35.04%) in normal condition. In stressed condition, cross NW 1014 x NW 4035 (30.63 %) followed by K 9162 x NW 4035 (24.12 %) and K 911 x AAI 11 (22.93%) exhibited the highest positive significant relative heterosis. Whereas, the cross combination NW 1014 x NW 4035 (27.76 %) depicted the highest positive significant heterobeltiosis followed by hybrids K 9162 x NW 4035 (19.43%) and NW 4081 x K 9162 (15.99%) which may be exploited for developing hybrids with better yield and yield related traits in wheat.
2.2 Combining ability and Gene action:

Line × tester analysis is one of the quickest methods of understanding the genetic nature of quantitatively inherited traits and it helps to ascertain the prepotency of parents.

The concept of combining ability has become very popular in the discipline of plant breeding since Davis (1927) suggested the use of inbred-variety cross (top cross) as a method of evaluating inbred lines of maize.

The concept of general and specific combining ability as a measure of gene action was proposed by Sprague and Tatum (1942). In this method, the total genetic variance is partitioned into the effect of general and specific combining abilities. The general combining ability (GCA) is defined as the average performance of a line in a series of crosses and is considered as a measure of additive gene action, whereas specific combining ability (SCA) is the deviation in performance of a cross combination from that predicted on the basis of the general combining ability of the parents involved in the cross. It is considered as a measure of non-additive gene action. SCA effects help to sort out superior crosses with respect to yield and different characters, which could be used further in breeding programme to exploit transgressive segregants.

The review on combining ability and gene action for different characters in wheat crop is briefly described in subsequent paragraphs.

Ahmad et al. (1979) studied 36 hybrids derived from 15 bread wheat varieties of diverse origin and found that variance components of specific combining ability for days to flower, grain yield per main spike and grain yield per plant were considerably higher than that for general combining ability variance indicating predominance of non-additive gene action for these traits. Inheritance of spike length and 1000-grain weight was influenced by partial dominance.

In a study on combining ability for grain yield and four related characters from 36 crosses among 9 parents of wheat (Triticum aestivum L.), Sharma et al. (1986) observed highly significant GCA variances for plant height and number of tillers per plant. SCA variances were significant for grain yield per main spike and grain yield per plant.

From a study of 6 genetically diverse wheat varieties and their F₁ hybrids, Rasal et al. (1991) found that additive gene effects were predominant for spikelets per spike, grains per spike and plant height. Parents NI 5439 and Raj 1771 showed the highest gca effects for tillers per plants, spikelets per spike, length of spike, grains per spike and grain yield.
per plant. The hybrids Raj 1771 × NI 5439, NI 5439 × NI 8669 and NI 5439 × NI 8664 depicted significant and positive \textit{sca} effects for grain yield.

Sharma \textit{et al.} (1992) evaluated 20 lines, 3 testers and their 60 \textit{F}$_{1}$S in bread wheat through Line × Tester mating design. They noted that HS 74 was good in GCA for days to heading, 1000-grain weight and grain yield, while WH 74, WH 147, CPAN 1283, WH 129 and WL 711 were good for grain yield. The crosses CPAN 1401 × HD 2009, UP 301 × WH 147, WL 410 × WH 147, HS 74 × WH 147 and E 8682 × WH 157 had high \textit{sca} effects for grain yield and had at least one parent with high \textit{gca} effect for yield and/or one of its component characters and were expected to give desirable transgressive segregants in segregating generations.

A 10 × 10 diallel analysis in bread wheat carried out by Mishra \textit{et al.} (1994), revealed the predominant role of additive gene effect in the expression of all the characters studied except biological yield and harvest index. The variance due to SCA was significant for days to flowering, plant height, days to maturity and yield per plant, indicating that non-additive gene effects were also important for these traits. The line CPAN 1992 was identified as good general combiner for grain yield and major yield components and HD 2329 for grain yield and harvest index.

Iqbal and Singh (1995) studied 15 genotypes and their 45 \textit{F}$_{1}$ hybrids from a partial diallel cross of wheat grown under rainfed and irrigated environments. It was found that harvest index was chiefly under the control of additive gene effects. The estimates of various parameters and gene effects exhibited less variation under both environments for harvest index than for total biomass and grain yield, indicating the suitability of harvest index as a selection criterion. The parents WH 147 and HD 2009 were good general combiners for total biomass and grain yield in both environments. Raj 1579 and Kharchia 65 were good general combiners for total biomass and grain yield while WH 147 for harvest index in the stress (rainfed) condition.

Fifteen genotypes of wheat were crossed in all possible combinations excluding reciprocals by Singh (1996) to work out combining ability for total biomass, grain yield and harvest index under two environments. He observed that the mean squares due to GCA and SCA were significant for all traits, the former being larger in the magnitude than the later in both environments. The GCA/SCA ratio was higher for harvest index than the other two characters indicating that harvest index was chiefly under the control of additive gene
effect, while the reverse was the case for total biomass and grain yield where non-additive gene effects were predominant.

Combining ability analysis for days to flowering and maturity was carried out by Kathiriya and Sharma (1996) by crossing eight bread wheat genotypes in half diallel fashion. They reported that the variances due to GCA and SCA were significant, the former being much larger in magnitude than the later in F1 and F2 generations under both normal and saline sodic condition as well as in pooled analysis. They (Kathiriya and Sharma 1996) further reported that the additive genetic components was higher in magnitude than non-additive component for plant height and flag leaf area indicating the preponderance of additive gene action in the inheritance of both the characters.

Mishra et al. (1996) studied genetic variances from data on 13 yield related traits of ten wheat parents and their 45 F1s. They reported significant additive and non-additive gene actions for the expression of plant height, ear length, days to maturity, number of ears per plant, grains per ear and 1000-grain weight. The characters such as days to flowering, flag leaf area, number spikelets per spike, yield per plant and harvest index showed non-allelic interaction. There was over dominance in the expression of all the characters in the F1 generation except for days to maturity and ears per plant, which showed complete dominance. The plant height, spikelets per ear, 1000-grain weight and harvest index showed partial dominance.

Rajora and Maheshwari (1996) studied combining ability using line × tester analysis (12 lines and 5 testers) in bread wheat. They reported that both additive and non-additive gene actions were important for grain yield per plant, days to heading, plant height, spikelets per spike and harvest index. The inheritance of tillers per plant, spike length, grains per spike and 1000-grain weight was under control of non-additive gene action. The GCA:SCA ratio showed the preponderance of non-additive gene action for all the traits except plant height. The lines UP 301, HD 2428, Sonalika and Raj 3520 and tester WH 147 emerged as good general combiners for grain yield and its various components.

A complete 5 × 5 diallel cross made by Taleei and Beigi (1996) in bread wheat revealed that the variances components attributing to both general combining ability (GCA) and specific combining ability (SCA) for plant height and grain yield per plant were highly significant, but GCA mean squares were higher than SCA mean square for plant height. GCA mean squares were also significant for harvest index, days to heading and 1000-grain
weight indicating the importance of additive genetic variance for these traits. For plant height and grain yield per plant, both additive and non-additive genetic variances were pronounced.

Vitkare and Atale (1996) crossed 15 wheat varieties in diallel fashion and evaluated to study gene action responsible for the inheritance of yield and its components. They reported that the expression of grain yield per plant was due to dominant genetic component, whereas for the expression of ear length, ear weight, grain weight per ear, number of grains per ear and 1000-grain weight additive as well as non-additive genetic variances were important.

Dhaduk and Shukla (1997) studied combining ability in bread wheat using $8 \times 8$ diallel set and found that Raj 1777 was good combiner for grain yield per plant, number of productive tillers per plant, length of main spike, number of spikelets per spike and number of grains per spike. The crosses Pitic 62 × Raj 1777 and Pitic 62 × GW 496 exhibited significant and positive SCA effects for grain yield per plant and other yield attributing characters.

Patil et al. (1997) studied 7 × 7 half diallel cross and found that GCA variances were greater than SCA variances for all the characters except weight of grains per spike, grain yield and 1000-grain weight, while both additive and non-additive gene effects were important for the inheritance of grain yield per plant. The parents NI 8611, NI 5439, NI 2189, Sonalike and Lok 1 were good general combiners for one or more important characters. The crosses NI 8611 × NI 5439, NI 3611 × NI 5643 and Kalyansona × HD 2189 were identified as best crosses, showing significant SCA effects for most of the traits.

Singh and Chatrath (1997) studied combining ability for grain yield and its related characters in a set of diallel cross involving 10 cultivars of bread wheat. Analysis of variance for GCA and SCA indicated significant effects for all the characters under study. The $2\sigma^2_g / (2\sigma^2_g + \sigma^2_s)$ ratio showed that the dominant gene effect was more important for grain yield and number of productive tillers per plant, while both additive and dominant gene effects were important for ear length, number of spikelets per spike, grain weight per plant and 1000-grain weight. For plant height, only additive gene effect was relatively more important.

Nine wheat genotypes were crossed in all possible combinations by Singh et al. (1997) to estimate the combining ability for harvest index, biological yield and grain yield.
under normal and stress environments. Additive genetic variation was important for harvest index, while for biological yield and grain yield, non-additive genetic variation was pronounced. Higher GCA/SCA ratio was observed for harvest index than those for the two traits. The general predictability ratio was near unity for harvest index, while its estimates were low and far from unity for biological and grain yields.

Katiyar (1998) conducted an 18 lines × 3 testers analysis in bread wheat (*Triticum aestivum* L.) and found that both GCA and SCA variances were significant for grain yield per plant. Genotypes UP 2373, BW 1049 and K 8103 were good general combiners for 1000-grain weight, while cross K 8353 × HD 2402 for 1000-grain weight and CB 85 × HD 2402 for grain density were the best specific cross combinations.

Sharma *et al.* (1998) derived the information on combining ability from data on nine yield related traits in the parents, F<sub>1</sub> and F<sub>2</sub> progenies from a 10 lines × 3 testers cross of bread wheat. HD 2285 × CPAN 3004 and Lok 1 × CPAN 2009 showed significant and positive SCA effects and superior per se performance for grain yield per plant. The parents involved in both these hybrids were also good combiners for most of the traits studied.

Chowdhary *et al.* (1999) crossed four wheat varieties in diallel fashion to test the nature of gene action under normal and stress environments. The graphical representation showed that the traits like flag leaf area, number of fertile tillers per plant and spike length were controlled by partial dominance with additive gene action. Whereas 100-grain weight and grain yield exhibited over dominance type of gene action under irrigated conditions.

Sangwan and chaudhary (1999) studied 9 × 9 diallel cross in wheat and reported the pre-dominant role of non-additive gene action for grain yield per plant. Both additive and non-additive gene actions were found equally important for tillers per plant and grains per ear.

From the study of combining ability, Rajora (1999) found that UP-301 and Raj-3077 were good general combiners for grain yield per plant, tillers per plant, grains per spike, 1000-grain weight, harvest index and days to heading. Among the females, WL 711 was the best combiner for grain yield, tillers per plant and grains per spike, and HD 2428 for grain yield, grains per spike and 1000-grain weight. Out of 60 crosses, 20 showed significant and positive specific combining ability effects for grain yield per plant.

Mohla *et al.* (2000) studied parental, F<sub>1</sub>, F<sub>2</sub> and back cross generations of spring wheat crosses WH 157 × WH 147 and Sonalika × CPAN 1444 for gene action. They
observed that dominance and additive × additive interactions were involved in the inheritance of days to heading, spike length and spikelets per spike. However, for biological yield, grain yield and harvest index, dominance, additive × additive and dominance × dominance epistasis were important.

Sheikh and Singh (2000) conducted combining ability analysis for the harvest index and its related traits in bread wheat and reported the role of the additive genetic component in the inheritance of all the characters studied, except the tillers number, total biomass and grain yield per plant for which the non-additive component was more important. Among the parents, WH 542, UP 2338, Raj 3765 and PBW 343 were found to be good general combiners for grain yield per plant. The crosses UP 2338 × Raj 3765 and WH 147 × PBW 343 in the normal environment and WH 542 × PBW 343 in the stress environment were adjudged as the best cross combinations for both grain yield per plant and harvest index. The Harrier’s × PBW 373 in the normal and WH 283 × WH 542 in stress environment were good specific combinations for the total biomass. The study revealed that the crosses, which had both or at least one parent as a good general combiner, might give desirable transgressive segregates.

Singh et al. (2000) evaluated 10 lines × 4 testers crosses along with their parents in late sown condition and observed the preponderance of non-additive genetic variance for days to flowering, days to maturity, number of effective tillers per plant, plant height, length of spike, weight of grains per spike, 1000-grain weight, grain yield per plant and harvest index. Lok 1, HD 2627 and HUW 234 were good general combiners for grain yield as well as for days to flowering, weight of grains per spike and 1000-grain weight. The crosses, Raj 3766 × HUW 234 and Lok 1 × HD 2285 were good specific crosses for grain yield per plant and 1000-grain weight. Recurrent intermitting and selection for the exploitation of non-additive genetic effects were suggested.

Islam et al. (2001) performed genetic studies based on combining ability analysis on nine wheat varieties in half-diallel under moisture stress and non-stress conditions. They reported that the non-additive genetic component of variation was more important than additive component for the traits like number of tillers per plant, biological yield per plant, harvest index and grain yield per plant, whereas the additive genetic component of variation was predominant for the characters like number of grains per ear and 1000-grain weight.
Seventy F₁ progenies developed by crossing 14 winter and 5 spring wheat lines using a line × tester mating design, along with their parents were studied by Kant et al. (2001). They found that the mean squares for days to flowering, weight of grain per spike and 1000-grain weight were highly significant. The mean squares due to female × male interactions were significant for all the characters studied except grains per ear and grain weight per ear. Additive genetic effects were found to play a key role in controlling the expression of days to heading, plant height, and spikelets per ear. MV 19 and stepniak / Karvuna among winter and PBW 65 among spring wheat were good general combiners for most of the yield attributes studied.

Fifty F₁ progenies developed by crossing 10 winter × 5 spring wheat lines along with their parents were evaluated by Gupta and Kant (2002). They observed that additive genetic effects played a key role in the genetic control of days to heading and plant height. Agatha among winter, and HD 2721 and UP 2338 among spring wheat genotypes were good general combiners for most of the attributes. The cross Agent × Raj 3765 had significant sca effects for most of the yield attributes.

Sudesh et al. (2002) concluded combining ability analysis involving four ‘gigas’ genotypes as testers with 10 diverse lines, for 13 morphological characters related to spike, grain and yield. They found that HD 2009 M and SG 8809 among testers and PBW 343, WH 542 and DI 9 among the lines were good combiners for most of the characters studied. Higher sca effect was observed for grain yield per plant in cross UP 2238 × HD 2000M followed by Raj 3765 × HD 2009 M and PBW 343 × SG 15. Most of the cross combinations involved either both or one of the parents with good combining ability.

Combining ability was studied through an 8 × 8 diallel set of wheat by Singh and Singh (2003). They recorded low values of the predictability ratio for days to maturity, total dry matter yield per plant, 100-seed weight and harvest index which indicated the predominance of non-additive gene effects for days to flower, flag leaf length, peduncle length and grains per spike, while additive gene effect had predominant role in the expression of plant height and effective tiller number.

Dhayal and Sasty (2003) studied combining ability in bread wheat under salinity and normal conditions using 10 × 10 diallel analysis. The significant mean squares due to GCA and SCA indicated that both additive as well as non-additive components contributed to the inheritance, although predominance of additive components was observed for days
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to flowering, plant height and 1000-grain weight in both the environments, while non-
additive gene effect was observed for number of tillers per plant, number of grains per
spike, grain weight per ear and grain yield per plant. The gca effects in both the environemnts revealed that none of the parents was observed to be a good general combiner
for all the desirable traits. Lok-1 and KRL 1-4 showed desirable gca effects for grain yield
under normal and saline environment, respectively. Parents K 65 followed by Raj 3077 had
desirable gca effects in both the environments for number of tillers per plant, number of
grains spike, 1000-grain weight and grain yield per plant.

Kumar et al. (2003) evaluated 8 lines, 3 testers and their 24 hybrids for combining
ability and gene action for grain yield and its related characters in wheat. The results
revealed that non-additive type of gene effect was more important than that of additive gene
action for days to 75% flowering and maturity, number of grains per spike, biological yield,
grain yield per plant and harvest index. The preponderance of additive type of gene action
was observed for plant height, spike length, 1000-grain weight and protein content.

Mavi et al. (2003) performed combining ability analysis in a 10 × 10 diallel cross
of bread wheat under two nitrogen regimes. The results showed that the GCA and SCA
variances and reciprocal effects were significant for most of the characters like days to
heading, number of tillers per plant, days to maturity, number of grains per ear and grain
yield per plant except reciprocal cross effect for 1000-grain weight. Higher magnitude of
GCA variance than the SCA variances were recorded under two environments for all the
traits except grain yield per plant and number of grains per ears in E1 indicated a
predominant role of additive genetic variance. Non-additive genetic variance was more
important in the inheritance of grain yield per plant and number of grains per ear. The
parent PBW 343 was the best general combiner for days to heading, number of tillers per
plant, grain yield per plant, 1000-grain weight and days to maturity followed by C 518 and
UP 2338. In general, the crosses expressing high sca effects involved parents with high ×
high, high × low and low × low gca effects.

Singh (2003) estimated genetics of yield components and their relevance to plant
ideotype concept in 80 wheat crosses by studying their combining ability and different
selection parameters in relation to plant type. The estimates of variance components
depicted the preponderance of non-additive genetic variance and overdominance for all the
characters. Grain yield per plant was significantly associated with the number of productive
tillers per plant, number of grains per spike and 100-seed weight. According to them the
ideal plant type of wheat was one with more productive tillers per plant, more grains per spike and bold seeds.

Joshi et al. (2004) studied general and specific combining ability analysis for grain yield and its components traits using 10 parents and their resulting 45 F₁s and 45 F₂s in wheat. The analysis of variance for combining ability revealed that the variances due to GCA and SCA were highly significant for plant height, flag leaf area, tiller per plant, spike length, harvest index, 1000-grain weight, protein content and grain yield per plant indicating that both the types of gene effects were important in controlling the inheritance of these characters. However, the GCA: SCA ratio normally fitted in favour of GCA in all the traits (except for 1000-grain weight in both F₁ and F₂ generations) indicating the preponderance of additive gene effects in the genetic control of the traits. The 1000-grain weight was primarily controlled by non-additive component of genetic variance. Among parents, Durgapura 65, HD 2285, Lok 1, Raj 1972 and HD 2329 were good general combiners for grain yield and for most of the yield components characters.

Pareek and Garg (2004) analysed a 6 × 6 diallel cross in wheat for yield and its contributing characters like tillers per plant, grains per spike, grain yield per spike and 1000-grain weight. The results showed the preponderance of non-additive gene action for grain yield per plant as well as for the most of the characters except for the tillers per plant.

Desai et al. (2005) estimated combining ability for quantitative traits in bread wheat through line × tester analysis and revealed that significant variations among males, females, and male × females for all the traits. The GCA and SCA variance ratio revealed the preponderance of non-additive gene action in governing the expression of all the traits except plant height. The estimates of gca effects revealed that the lines NI 5439, Sonalika, Pusa 4 and the tester DWR 248 were better general combiners for grain yield.

Sharma and Garg (2005) studied combining ability effects for twelve metrical traits in bread wheat using fifteen lines, four testers and their sixty hybrids under four environments. Analysis of variance for combining ability revealed that both additive and non-additive gene action were present. However, non-additive gene action was predominant for all the characters viz., days to flowering, days to maturity, plant height, productive tillers per plant, spike length, number of spikelets per spike, number of grains per spike, 1000-grain weight, biological yield per plant and grain yield per plant. Among
the lines, Raj 442, Sonalika, UP 2338, Job 666 and among testers, Lok 1 were good combiners for grain yield and most of other related traits.

In order to examine the genetic mechanisms controlling biomass, protein content and grain yield, eight parental lines (Pak 81, LU 26S, Barani 83, Rawal 87, Rohtas 90, Chakwal 86, Inqilab 91 and 5039) were crossed in all possible combinations through diallel mating system by Muhammad and Khan (2006). Combining ability analysis revealed that general combining ability effects were highly significant for biomass, protein content and grain yield. The general combining ability (GCA) variances were greater than specific combining ability (SCA) variances for biomass per plant and protein content, which showed the predominance of additive gene effects. SCA variance was greater than GCA variance for grain yield per plant that showed the predominance of non-additive gene effects. Among the eight parents, LU 26S and Chakwal 86 appeared to be the best general combiners for all the characters studied. Due to the preponderance effects of additive genes, it seems that single plant selection in segregating generations would be effective for improving the traits.

Combining ability analysis over environments for grain yield and its components in bread wheat was studied by Dhadhal and Dobariya (2006). Analysis of variance for combining ability pooled over environments revealed that the mean squares due to lines, testers and line × testers were significant for days to flowering, days to maturity, plant height, spike length, number of spikelets per spike and number of grains per spike. This indicated the importance of both additive and non-additive gene effects in the genetic control of these characters. Estimates of general combining ability effects revealed that none of the parents was a good general combiner simultaneously for days to flowering, days to maturity, plant height, productive tillers per plant and 1000-grain weight. Chiloero × GW 173 and 7C Nad 63 tab’s × PBW 373 showed significant and positive specific combining ability for grain yield and some of its components.

Vanparya et al. (2006b) evaluated fourteen parents (ten lines and four testers) and 40 F1s using line × tester analysis in bread wheat. They reported that both additive and non-additive gene actions were important for inheritance of all the characters studied. However, the SCA/GCA ratio of components showed the preponderance of additive gene effect for days to heading, plant height, length of main spike and spikelets per spike. The preponderance of non-additive gene effects were found for grain yield per plant, tillers per plant, peduncle length of main spike, days to maturity, grains per spike, 100-grain weight,
grain yield per spike and harvest index. The lines, DL 803-3 and PBW 316 and tester GW 496 emerged as good general combiners for grain yield and its various compounds.

Chowdhary et al. (2007) studied 5 × 5 complete diallel cross in wheat. General combining ability variance was highly significant for tillers per plant, peduncle length of main spike, days to maturity and grains per spike. Specific combining ability variance was highly significant for tillers per plant, peduncle length per main spike and grains per spike. Additive gene effect controlled the expression of all the traits as evident by greater mean squares for general combining ability except peduncle length where an expression of non-additive gene effect was noticed.

Tahmasebi et al (2007) evaluated diallel cross of eight bread wheat cultivars in two environments to estimate genetic parameters for yield and yield components. The mean squares due to GCA were significant for tillers per plant, peduncle length for main spike, days to maturity and grains per spike in both environments. The ratio of GCA to SCA indicated the importance of additive gene effect in controlling plant height, spike length and number of grains per spike in both environments and number of spikelets per spike in E2.

Singh et al. (2007) estimated combining ability for yield and associated traits in bread wheat. Data were recorded for days to heading, days to maturity, number of effective tillers per plant, plant height, spike length, number of spikelets per spike, number of grains per spike, flag leaf area, 1000-grain weight, biological yield per plant and harvest index and grain yield per plant. The analysis of variance for combining ability revealed that GCA as well as SCA effects were highly significant for grain yield per plant under study in both the environments. The SCA/GCA variance ratio showed the preponderance of additive gene effect for days to heading, plant height, number of tillers per plant, length of main spike and grain yield per plant. The preponderance of non-additive genetic effects was found for biological yield per plant and 1000-grain weight.

Dhadhal et al. (2008) evaluated combining ability analysis using line × tester (11 lines and 3 testers) mating design in bread wheat which revealed that both additive and non-additive gene actions were important for grain yield per plant, days to heading, days to maturity, number of effective tillers per plant, length of main spike, number of spikelets per spike, number of grains per spike, 1000-grain weight and harvest index. The inheritance of grain yield per plant, days to heading, days to maturity, length of main spike, number of
spikelets per spike and 1000-grain right was mainly under the control of additive gene action. The lines HUW 234, GW 322, GW 273, 7C Nad 63 tab’s, MP 3077 and testers PBW 373 were good general combiners for grain yield and some of its components. Eight crosses showed significant and desirable $sca$ effects for grain yield per plant. The cross Chilero × GW 173 was the most promising as it had high $sca$ effects for length of main spike, number of spikelets per spike, number of grains per spike, and 1000-grain weight. Biparental mating of few cycles of recurrent selection was suggested to exploit both additive and non-additive gene actions and to obtain transgressive segregants for grain yield per plant in advanced generations.

Seboka and Singh (2009) estimated the data from eight parents and their F$_1$ progenies of half diallel crosses for combining ability for yield and yield related components. Significant differences among all the genotypes were apparent for yield per plant, plant height and spikelets per spike. Both $gca$ and $sca$ mean squares revealed significant differences for plant height, harvest index, grain yield per plant, 1000-kernel weight and maturity traits, indicating the important of both additive and non-additive gene actions in the inheritance of these traits with the predominant effect of non-additive gene action. For the remaining traits, only mean square due to $gca$ showed significant variation, indicating the greater importance of additive gene action in controlling the inheritance of these characters. Abola gave highly significant $gca$ effects in the desirable direction and was the best general combiner for most of the traits, followed by Galema and Sofumer, while Dashen was the only parent which showed significant positive $gca$ effect for grain yield per plant. Cross combinations of Dashen × Galema, Abola × Dure, Dashen × Meda-Welabu, Abola × Galema, and Galema × Dure exhibited significant $sca$ effects in the desired direction for at least two and, at most, for four traits, for which $sca$ variance showed significant differences.

Sami et al. (2010) determined gene action for grain yield and its component traits in a 6 × 6 diallel cross involving six wheat varieties namely Sehar 06, Pb 96, GA 2002, Barani 83, Kohistan 97 and Chakwal 86. Additive gene action with partial dominance was observed for plant height, number of tillers per plant, spike length, number of spikelets per spike and grain yield per plant, while overdominance was observed for peduncle length. Non-allelic interaction was absent for all the traits studied.

Kamaluddin et al. (2011) estimated combining ability analysis for protein content, days to 50 % flowering, days to 50 % heading in growing days (GDD), days to 50 %
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heading, days to 50 % heading in growing days (GDD), days to 50 % physical maturity, days to 50 % physiological maturity in growing days (GDD), No. of grains per spike, 1000 grain weight and grain yield per plant in spring wheat. Additive as well as dominant gene action was responsible for expression of these traits. Most of the genotypes were found to be superior general combiners for protein content and other traits studied. Likewise, crosses involving diverse parents showed significant SCA effects for protein content and other traits. To ensure in further increase in protein content with optimum maturity duration, combinations of desirable desirable component trait is advocated. Biparental and/or diallel selective mating design would be useful methods for further improvement of protein content with optimum level of maturity time and grain yield in spring wheat.

Kumar et al. (2011) studied combining ability analysis in a 7 × 7 diallel set of bread wheat. On the basis of overall performance, parent K 7903 was found to be desirable combiner for early flowering and shorter plant height. The parent K 9107 was responsible for early flowering, number of tillers/plant, plant height, number of spikelets per spike, grain number, 1000-grain weight, seed rigidity and grain yield per plant. Similarly, the parent GW 373 was responsible for early flowering and more tillers per plant and parent K 9162 was responsible for more tillers per plant, more spikelets per spike, grain number, more seed hardness, and grain yield per plant while K 9351 resulted in shorter plant height and enhanced grain yield.

Zahid et al. (2011) estimated combining ability effects and variances for yield and quality related traits from the data 8 × 8 diallel cross of spring wheat. The general combining ability effects were significant for all the characters except days to maturity, whereas specific combining ability effects were significant for most of the characters except grain yield, flag leaf area, number of spikelets per spike, protein content and lysine contents. The variances due to SCA were greater than GCA for most of the characters indicating the importance of non-additive gene action for most of the traits.

Jain and Sastry (2012) crossed six lines with four testers in a line x tester fashion to determine the general and specific combining ability for yield and its traits like days to 50 % flowering, plant height, number of productive tillers/plant, grain weight per ear, number of grains per ear, biological yield per plant, 1000-grain weight and harvest index in wheat. The mean square due to gca and sca were significant for most of the traits which indicated the presence of both additive and non additive gene effects for controlling the expression of yield and yield contributing characters.
Singh et al. (2012) studied combining ability for yield, its contributing traits and quality parameters in 15 parental genotypes (12 lines and 3 testers) using a line x tester mating design. The differences among genotypes were found highly significant for all the characters studied. Estimates of variance due to general combining ability (gca) and specific combining ability (sca) and their ratio revealed that both additive and non-additive gene effects were important for different characters studied.

Lohithaswa et al. (2013) estimated combining ability for grain yield and its components using 5 lines, 7 testers and 35 crosses produced in line x tester mating system in durum and emmer wheat. The general and specific combining ability variance ratio revealed the preponderance of additive gene action for all the traits viz., days to 50% flowering, days to maturity, plant height, peduncle length, spike length, number of spikes per m², number of tillers per plant, number of seeds per spike, total biomass per plant, 1000-grain weight, grain yield per plant and harvest index except for number of seeds per spike. Significant gca effects for grain yield and its component traits were exhibited by the lines Vijay and DK 1001 and testers DWR 1006 and Raj 1555. Fourteen crosses recorded significant sca effects for grain yield and related traits.

Singh et al. (2013) studied combining ability using a half diallel of 10 parents. The results revealed the importance of both additive and non-additive genetic variances for control of various traits. However, the ratio of GCA/SCA revealed preponderance of non-additive gene actions in almost all the traits viz., days to 50% flowering, days to maturity, plant height, tillers per plant, peduncle length, spike length, number of spikelets per spike, number of grains per spike, grain yield per spike, 1000-grain weight, biological yield per plant, harvest index and grain yield per plant. Parents Raj 4063, HD 2851 and WH 789 were the good general combiners, whereas crosses viz., WH 789 × NW 3015, HUW 468 × UP 2614 and HS 448 × Raj 4063 were found to be best specific combiners for grain yield per plant.

Attia et al. (2014) studied combining ability in a 6 × 6 diallel set of crosses. Many hybrids showed desirable significant or highly significant sca effects for all studied traits like plant height, number of spikes per plant, number of kernels per spike, grain yield per plant, 100-kernel weight, total plant weight, straw yield and harvest index. The overall study revealed that the best parents and cross combinations could be effectively utilized in wheat breeding improvement. The importance of additive and non-additive genetic effects...
were also noted and suggested that the use of integrated breeding strategies can efficiently utilize the additive and non-additive genetic effects.

Barot et al. (2014) evaluated 12 parents and their 32 F₁s for the study of combining ability and gene action in wheat using a line × tester (4 lines and 8 testers) mating design. They revealed that both additive and non-additive gene actions were important for control the expression of all the traits. The magnitude of general combining ability variances was higher than the specific combining ability variances for the characters viz., days to 50% heading, days to maturity, plant height, number of effective tillers, length of main spike, grain yield per plant, spikelets per spike, grain yield per spike, 100-grain weight, harvest index and protein content. This indicated preponderance of additive gene effects in inheritance of these traits. Among females, GW 11 and among males, GW 322 were found to be good general combiners for grain yield per plant, harvest index and protein content.

Dholariya et al. (2014) studied combining ability and nature of gene interactions that contribute to grain yield and its attributing traits of wheat using 28 bread wheat hybrids developed by crossing 8 commercial varieties in a diallel mating design. The results indicated the occurrence of both additive and non-additive type of gene interactions for all the characters studied. The estimate of GCA effects indicated that the parents GW 366, GW 411, K 583, KRL 213 and LOK 1, were identified as good general combiners revealing their ability in transmitting additive genes in the desirable direction to their progenies. The hybrids viz., GW 366 x HD 2687, GW 366 x LOK 1 and LOK 1 x KRL 213 were found to be good specific crosses for grain yield per plant in which GW 366 x HD 2687 was found to be the best specific combiner for number of effective tillers per plant, length of main spike, number of spikelets per main spike, number of grains per main spike, 100-grain weight, biological yield per plant and harvest index.

Pansuriya et al. (2014) carried out a study on combining ability through a 10-parental diallel cross of aestivum wheat (Triticum aestivum L.). The pooled analysis of variances for combining ability suggested the role of both additive and non-additive gene action with preponderance of non-additive gene effects in the expression of all the traits studied. The parents GW 366, K 9906 and WR 885 were found to be good general combiners for grain yield per plant. The parents LOK 1, DL 788-2 and Raj 3765 expressed significant and negative (desirable) GCA effects and were emerged as good general combiners for early maturity. The parents DL 788-2 and Raj 3765 for short stature and K 9906, KRL 213 and GW 366 for number of effective tillers, length of main spike and for
spikelets per spike were emerged as good general combiners. The cross K 9906 x RAJ 3765 was having highest grain yield per plant coupled with highest $sca$ effect for the same trait followed by GW 173 X WH 1059 and K 9906 X WR 885.

Kerkhi and Kumar (2015) carried out combining ability analysis in a 10 × 10 diallel cross of spring wheat (Triticum aestivum L.). The analysis of variance for combining ability revealed that the variance due to $gca$ and $sca$ were highly significant for all the characters indicated that both the additive and non-additive gene actions were involved in the expression of the traits. The genotypes WH 1094, PBW 590 and PBW 373 were considered as good general combiners, while hybrids *viz.*, DBW 58 x DBW 17, PBW 550 x PBW 373, MP 1236 x PBW 373, WH 1094 x PBW 590, PBW 590 x PBW 373, RAJ 3765 x HD 2687, PBW 590 x WH 711, MP 1236 x PBW 550, RAJ 3765 x DBW 58, HD 2687 x WH 711 and MP 1236 x WH 1094 as good specific combinations for grain yield and other yield contributing and quality traits. The promising parents namely PBW 373, PBW 590 and WH 1094 which are having high $gca$ effects in desirable direction for yield components and for quality traits may be incorporated in crossing programme to have better genotypes for yield better and quality. The crosses *viz.*, PBW 550 x PBW 373, MP 1236 x PBW 373, WH 1094 x PBW 590, MP 1236 x PBW 550 and RAJ 3765 x DBW 58 showed good $sca$ effects for major yield and more than six yield components characters.

Natasa et al. (2015) studied combining ability and gene action involved in the expression of the traits *viz.*, grain weight per spike and grain weight per plant of wheat in *F$_1$* generation, of 5 × 5 half diallel cross of bread wheat varieties (Triticum aestivum L.). The results of combining ability analysis indicated that among the parents, genotypes Sara, Pobeda and Renesansa were found to be good general combiners for the both investigated traits. The best specific crosses for both traits were Sara × Partizanka, Pobeda × Sara, Renesansa × Partizanka, Partizanka × Pesma and Pobeda × Pesma. Most of the specific crosses involved high × high, high × low and low × low general combiners. The results of regression analysis, as well as the analyses of components of genetic variation indicated over-dominance in the inheritance of examined traits.

Ahmad et al. (2016) assessed the combining ability for yield and yield contributing traits along with quality parameters of wheat. Twenty eight hybrids were synthesized in a 8 × 8 diallel fashion excluding reciprocals. The analysis of variance revealed that the genotypes were highly significant for all the characters studied. The results revealed that non-additive genetic variance played a predominant role in the inheritance of most of the
traits. The best combinations mostly involved good × poor and poor × poor general combiners for the characters under study. On the basis of gca effects, 3 parents viz., UP 2754, DBW 17 and UP 2696 were found as good general combiners for grain yield and quality traits. BL 3065 × DBW 16, BL 3065 × UP 2754 and BL 3065 × UP 2696 were observed as good specific crosses for grain yield and its contributing traits.

Jatav et al. (2017) carried out combining ability analysis using line × tester mating design involving 7 lines and 3 testers under water stress and non-stress environments. The analysis of genetic components revealed that both additive as well as non-additive components were prevalent for the control of grain yield and its components under both water stress and non-stress environments except spike length under stress environment. The combining ability effects revealed that parent DL 803-3 was identified as good general combiner for grain yield under both water stress and non-stress environments while GW190 and GW 173 for grain yield under stress environment. The significant specific good combining cross ‘GW 322 X GW 173’ was having one promising parent for grain yield under stress condition.

Murugan and Kannan (2017) carried out combining ability analysis by line × tester mating design using 7 lines and 4 testers. The estimation of SCA variance was higher than GCA variance for all the characters indicating that non-additive genetic variance was higher than additive genetic variance for these characters. The parent PBW 343 exhibited desirable significance gca effect for days of flowering, spike length, number of spikelets per spikes, 1000-grain weight and biological yield. The parent UP 2338 exhibited desirable significance gca effect for days of maturity and grain yield per plant. The best cross on the basis of sca effect was UP 2338 x Pavon 76 for days to flowering, days of maturity, plant height, grain yield per plant and biological yield.

Yadav et al. (2017) analyzed combining ability and gene action using a half diallel of ten parents in bread wheat (Triticum aestivum L.). Combining ability analysis revealed the importance of both additive as well as non-additive genetic variances for control of various traits. However, the ratio of GCA/SCA variance revealed preponderance of non-additive gene action in almost all the traits. Parent Raj 4120 was the good general combiner, whereas crosses Raj 4120 × WH 1021 and Raj 4120 × DBW 17 were found to be good specific combiners for grain yield per plant and some of the yield contributing traits.