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Combining Ability Analysis Is a Breeding Approach to Develop Drought Tolerance of Wheat Genotypes

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Abstract: Estimation of combining ability is an essential process in cereal breeding and dissection of the genetic basis of combining ability would enable wheat breeding.The efficiency of breeding strategies to enhance drought tolerance in wheat could be increased further if some of the complications in gene-to-phenotype (G → P) relations related with epistasis, pleiotropy and genotype-by-environment interactions could be captured in realistic G → P models and characterized in a quantifiable manner useful for variety. Wheat is a staple food crop in Pakistan. Wheat is a rich and economical source of protein. Prerequisite of food is aggregating day by day with the growing population. Demand of wheat is also increasing with high population. Wheat breeders are trying to get maximum yield with limiting resources. Water limitation is a big problem among the major reasons. It is a great challenge for a plant breeder to face different types of drought. Due to water stress the grains are desiccated and also results in early maturity of the crop. Wheat is grown under a diverse range of areas and environmental conditions. The present review will help the readers to understand breeding of wheat under drought conditions. This review showed that desiccation tolerance index and percent seedling recovery may be useful for seedling parameters. Drought tolerant wheat genotypes give the best production in rainfed areas. It might be concluded that the lines with increased general combining ability effects would give better results for improving grain yield and spike traits.

Key words: Combining ability · *Triticum aestivum L.* Drought · GCA · SCA · Gene action

INTRODUCTION

Wheat (*Triticum aestivum L.)* is a member of family Poaceae and is the king of cereals in many countries of the world including Pakistan. It is staple food crop of one- third of world's community. In South Asia, cultivation of wheat is in central, northern and north western India, while in Pakistan it is adapted to the plain areas. It is important in regard to nutritive value, production, storage space qualities, utilization, adaptation and transaction [1]. Wheat is a rich and cheaper source of protein. It is backbone of economy of Pakistan with share of 10.1 % value added in agriculture and contributes 2.2 % to gross domestic product (GDP) of Pakistan. Wheat production has increased from 23.5 million tons to 24.2 million tons showing an increase of 3.2 % but the target was not achieved; there was 5 % decline in yield [2-5]. At present, the estimated population of Pakistan is over 187 million. Requirement of food is increasing day by day with the growing population. Demand of wheat is increasing with increasing population. So there is a need to breed varieties with high productivity even in water stress conditions. Wheat breeders are trying to get maximum yield with limiting resources [6,7].

Water limitation is a big problem among the major reasons. It is a great challenge for a plant breeder to face different types of drought [8,9]. There is severe shortage of water in canal irrigated areas due to low level of water in rivers and unequal distribution of water to provinces. Due to water stress the grains are desiccated and also results in early maturity of the crop. Wheat is grown under a diverse range of areas and environmental

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conditions. The growing period for wheat after rice is enough while it is late when grown after either cotton or sugarcane. Therefore these problems should be eliminated. Breeders are doing their best to develop wheat cultivars with high yield as well as drought tolerance. The present review will help the readers to understand breeding of wheat under drought conditions.

Seedling Parameters: The seedling traits emergence percentage, emergence index, emergence rate index, mean emergence time and percent seedling recovery were evaluated under water deficit conditions. Significant differences were shown among genotypes in most of the traits. Genetic variance estimates were smaller than phenotypic variance for all traits. Positive correlations were shown by all the traits. These estimates showed that desiccation tolerance index and percent seedling recovery were useful for seedling parameters [10,11].

Bread wheat genotypes It were evaluated for germination percentage, root length, shoot length, root to shoot length ratio and coleoptiles length under labortary conditions. All the characters showed considerable variation. Suppression of variability was observed under moisture stress conditions. The most sensitive trait observed was the seed vigour followed by shoot length, germination percentage and root length. The magnitude of genetic components of variance and heritability was lower under osmotic stress condition. Correlation studies indicated that the osmotic membrane stability of the leaf segment was the most important trait, followed by root-to-shoot ratio and root length on the basis of their relationships with other traits [2,3,7,12]. Forty wheat genotypes were screened for drought tolerance using 0, 7.5, 15 and 22.5% polyethylene, ethylene glycol 6000 solutions. The wheat genotype Lyalpur-73 was found the best for germination percentage (87.5%). Wheat genotypes Pasban 90 and WC-18 possessed maximum root length (9.9 cm) and seedling vigor (7.4). The genotype Auqab-2000 showed maximum shoot length (8.3cm). Germination percentage and germination rate index showed positive correlation with all other traits. Root length showed positive association with shoot length and coleoptile length. While shoot length had positive correlation with coleoptile length and seedling vigour. Drought tolerant wheat genotypes gave the best production in rainfed areas [13-15].

Combining Ability: Grain yield and seven other agronomic characters under normal and salt stressed conditions were studied. Absence of epistasis for twelve out of sixty four cases studied in cross combinations was noticed under both environments. In all the cases the relative importance of additive-dominance effects varied with characters, crosses and environment suggesting that epitasis were not operative in this instance. The estimators of more dominant effect appear to be more independent of epistatic effect then the additive estimator for spike per plant. Additive gene effect was observed for spike length in three crosses under normal condition showed the feasibility of selecting longer in these crosses [16-18].

Line × tester analysis using 3 lines (females) and 3 testers (males) was performed for morpho-physiological characters in bread wheat genotype. For grain yield per plant, number of grains per spike and number of tillers per plant, Chakwal 86 showed highest positive general combining ability effects, while for flag leaf area Barani-83 revealed highest positive general combining ability effects. For epidermal cell size negative specific combining ability effects were observed in the cross Kohistan-97 × MH-97. For grain yield per plant, number of grains per spike and number of tiller per plant positive SCA effects were observed in cross Kohistan-97 × Pasban 90. Negative SCA effects were estimated for grain yield and number of grain per spike 55% and 65% respectively. The positive SCA effects were found for number of tillers per plant, flag leaf area and epidermal cell size 44 percent [11,19,20].

Combining ability through line × tester analysis involving the three varieties Barani 83, Chakwal 86, Kohistan-97 as lines and three varieties viz. Pasban 90, Punjab 96 and MH-97 as testers, for physio-morphological traits was studied. Among the lines, Chakwal 86 showed the highest positive general combining ability effects for number of spikelets per spike and grain yield per plant. The cross combinations Barani 83 × Punjab 96 exhibited maximum specific combining ability effects for number of spikelet per spike and spike length [17]. They reported that spring × winter wheat crosses were performed in line × tester fashion to determine the combining ability effects. They crossed ten winter wheat varieties as females with 5 testers males and evaluated 50 hybrids with their parents for economic yield. Except, grain yield per plant, remaining characters revealed significant mean squares due to male and female interaction. Grain yield per plant and plant height were controlled by additive gene action. For most of the traits, the good general combiners, among spring wheat genotypes were UP 2338, HD 2721 and among winter wheat genotype were Agatha and Valley. For most of the traits, significant SCA effects were observed in the cross Agent Raj×3765 [21-24].

The combining ability for yield and yield attributes such as spike length, 1000- kernel weight, plant height and number of spikelets per spike was determined by akbar *et al*. 2009. The mean squares for general and specific combining ability were significant for all traits. Specific combining ability variance was higher than general combining ability variance indicating that the value of non additive type was more important than aditive of gene action for all traits. 4943B was a good general combiner for grain weight per plant, whereas Punjab -96 ×4943 was the best cross combination [25,26,19].

Analysis of combining ability including "gigas" genotypes as tester with 10 different lines of wheat was performed for 7 morphological traits such as ear length, plant height, number of spikelets per spike, number of spikes per plant, grain weight per plant and number of seeds per ear. Higher GCA variances were observed for grain weight per plant. In most crosses, there is contribution of two or one of the parents with best combining ability expressing the importance of additive gene action [27,16,28,20]. The combining ability of plant height, number of spikelets per spike and grain weight per spike was evaluated by using line × tester analysis. Three testers, five lines and fifteen hybrids of wheat and durum wheat were used. The line NS31/96 and Yanterodeskii was the best general combiner. The hybrids having best specific combining ability were produced [14,15,29,8].

Twenty four F_1 progenies were developed by eight winter and three spring wheat lines utilizing line × tester fashion along with their parents for yield and yield attributes. Means square for all traits under consideration were highly significant. Female × male interactions mean squares were significant for all traits except for days to maturity. Additive gene action was seen to play a vital role in genetic control of days to maturity and days to heading. Among winter wheat, the genotypes Marisdoe and Maldova and among spring wheat, genotypes NP-4 and NP-846 were the best general combiners for most of the characters studied. Cross combinations Burgas-2 × NP-846, Marsidoe × NP-809 and TW-238 × NP-4 had significant SCA effects for yield and yield components [30,16,28,31,21].

Agronomic Traits: Genetic architecture of some important agronomic trait in durum wheat was studied. Gene action and component of variance analysis were made. Mean squares for GCA were highly significant for spike length, tiller per plant, grains per spike and number of spikelets per spike, significant for plant height and flag leaf area and non significant for grain yield per plant and thousand grain weight. For mean squares of SCA except fertile tiller per plant, all other traits were highly significant. The magnitude of specific combining ability variance were less than general combining ability variance for tillers per plant, spike length, flag leaf area, grain yield per plant and 1000-grain weight, suggesting that additive genetic variance controls these traits [32,22-25]

Analysis of combining ability for six plant characters was performed. GCA and SCA were highly significant for 100-grain weight, spikelets per spike, days to maturity, plant height and grain yield per plant. SCA variance was higher than GCA variance, except for plant height. The variety Shalimar-88 was good general combiner for 100-grain weight and grain yield, whereas genotypes Sutlej-86 and Blue Silver expressed better potential for plant height. Cross combinations like Barani-83 × Pirsabak-91, Blue Silver× Pirsabak-91 and Silver blue × Sutlej-86 were good specific combiners for grain yield [8,15,33-35].

The mode of inheritance, gene effects and combining ability of grain weight per spike and harvest index were determined using 5 females, 3 testers and 15 hybrids of durum wheat. The results showed that grain weight was affected by non-additive genes. The mode of inheritance was dependent on cross combination and the year of growing. In 1st year, no genotype showed significant GCA effects for grain weight per spike while in 2nd year, genotype Kundru was the best general combiner. Positive SCA effects were associated with crosses of two genetically different parents having one as a good general combiner [23,36-38]. Three wheat genotypes and their combining ability effects were measured. PBW-222, LU-26S and Uqab-2000 as testers and two lines 8961 and 8652 as female parents were used. The traits plant height, tillers per plant, spikelets per spike, number of grains per spike and flag leaf area showed significant general combining ability as well as specific combining ability variances. The magnitude of GCA variance was greater than the SCA variance indicating that the additive genetic variance control for flag leaf area, number of grains per spike, spike length and spikelets per spike. The traits plant height, number of tillers per plant, spikelets per spike and grain yield showed high specific combining ability, assuring the presence of non-additive genetic effects [12,32,39-41].

Eight parent lines of wheat viz. Pak-81, Barani-83, LU26S, Rohtas-90, Chakwal-83, Inqilab-91, Rawal-87 and 5039 were analyzed [30,37,38,42]. These were crossed in all possible combinations to evaluate combining ability effects for yield and spike attributes. General combining ability effects were significant for number of spikelets per spike, spike length, spike density, number of grains per spike and grain weight per plant. The SCA variances were higher than GCA variances which indicate the predominance of non additive type of genetic effects. Among the parent lines, genotypes Barani-83 and Rohtas-90 were the good general combiners for all spike traits, while the genotype LU26S was good for grain weight per plant. It might be predicted that the lines with increased general combining ability would give better results for improving grain yield and spike traits. General combining ability, Specific combining ability and reciprocal effects for different yield traits like number of productive tillers per plant, flag leaf area, ear length, number of spikelets per spike, number of seeds per spike, 1000-seed weight and grain weight per plant were analyzed. General combining ability mean squares were higher than specific combining ability mean squares for all traits except for number of fertile tillers per plant, number of seeds per ear and 1000-seed weight. Other traits expressing high specific combining ability effects showed non additive gene action [5,24,38,43].

A research in 2 successive seasons was performed to analyze 6 wheat lines which were mated with 3 testers for producing 18 cross combinations by utilizing line × tester analysis [12,43,32,40].The traits used for analysis were heading duration, number of ears per plant, plant height, spike length, number of spikelets per spike, days to maturity, mother shoot spike weight, grain yield per plant and thousand grain weight. The analyzed treatments such as parents, crosses, parents vs crosses, lines, testers and line × tester interaction showed a great variance for all traits, with the exception of number of days to maturity, number of spikes per plant, plant height, number of spikes of tester, spike length and days to maturity for lines × tester interaction. The superior combiners were lines P1, P3 and P6 for yield and its associated attributes, while, for shortness, best combiners were lines 2,5 and 6, whereas, lines 1,2,4 were better parental lines for earliness. These genotypes could be used as genetic material to improve yielding ability wheat cultivars in subsequent breeding schemes [35,6,7,4,5,40].

Gene action in 25 crosses of spring wheat for grain weight and its associated traits under arid conditions was studied (Cheema *et al*. 2007). Great differences were shown by genotypes for number of effective tillers per plant, number of seeds per ear, number of spikelets per spike, spike length, 1000-seed weight and grain weight per plant. Combining ability investigation exhibited that mean squares for specific combining ability were greater than those for general combining ability. The cross combinations GPW-272 × GPW37, GPW-72 × GPW-36 and GPW-273 × GPW37 showed superiority in accordance with specific combining ability for number of seeds per spike, number of effective tillers per plant and seed yield could be useful in improvement of good and widely adopted wheat varieties for arid areas [13-15, 29,35].

Some important morphological traits were studied like plant number of days taken to heading, number of spikelets per spike, 1000-grain weight and grain yield per plant with the help of triple test cross and also by line × tester analysis (Esmail, 2007). Significant epistasis was shown for these traits due to high values of specific combining ability. Moreover the analysis through line × tester analysis indicated that there were predominantly non-additive genetic effects for all traits [3, 6-8,33,34].

The combining ability and gene effects of plant height and number of spikelets per spike were studied in durum wheat (Gorjanovic and Balalic, 2004). Additive genes played important role in inheritance of spike length in the 1st year, while number of spikelets per spike and plant height in both years. Variety Belfugito was found the best general combiner in two hybrids as Belfugito × Alifen and Belfugito × Yavaros 79. Results showed that combining ability effects were associated with crossing of different parents having one parent as a general good combiner [2,4,12,36].

Combining ability of different yield related traits in eight wheat genotypes was determined by (Hassan *et al*. 2007). Their F_1 hybrids for all the traits like 1000-grain weight number of grins per spike, grain yield per plant and number of tiller per plant, among parents significant differences were observed for general and specific combining ability variance. Tatara was found as the best general combiner for 1000-grain weight, grains per spike and grain yield per plant. (Hassan *et al*. 2007) reported that Ghaznavi-88and Khattakwal were the best general combiner for number of grains per spike and number of tillers per plant and the crosses Tkb × Tal, GZ × Inq, KW × PS, Inq × ID, KW × GZ and KW × Tkb were identified as having high SCA effects for grains per spike, number of tiller per plant, grain weight per spike and grain yield per plant [1,3-5,44].

(Khan *et al*. 2007) analyzed wheat cultivars were screened for combining ability and data were collected from F_1 generation for plant height number of productive tillers per plant, number of seeds per spike, 1000-kernel weight and grain weight per plant. The additive type of genetic effects were recorded in number of grains per spike, plant height and grain weight per plant, whereas, number effective tillers per plant and 1000- grain weight were governed by non additive type of genetic effects. The cultivar, Uqab-2000 was superior general combiner for 1000-grain weight, grain yield, number of fertile tillers per plant and plant height; whereas the genotype V-00055 was the best general combiner for plant height, number of seeds per spike and grain yield. The cross combinations SH-2002 × Uqab-2000 and V00125 × V00055 were the best specific combiners for grain weight per plant and yield attributes [16,27,28,31,21].

Gene action and combining ability in bread wheat were studied by (Dhadhal, 2008). Additive gene action was revealed for days to heading, days to maturity, number of spikelets per spike, 1000-grain weight and yield per plant. The lines HUW 234, GW 322, GW 273, 7C Nad 63 tab's, MP 3077 and tester PBW 373 were excellent general combiners for grain yield and some of its components. Eight crosses exhibited significant and desirable SCA effects for grain yield per plant. The cross Chilero × GW 173 had high SCA effects for length of main spike, number of spikelets per spike, number of grains per spike and 1000-grain weight [7,4,5,9,42,30].

(Kashif and Khan, 2008) evaluated seven bread wheat genotypes were evaluated the combining ability effects of these varieties for yield associated characters i.e. spikelets per spike, tillers per plant, grains per spike, plant height, 1000-grain yield and yield per plant. They reported that the best general combiner for grain yield per plant, grains per spike, spikelets per spike and tillers per plant was GA-2002, while for grain yield, SH-2002 was good general combiner. For 1000-grain weight the best combiner was Chenab 2002 [39,22-25].

Additive and non-additive digenetic epistatic model gene action for different characters related to yield were studied (Krystkowiak *et al*. 2009). For number of grains per spike and 1000-grain weight, over dominance additive gene effect were observed, where as for biological yield, grains yield and number of spikes per plant, non additive gene effects were predominant [31]. Significant results were found for general combining ability effects. The inheritance of plant height, number of tillers per plant and spikelets per spike was controlled by the additive genetic effects. Grain yield showed high values of specific combining ability due to non-additive genetic effects [26,28,37-39].

Experimental research was conducted to estimate the general combining ability (GCA) and specific combining ability (SCA) of wheat genotypes for some quantitative traits in a set of line×tester crosses developed from five parents of bread wheat (*Triticum aestivum* L.) of which three were considered as lines (Khirman, Mehran, Kiran) and two as testers (TD-1 and. Marvi) (Malano, 2008). The characters studied were plant height, number of tillers per plant, spike length, spikelets per spike and seeds per spike, seed index and yield per plant. The experiment was carried out in a randomized complete block design with four replications during Rabi season 2007. The mean squares due to F_1 hybrids, female lines, male testers and their interactions were significant for all the characters, except spike length, where only testers were significant, while for spikelets per spike, only testers were non-significant [17,18,25].

A study at Wheat Research Institute, AARI, Faisalabad was conducted to assess combining ability effects and variances for important agronomic characters in bread wheat using line × tester mating design (Akbar *et al.* 2009). HI666/PVN"S", HUBARA"S", Faisalabad-85 and Faisalabad-83 were used as female (lines). Male testers were Faisalabad-08, PBW65 / ROER / 3 / PB6 // MIRLOW / BUC and PBW502. Plant height, tillers per plant, days to 50 percent heading, days to 50 percent maturity, spike length, spikelets per spike, 1000 grain weight and grain yield per plant were assessed. Among lines, Faisalabad 83 and Faisalabad-85 were good general combiners for agronomic traits. The testers PBW 65 and PBW 502 were found excellent general combiners for grain yield. Among the hybrids, Faisalabad-85 × PBW-502 and Faisalabad-83 × PBW-65 showed the best performance for yield and yield related traits [29,40,41,18].

An experiment was performed to check the hybrid vigour and specific combining ability effects for flag leaf area, plant height, grain weight per plant and 1000-grain weight (Krystkowiak *et al*. 2009). Eighteen parental genotypes of wheat were used and 76 F_2 hybrids attained after making crosses in line × tester analysis design. Out of 76 cross combinations, fifteen cross combinations denoted higher specific combining ability effects for 1000-grain weight and plant height, thirty cross combination for grain weight per plant and ten cross combinations for flag leaf area. Grain weight per plant and 1000-grain weight expressed high SCA as well as GCA variances. Especially for 1000-grain weight, SCA variances were lower in magnitude than GCA variances [28]. Experiments using randomized complete block design were conducted to study the influence of different water stresses applied on the yield and yield components of wheat varieties (Lohitshawa *et al*. 2013). The 5 water stress treatments were applied, i.e. T1 (control), T2 (post flowering drought), T3 (Pre-flowering drought), T4 (Tillering stage drought) and T5 (terminal drought).

Water stress badly affected all the traits in all varieties but T5 was the most vulnerable. Good performance in control as well as at terminal drought stress was shown by varieties Sarsabz and Kiran-95[15,8,34,6,2,22].

Twenty bread wheat genotypes were evaluated to estimate general and specific combining ability for some quantitative characters in bread wheat at El- Gemmeiza Agricultural Research Station during the two successive seasons 2006/2007 and 2007/2008 (Moussa and Morad, 2009). Genotypes were crossed with four local wheat cultivars Gemmeiza 9, Gemmeiza 10, Sakha 94 and Giza 168 as testers (T1, T2, T3 and T4, respectively) to produce eighty crosses using line tester analysis. The characters studied were; number of days to heading, number of days to maturity, plant height, number of spikes per plant, number of kernels per spike, kernel weight and grain yield per plant. The genotypes (parents and crosses) exhibited highly significant variation for all characters studied indicating the presence of genotypic differences among these twenty four genotypes under investigation. The mean squares of parent vs. crosses were highly significant for all characters. Further, partitioning of crosses mean squares i.e. line and tester mean squares were highly significant for all characters studied. The GCA/SCA ratio exceeded the unity for most characters studied except for heading date and kernel weight indicating that, additive genetic variance was predominantly controlling the inheritance of these traits. The parental lines 11, 12 and 16 and testers Gemmeiza 9 and Gemmeiza 10 (T1 and T2, respectively) might be selected as parental materials for wheat breeding programs. Moreover, lines number 11 and 12 had the highest general combining ability for all traits except plant height and kernel weight. The lines and testers which showed combining ability for grain yield were also good combiners for at the least one of the yield components [19].

The combining ability was estimated by using five lines and three testers of wheat in line × tester analysis mating fashion (Cifi and Yagdi, 2010). They studied the morphological traits like spike length, plant height, grains per spike, spikelets per spike, grain weight per spike and 1000-grain weight. It was found that heredity of these traits was controlled by non-additive gene effects [6,12,36,5,1].

The agronomic and morphological traits of twenty five durum wheat genotypes were studied under drought stress and normal irrigation conditions in green house. The analysis of variance indicated significant differences among the genotypes in all traits, except harvest index. Grain yield has shown positive and significant correlation for morphological traits.

Six genotypes of wheat were evaluated by using line × tester method for combining ability of yield and yield related traits. Chakwal-86, Chakwal-97 and Punjab-81 showed good GCA effects among female lines, while Faisalabad-83 and Poven-76 among the testers for almost all the traits. Among the hybrids, Chakwal-97 × Faisalabad-83 was better for yield and yield related traits.

(Majeed *et al*. 2011) investigated the combining ability effects for yield and yield related traits using line × tester analysis. Among the lines, Drina NS 720, China 84-40022, WW-7 and Nordresprez were good general combiners for grain yield. The testers PBW 343 and Raj 3765 were the best general combiners for yield and yield related traits. Excellent combiners among the crosses were WW-7 × Raj 3765, Drina NS 720 × PBW 343, Nordresprez × PBW 343 and China 84-40022 × PBW 343 [45,42,37,40,24].

Six wheat varieties under three water regimes i.e. 100% field capacity (FC), 35% FC and 25% FC were studied (Khakwani *et al*. 2011). All the traits exhibited highly significant differences while water stress conditions decreased them. The superior variety Hashim-8 indicated higher relative water content (RWC), total grain yield per plant, biological yield per plant and harvest index. It was proved best variety for selection criteria in wheat breeding program for drought resistance [41,27,28,21,23,25].

Among the major abiotic stresses, drought has the most devastating effects on crop growth and yield. It is the main limiting factor for wheat productivity. The effects of drought stress on yield and some morphological traits were studied (Saif ul malook *et al*. 2014ab). The experiment was conducted by Shamsi and Kobraee (2011) using split plot design in RCBD with three replications. Main plots included four treatments like I_1 (stem elongation stage), I_2 (booting stage), I_3 (grain filling stage) and I_4 (full irrigation, control). The subplots included cultivars treatment at three levels: Chamran (C1), Marvdasht (C2) and Shahriar (C3). Significant differences were observed between treatments. Highest grain yield was obtained by I_4, while I_1 gave the lowest yield. Comparing to the I_4, there was a yield decrease by I_1, I_2 and I_3 (81, 53 and 40 % respectively). In response to moisture stress at growth stages, severe damage was shown by C3 while C1 gave more yield stability under such conditions [19].

General and specific combining ability for yield contributing traits was studied by crossing six lines and four testers (Saleem and El-SAwi, 2006). GCA / SCA means square ratio indicated that non additive gene action was predominant. The best general combiner was K-65 and Raj-3077 among testers and HD-2687 and WH-542 among lines. Highest magnitude of heterobeltiosis and *per se* performance for grain yield were shown by hybrids WH-542 × Raj-3077 and WH 542 × K65. So, close association between SCA effects and heterobeltiosis was observed [37]. Four female genotypes and six male genotypes and 24 F_1s were developed by line × tester mating design. The traits like plant height, heading date, spike length, seeds per spike, 1000-seed weight and yield per plant were studied. Dominant gene action was revealed by GCA to SCA variances ratio for these traits [31].

Four males and 12 females of bread wheat were studied for twelve components traits of yield [3]. Characters studied were plant height, spike length, heading data, maturity date, seeds per spike, seed weight per spike, 1000-seed weight, biological yield, seed index and yield per plant. Spike length and 1000-grain weight showed higher SCA variance than GCA variance for yield. Among the hybrids, BW459 × RAJ 3777, K9006 × UP2425 and HD2425 × UP2425 were potentially combiners for yield contributing traits. (Saif-ul-malook *et al*. 2014ab) evaluated the genetics of yield related traits in 28 genotypes. Data were taken on the traits like plant height, spike length, productive plant tillers, spikelets per spike, seeds per spike, maturity date. The above studied traits showed variability in genotypes by analysis of variance. Dominant gene action was prominent in the inheritance of most studied traits. (Shabbir *et al*. 2012) studied the genetics of yield and its associated traits of wheat. The traits like plant height, heading date, maturity date and yield per plant were studied. The general and specific combining ability variances were significant for all traits. Results revealed that additive and dominance gene action were not equally important in the heredity of these traits. The genotypes Parab-2 and Chaman for dwarfness, early heading and maturity and Marvdasht for grain yield were best general combiners [32,38,39].

Eight genotypes of wheat with Chakwal-50 (control) were evaluated for spike traits under moisture stress conditions (Bibi *et al*. 2013). The parental lines i.e. Chakwal-50, GD-159 and GD-171 and crosses, i.e. GD-170 × GD-159 and GD-153 × GD-171 were found to be the most tolerant to moisture stress. The parent GD-153 remained best for spikelets per spike, spike density and GD-171 for spike length, grain yield per plant, while GD-102 for maximum awn length and grains per spike. Whereas, the cross GD-170 × GD-159 was found to be the best for increased spike length and the crosses GD-170 × GD-159, GD-170 × GD-189, GD-153 × GD-171 for yield and yield components. These superior genotypes and crosses can be used to develop new varieties for irrigated as well as arid areas [34].

Nine bread wheat genotypes by using line × tester mating design were studied and significant genetic variability was observed for all characters (Fellahi *et al*. 2013). The hybrids showed superior grain yield than their parents. A901 and Wifak, MD, HD1220 and Rmada were the best combiners for number of fertile tillers, number of grains per spike and 1000-kernel weight. A901 × Wifak and AA × MD was the excellent specific combiner for plant height and number of grains per spike. The ratios of σ^2 GCA/σ^2 SCA showed that both additive and non-additive gene effects were present [4].

The ratio of general to specific combining ability variances revealed the more important role of additive gene action for all the traits, except number of seeds per spike (Lohithaswa *et al*. 2013). The lines Vijay and DK-1001 and testers DWR-1006 and Raj-1555 showed significant GCA effects while 14 crosses exhibited significant SCA effects for grain yield and its component. The cross NIDW-15 × RAJ-1555 exhibited significant SCA effects in the desired direction for leaf rust and protein content [22]. Five spring cultivars were evaluated for general and specific combining ability for yield and its contributing traits like plant height, spike length, spikelets per spike, plant tillers, biological yield per plant, 1000-seed weight, harvest index and yield per plant (Shamsi and Kobrae 2011). All the yield related traits showed significant effects of general and specific combining ability variances. It was observed that dominant genes were important in the inheritance of all traits [36].

CONCLUSION

The traits number of ears per plant, plant height, spike length, number of spikelets per spike, days to maturity, mother shoot spike weight, grain yield per plant and thousand grain weight may be helpful to develop drought tolerant wheat genotypes. It was concluded that the lines with increased general combining ability would give better results for improving grain yield and spike traits.

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