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Combining ability and heritability estimation for elite genotypes in hexaploid wheat (*Triticum aestivum* L.)

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Abstract

Wheat breeders are also well known of the phenomenon that in a hybridization programmes, certain crosses pass-on more favorable genes towards the progenies than others. Thus, identification of potential parents and hybrids remained main concern to cotton breeders for improving various yield and biomass traits in wheat breeding programmes. Genetic inheritance pattern deals with the nature of gene action. The present study was carried out in two different locations of Sindh (Tandojam and Sakrand) under the Directorate of Wheat Research Institute Sakrand. In order to estimate the combining ability six parents (TD-1, TJ-83, Imdad, Moomal, SKD-1 and Mehran) were chosen for the study of 6 × 6 half diallel crosses. The seed of six parents along with their F^1 hybrids were sown in a randomized complete block design comprising of four replications. Data were recorded and evaluating from following characters viz., tillers plant^{-1}, spike length (cm), grains spike^{-1}, grain yield plant^{-1}, seed index and harvest index (%). The mean squares from analysis of variances for genotypes, crosses and parents were significant for all the traits studied. In both I and II locations the data showed that all the characters such as tillers plant^{-1}, spike length, grains spike^{-1}, grain yield plant^{-1}, seed index and harvest index (%) showed dominance type of gene action the degree of dominance revealed that ratio of dominance over additive genes and above unity (≥ 1.0) for all characters. The data further discovered that in all the traits revealed dominance, partial dominance and over dominance types of gene action.

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Introduction

Wheat (*Triticum aestivium* L.) is the most important cereal crop cultivated throughout the major agro-climatic regions of the world and belongs to the family Poaceae (Debasis and Khurana, 2001). It is nearly 30% of global cereal production covering an area of 220 million hectare with an average productivity of 3.2 tones ha-1 (FAO, 2015). Among cereals, wheat is the second most important crop next to rice in production. In Pakistan, the contribution of wheat crop is about 9.6% and around 1.9% in gross domestic production. Around 9052 ha of area of Pakistan is under wheat cultivation which showed a decline of 1.9% compared to 9224 ha during last year. Wheat production was estimated at 25.750 million tonnes during 2016witnessing an increase of 0.5 percent over the last year's production of 25.633 million tonnes. (GOP 2016-17). Being one of the most important food crops of the world, it occupies one-sixth (17%) of wheat acreage world over, feeding nearly half of the world population and providing one-fifth of total food calories and protein in human diet (Singh *et al*., 2016).

For wheat breeders, the search for desirable germplasm is a continuous process and the development of new elite germplasm is the unending goal. In this context, knowing the extent of inheritance of desirable traits from parents to the offspring is utmost important for further wheat improvement. Diallel mating design is being used to estimate general combining ability (GCA) and specific combining ability (SCA) variances and their effects.

It also eliminates the need to proceed further, raising advanced generations to break such linkages and thus facilitate recombination for the emergence of balanced homozygous lines. In the meantime, trait information is being used to make strategic crosses based on combining useful stress-adaptive traits with the possibility of realizing additive gene action in the selected progeny (Trethowan and Reynolds, 2007). Therefore, wheat breeders strive to gain comprehensive information on the extent and genetic basis of the variability regarding important parameters in the parental material.

The present study is designed to obtain information on the nature and magnitude of genetic components of variation controlling the expression of yield and its component traits in wheat.

Materials and methods

The six bread wheat parents/varieties viz., TD-1, TJ-83, Imdad-2005-2005-2005, Moomal-2002, SKD-1 and Mehran-89 were sown three meter long and 10 rows of each varieties, keeping 30 cm spacing between row to row at the field of Wheat Research Station, Tandojam, for attempting 6×6 half diallel crosses.

Statistical Analysis

Analysis of variance

The data collected on various yield associated traits of wheat genotypes were subjected to analysis of variance according to procedures outlined by Steel and Torice (1980) using the statistical factorial plot model as under:

$Yijk = u+pi+xj+yij+Bk+(xB) jk+\Sigma ijk$

Analysis of variance calculated through Gomez and Gomez 1984.

Combining ability effects

The combining ability analysis including mean squares and their effects were calculated by using method-2, Model-I of Griffing's (1956) which includes parents and their F_{1s}. The following statistical model was adopted.

$Yij = u+gi+gi+sij+rij\ 1/bc\ \Sigma\Sigma eijkl.$

The sum of squares due to general combining ability (GCA) and specific combining ability (SCA) were calculated as under:

SS due to GCA = $1/n+2\ [\Sigma(Yi.+Yii)^2 - 4/n\ Y^2..]$.

SS due to SCA = $\Sigma\Sigma\ Yij^2 - 1/n+2\ \Sigma\ (Yi.+Yii)^2 +2/(n+1)(n+2)\ Y^2..$

S.S. due to error = SS Error/r.

Estimation of components of variance

$\sigma^2g = 2/n+2(Mg - Me)$

$\sigma^2s = Ms - Me$

$\sigma^2e = Me$

Where σ^2g, σ^2s and σ^2e are the estimates of variances due to general combining ability, specific combining ability and environmental variances respectively.

The general combining ability (GCA) and specific combining ability (SCA) effects are worked-out as under:-

gi = 1/n+2 [Σ (Yi.+Yii) - 2/n Y..]

sij = Yij – 1/n+2(Yi.-Yii+Y.j+Yjj) + 2/(n+1)(n+2) Y..

Heritability estimates

Broad sense heritability

Broad sense heritability on mean basis was will be determined from variance components as under:

$$H^2 = \frac{\sigma^2 G}{\sigma^2 p + \sigma^2 e/r}$$

Phenotypic correlation

The association among physiological and yield traits was determined with the common formula as under:

$$r = \frac{\left[\sum xy - \frac{(\sum x)(\sum y)}{n}\right]^2}{\sqrt{\sum x^2 - \frac{(\sum x)^2}{n} \sum y^2 - \frac{(\sum y)^2}{n}}}$$

Results

Six high yielding commercial wheat varieties viz., TD-1, TJ-83, Imdad-2005-2005, Moomal-2002-2002, SKD-1 and Mehran-89 were crossed in half diallel design and fifteen F_1 hybrids were obtained during wheat growing season 2010-11. The F_1 seeds were harvested separately and seeds were stored at proper storage conditions for next year sowing. During the year 2011-12, F_1 seeds along with each parents were sown at lines two different locations at Tandojam and Sakrand to determine the combing ability, correlation, heritability and mean performance of different yield traits of F_1 generations as compared to their parents at two different ecological zones of Sindh. The results are described here under.

Analysis of variance (ANOVA) of yield characters/ morphological characters

Mean squares from analysis of variance indicated that the locations had significant (P≤0.05) impact on days to 75% heading, days to 75% maturity, plant height (cm), peduncle length (cm), inter node length (cm), tillers plant^{-1}, spike length (cm), spikelet spike^{-1}, number of grains spike^{-1}, grain yield plant^{-1}, seed index and harvest index. Genotypes also differed significantly (P≤0.01) in their performance for all the traits at two locations. The interaction of locations × genotypes were also significant (P≤0.01) for yield and other morphological traits. The mean square for differents traits from parents, hybrids, parents v/s hybrids, hybrids v/s locations, GCA and SCA variances were also significant (P≤0.01). These results could be useful for selection of superior F_1 hybrids from different locations. Mean performance of morphological and yield traits are given in (Table 1.)

Table 1. Mean squares from analysis of variance for various quantitative traits of 15 F_1 population and 6 parental lines of wheat evaluated at two locations (Tandojam and Sakrand) of Sindh.

Source of variation	D.F.	Days to 75% heading	Days to 75% Maturity	Plant height	Peduncle length	Inter node length	No. Tillers plant^{-1}
Replications	3	0.74	0.143	5.957	2.88	5.49	3.57
Genotypes	20	328.00**	297.26**	331.80**	82.74**	101.68**	29.27**
Locations	1	221.72**	152.38**	12.65**	35.65**	12.21**	37.14**
G × L	20	13.37**	4.54*	47.85**	3.76**	1.72**	2.19**
Hybrids	14	274.67**	321.99**	220.86**	53.66**	52.86**	10.30**
Parents	5	490.75**	239.95**	671.99**	153.46**	153.91**	2.63**
H vs P	1	262.12**	237.75**	183.95**	136.30**	523.93**	428.38**
P vs L	5	5.15*	3.03**	3.18**	3.29**	0.98	1.80**
H vs L	14	15.96**	5.28**	9.26**	2.77**	2.11	2.38**
GCA	5	350.40**	242.85**	350.89**	40.25**	85.41**	18.25**
SCA	14	250.28**	220.25**	320.19**	35.20**	41.35**	14.28**
Error	123	1.55	0.85	5.60	1.13	1.43	0.87

Source of variation	D.F.	Spike length	No. Spike-lets spike^{-1}	No. Grains spike^{-1}	Grain yield plant^{-1}	Seed index	Harvest index
Replications	3	0.07	1.99	4.72	7.46	3.76	3.70
Genotypes	20	13.15**	24.26**	116.18**	63.49**	44.69**	33.19**
Locations	1	57.75**	61.92**	424.33**	126.53**	175.78**	2.36
G × L	20	0.48	4.56*	2.53*	4.96*	0.71	2.03
Hybrids	14	6.37*	19.54**	93.08**	51.97**	29.72**	40.15**
Parents	5	5.10*	2.48	168.38**	27.75**	91.79**	26.28**
H vs P	1	148.45**	199.23**	178.75**	403.35**	18.87**	59.73**
P vs L	5	0.18	0.08	0.93	3.51**	0.69	0.68
H vs L	14	0.52	4.77*	3.29*	6.32**	0.77	1.89
GCA	5	25.44**	49.23**	380.23**	145.55**	165.28**	28.23**
SCA	14	24.36**	14.28**	389.40**	120.43**	120.47**	25.32**
Error	123	0.33	2.06	0.98	2.84	2.87	3.13

*, ** = Significant at 5 and 1% probability level respectively.

General combining ability (GCA) and specific combining ability (SCA) for morphological and yield traits

The general combining ability (GCA) and specific combining ability (SCA) effects of parents and F_1 hybrids for morphological and yield traits are presented in (Tables 02-4). The character wise results are given here under for both locations (Tandjam and Sakrand).

Days to 75% Heading

The parent TD-1 showed negative (-2.87 and -2.41) GCA effects for the trait days to 75% heading at both locations Tandojam and Sakrand followed by TJ-83 (-6.22 and 5.50) respectively. Whereas the genotypes like Imdad-2005-2005, Moomal-2002, SKD-1 and Mehran-89 showed positive (4.44, 1.28, 1.03 and 3.06) GCA effects for days to 75% heading at location-I (Table-2). However at location-II above genotypes were observed as (3.81, 1.56, 0.03 and 2.50 gca) for days to 75% heading respectively. Among F_1 hybrids eight hybrids indicated negative SCA effects varied from (-1.63 to -5.00) and other seven hybrids were recorded with positive SCA effects for days to 75% heading at location-I (Table-3). However seven F_1 hybrids showed negative SCA effects and eight hybrids observed with positive SCA effects for days to 75% heading at location-II. Among the F_1 hybrids, TJ-83 × Mehran-89 observed maximum (9.25 and 8.68) SCA effects for days to 75% heading at both locations followed by TD-1 × Moomal-2002 (4.08 and 4.02) SCA, respectively. The Data has been given at (Table 2 and 4).

Days to 75% maturity

The parent Moomal-2002 showed negative (-0.81 and -0.01) GCA effects for days to 75% maturity followed by TD-1 (-2.47 and 2.26), TJ-83 (-4.56 and -4.35) and Moomal-2002 (-0.81 and -0.01) at both locations respectively. Other parents like Imdad-2005-2005 and Mehran-89 indicated positive (4.38 and 4.18, 3.34 and 3.08) GCA effects for days to 75% maturity at both locations (table-2). Whereas parent SKD-1 recorded with positive (0.13) GCA effect at location-I and negative (-0.64) GCA effect for days to 75% maturity at location-II. Among F_1 hybrids showed negative SCA effects ranged from (-1.08 to -8.15) and other seven F_1 hybrids positive SCA effects varied from (0.35 to 7.07) for days to 75 maturity at location-I (Table-3). Whereas10 F_1 hybrids showed negative SCA effects ranged from (-0.25 to -9.00) and other five F_1 hybrids showed positive SCA effects varied from (1.16 to 6.69) for days to 75% maturity at location-II. Among F_1 hybrids TJ-83 × Mehran-89 observed with maximum (7.07 and 6.69) SCA effects for days to 75% maturity at both locations respectively followed by Imdad-2005-2005 × SKD-1 (5.82 and 5.88) SCA effect for days to 75% maturity at both locations (Tandojam and Sakrand) respectively.

Plant height

The parent SKD-1 showed negative (-0.05 and -0.99) GCA effects for plant height at both locations (Tandojam and Sakrand) followed by parents TJ-83 and TD-1, were recorded (-0.93 and -1.29 and -0.89

and -5.90) respectively (Table-2). However, other parents like Imdad-2005-2005, Moomal-2002 and Mehran-89 recorded with positive (1.14 and 1.79, 3.08 and 3.01 and 3.65 and 3.38) respectively GCA effects for plant height at both locations respectively.

Among F_1 hybrids nine crosses observed with negative SCA effects ranged from (-0.86 to -13.50) another six hybrids showed positive SCA effects varied from (0.88 to 5.25) SCA effects for plant height at location I (Table-3). However, seven hybrids recorded negative SCA effects ranged from (-0.82 to -5.72) for plant height at location II. Whereas eight crosses showed positive SCA effects ranged from (0.02 to 4.25) for plant height at location II.

Among F_1 hybrids Imdad-2005-2005 × SKD-1 observed with maximum (5.82 and 4.25) SCA effects for plant height at both locations (Tandojam and Sakarand). The Data is given in (Table 3 and 4) respectively.

Peduncle length

The parent SKD-1 recorded with negative (-0.11) GCA effects followed by TD-1 (-3.47) for peduncle length whereas other genotypes showed positive GCA effects ranged from (0.52 to 1.74) for peduncle length at location I Tandojam (Table-2). However, TD-1 showed negative (-6.47) GCA effects for peduncle length, whereas, other genotypes showed positive GCA effects ranged from (0.71 to 2.00) at location II Sakarand.

Among F_1 hybrids, ten crosses were recorded with negative SCA effects ranged from (-0.46 to 5.55) for peduncle length, whereas, other five F_1 hybrids showed positive (0.11 to 3.43) SCA effects for peduncle length at location I (Tandojam) (Table-3).

However, seven F_1 hybrids have shown negative SCA effects ranged from (-1.19 to -7.22) for peduncle length whereas eight F_1 crosses with observed positive SCA effects ranged from (0.03 to 4.03) for peduncle length at location II. Among all F_1 hybrids Imdad-2005-2005 × SKD-1 has shown maximum (3.43) SCA effects for peduncle length at location I. Whereas, F1 hybrids TD-1 × Imdad-2005-2005 and TD-1 × Mehran-89 were showed maximum (4.03 and 3.74) SCA effects, respectively (Table 3).

Internode length

Among the parents, SKD-1, Moomal-2002, TJ-83 and TD-1 were showed negative (-0.06, -0.09, -0.52 and 3.72) GCA effects for internode length respectively table 2. The parents Imdad-2005-2005 and Mehran-89 showed positive (0.50 and 4.49) GCA effects for internode length respectively.

The data further revealed that eight F_1 hybrids showed negative SCA effects ranged from (-0.04 to -9.33) for internode length at location I (Tandojam) table 3. However seven F_1 crosses recorded with positive SCA effects ranged from (0.42 to 3.02) for internode length at location I.

F_1 hybrids showed negative SCA effects varied from (-0.26 to -7.63) at location II (Sakarand). The other seven F_1 crosses recorded positive SCA effects ranged from (0.37 to 1.18) for internode length at location II. Whereas, F_1 hybrid TD-1 × SKD-1 was observed with maximum (3.02) for inter node length at location I (Tandojam). However, F_1 hybrid TJ-83 × SKD-1 was showed maximum (1.18) for internode length at location II.

Number of Tillers plant^{-1}

The parents SKD-1 and Moomal-2002 showed negative (-0.30 and 0.77) GCA effects for number of tillers plant^{-1}, whereas parents TJ-83 and, TD-1, Imdad-2005-2005 and Mehran-89 recorded with positive (0.17, 0.26, 0.32 and 0.32) GCA effects for numbers of tillers plant^{-1} at location I, respectively (Table 2). The varieties Moomal-2002 and SKD-1 showed negative (-2.00 and 4.25) GCA effects, whereas, genotypes Mehran-89, TJ-83, Imdad-2005-2005 and TD-1 observed with positive (0.25,0.75.1.25 and 4.00) GCA effects at location -1 (Tandojam), respectively (Table-2).

The single hybrid was observed with negative (-0.09) SCA effects, whereas other fourteen F_1 hybrid have shown positive (0.10 to 4.25) gca for the character number of tillers plant -1 at location I. However, five F_1 hybrids showed negative SCA effects ranged from (-0.13 to -0.85) for the tillers plant^{-1} at location II (Sakrand). The ten F_1 crosses showed positive SCA

effects (0.31 to 3.62) for tillers plant^{-1} at location II (Table-3). The F_1 hybrid Imdad-2005-2005 × Mehran-89 recorded with maximum (4.25) SCA impacts for tillers plant^{-1} at location I, F_1 hybrid TD-1 × TJ-83 observed with maximum (3.62) SCA effects for tillers plant^{-1} at location II.

Spike length

The parents Moomal-2002, Mehran-89 and SKD-1 showed negative (-0.12,-0.13,-0and-0.24) GCA effects for spike length, whereas the parents TJ-83, TD-1 and Imdad-2005-2005 had shown positive (0.18, 0.30 and 0.35) GCA effects for spike length at location I respectively (Table-2). The parents Moomal-2002, SKD-1 and TJ-83 were recorded negative (-0.13, -0.30 and -0.46) GCA effects, whereas, varieties Mehran-89, Imdad-2005-2005 and TD-1 recorded positive (0.02, 0.43 and 0.45) GCA effects for spike length at location II, respectively (Table-3). The two F_1 hybrids showed negative (-0.41 and -1.65) SCA impacts whereas other thirteen F_1 hybrids showed positive SCA effects ranged from (0.16 to 1.73) for spike length at location I. Five F_1 hybrids showed negative SCA effects ranged from (-0.18 to -1.77), however ten F_1 hybrids showed positive SCA impacts ranged from (0.15 to 1.91) for spike length (cm) at location II.

Number of spikelet spike^{-1}

The parents Moomal-2002 SKD-1 showed negative (-0.19 and -0.69) GCA effects, however the parents Imdad-2005-2005, TJ- 83, TD-1 and Mehran-89 recorded positive (0.13, 0.19, 0.25 and 0.31) for GCA effects at location I respectively (Table-2). The parents TD-1, SKD-1, Mehran-89 and Moomal-2002 gave negative (-0.17, -0.23, -0.23 and -0.35) GCA values, whereas, Imdad-2005-2005 and TJ-83 genotypes recorded with positive (0.21 and 0.77) GCA effects for number of spikelet spike^{-1} at location II respectively (Table-4).

Among the F_1 hybrids six hybrids showed negative SCA effects ranged from (-0.35 to 1.85), whereas, ten observed with positive SCA impacts varied from (0.27 to 4.27) for number of spikelet spike^{-1} at location I (table-3). The five F_1 hybrids were recorded negative SCA effects ranged from (-0.02 to -1.08), however ten F_1 hybrids showed positive SCA effects ranged from (0.55 to 2.61) for number of spikelet spike^{-1} at location II respectively (Table-4).

The data further revealed that F_1 hybrid TD-1 × TJ-83 observed with maximum (4.25) SCA effects for number of spikelet spike^{-1} at location I. Whereas, hybrid TJ-83 × Moomal-2002 was showed maximum (2.61) SCA effects for number of spikelet spike^{-1} at location II.

Number of grains spike^{-1}

Genotypes TJ-83, Moomal-2002 and SKD-1 showed negative (-0.59, -0.74 and -2.46) GCA effects, whereas varieties Mehran-89, Imdad-2005-2005, and TD-1 observed positive with (0.001, 1.41 and 2.38) GCA effects for this trait at location I respectively (Table-2). Whereas, genotypes SKD-1, Moomal-2002 and TJ-83 showed negative (-0.06, -0.94 and -1.00) GCA effects, however, genotypes Mehran-89, Imdad-2005-2005 and TD-1 recorded with positive (0.03, 1.3872.59) GCA effects for number of grains spike^{-1} at location II (Sakrand), respectively.

The six F_1 hybrids recorded negative SCA impacts ranged from (-0.90 to -3.88) for grains spike^{-1}, whereas, nine F_1 hybrids showed positive effects ranged from (0.34 to 5.13) SCA effects for grains spike^{-1} at location I. However, among all F_1 hybrids, six crosses recorded with negative ranged from (-0.27 to -5.70) SCA effects, whereas nine F_1 hybrids were observed with positive ranged from (0.17 to 6.98) for grains spike^{-1} at location II (Sakrand).

Among all F_1 hybrids, cross TJ-83 × Moomal-2002 showed that highest (5.13) SCA effects for grains spike^{-1} at location I (Tandojam), whereas hybrid TD-1 × TJ-83 also showed maximum (6.98) SCA effects for grains spike^{-1} at location II (Table-3).

Grain yield plant^{-1}

Genotypes TJ-83, Moomal-2002 and SKD-1 showed negative (-0.15, -0.74 and -1.39) GCA effects, whereas the genotypes Mehran-89, Imdad-2005-2005 and TD-1 observed with positive (0.05, 0.42 and 1.79) GCA impacts for grain yield plant^{-1} at location I

(Tando jam). However varieties TJ-83, Moomal-2002 and SKD-1 have shown negative (-0.91, -1.07 and -1.29) GCA effects, whereas, genotypes Imdad-2005-2005, Mehran-89 and TD-1 showed positive (0.18, 0.56 and 2.53) GCA effects for grain yield plant^{-1} at location II (Sakrand), respectively.

Five F_1 hybrids recorded negative SCA effects ranged from (-0.09 to -1.28), whereas, ten crosses showed positive 0.37 to 3.88 SCA effects for grain yield plant^{-1} at location I (Table-3). However six crosses were gave negative ranged from (-0.06 to -2.18) SCA effects, whereas nine F_1 hybrids were recorded positive ranged from (0.14 to 5.17) SCA impacts for grain yield plant^{-1} at location II (Sakrand) (Table-4). Among F_1 hybrids the cross TD-1 × TJ-83 was recorded with maximum (4.25 and 5.17) SCA effects for grain yield plant^{-1} at both locations (Tando Jam and Sakrand), respectively (Table-4).

Seed index

Genotypes Imdad-2005-2005, TJ-83, Moomal-2002 and SKD-1 recorded negative (-0.23, -0.75, -0.80 and -0.87) GCA effects, whereas, varieties Mehran-89 and TD-1 showed positive (0.68 and 1.97) GCA effects for 1000-grain weight at location I respectively (Table-3). However, genotypes Moomal-2002, TJ-83 and SKD-1 observed with negative (-1.01, -1.04 and -1.08) GCA effects, whereas genotypes Imdad-2005-2005, Mehran-89 and TD-1 had shown positive (0.11, 0.69 and 2.33) GCA effects for seed index at location II (Sakrand), respectively (Table-4).

Among F_1 hybrids, seven crosses were observed with negative ranged from (-0.05 to -1.60) SCA effects, whereas, eight F_1 hybrids showed positive 0.12 to 3.98) GCA effects for 1000-grain weight at location I (Table-3). However 8 crosses were observed negative ranged from (-0.03 to -2.35) SCA effects whereas, 7 F_1 hybrids recorded with positive ranged from (0.15 to 4.11) SCA effects for 1000-grain weight at location II (Table-4).

The F_1 hybrid TJ-83 × Moomal-2002 recorded with maximum (3.98) SCA effects for 1000-grain weight at Location I, whereas cross TD-1 × TJ-83 gave maximum (4.11) SCA effects for 1000-grain weight at location II (Sakrand) (Table-4).

Harvest index

Genotypes Imdad-2005-2005, Mehran-89 and SKD-1 showed negative (-0.74, -0.74 and -0.11) GCA effects, whereas, Moomal-2002, TJ83 and TD1 were observed with positive (0.89 and 1.42) for harvest index at location I respectively (Table-3). However, Moomal-2002, Imdad-2005-2005, Mehran-89 and SKD-1 were recorded with negative (-0.27, -0.49, -0.62 and -1.08) GCA effects, whereas TD-1 and TJ-83 showed positive (1.07 and 1.39) GCA effects for harvest index at location II (Sakrand), respectively (Table-4) Ten F_1 hybrids crosses were recorded negative ranged from (-0.24 to -3.96) SCA effects, whereas, five F_1 hybrid observed with positive (0.01 to 2.39) SCA effects for harvest index% at location I (Tandojam). Six F_1 hybrids were observed with negative (-0.30 to -1.80) SCA effects, however, 9 crosses showed positive ranged from (0.04 to 6.73) SCA effects for harvest index % at location II (Table-4).

Among the F_1 hybrids, the cross TD-1 × TJ-83 showed maximum (02.39) SCA effects for harvest index % at location I (Tandojam), whereas, F_1 hybrid Imdad-2005-2005 × Mehran-89 recorded maximum (6.29) SCA effects for harvest index at location II (Sakrand). The data are given in (Tables 2, 3 and 4).

Table 2. General Combining Ability (GCA) effects of the parents for morphological and yield traits of wheat genotypes at Tandojam and Sakrand (Location-I and II) of Sindh.

Genotypes	TD-1	TJ-83	Imdad-2005-2005	Moomal-2002	SKD-1	Mehran-89	S.E.(gi)
Days to 75% heading	-2.87	-6.22	4.44	1.28	1.03	3.06	0.10
Days to 75% maturity	-2.47	-4.56	4.38	-0.81	0.13	3.34	0.14
Plant height	-6.89	-0.93	1.14	3.08	-0.05	3.65	0.20
Peduncle length	-3.47	0.52	0.44	1.74	-0.11	0.88	0.10
Inter node length	-3.72	-0.52	0.50	-0.09	-0.06	4.49	0.20
No. Tillers plant^{-1}	0.26	0.17	0.32	-0.77	-0.30	0.32	2.52

Genotypes	TD-1	TJ-83	Imdad-2005-2005	Moomal-2002	SKD-1	Mehran-89	S.E.(gi)
Spike length (cm)	0.32	0.18	0.35	-0.12	-0.24	-0.13	2.56
No. Spikelets spike^{-1}	0.25	0.19	0.13	-0.19	-0.69	0.31	0.14
No. Grains spike^{-1}	2.38	-0.59	1.41	-0.74	-2.46	0.001	0.10
Grain yield plant^{-1}	1.79	-0.15	0.42	-0.74	-1.39	0.05	0.26
Seed index	1.97	-0.75	-0.23	-0.87	-0.80	0.68	0.14
Harvest index (%)	1.42	0.89	-0.74	0.17	-0.99	-0.74	0.18
Location – II							
Days to 75% heading	-2.41	-5.50	3.81	1.56	0.03	2.50	0.10
Days to 75% maturity	-2.26	-4.35	4.18	-0.01	-0.64	3.08	0.10
Plant height	-5.90	-1.29	1.79	3.38	-0.99	3.01	2.95
Peduncle length	-6.47	0.71	1.12	2.00	1.00	1.65	2.79
Inter node length	-2.98	0.40	0.96	0.58	-0.17	1.21	2.89
No. Tillers plant^{-1}	4.00	0.75	1.25	-2.00	-4.25	0.25	0.14
Spike length (cm)	0.45	-0.46	0.43	-0.13	-0. 30	0.02	2.29
No. Spikelets spike^{-1}	-0.17	0.77	0.21	-0.35	-0.23	-0.23	0.20
No. Grains spike^{-1}	2.59	-1.00	1.38	-0.94	-0.06	0.03	0.14
Grain yield plant^{-1}	2.53	-0.91	0.18	-1.07	-1.29	0.56	0.10
Seed index	2.33	-1.04	0.11	-1.01	-1.08	0.69	0.22
Harvest index (%)	1.07	1.39	-0.49	-0.27	-1.08	-0.62	2.66

Table 3. Specific Combining Ability (SCA) effects of F1 hybrids for morphological and yield traits of wheat at Tandojam (Location-I) of Sindh.

F_1 hybrids	Days to 75% heading	Days to 75% maturity	Plant height	Peduncle length	Inter node length	No. Tillers plant^{-1}
TD-1 × TJ-83	-2.86	-3.64	-0.86	-1.08	0.49	2.22
TD-1 × Imdad-2005-2005	3.49	1.42	-1.94	-1.00	-0.04	1.07
TD-1 × Moomal-2002	4.08	0.35	2.19	0.20	2.94	-0.09
TD-1 × SKD-1	3.40	-1.58	0.88	-0.46	3.02	0.69
TD-1 × Mehran-89	-1.63	-1.08	-2.77	0.56	-5.02	0.82
TJ-83 × Imdad-2005-2005	-3.13	-6.24	-0.87	-1.99	0.76	0.23
TJ-83 × Moomal-2002	-4.82	-2.30	-1.55	-1.54	-0.39	1.26
TJ-83 × SKD-1	-1.47	-2.74	1.32	-0.94	0.42	0.54
TJ-83 × Mehran-89	9.25	7.07	-2.37	-3.03	-6.12	1.16
Imdad-2005-2005 × Moomal-2002	1.52	2.26	-3.51	-0.96	1.59	0.10
Imdad-2005-2005 × SKD-1	3.37	5.82	5.25	3.43	0.65	1.38
Imdad-2005-2005 × Mehran-89	2.59	3.60	-4.45	-3.35	-5.74	4.25
Moomal-2002 × SKD-1	-1.32	2.49	1.82	1.47	-1.37	2.22
Moomal-2002 × Mehran-89	-3.10	-4.71	1.12	0.11	-3.64	0.60
SKD-1 × Mehran-89	-5.00	-8.15	-13.50	-5.55	-9.33	0.63
SE(si)	0.70	0.72	1.06	0.58	1.09	0.44
	Spike length	Spikelets spike^{-1}	Grains spike^{-1}	Grain yield plant^{-1}	Seed index (1000 grain wt.)	Harvest index (%)
TD-1 × TJ-83	0.16	4.27	4.25	2.70	3.40	2.39
TD-1 × Imdad-2005-2005	0.33	-0.67	-1.00	3.88	-0.67	0.26
TD-1 × Moomal-2002	-1.65	-0.35	-1.37	1.54	-1.33	-0.27
TD-1 × SKD-1	1.73	-1.85	-3.88	0.94	-1.60	-2.24
TD-1 × Mehran-89	1.12	3.15	1.44	-0.26	0.37	-2.74
TJ-83 × Imdad-2005-2005	1.38	1.40	2.47	0.82	1.77	-3.96
TJ-83 × Moomal-2002	0.23	1.71	5.13	2.73	3.98	1.64
TJ-83 × SKD-1	1.35	-1.29	-0.90	-1.11	0.12	-1.21
TJ-83 × Mehran-89	0.22	-0.79	0.63	-0.06	-0.62	-1.71
Imdad-2005-2005 × Moomal-2002	0.20	0.27	1.37	-0.09	-0.62	-1.24
Imdad-2005-2005 × SKD-1	1.59	1.77	0.34	1.32	-0.86	-1.58
Imdad-2005-2005 × Mehran-89	-0.41	2.27	0.87	0.37	2.90	0.67
Moomal-2002 × SKD-1	0.31	2.58	3.75	-1.28	1.93	0.01
Moomal-2002 × Mehran-89	0.68	1.58	-0.97	1.02	-0.05	-0.24
SKD-1 × Mehran-89	0.93	-0.42	-2.75	2.43	1.30	-0.33
SE(si)	0.44	0.71	0.56	1.41	0.82	0.97

Table 4. Specific Combining Ability (SCA) effects of F_1 hybrids for morphological and yield traits of wheat at Sakrand (Location-II) of Sindh.

F1 hybrids	Days to 75% heading	Days to 75% maturity	Plant height	Peduncle length	Inter node length	No. Tillers plant^{-1}
TD-1 × TJ-83	5.58	-0.97	-1.27	2.93	-0.26	3.62
TD-1 × Imdad-2005-2005	1.52	-0.25	0.64	4.03	0.93	0.31
TD-1 × Moomal-2002	4.02	1.19	-2.94	3.40	-3.19	-0.29
TD-1 × SKD-1	3.30	-1.44	0.18	2.40	0.56	-0.25
TD-1 × Mehran-89	-3.42	-0.40	-0.82	3.74	-1.82	1.18
TJ-83 × Imdad-2005-2005	-2.64	-4.65	0.02	-2.16	0.55	1.46
TJ-83 × Moomal-2002	-5.89	-3.72	-4.55	-1.79	-2.07	-0.13
TJ-83 × SKD-1	-4.07	-2.09	2.07	0.71	1.18	-0.85
TJ-83 × Mehran-89	8.68	6.69	-2.93	-2.20	-2.20	0.84
Imdad-2005-2005 × Moomal-2002	1.80	3.75	0.88	-1.19	0.62	1.31
Imdad-2005-2005 × SKD-1	2.83	5.88	4.25	2.81	0.37	1.59
Imdad-2005-2005 × Mehran-89	2.36	1.16	-5.72	-3.35	-2.50	2.03
Moomal-2002 × SKD-1	-1.67	-1.69	1.41	-2.07	-2.00	1.75
Moomal-2002 × Mehran-89	-3.89	-4.90	0.91	0.03	0.62	-0.57
SKD-1 × Mehran-89	-4.60	-9.00	-12.00	-7.22	-7.63	2.21
SE(si)	0.58	0.59	0.51	0.48	0.50	0.84
	Spike length	Spikelets spike^{-1}	Grains spike^{-1}	Grain yield plant^{-1}	Seed index (1000 grain wt.)	Harvest index (%)
TD-1 × TJ-83	0.15	2.42	6.98	5.17	4.11	2.23
TD-1 × Imdad-2005-2005	0.75	-0.02	-1.89	4.32	-1.59	0.35
TD-1 × Moomal-2002	0.74	-0.95	-0.58	-2.18	-1.53	-0.36
TD-1 × SKD-1	-1.53	-1.08	-5.70	-0.71	-2.35	-1.80
TD-1 × Mehran-89	1.91	1.92	1.95	0.45	-0.13	4.32
TJ-83 × Imdad-2005-2005	1.41	0.55	3.70	-1.74	2.01	-2.71
TJ-83 × Moomal-2002	0.35	2.61	4.01	3.01	3.94	1.07
TJ-83 × SKD-1	1.77	1.48	-1.86	-0.77	-0.03	-0.30
TJ-83 × Mehran-89	-0.18	-1.02	-0.96	-0.06	-1.06	5.06
Imdad-2005-2005 × Moomal-2002	-0.30	1.17	0.64	2.17	-0.74	-0.80
Imdad-2005-2005 × SKD-1	1.39	1.05	0.76	1.39	-0.88	-0.74
Imdad-2005-2005 × Mehran-89	-1.77	1.55	0.17	-0.46	3.34	6.29
Moomal-2002 × SKD-1	0.70	1.06	4.32	0.14	2.13	0.04
Moomal-2002 × Mehran-89	0.73	1.06	-0.27	0.79	0.15	5.92
SKD-1 × Mehran-89	-1.10	-1.02	1.39	3.76	-0.72	6.73
SE(si)	0.40	1.03	0.85	0.66	1.18	0.46

Correlation among morphological and yield traits

Days to 75% heading

Days to 75% heading were significantly and positively associated with days to 75% maturity (r = 0.85**), plant height (r = 0.24*), peduncle length (r = 0.33**) and internode length (r = 0.26*), while, negatively correlated with harvest index % (r = -033**). However, days to 75% heading was non-significant but positive associated with tillers plant^{-1} (r = 0.10), spike length (r = 0.10), grains spike^{-1} (r = 0.01), grain yield plant^{-1} (r = 0.02) and seed index (r = 0.02) respectively. Whereas, spikelets^{-1} was negative but non-significant (r = -0.06) with days to 75% heading. The results are given in (Table-5).

Days to 75% maturity

Days to 75% maturity were significantly and positively associated with pant height (r = 0.36**), peduncle length (r = 0.04**) and internode length (r = 0.44**), while, negatively associated with tillers plant^{-1} (r = 0.04), spike length (r = 0.01), spikelets spike^{-1} (r = 0.08) and grain yield plant^{-1} (r = 0.06) respectively. Whereas, grains spike^{-1} (r = 0.07) and seed index (r = 0.01) were non-significant but positively correlated with days to 75% maturity, respectively (Table-5).

Plant height

Plant height were significantly and positively correlated with peduncle length (r = 0.77**) and internode length (r = 0.73**), whereas negatively associated with tillers plant^{-1} (r = -0.23*), spike length (r = -0.22*), grains spike^{-1} (r = -0.06), grain yield plant^{-1} (r = -0.27*), seed index (r = -0.8) and harvest index (r = -0.01) respectively. However, spikelets spike^{-1} (r = 0.01) was non-significant but positively associated with plant height (Table 5).

Peduncle length

Peduncle length was significantly and positively associated with internode length (r = 0.8**), whereas the negatively were associated with tillers palnt^{-1} (r = -0.37**), spike length (r = -0.21*), grains spike^{-1} (r = -0.21*), grain yield plant^{-1} (g) (r = -0.38**) and seed index (r = -0.24*) respectively. However harvest index (r = -0.14) was non-significant but negatively correlated with peduncle length (Table-5).

Number of tillers plant^{-1}

Number of tillers plant^{-1} were significantly and positively associated with spike length (r = 0.57**), spikelets spike^{-1} (r = 0.52**), grains spike^{-1} (r = 0.48**), grains yield palnt^{-1} (r = 0.59**) and seed index (r = 0.48**), whereas harvest index (r = 0.06) was significantly associated with tillers palnt^{-1} (Table-5).

Spike length

Spike length was significantly and positively associated with the spikelets spike^{-1} (r = 0.51**), grains spike^{-1} (r = 0.50**), grain yield plant^{-1} (r = 0.47**) and seed index (r = 0.45**), respectively, however harvest index (r = -0.22*) was significantly associated with spike length (Table-5).

Spiklets spike^{-1}

The spikelets spike^{-1} were significantly and positively associated with the grains spike^{-1} (r = 0.48**), grain yield^{-1} (r = 0.36**) and seed index (r = 0.44**) respectively. Whereas harvest index (r = 0.01) was non-significant but positively associated with spikelets spike^{-1} (Table-5).

Grain yield plant^{-1}

Grain yield plant^{-1} was significantly and positively associated with seed index (r = 0.50**), whereas harvest index (r = 0.13) was non-significant but positively associated with grain yield plant^{-1}(Table-5).

Seed index (1000 grain weight)

Seed index (1000 grain weight) was non-significantly associated with harvest index (Table-5).

Table 5. Correlation (r) over the locations (Tandojam and Sakrand) for various quantitative traits in wheat genotypes.

Characters	Days to 75% heading	Days to 75% maturity	Plant height	Peduncle length	Inter node length	Tillers plant^{-1}	Spike length	Spike-lets spike^{-1}	Grains spike^{-1}	Grain yield plant^{-1}	Seed index	Harvest index
Days to 75% heading	-	0.85**	0.24*	0.33**	0.26*	0.10	0.10	-0.06	0.01	0.02	0.02	-0.33**
Days to 75% maturity		-	0.36**	0.44**	0.44**	-0.04	-0.01	-0.08	0.07	-0.06	0.01	-0.26*
Plant height			-	0.77**	0.73**	-0.23*	-0.22*	0.01	-0.06	-0.27*	-0.8	-0.01
Peduncle length				-	0.83**	-0.37**	-0.21*	-0.11	-0.21*	-0.38**	-0.24*	-0.14
Inter node length						-0.42**	-0.39**	-0.21*	-0.19	-0.37*	-0.19	-0.09
Tillers plant^{-1}					-		0.57**	0.52**	0.48**	0.59**	0.48**	-0.06
Spike length						-		0.51**	0.50**	0.47**	0.45**	-0.22*
Spike-lets spike^{-1}							-		0.48**	0.36**	0.44**	0.01
Grains spike^{-1}								-		0.59**	0.71**	0.24*
Grain yield plant^{-1}									-		0.50**	0.13
Seed index										-		0.18

*, ** = Significant at 1 and 5% probability level respectively

Heritability Estimates (Broad sense)

The heritability estimates in broad sense (h^2 b.s) for yield and yield contributing traits are given in (Table 6 -7). Heritability parameters are estimated for yield and yield related characters. The yield related characters showed maximum heritability estimates in broad sense for days to 75% heading (h^2 = 99.52%), days to 75% maturity (h^2 = 99.72%), plant height (h^2 = 98.31%), peduncle length (h^2 = 98.60%), internode length (h^2 = 98.58%), number tillers plant^{-1} (h^2 = 96.99%), spike length (h^2 = 97.57%),

spikelets spike^{-1} (h^2 = 91.43%), grains spike^{-1} (h^2 = 91.80%), grain yield plant^{-1} (h^2 = 95.53%), Seed index (h^2 = 93.56%) and harvest index (h^2 = 90.60%) respectively. The results is given in (Table 6).

Table 6. Heritability (h^2 b.s%) estimates over the locations (Tandojam and Sakrand) for various quantitative traits in wheat.

Characters	σ^2p	σ^2g	Heritability	Heritability (h^2 b.s%)
Days to 75% heading	328	81.61	0.9952	99.52
Days to 75% maturity	297.27	74.11	0.9972	99.72
Plant height	331.80	81.55	0.9831	98.31
Peduncle length	82.75	20.40	0.9860	98.60
Inter node length	101.68	25.06	0.9858	98.58
Number of Tillers plant^{-1}	29.27	7.1	0.9699	96.99
Spike length	13.16	3.21	0.9757	97.57
Spikelets spike^{-1}	24.27	5.55	0.9143	91.43
Grains spike^{-1}	116.19	2.80	0.9180	91.80
Grain yield plant^{-1}	63.49	15.16	0.9553	95.53
Seed index (1000 grain wt.)	44.70	1046	0.9356	93.56
Harvest index (%)	33.20	7.52	0.9060	90.60

Discussion

Mean square from analysis of variance indicated that locations had significant impact on days to 75% heading, days to 75% maturity, plant height, peduncle length, internode length, tillers plant^{-1}, spike length, spikelet spike^{-1}, grains spike^{-1}, grain yield plant^{-1}, seed index and harvest index. Genotypes also differed significantly in their performance for all the traits at two locations. The interaction between locations × genotypes were also significant for yield and other morphological traits. Whereas parents, hybrids, parents v/s hybrids, hybrids v/s locations, GCA and SCA variances were also significant for all the traits. These results could be useful for selection of superior F_1 hybrids at different locations. Mean performance of morphological and yield traits results also confirmed with results obtained by (Cifci and Yagdi (2010) and Kutlu and Olgun (2015). The data are given in (Table-1).

General Combining Ability (GCA) and Specific Combining ability (SCA) for Morphological and Yield Traits

Days to 75% Heading

TD-1 was recorded negative GCA effects followed by TJ-83 for days to 75% heading at both locations. Whereas, hybrids like TJ-83 x Mehran-89 and TD-1 × Moomal-2002 recorded negative SCA effects for said trait at both location (Tables 2, 3 and 4). Our findings are agreed with Akbar *et al.* (2009), Adel *et al.* (2013), Pagliosa *et al.* (2017) and Muhammad and Hussain (2017).

Days to 75% maturity

Among the parents, Moomal-2002 and TD-1 recorded negative GCA effects for days to 75% maturity at both locations. The F_1 hybrids like TJ-83 x Mehran-89 and Imdad-2005-2005 × SKD-1 showed negative SCA effect for days to 75% maturity at both locations. The findings were confirmed by Kamaluddin *et al.* (2007), Akram *et al.* (2008) and Tsenov (2009).

Plant height

SKD-1, TJ-83 and TD-1 recorded negative GCA effects for plant height at both locations (Tandojam and Sakarand). However, the F_1 hybrids viz. Imdad-2005-2005 x SKD-1 observed maximum SCA effects for plant height at both locations. Similar findings of presence of additive and non additive gene effects were reported by Bao *et al.* (2009) and Seboka *et al.* (2009). The data are given in Tables 2, 3 and 4.

Peduncle length

Among the cultivars, SKD-1 and TD-1, GCA effects showed negative for peduncle length at both conditions. Whereas, other genotypes like Moomal-2002 and Imdad-2005-2005 recorded positive GCA effects at both locations. However, five F_1 hybrids recorded positive SCA effects for peduncle length at location I. Eight F_1 crosses observed positive SCA effects for peduncle length at location II. The high scorers were Imdad-2005-2005 × SKD-1, TD-1 × Imdad-2005-2005 and TD-1 × Mehran-89. It is an important morphological plant trait in wheat for

development of early maturing cultivars mostly wheat breeders select desirable plants with greater peduncle length. It is controlled by additive gene action. Our findings confirmed the results of Kutlu and Olgun, (2015). The data are given in Tables 2, 3 and 4.

Internode length

SKD-1, Moomal-2002, TJ-83 and TD-1 showed negative GCA effects for internode length and Imdad-2005-2005 and Mehran-89 recorded positive GCA effects for inter node length. Whereas, F_1 hybrids TD-1 × SKD-1 and TJ-83 × SKD-1 showed maximum SCA effects for internode length at location I (Tandojam) and at location II (Sakarand) respectively Allah *et al.* (2010). Related studies by explained that plant height was positively correlated with length of various internodes, particularly, peduncle length contributing a great deal to plant height. The data are given in Tables 2, 3 and 4.

Number of Tillers plant^{-1}

Tillers per plant is the one of most important yield trait which increases the grain yield directly. The parents likes, SKD-1 and Moomal-2002 showed negative GCA effects for the trait. While, TJ-83 and TD-1, Imdad-2005-2005 and Mehran-89 showed positive GCA effects for number of tillers plant^{-1} at location I and locations II. The F_1 hybrids; Imdad-2005-2005 × Mehran-89 and TD-1 × T.J-83 observed maximum SCA effects for tillers per plant at both locations. Our findings confirmed the findings as reported by Allah *et al.* (2010), Cifci and Yagdi (2010) and Farooq *et al.* (2010). The data are given in Tables 2, 3 and 4.

Spike length

The wheat inflorescence is known as a spike. It contain grains the major constituent of yield and ultimately it contribute a lot to the grain yield. The varieties Moomal-2002, Mehran-89 and SKD-1 GCA effects were negative recorded for spike length, whereas, the parents TJ-83, TD-1 and Imdad-2005-2005 GCA effects recorded positive for spike length at location 1 (Tando jam). The parents; Moomal-2002, SKD-1 and TJ-83 recorded negative GCA effects whereas varieties; Mehran-89, Imdad-2005-2005 and TD-1 recorded positive GCA effects for spike length at location II. The two F_1 hybrids showed negative SCA effects whereas, other thirteen F_1 hybrids were observed positive SCA effects for spike length at location 1 (Tando jam). The five F_1 hybrids observed negative SCA effects however, ten F_1 hybrids showed positive SCA effects ranged from 0.15 to 1.91 for spike length at location II (Sakrand). Our results are agreed with different researchers i.e Akbar *et al.* (2009), Cifci and Yagdi (2010) and Farooq *et al.* (2010). The data are given in Tables 2, 3 and 4.

Number of spikelet spike^{-1}

The varieties Imdad-2005-2005, TJ-83, TD-1 and Mehran-89 showed positive GCA effects, whereas, varieties Moomal-2002 and SKD-1 GCA effects were recorded negative for number of spikelets spike^{-1} at location I. The genotypes Imdad-2005-2005 and TJ-83 were gave positive GCA effects, however, the varieties TD-1, SKD-1, Mehran-89 and Moomal-2002 recorded with negative GCA effects for number of spikelets spike^{-1} at location II. The nine F_1 hybrids showed positive SCA effects, whereas, six hybrids gave negative SCA effects for spikelets spike^{-1} at location I. Ten F_1 hybrids gave positive SCA effects, however, five F_1 hybrids SCA effects observed negative for number of spikelets spike^{-1} at location II. The F_1 cross TD-1 × TJ-83 showed the highest SCA effects for spikelets spike^{-1} at location I. However cross TJ-83 × Moomal-2002 recorded the lowest SCA effects for spikelets spike^{-1} at location I. Our findings confirmed Kutlu and Olgun, (2015). The data are given in Tables 2, 3 and 4.

Number of grains spike^{-1}

The positive GCA effects were observed from the varieties Mehran-89, Imdad-2005-2005 and TD-1. However, the varieties TJ-83, Moomal-2002 and SKD-1 gave GCA effects negative for number of grains spike^{-1} at both locations. Nine F_1 hybrids observed SCA impacts positive for grains spike^{-1}. However, six F_1 hybrids gave SCA impacts negative for grains spike^{-1} at both locations. The F_1 hybrid TJ-83 × Moomal-2002 gave SCA impacts highest for grains spike^{-1} at location 1(Tandojam), however, cross TD-1 × TJ-83 showed SCA effects highest for grains spike^{-1} at

location II (Sakrand). Our findings were agreed with Akram *et al.* (2009), Khodarahmi *et al.* (2010) and Ojaghi and Akhendova. The data are given in Tables 2, 3 and 4.

Grain yield plant^{-1}

The varieties Mehran-89, Imdad-2005-2005 and TD-1 showed highest GCA effects for grain yield plant^{-1} GCA for grain yield plant^{-1} at location 1 and location II for grain yield plant^{-1}. Whereas, TD × TJ-83 gave maximum SCA effects for grain yield plant^{-1} at both locations (Tando jam and Sakrand). Our findings confirmed the results of Khodarahmi *et al.* (2010) and El-Rawy *et al.* (2018). The data are given in Tables 2, 3 and 4.

Seed index

Mehran-89 and TD-1 gave higher GCA effects at location I and Moomal-2002, TJ-83 and SKD-1 for location II. Hybrid TJ-83 × Moomal-2002 showed highest SCA at Location I (Tandojam.) and TD-1 × TJ -83 at location II (Sakrand) for seed index. Our findings agreed with Akbar *et al.* (2009), Akram *et al.* (2009), Yucel *et al.* (2009) and Cifi and Yagdi (2010). The data are given in Tables 2, 3 and 4.

Harvest index

Moomal-2002, TJ-83 and TD1 recorded maximum GCA effects for harvest index % at location I and at location II for harvest index. The F_1 hybrids TD-1 × TJ-83 gave higher SCA effects for harvest Index % at location I and Imdad-2005-2005 × Mehran-89 at location II. Our results agreed with Khattab *et al.* (2010), Kutlu and Olgun (2015) and Rahul and Kandalkar (2018). The data are given in Tables 2, 3 and 4.

Correlation among morphological and yield traits

Days to 75% heading

Days to 75% heading were significantly and positively associated with days to 75% maturity, plant height, peduncle length, internode length and negatively associate with harvest index%. Khokhar *et al.* (2010) and Desheva, (2016). The data are given in Table 5.

Days to 75% maturity

Days to 75% maturity were significantly and positively associated with plant height, peduncle length, internode length and negatively associated with tillers plant-1 with days to 75% maturity. Our results confirmed with Anwar *et al.* (2009) and Yagdi and Sozen (2009). The data are given in Table 5.

Plant Height

The plant height was significantly and positive associated with peduncle length, internode length and negatively associated with tiller plant^{-1}, spike length, grains spike^{-1} and grain yield plant^{-1}. Our findings are agreed with Aydin *et al.* (2010) and Khokhar *et al.* (2010). The data are given in Table 5.

Peduncle length

The information regarding peduncle length it was significantly and positively associated with internode length and negatively associated with tillers palnt^{-1}, spike length, grains spike^{-1}, grain yield plant^{-1} and seed index. Our results were in agreement with Majumder *et al.* (2008) and Khan and Hassan (2017). The data are given in Table 5.

Internode length

It is observed that internode length negatively correlated with number of tillers plant^{-1}, spike length, spiklets spike^{-1}, grains spike^{-1}, grain yield plant^{-1}, seed index and harvest index. Our findings were agreed with the results of Majumder *et al.* (2008). The data are given in Table 5.

Number of tillers plant^{-1}

It is observed that tillers plant^{-1} were significantly and positively associated with spike length, spikelets spike^{-1}, grains spike^{-1}, grains yield palnt^{-1} and seed index. Our findings were confirmed with the research findings of Ajmal *et al.* (2009). The data are given in Table 5.

Spike length

The significant association was observed among spike length with spikelets spike^{-1}, grains spike^{-1}, grain yield plant^{-1}, seed index and negative with harvest index. Our results agreed with Dharmendra and Singh (2010) and Asghar *et al.* (2016). The data are given in Table 5.

Spiklets spike^{-1}

The spikelets spike^{-1} were significantly and positively associated with the grains spike^{-1}, grain yield plant^{-1}

and seed index. Our findings were confirmed with different researchers Ajmal *et al.* (2009) and Anwar *et al.* (2009) and Yaqoob *et al.* (2016). The data are given in Table 5.

Grain yield plant^{-1}

The grain yield plant^{-1} was significantly and positively associated with seed index. Our findings confirmed with results achieved by different scientists Akram *et al.* (2009) and Arshad *et al.* (2017). The data are given in Table 5.

Seed index

Seed index was positive but non-significantly correlated with harvest index. Our findings was confirmed with Khan and Dar (2010). The data are given in Table 5.

Harvest index

Harvest index was positive but non significance with seed index. Some researchers indicated that the positive correlation between grain yield and yield components traits in wheat such as harvest index (Ghaderi *et al.*, 2009), biological yield (Ghaderi *et al.*, 2009 and Kandic *et al.*, 2009), grains spike^{-1} (Khan *et al.*, 2010) and thousand kernel weight Alpay (2018). The data are given in Table 5.

Heritability Estimates (Broad sense)

Research for development of new wheat varieties was based on genetic variation through selection and hybridization. Genetic variation for morphological traits and yield depends upon mode of inheritance and gene action. The percentage of heritability was higher for days to 75% heading (99.52), days to 75% maturity (99.72), plant height (98.31), peduncle length (98.60), internode length (98.58), number of tillers plant^{-1} (96.99), spike length (97.57), spiklets spike^{-1} (91.43), grains spike^{-1} (91.80), grain yield plant^{-1} (95.53), seed index (93.56) and harvest index (90.60). Our findings confirmed with different scientists Yaqoob (2016) and Khan, and Hassan. (2017). The data are given in Table 6.

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