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Heterosis and correlation studies in F1 hybrids of hexaploid wheat (*Triticum aestivum L.*) cultivars

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Abstract

The goal of the study was to determine whether the heterotic influence and phenotypic link between a numbers of yield variables in F1 hexaploid wheat hybrids could be controlled (*Triticum aestivum L.*). Our research trail was held at the Botanical Garden of Sindh Agricultural University's Department of Plant Breeding and Genetics in Tandojam, Pakistan. Six parental varieties (Sunhri, PBGST2, Sarsabz, TD1, TJ83, and Moomal) and nine F1 hybrids (TJ83 x TD1, PBGST2 x TD1, TJ83 x Moomal, TD1 x Moomal, TD1 x Sarsabz, Sarsabz x Sunhri, and TJ83) were supplied with material seed by the Department of Plant Breeding. After eight characters were evaluated, the experimental fields were selected and put into a randomised complete block design with four repetitions. The hybrids differed considerably (P 0.01) for every trait examined with the exception of plant height and maturity up to 75% of the time, whereas the parents showed no differences in grain yield. There was significant heterosis in the F1 hybrids, as seen by the mean square of the parent and the hybrid. Overall, maturity was important up to 75% of the time, even if it was negatively correlated with the majority of production metrics, meaning that genotypes with early maturation produced lower yields. The spikelets spike-1, seed index, and harvest index in plant-1 were all adversely connected with plant height, however grain yield was significantly and favourably correlated with all yield indices. These findings showed that choosing plants that produce more grain could be based on one or more yield components.

Keywords: Wheat; Heterosis; Correlation; Genotypes; Yield

1. Introduction

A common crop grown for human consumption is wheat (*Triticum aestivum L.*) in many parts of the world (Singh et al. 2015). The most well-known type of wheat in the Triticum group is bread wheat (*Triticum aestivum L.*). The most widely cultivated wheat in the world is *T. aestivum* L., which is also a hexaploid (2n = 6x = 42). 2016 (Bhutto et al.). The most important grain crop in the world is wheat, which is also a staple diet for the planet's rising human population. Grain yield is influenced both positively and negatively by genetic and environmental factors (Iftikhar et al. 2012; Nie et al.

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2019). In cereal crops, wheat is the third most significant source of calories (Masood et al. 2014). In the last 50 years, the agricultural industry has grown so quickly that cereal agriculture now accounts for 50% of the world's food output (Sharma et al. 2015). Three main factors have been connected to a rapid growth in wheat production. Genetically modified hybrid types produced through new breeding techniques provide the highest yield of all hybrid varieties. Reduced irrigation area, excessive reliance on fertilisers, especially those containing phosphorus (P) and nitrogen (N), and (Nie et al. 2019). In general, access to places with more irrigation and fertiliser use is limited. New breeding methods are therefore needed to increase wheat yields (Ansari and Ansari 1997; Ni et al. 2013). According to projections made by the UN, boosting wheat output is essential for guaranteeing global food security (FAO). Particularly in low-yielding regions where wheat is frequently farmed, new techniques for enhancing crop output are gaining traction (Tester and Langridge 2010). Increasing yield in a hybrid wheat variety through heterosis (hybrid vigour) is one of the most promising strategies. It is believed that heterosis had a significant role in the rise in wheat yields from 3.5 to 15%. (2012) Longin and associates the complexity of wheat inbreeding made it previously impossible to study wheat heterosis (Hassan et al. 2006).

Over the past ten years, the hybrid wheat programme has become increasingly important in modifying the overall area of hybrid farming around the world. Interest in developing hybrid wheat peaked in the 1960s, when male sterility and hybrid wheat restoration techniques were discovered (Kumar and Janeja 2018). However, hybrid system research was inapplicable, which made adoption challenging (Whitford et al. 2013). With great potential for creating new wheat varieties, genetic engineering is now being employed to produce a number of novel hybrid breeding innovation approaches (Kempe and Gils 2011). Breeders need to focus on wheat varieties with high yields and pest and environmental tolerance (Ehdaie and Waines 1989). Finding the factors that cause poor yields is difficult because yield is one of the most complex quantitative features of most species (Singh et al. 2010). Utilizing trait-based selection, wheat breeders can improve yield and associated characteristics (Khan et al. 2014; Tariq et al. 2014). 4,444 hybrid varieties share the traits of having higher yields, increased yield stability, and increased tolerance to biotic and abiotic stresses (Schnable and Springer 2013). In order to determine if the proportion of hybrids (F1) has grown or decreased in comparison to their intermediate and superior parents, heterotic research might be very helpful (Kalhoro et al. 2015). The majority of heterobeltiosis cases include a person with combined hybrid abilities. Positive heterosis is chosen for yield growth and general component selection, whereas negative heterosis is preferred for early maturity and short plant height (Alam et al. 2004). Some of the most popular genetic explanations for the formation of hybrid vitality include those relating to the impacts of dominant, over-dominant, and epistasis genes (Birchler et al. 2010). Contrarily, the application of heterosis is acknowledged as plant breeding's greatest success. In comparison to conventional plant breeding techniques, wheat heterosis hybrid breeding produces more information. In terms of breeding strategies and practises, heterosis also offers helpful data about parental ability (Borghi et al. 1988; Ni et al. 2013). To identify true heterotic cross groups, the examination of heterosis versus better parents (heterobeltiosis) may be helpful. It is thought that using the indirect selection average for a strong inherited characteristic (Aycicek and Yildirim 2006). Spikelet length and ear of spikelet 1, tiller and plant and grain and plant yield, and spikelet and tiller and plant have all been proven to be positively correlated (Khan and Dar 2010). Evaluation of heterosis and correlation in hexaploid wheat cultivars was the goal of the current study. The goal of the study was to determine if wheat varieties in hybrid combinations could identify the heterosis (percent) of middle and enhanced parents as well as the correlation between significant F1 performance indicators.

2. Material and methods

The Department of Plant Breeding and Genetics at Sindh Agricultural University in Tandojam gave the six seed parents and their nine F1 hybrids. The experiment made use of a randomised whole block design with four replications. The Faculty of Plant Breeding and Genetics within the Faculty of Plant Cultivation was where the study was carried out. The experimental plots consisted of four 10-foot-long rows. Plant and row spacing was chosen at 20.0 cm and 5.0 cm, respectively. Standard protocols were followed for agronomic practises, soil characteristics, weed control, irrigation, and fertiliser application. The following are specific materials and procedures: In this study, six parents, including Sunhri, PBGST-2, TJ-83, Sarsabz, TD-1, and Moomal, were analysed. There were also 10 F1 hybrids, including TJ-83 x TD-1, PBGST-2 x TD-1, TJ-83 x Moomal, Moomal x TD-1, TD-1 x Sarsabz, Sarsabz x TJ-83 Data was gathered for all characteristics from 10 randomly chosen plants from each genotype in each replication.

2.1. Statistical analysis

Excel was used to collect the data in order to build a database for analysis. Using a statistical method developed by Gomez and Gomez, the analysis of variance was carried out to screen out genotype performance (1984). While correlations were computed using the approach (Fehr 1991) and heterosis was estimated (Raghavrao 1983).

3. Results

The outcomes for various qualities are as follows: All variables were substantially different across genotypes, including maturity up to 75% of the time, plant height, spikelength, spikelet/spike, grain/spike, seed index, grain yield/plant, harvest index, and total dry matter (p0.01). The genotypes were utilised to separate the parents and F1 hybrids. Mean squares from analysis of variance showed that hybrids and parents differed considerably for various plant traits, with the exception of grain yield/plant, which was not statistically different between the parents. Significant mean squares for parents vs. F1 hybrids showed the importance of heterotic effects.

3.1. The average percentage of F1 hybrids and their parents.

Table 2 displays the average percentage of parent data that included information on parent performance. Parents took an average of 115.43 days to attain maturity at 75%, whereas F1 hybrids needed somewhat less time (109.12). Statistics show that father Sunhri reached maturity in the quickest amount of time, while father TJ83 took the longest (119.50 days) (108.90). The plant's height was 58.20 cm for the F1 hybrids vs 78.41 cm for the parents, showing that the F1 hybrids were more desirable and shorter than the parents and could be considered stable in storage. PBGST02 plants were larger than parent TD1 plants (85.55 cm), which were smaller (64.20 cm). Parents produced spikes that were, on average, shorter (11.46 cm) than F1 hybrids (12.10 cm). Among the parents, TD1 produced the spines with the largest length (12.40 cm), whereas Sarsabz produced the spines with the smallest length (10.60 cm). The F1 hybrids generated 18.83 spikelets on average compared to the parents' 15.91 spikelets. Sunhri had the most spikelets/tips (17.10) of the parents, while Sarsabz had the fewest (14.00). Parents had an average grain/spike of 42.25, whereas F1 hybrids had a markedly higher grain/spike (74.04).

Table 1 Mean squares from analysis of variance for various traits in different wheat varieties and F_1hybrids

Characters	Mean squares					
	Replication D.F. = 3	**Genotypes D.F. = 8**	**Parents (P) D.F. = 5**	**F_1 hybrids (H) D.F. = 8**	**Parents vs Hbirds D.F. = 1**	**Error D.F. = 42**
Days to 75% maturity	20.00	53.65**	62.18**	6.86	385.33**	5.28
Plant height	340.401	412.70**	222.77**	3.83	4323.42**	39.52
Spike length	0.94	2.61**	2.35**	3.83**	33.23**	0.39
Spikelet's spike^{-1}	2.11	14.84**	5.71**	16.16**	49.96**	1.76
Grains spike^{-1}	586.4	891.23**	88.22**	196.66**	10462.82**	70.99
Seed index	1.825	200.06**	47.23**	306.96**	108.96**	11.06
Grain yield plant^{-1}	586.4	891.23**	8.54	62.87**	2052.32**	12.06
Harvest index	14.9	20.76**	6.88**	32.28**	23.04**	2.62
Total dry matter	227.93	838.54**	22.47**	418.53**	827.97**	43.69

Parent TJ83 had the most grains per spike (49.65), whereas parent Sarsabz had the least grains per spike (35.35). The F1 hybrids' seed index was 34.94 g as opposed to the parents' average of 39.40 g. This notable variation between parents and hybrids might be attributed to hybrids having more grains than their parents, which results in a lower seed index. Sunhri had the greatest semen index (45.21 g) among the fathers, whereas TJ83 had the lowest semen index (35.97 g). The average amount of grain produced by the parents was 17.69 g, whereas the F1 hybrids produced 31.47 g. The heterotic effects of F1 hybrids resulted in a significant increase in grain production. Sarsabz recorded the highest output per plant (19.30 g), whereas Sunhri reported the lowest yield per plant (15.75 g). The F1 hybrids' harvest index was 46.34 percent whereas the harvest index of the parents was 42.78 percent. Parental performance index was highest for Sarsabz (44.97%), and lowest for Moomal (42.63 percent). In comparison to the parents' average total dry mass of 14.00 g, the F1 hybrids produced much higher biomass (67.91 g). Due to heterotic influences, our findings showed that the hybrids accumulated more total dry matter than their parents. Sunhri had the least biomass of the parents, but TD1 had the most total dry matter per plant (44.00 g) (38.20 g). The average percentage of F1 hybrids is shown in Table 2. The TJ83 x TD1 cross needed the least amount of time (days), whereas the Moomal x TJ83 cross attained maturity at 75%

in the shortest length of time (111.35 days) (107.8). In terms of plant height, the Moomal x TJ83 cross resulted in shorter 54.20 cm plants whereas the TJ 83 x Sarsabz cross produced taller 64.15 cm plants. The TD1 x Sarsabz cross had the highest value for the length of a column (13.15) and the Moomal x TJ83 cross had the lowest value (10.90) among the other crosses. The most spikelets were produced by TJ83 × TD1 (20.90), whereas the least were produced by PBGST2 x TD1 (15.10). The PBGST2 x TD1 hybrid only generated a little quantity of tip1 grain compared to other crossings, but the TJ 83 x Sarsabz cross produced more grain seeds per ear (84.20) than other crosses (63.45). The TJ 83 x Moomal hybrid had a higher seed index (44.19 g), whereas the TJ 83 x Sarsabz cross had the lowest seed index (21.41 g). The PBGST2 x TD1 hybrid produced the smallest grain crop1, whereas the TJ83 x Sarsabz cross produced the biggest grain crop1 (36.45 g) (26.00 g). The Moomal x TJ83 (43.23) cross had the lowest harvest index (percent), whereas the TJ83 x TD1 (51.66) cross had the greatest. PBGST-2 x TD-1 generated plants that weighed less biomass per plant (83.15 g), whereas Hybrid TJ 83 x Sarsabz produced plants that weighed more biomass per plant (83.15 g) in terms of total dry matter (52.20 g).

Table 2 Mean performance of F_1hybrids along with their parents for various quantitative traits in bread wheat genotypes

Parents	Days to 75% maturity	Plant height (cm)	Spike length (cm)	Spikelet's spike	Grains spike^{-1}	Seed index (g)	Yield plant^{-1}	Yield plant^{-1}	Total dry matter (g)
Parents									
Sunhri	108.90	78.45	12.15	17.10	42.15	45.21	15.75	41.23	38.20
PBGST-2	114.90	85.55	11.80	15.10	44.00	40.95	16.25	38.78	41.90
Sarsabz	113.30	78.40	10.60	14.00	35.35	36.61	19.30	44.47	43.40
TD-1	117.50	64.20	12.40	17.00	42.30	37.67	18.30	41.59	44.00
TJ-83	119.50	82.45	11.20	15.90	49.65	35.97	17.50	44.13	39.65
Moomal	118.50	81.45	10.65	16.40	40.05	40.01	19.05	46.46	41.00
Average	115.43	78.41	11.46	15.91	42.25	39.40	17.69	42.78	41.35
F_1 hybrids									
TJ-83 x TD-1	107.8	58.90	13.75	20.90	75.15	40.46	32.50	49.77	65.30
PBGST-2 x TD-1	107.85	61.45	11.60	15.10	63.45	41.61	26.00	49.80	52.20
TJ-83 x Sunhri	108.15	54.95	12.60	19.70	74.85	44.19	31.60	49.12	64.33
Moomal x TD-1	109.45	56.00	12.65	19.80	75.95	27.40	31.35	44.21	70.90
TD-1 x Sarsabz	108.50	58.40	13.15	20.80	82.90	43.16	35.45	46.92	75.55
Sarsabz x Sunhri	108.25	59.75	11.85	16.90	73.45	40.93	26.10	46.44	56.20
TJ- 83 x Sarsabz	110.55	64.15	11.20	19.90	84.20	21.41	36.45	43.83	83.15
Moomal x TJ-83	111.35	54.20	10.90	17.00	64.40	26.18	28.40	43.96	64.60
Sunhri x TD-1	110.20	56.00	11.25	19.40	73.15	29.18	35.45	44.87	79.00
Average	109.12	58.20	12.10	18.83	74.04	34.94	31.47	46.34	67.91
LSD (5%)	3.28	8.97	0.89	1.89	12.02	5.42	4.95	2.31	9.43

3.2. F1 hybrids with heterotic effects

Hybrid vigour was used to examine the ability of F1 hybrids to boost various yields and related characteristics. Table 3 displays the results of the hybrid's heterotic influence on the F1 hybrid from days to 75%. The results showed that heterobelthiosis and comparative heterosis were both negative in all of the F1 hybrids. Destructive heterosis varies from 2.65 to 9.11 percent, whereas heterosis itself ranges from 6.21 to 9.97 percent. When compared to TJ83 x TD1, TJ83 x Sunhri displays the largest negative relative heterosis (9.11 percent) (9.02 percent). Heterobeltiosis was present in TJ83 TD1 (9.79%) but not in TJ83 x Sunhri (9.79%). 97.79 percent. 9.49%. All unfavourable hybrids were expected to take seven days to attain 75 percent maturity, resulting in premature hybrids. Table 4 displays how heterozygous F1 crosses affected plant height. The findings demonstrate that the heterobeltiosis of all hybrids and the relative heterosis of the middle parents are both negative. Heterobeltiosis can range from 22.19 to 43.35, whereas negative paternal heterosis can range from 16.19 to 36.64. The Moomal x TD1 (36.64) junction has the largest relative value of heterosis, followed by the TJ83 x Sunhri junction (32.94). PBGST2 x TD1 and Moomal x TD1 both had heterobeltiosis scores of 43.35 percent, which was the highest (41.30 percent). Negative heterobeltiosis is the best method for increasing plant height. The cereal plant is directly impacted by the ear length since extended spikelets have more spikelets, which leads to more kernels/ears and a higher grain production. Table 5 displays the relative heterosis and heterobelithiosis of the F1 hybrids. In contrast to the heterobelthiosis, which ranged between 12.50 and 9.27 percent, the relative heterosis of the peak length varied between 16.52 and 8.35 percent. The TJ83 x TD1 cross has the greatest relative heterosis value (16.52 percent). TJ83 x Sunhri and Sunhri x TD1 showed a hybrid influence of 12.50 and 9.27 percent, respectively, for heterobelithiosis, although Sunhri x TD1 exhibited the lowest value (8.35 percent). The heterotic effects of spikelets on Spike1 are shown in Table 6. Eight of nine hybrids and two of nine hybrids, with values ranging from 33.11 percent to 5.91 percent and 25, 15 percent to 11.17 percent, respectively, exhibited a favourable relative impact of heterosis and heterobeltiosis. Relative heterosis was highest in the TD1 x Sarsabz cross (34.19%) and lowest in the PBGST2 x TD1 cross (5.91 percent). The PBGST2 x TD1 crossover had the lowest heterobeltiosis value (0.15%), whereas the TJ83 x Sarsabz crossover had the highest (25.15%). (11.17 percent). The figures showed that among the remaining crosses, TJ83 x TD1 and TJ83 x Sarsabz produced the most perfect hybrids and had the greatest heterotic impact. The effects of average F1 hybrids and superior parents on the Spike1 grain count in hexaploid wheat are shown in Table 7. Surprisingly, the relative and heterobiotic impacts of the nine hybrids ranged from positive relative and heterobiotic effects of 43.58 percent to positive relative and heterobiotic effects of 113.52 percent, respectively. Of all the hybrids, TD1 x Sarsabz had the highest relative heterosis (113.52%) and the greatest heterobeltiosis crossover (95.98 percent). Table 8 in hexaploid wheat illustrates how the seed indices of the middle and upper parents are affected by F1 hybrid heterosis. Positive relative heterosis and heterobeltiosis were present in five of the nine hybrids. As a result, hybrids with the highest relative heterosis had more heterobeltiosis. The relative heterosis of the semen index in the TJ83 x Sunhri and TJ83 x Sarsabz crosses was found to range between 16.32 and 41.84 percent. Heterobeltiosis is a kind of heterobeltiosis, and the areas found for TD1 x Sarsabz and TJ83 x Sarsabz were 14.60 percent and 43.15 percent, respectively.

Table 3 Heterotic effects of F_1hybrids over their mid and better parents for days 75% maturity in hexaploid wheat

Hybrids	Male parent	Female parent	Mid parent	F_1 hybrids	% increase (+) or decrease (-) of F_1s over	
					Relativeheterosis (%)	Hetero-beltiosis (%)
TJ-83 x TD-1	119.5	117.5	118.5	107.80	-9.02	-9.79
PBGST-2 x TD-1	114.9	117.5	116.2	107.85	-7.18	-8.21
TJ-83 x Sunhri	119.5	118.5	119.0	108.15	-9.11	-9.49
Moomal x TD-1	118.5	117.5	118.0	109.45	-7.24	-7.63
TD-1 x Sarsabz	117.5	113.3	115.4	108.50	-5.97	-7.65
Sarsabz x Sunhri	113.3	117.5	115.4	108.25	-6.19	-7.87
TJ-83 x Sarsabz	119.5	113.3	116.4	110.55	-5.02	-7.48
Moomal x TJ-83	118.5	119.5	119	111.35	-6.42	-6.82
Sunhri x TD-1	108.9	117.5	113.2	110.20	-2.65	-6.21

The best hybrids were TJ83 x Sunhri and TJ83 x Sarsabz because they had greater relative heterosis and heterobeltiosis impacts and may be the first option for increasing the wheat seed index. When compared to the average and best parents, hexaploid F1 hybrids' performance suffers from heterosis, as seen in Table 9. The findings showed that considerable relative heterosis and heterobeltiosis were present in all nine hybrids. Relative heterosis had a 38.82 to

108.22 percent effect compared to heterobeltiosis' 35.23 to 93.71 percent influence, The Sunhri x TD1 cross exhibited the largest relative heterosis (108.22), while Sarsabz x Sunhri had the lowest, with values of 93.71 and 35.23, respectively (38.82). Six hybrids showed a heterobeltiosis impact of greater than 65%. For the harvest index in hexaploid wheat, Table 10 displays the heterotic impacts of F1 hybrids on better and better parents. Despite having positive relative heterosis in eight of the nine hybrids, only six of them showed positive heterobeltiosis effects. The score for positive heterobeltiosis varied from 14.35 to 3.37 percent, whereas the score for relative heterosis ranged from 0.03 to 17.39 percent. For the plant1 grain yield trait, the TJ83 x TD1 hybrid had the greatest value (17.39), whereas the Moomal x TJ-83 cross had the lowest value (-1.52). The results of relative heterosis and heterobelthiosis are summarised in Table 11. The proportion heterosis of F1 hybrids varied between 21.53 to 100.24 percent, according to the data. The Sunhri x TD1 cross (100.24 percent) and TJ83 x Sarsabz cross (100.24 percent) had the highest relative heterosis, respectively (92.21 percent). The crossover PBGST02 x TD1 showed the lowest relative heterosis for total dry matter (21.53 percent). In heterobeltiosis, the highest value was found for the TJ83 x Sarsabz cross (91.58 percent), while the lowest value was found for the PBGST02 x TD1 cross (18.63 percent).

Table 4 Heterotic effects of F_1hybrids over their mid and better parents for plant height in hexaploid wheat

Hybrids	Male parent	Female parent	Mid parent	F_1 hybrids	% increase (+) or decrease (-) of F_1s over	
					Relative heterosis (%)	Hetero-beltiosis (%)
TJ-83 x TD-1	82.45	64.20	73.32	58.90	-19.67	-28.56
PBGST-2 x TD-1	85.55	64.20	74.87	50.21	-32.94	-41.30
TJ-83 x Sunhri	82.45	81.45	81.95	54.95	-32.94	-33.35
Moomal x TD-1	81.45	64.20	72.82	46.14	-36.64	-43.35
TD-1 x Sarsabz	64.2	78.40	71.30	58.40	-18.09	-25.51
Sarsabz x Sunhri	78.4	64.20	71.30	59.75	-16.19	-23.78
TJ-83 x Sarsabz	82.45	78.40	80.42	64.15	-20.23	-22.19
Moomal x TJ83	81.45	82.45	81.95	54.20	-33.86	-34.26
Sunhri x TD-1	78.45	64.20	71.32	56.00	-21.48	-28.61

Table 5 Heterotic effects of F1 hybrids over their mid and better parents for spike length in hexaploid wheat

Hybrids	Male parent	Female parent	Mid parent	F_1 hybrids	% increase (+) or decrease (-) of F_1s over	
					Relative heterosis (%)	Hetero beltiosis (%)
TJ-83 x TD-1	11.2	12.4	11.80	13.75	16.52	10.88
PBG02 x TD-1	11.8	12.4	12.10	11.60	-4.13	-6.45
TJ-83 x Sunhri	11.2	10.6	10.92	12.60	15.33	12.5
Moomal x TD-1	10.65	12.4	11.52	12.65	9.76	2.01
TD-1 x Sarsabz	12.4	10.6	11.50	13.15	14.34	6.04
Sarsabz x Sunhri	10.6	12.4	11.50	11.85	3.04	-4.43
TJ-83 x Sarsabz	11.2	10.6	10.90	11.20	2.75	1.23
Moomal x TJ83	10.6	11.2	10.92	10.90	-0.22	-2.67
Sunhri x TD-1	12.15	12.4	12.27	11.25	-8.35	-9.27

Table 6 Heterotic effects of F1 hybrids over their mid and better parents for spikelet's spike-1 in hexaploid wheat

Hybrids	Male parent	Female parent	Mid parent	F_1 hybrids	% increase (+) or decrease (-) of F_1s over	
					Relative heterosis (%)	Hetero-beltiosis (%)
TJ-83 x TD-1	15.9	17.0	16.45	20.9	27.05	22.94
PBGST-2 x TD-1	15.1	17.0	16.05	15.1	-5.91	-11.17
TJ-83 x Sunhri	15.9	16.4	16.15	19.7	21.98	20.12
Moomal x TD-1	16.4	17.0	16.70	19.8	18.56	16.47
TD-1 x Sarsabz	17	14.0	15.50	20.8	34.19	22.35
Sarsabz x Sunhri	14	17.0	15.50	16.9	9.03	-0.58
TJ-83 x Sarsabz	15.9	14.0	14.95	19.9	33.11	25.15
Moomal x TJ-83	16.4	15.9	16.15	17.0	5.26	3.65
Sunhri x TD-1	17.1	17.0	17.05	19.4	13.78	13.45

Table 7 Heterotic effects of F1 hybrids over their mid and better parents for number of grains spike-1 in hexaploid wheat

Hybrids	Male parent	Female parent	Mid parent	F_1 hybrids	% increase (+) or decrease (-) of F_1s over	
					Relative heterosis (%)	Hetero-beltiosis (%)
TJ-83 x TD-1	49.65	42.30	45.97	75.15	63.45	51.35
PBG02 x TD-1	44.00	42.30	43.15	63.45	47.04	44.2
TJ-83 x Sunhri	49.65	40.05	44.85	74.85	66.88	50.75
Moomal x TD-1	40.05	42.30	41.17	75.95	84.45	79.55
TD-1 x Sarsabz	42.3.0	35.35	38.82	82.9	113.52	95.98
Sarsabz x Sunhri	35.35	42.30	38.82	73.45	89.18	73.64
TJ-83 x Sarsabz	49.65	35.35	42.5	84.2	98.11	69.58
Moomal x TJ83	40.05	49.65	44.85	64.4	43.58	29.7
Sunhri x TD-1	42.15	42.30	42.22	73.15	73.23	72.93

Table 8 Heterotic effects of F1 hybrids over their mid and better parents for seed index in hexaploid wheat

Hybrids	Male parent	Female parent	Mid parent	F_1 hybrids	% increase (+) or decrease (-) of F_1s over	
					Relative heterosis (%)	Hetero-beltiosis (%)
TJ-83 x TD-1	35.97	37.66	36.81	40.46	9.88	7.41
PBGST-2 x TD-1	40.94	37.66	39.3	41.61	5.85	1.61
TJ-83 x Sunhri	35.97	40.01	37.99	44.19	16.32	10.45
Moomal x TD-1	40.01	37.66	38.83	27.4	-29.44	-31.51
TD-1 x Sarsabz	37.66	36.6	37.13	43.16	16.23	14.6
Sarsabz x Sunhri	36.6	37.66	37.13	40.93	10.22	8.67
TJ-83 x Sarsabz	35.97	37.66	36.81	21.41	-41.84	-43.15
Moomal x TJ83	40.01	35.97	37.99	26.18	-31.09	-34.57
Sunhri x TD-1	45.2	37.66	41.43	29.18	-29.59	-35.46

Table 9 Heterotic effects of F1 hybrids over their mid and better parents for grain yield plant-1 in hexaploid wheat

Hybrids	Male parent	Female parent	Mid parent	F_1 hybrids	% increase (+) or decrease (-) of F_1s over	
					Relative heterosis (%)	Hetero beltiosis (%)
TJ-83 x TD-1	17.5	18.30	17.90	32.50	81.56	77.59
PBGST-02 x TD-1	16.25	18.30	17.27	26.00	50.50	42.07
TJ-83 x Sunhri	17.5	19.05	18.27	31.60	72.91	65.87
Moomal x TD-1	19.05	18.30	18.67	31.35	67.87	64.56
TD-1 x Sarsabz	18.3	19.30	18.80	35.45	88.56	83.67
Sarsabz x Sunhri	19.3	18.30	18.80	26.10	38.82	35.23
TJ-83 x Sarsabz	17.5	19.30	18.40	36.45	98.09	88.86
Moomal x TJ-83	19.05	17.50	18.27	28.40	55.40	49.08
Sunhri x TD-1	15.75	18.30	17.02	35.45	108.22	93.71

Table 10 Heterotic effects of F1 hybrids over their mid and better parents for harvest index in hexaploid wheat

Hybrids	Male parent	Female parent	Mid parent	F_1 hybrids	% increase (+) or decrease (-) of F_1 over	
					Relative heterosis (%)	Hetero-beltiosis (%)
TJ-83 x TD-1	45.17	42.83	44	51.66	17.39	14.35
PBGST-02 x TD-1	43.68	42.83	43.26	49.38	14.13	13.03
TJ-83 x Sunhri	45.17	42.62	43.9	49.02	11.66	8.52
Moomal x TD-1	42.62	42.83	42.73	44.03	3.03	2.78
TD-1 x Sarsabz	42.83	45.97	44.4	44.42	0.03	-3.37
Sarsabz x Sunhri	45.97	42.83	44.4	47.59	7.18	3.52
TJ-83 x Sarsabz	45.17	45.97	45.57	45.64	0.15	-0.71
Moomal x TJ-83	42.62	45.17	43.9	43.23	-1.52	-4.30
Sunhri x TD-1	44.26	42.83	43.55	45.64	4.79	3.10

Table 11 Heterotic effects of F1 hybrids over their mid and better parents for total dry matter in hexaploid wheat

Hybrids	Male parent	Female parent	Mid parent	F_1 hybrids	% increase (+) or decrease (-) of F_1s over	
					Relative heterosis (%)	Hetero beltiosis(%)
TJ-83 x TD-1	39.65	44.0	41.82	65.3	56.12	48.4
PBGST-02 x TD-1	41.90	44.0	42.95	52.2	21.53	18.63
TJ-83 x Sunhri	39.65	39.3	39.47	64.3	62.96	62.24
Moomal x TD-1	39.30	44.0	41.65	70.9	70.22	61.13
TD-1 x Sarsabz	44.00	43.4	43.70	75.6	72.88	71.7
Sarsabz x Sunhri	43.40	44.0	43.70	56.2	28.60	27.72
TJ-83 x Sarsabz	39.65	43.4	41.52	83.2	100.24	91.58
Moomal x TJ-83	39.30	39.6	39.47	64.6	63.64	62.92
Sunhri x TD-1	38.20	44.0	41.10	79.0	92.21	79.54

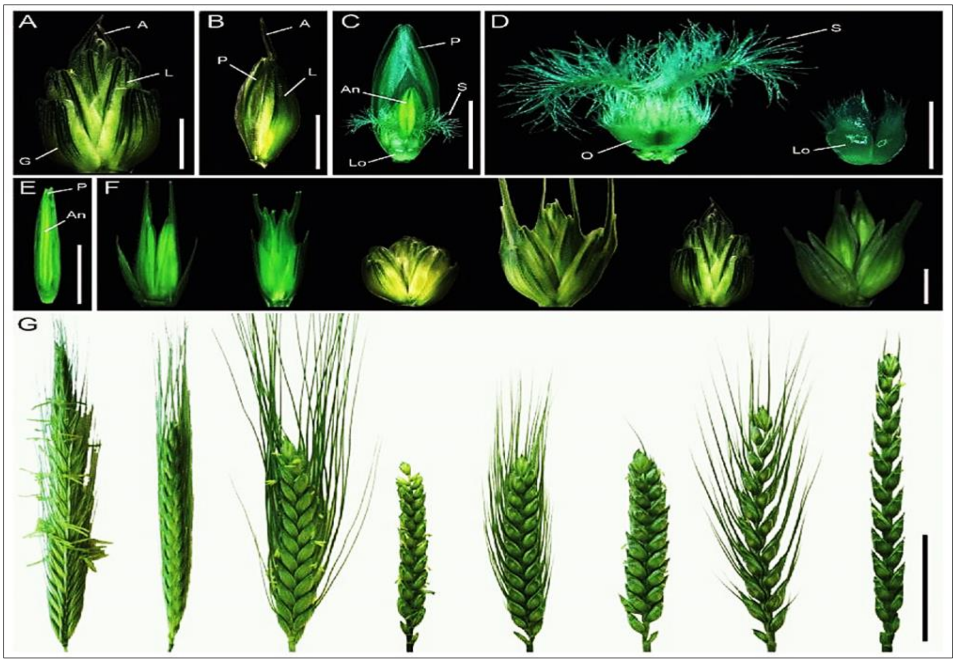

Figure 1 Flowers and wheat ears have a similar structure. Wheat spikelets (a). Foil (b) Palea and reproductive tissues are included in this category. (d) Female reproductive tissue and lodicula. f) Cereal buds that have been dried (rye). (f) Spikelets of Triticeae species, from left to right: rye, T. monococcum ssp. boeticum, three *T. aestivum* varieties (Chinese Spring, Magenta, and Kite), and *T. aestivum* Landrace. (g) rye, T. monococcum ssp. oeticum, T. turgidum ssp. Durum wheat types, and five *T. aestivum* (bread wheat) ears, from left to right: rye, T. monococcum ssp. oeticum, T. turgidum ssp (Chinese Spring, Cadoux, Ghurka and Sentinel, Kite). 5mm rods (A-C, E, F); 2mm rods (D); 5 cm (g). G, gluma; L, lemma; Lo, lodicule; O, ovary; P, pale; S, stigma. A, awn; An, anthers; G, gluma; L, lemma; Lo, lodicule; O, ovary; P, pale; S, stigma.

4. Discussion

Spikelets spikelets1 (r= 0.418 **), total dry matter (r = 0.717 **), and plant grain yield1 (r= 0.63 **) were all negatively but substantially correlated with seed index. Only the spikelet/tip and column length had positive correlations (r= 0.527 and r= 0.528, respectively). The correlation between total dry matter (r = 0.14) and plant1 grain yield (r = 0.26) was positive but not statistically significant. This characteristic verified the positive and substantial correlation between total dry matter (r = 0.765 **) and grain/plant production (r = 0.786 **). The connection between total dry matter and grain/plant is positive (r=0.97**). Except for grain/plant production, which is significant in both parents and hybrids, all of the characteristics exhibited significant changes in both the parents and the hybrids. The parents often needed several days to attain 75% maturity, however the F1 hybrids need a lot less time. In a related study, parents of 75% of hybrids took longer than F1 wheat to reach maturity (Baloch et al. 2016). (Baloch et al. 2016). The F1 hybrids were shorter, more popular, and more resistant to accommodation than the parents, whose plant height was 78.41 cm for the parents and 58.20 cm for the F1 hybrids. The parents produced ears that were 11.46 cm shorter than those of the F1 hybrids, who had ears that were longer (12.10 cm). The parents often required several days to attain maturity at 75%, but the F1 hybrids needed a lot less time and had 42.25 grains per ear, but they also exhibited a significant rise in grain production (74.04). (Table 2). The parents also had a higher plant, shorter spikelets, fewer spikelets/ears, and kernels/ears than F1 hybrids (Kalhoro et al. 2015). The average seed index for the parents was 39.40 g, whereas the seed index for the F1 hybrids was 34.94 g. The vast difference between parents and hybrids may be explained by the hybrids' higher kernel density, which led to a lower seed index. In comparison to the parents' average plant weight of 17.69 grammes, the F1 hybrids averaged 31.47 grammes. F1 hybrids generated considerably more grain as a result of their heterotic effects. Darshan and Marker found that Formaize LM13 X IC32809 hybrids produced greater grain per plant (2019). The F1 hybrids had a harvest value of 46.34 percent compared to the parents' harvest index of 42.78 percent. F1 wheat hybrids (TJ83 Sarsabz) outperformed their parents in terms of harvest index (Baloch et al. 2016). The average parent produced 14.00 g of dry mass, but the average F1 hybrid produced 67.91 g more biomass. These results show that hybrids gained more total dry matter than their parents as a result of heterotic effects (Table 2).

Effects of F1 Hybrids on Heterosis Table 5 depicts the effects of heterosis and heterobeltiosis in F1 hybrids and parents throughout the course of the 75 years before maturity and demonstrates that all hybrids exhibited a favourable correlation between heterosis and heterobeltiosis. A range of 2.65 to 9.11 percent of individuals had negative heterosis, while a range of 6.21 to 9.79 percent had heterobeltiosis. The most significant but intended negative relative heterosis is seen in the TJ83 x TD1 crossing (9.11 percent), which is followed by TJ83 x Sunhri (9.02). Most heterobeltiosis occurs in the TJ83 x TD1 cross (9.79%), then in the TJ83 x Sunhri cross (9.49 percent). The impacts of heterotic influences on plant height in F1 hybrids are shown in Table 4. Because shorter plants are thought to be more stable, negative heterosis is preferred. It was discovered that both relative heterosis and heterobelthiosis had negative effects. In contrast to heterobeltiosis, which was measured in the range of 22.19 to 43.35, negative relative heterosis was recorded in the range of 16.1992 to 36.6426. The two combinations with the greatest relative heterosis value were Cross-Moomal x TD1 and TJ83 x Sunhri. The greatest heterobeltiosis value is seen in PBGST02 x TD1, followed by Moomal x TD1 and Moomal x TD1. In line with the most recent findings, negative heterosis for plant height was found (Singh et al. 2004; Chowdhry 2005; Shehzad et al. 2005). Each plant's seed production was directly influenced by spikelet length, with longer spikelets producing more spikelets. While heterobeltiosis varied from 12.50 to 9.27, relative heterosis ranged from 16.52 to 8.35. The Sunhri x TD1 junction displayed the least amount of column length heterosis, whereas the TJ83 x TD1 intersection displayed the greatest. Sunhri x TD1 and TJ83 x Sunhri, respectively, had the heterobeltiosis peak durations with the biggest (12.50) and smallest (9.27) values. Our results corroborate those of Prakash et al. (2006), Jiang et al. (2017), and Akbar et al. (2010), who discovered peak heterosis length and maximum and highly significant heterosis. The TD1 x Sarsabz cross had the highest relative heterosis (34.19 percent), whereas the PBGST02 x TD1 cross had the lowest relative heterosis (5.91 percent). When compared to the PBGST2 x TD1 cross, the heterobeltiosis rate in the TJ83 x Sarsabz cross was higher (25.15 percent) (11.17 percent). And (Bari et al (Hussain et al., 2007; Singh et al., 2010). By 2004, positive heterosis for ear spikelets had also been recorded. The heterotic effects of F1 hybrids compared to their average and best parents for Grains Spike1 in hexaploid wheat showed that the TD1 x Sarsabz cross had a higher proportion of relative heterosis (113.52 percent), whereas the Moomal x TJ83 cross had a minimal relative heterosis of 43.58 percent. The TD1 x Sarsabz crossover (95.98) had the most effects on heterobeltiosis, whilst the Moomal x crossover TJ83 had the least effects (29.70 percent). According to Kumar and Janeja (2018) and Singh et al. (2010), who discovered a substantial positive heterosis for grains per ear, our results are in line with theirs. According to the results of the previous study, the parents Moomal and Kiran, as well as the hybrids Marvi x TJ83 and TD1 TJ83, can be used in another breeding method to produce high-yielding types. When compared to their mean and better parents for the seed index, the relative heterosis in the TJ83 x Sunhri and TJ83 x Sarsabz hybrids for bread wheat varied from 16.32 to 41.84. It ranges from 14.60 to 43.15 for TD1 x Sarsabz or TJ83 x Sarsabz heterobeltiosis. Our research (Chowdhry, 2005) indicates that there is a sizable and acceptable amount of intermediate parenting, as well as improved parental heterosis for semen index. When grain yield1 seedlings were compared to their average and best parents, the heterotic effects of the F1 hybrids showed that the Sunhri x TD1 cross had the highest relative heterosis (108.22 percent), while the Sarsabz x Sunhri cross had the lowest relative heterosis (38, 82 percent). The hybrids Sunhri x TD1 and Sarsabz x Sunhri showed the largest and lowest heterotic impacts in terms of heterobeltiosis, respectively (93.71 and 35.23 percent, respectively). Both (Kumar and Janeja 2018) and (Hussain et al. 2007; Akbar et al. 2010) found very high relative heterosis and enhanced parental heterosis for grain production per plant. The Moomal x TJ83 cross, on the other hand, had the lowest relative heterosis of 1.52, while the TJ83 x TD1 cross had the greatest relative heterosis of 1.52. Heterobeltiosis values in TJ83 x TD1 and TD1 x Sarsabz ranged from 14.35 to 3.37 percent. The results of relative heterosis and heterobelthiosis for total dry matter are shown in Table 11. The relative heterosis of the F1 hybrids varied from 21.53 to 100.24 percent. However, Sunhri x TD1 and the hybrid TJ83 x Sarsabz (100.24) have the highest relative heterosis (92.21 percent). The PBGST02 x TD1 (21.53 percent) cross showed the lowest relative heterosis for the characteristic total dry matter. Heterobeltiosis was used to establish the highest dry matter content for the TJ83 x Sarsabz cross (91.58%) and the lowest dry matter content for the PBGST02 x TD1 cross (18.63%). Correlations Correlation coefficients had a significant role in the nine returns and their related properties. It was discovered that plant height was positively correlated with grain/plant yield. Spikelets and spikelets had a beneficial relationship with the growth of plants and grains. Days to 75% maturity were significant and correlated well with grain and plant yield. Iftikhar et al. (2012) and Ali et al. (2008) confirmed the conclusions of this study, stating that the grain/plant yield is crucial and that it is divided into tiller/plant, spikelets/spilets, and grain/ears1. Additionally, a strong correlation between Plant 1's operations and grain yield was discovered (Shehzad et al. 2005). (for example, the number of tillers produced by Plant 1, the length of an ear, the number of spikelets in an ear, and the weight of 1,000 grains). It was discovered that there are genotypic and phenotypic relationships between grain yield and other yield components such tillering per plant, number of ears per square metre, number of grains per ear, total biomass per plant, harvest index, and 1000 grain load (Abro et al., 2022; Gelalcha and Hanchinal 2013). Plant height has a substantial positive connection with ear length, spikelets/spike, grains/spike, and grains/spikelet, according to Jamali (2009), suggesting that more positive correlations may be reached through increased grain yield and stringent wheat selection criteria.

Table 12 Correlations coefficient(r) between yield traits of parents and F1 hybrids in wheat

Characters	Days to 75% maturity	Grains spike^{-1}	Harvest index	Plant height	Seed index	Spike length	Spikelets spike^{-1}	Total dry matter	Yieldplant^{-1}
Days to75% maturity	-	-0.747**	-0.600**	0.720**	0.362*	-0.444**	-0.504**	-0.617**	-0.682**
Grains spike^{-1}		-	0.388**	-0.738**	-0.642**	0.362**	0.779**	0.895**	0.930**
Harvest index			-	-0.257*	0.015	0.340**	0.203	0.191	0.323**
Plant height				-	0.580**	-0.339**	-0.540**	0.716**	0.747**
Seed index					-	0.105	-0.418**	-0.717**	-0.630**
Spike length						-	0.527**	0.14	0.206

In order to identify one or more qualities that are strongly connected to yield and can be enhanced through indirect selection, the correlation coefficients between grain yield and processes were determined. Table 12 displays the results. Days to 75% maturity were significantly correlated with grain/ear (r= 0.747 **), harvest index (r= 0.600 **), ear length (r= 0.444 **), wheat ears/ears of wheat (r= 0.504 **), cereal production plant1 (r= 0.682 **), and total dry matter (r= 0.617 **) but not with total dry matter. However, 75% of the maturation days and the seed index (r = 0.362 **) showed a significantly positive correlation on the plant height (r = 0.720 **), grains/spike was significant and was positively correlated with the harvest index (r = 0.388 **), and the yield of the plant1 (r= 0.362 **), ear/ear (r = 0.779 **), grain/plant yield (r = 0.930 * *), total dry matter. Plant height interacted well with grain/plant yield (r= 0.747 * *), total dry matter (r= 0.716 **), and seed index (r= 0.580 **). Peak duration and Spike1 both showed a weak but significant connection (r = 0.339 and 0.54, respectively). Spikelets spikelets1 (r= 0.418 **), total dry matter (r = 0.717 **), and plant grain yield1 (r= 0.63 **) were all negatively but substantially correlated with seed index. Only the spikelet/tip and column length had positive correlations (r= 0.527 and r= 0.528, respectively). The correlation between total dry matter (r = 0.14) and plant1 grain yield (r = 0.26) was positive but not statistically significant. This characteristic verified the positive and substantial correlation between total dry matter (r = 0.765 **) and grain/plant production (r = 0.786 **). The connection between total dry matter and grain/plant is positive (r=0.97**).

5. Conclusion

In wheat genotypes, the relationship between numerous economically significant traits including ear length, spikelet1, ear1, seed index, harvest index, plant height, and total dry matter was investigated. For all of the variables examined, hexaploid research showed that genotypes varied considerably (P 0.01). An alarming amount of heterosis may be seen in the average parent proportion when compared to F1 hybrids. According to average production, Sunhri, the father, produced more spikelet tips1, had a higher seed index, and needed at least days to attain 75 percent maturity. The TJ83 x TD1 hybrid had more spikelets and a higher seed index, but it took longer to reach 75 percent maturity. The TJ83 x TD1 hybrid also had the most wanted positive heterobeltiosis for the floor's culture index and total dry matter, according to the F1 hybrids' beneficial heterosis, and the highest desired negative heterobeltiosis for maturity up to 75% of the days. Overall, the correlation coefficient showed a negative link between days to 75% maturity and the majority of yield measures, indicating that genotypes with earlier maturation had lower yields. Grain tip1, seed index, and harvest index were similarly negatively correlated with plants' height, while plant grain1 yield was substantially and positively correlated with all factors that affect production. The results indicate that heterosis and correlation studies of a variety of yield factors may be used to boost grain output and give useful harvesting criteria for selecting plants with desirable features and high yielding plants.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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