ESTIMATION OF CORRELATION AND PATH COEFFICIENT OF SOME AGRONOMICALLY IMPORTANT POLYGENIC TRAITS IN *TRITICUM AESTIVUM* L.

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ABSTRACT: *The experimental study was conducted to evaluate 24 bread wheat genotypes including 18 cultivars and 6 advance lines for interrelationship between yield and yield related parameters. In the study, direct and indirect effects of different morphological traits were also determined through path coefficients analysis. These genotypes were sown in randomized complete block design (RCBD) with three replications. At maturity, data was collected for plant height, flag leaf area, number of tillers per meter, spikelets per spike, peduncle length, spike length, spike weight, spike density, grains per spike, 1000-grain weight, grain weight per spike, biological yield per meter, grain yield per meter and harvest index. Highly significant correlation was observed between grain yield thousand grain weight and biological yield. Number of tillers per meter length had negative but significant correlation with spike length and grain weight. Path coefficient analysis revealed that plant height, peduncle length, tillers per meter, spikelets per spike, spike weight, number of grains per spike, harvest index and biological yield had positive direct effect on grain yield.*

Key words: *Triticum aestivum* L., Randomized complete block design (RCBD), Correlation, Path coefficient, Morphological traits

INTRODUCTION:

Wheat (*Triticum aestivum* L.) is the staple food for most of the population of world. In Pakistan, the major component of people's diet is wheat. Wheat contributes 10.3% to value added in agriculture and 2.2% in GDP. In 2013-14, wheat was sown on an area of 9039 thousand hectares from which 25.3 million ton production was achieved with an increase of 1.2% on last year in production [1].

Cereal crops belong to the *Poaceae* family, a large family consisting of important group of food plants. Maximum numbers of human beings fulfill their food requirements from the members of this family by getting 50% of proteins as well as 60% of calories. It is a Rabi crop occupies 70% of winter season and 37% of total cultivated area of Pakistan. The diversified food requirements of both urban and rural areas of Pakistan are accomplished through wheat crop to some extent yet the production is not satisfactory to overcome the needs of this country.

Grain production is a complex phenomenon, fluctuates widely as a result of its interaction with environment entailing several contributing factors. The grain yield is directly and indirectly influenced by these factors and the main aim of a breeder is to estimate the extent and kind of association between grain yield and is contributing traits. The yield enhancement requires more variability. Correlation and path coefficient analysis are logical steps towards the understanding of relationship of plant traits. Present study is planned to find out the variability present in bread wheat for different yield-related traits, inter relationship between different plant characters and grain yield. Correlation analysis does not expose the actual relationship between different heritable traits and provide inadequate information that can lead to false results [2].

On other hand, path analysis measures both direct and indirect effects of one trait upon other by splitting the correlation coefficient into direct and indirect effect [3]. Genetic diversity analysis will help us in selecting the diversified genotypes to produce transgressive segregants.

MATERIAL AND METHODS:

The planned research was conducted in the research field of the Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad. The research material consisting of 24 genotypes including 18 commercial varieties (Fd-85, Kohnoor-83, Fd-83, Pb-85, Chakwal-86, Rawal-87, Inqlab-91, Watan-93, Parwaz-94,Shahkar-95, Pb-96, MH-97,Chenab-2000,Uqab-2000,GA-2002, AS-2002, Ufaq-2002, SH-2002) and 6 advance wheat lines(9708, 9718, 9750, 9751, 9757, 9887). Seeds of commercial cultivars/advance lines were collected from Ayub Agriculture Research Institute (AARI) and Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad. These 24 genotypes were evaluated for different morphological characteristics that directly or indirectly influence grain yield. Randomized complete block design was used with three replications for sowing in the field. Length of each row was 5 meter and row to row distance was 9 inches. Normal agronomic and cultural practices were followed uniformly for all experimental units. The experiment was carried out under normal agronomic and cultural practices and normal fertilizer as well as irrigation was applied. The Drill method was used for planting seeds of commercial genotypes and advance lines using randomized complete block design in three replications during November 2013. The row to row distance was maintained 60 cm. At maturity ten plants from the parents and their crosses were taken randomly from each genotype in each replication and data were recorded for these plants and average was calculated for the following pre and postharvest traits.

Plant height (cm)

Plant height was measured from ground level to the top of the spike excluding awns in centimeters with the help of meter rod.

Peduncle Length (cm)
Peduncle length of mother shoot was measured in centimeter by measuring the length between uppermost node and base of spike.

Tillers per meter
Total number of productive tillers was counted from each marked one meter length.

Flag leaf area
When the plant leaves were fully green and turgid than the length and breadth of flag leaf of mother shoot of each selected plant was measured. Flag leaf area was estimated according to [4].

Spike length
At maturity, the length of mother shoot spike was measured in centimeters excluding the awns of selected plants from each entry. It was measured from base of spike to its tip without awns.

Spikelets per spike
The spikelets were counted from randomly selected mother shoot spikes manually.

Spike density
Spike density of randomly selected plants from each genotype was calculated by the following formula

$$\text{Spike Density} = \frac{\text{Number of spikelets per spike}}{\text{Spike length}}$$

Spike weight
Ten randomly selected spikes were obtained from the mother shoot and their weight was calculated with the help of electrical balance.

Thousand grain weight
1000 grain weight was estimated from the bulked seed of wheat harvested for yield in grams with the help of electrical balance.

Grain weight per spike
At maturity, number of grain in each selected spike was counted manually.

Number of grains per spike
At the time of maturity the ten mother shoots from parents and forty mother shoots from crosses were harvested separately and number of grains was calculated.

Harvest index
It is the ratio of grain yield per meter by biological yield per meter length. It is measured in percentage.

Biological yield
Total biomass of a plant including its spikes and grains is measured in grams.

Grain yield
At maturity the selected row of each line/variety from each replication was harvested**.** The grain yield was estimated using Electric balance in grams.

Statistical Analysis
The data collected were subjected to analysis of variance [5] to estimate variation among the genotypes. The significance data were further subjected to Duncan's New Multiple Range Test [6]. Path coefficient analysis [3] was used to find the direct and indirect effect of different traits on grain yield per plant.

Correlation Analysis
Correlations were estimated using the procedures adapted mentioned below [7].

$$rp = \frac{\text{Cov pij}}{\sqrt{(Var\ pi)}(Var\ pj)}$$

Where, rp is the phenotypic correlation coefficient, Cov pij, Var pi and Var pj are the estimates of variety/line components of covariance and variances, respectively for ith and jth traits.

Significant Test for Correlation
Statistical significance of phenotypic correlation was determined by using "t" test described by [5]. Correlation was considered significant if "t" calculated was greater than "t" tabulated.

$$T_{(cal)} = \frac{r}{\sqrt{1-t^2}/\ n-2}$$

Where:
r = phenotypic correlation coefficient
n = Total number of observations

Path Coefficient Analysis
The procedure of path coefficient analysis was followed [3]. Grain yield was kept as resultant and yield improving traits as casual variables. The direct and indirect effects of components were estimated on grain yield per plant. Two different statistical software, Statistix 8.1 and SPSS 16.0 will be used to analyze the data and infer valuable results.

RESULTS AND DISCUSSION:
Analysis of variance revealed that all twenty four genotypes possess highly significant differences among themselves for these traits.

Plant height
Maximum plant height showed by wheat varieties GA-2002 exhibited 129.56 cm. While genotype AS-2002 showed minimum plant height having mean value 98.32 cm given in Table 1. Coefficient of variability (CV %) is 2.47.

Peduncle length
Maximum peduncle length was observed in GA-2002 with mean value 48.122 cm while minimum peduncle length was observed in 9750 advance line that was 36.544 cm (table 1). Value of coefficient of variability (CV %) is 3.50.

Number of tillers per meter
Advance line 9718 had maximum number of tillers/m with mean values 183. Lowest number of tillers per meter was exhibited by FD-85 having mean value 97 given in table 1. Value for coefficient of variability (CV %) is 12.89.

Flag leaf area
Highest flag leaf area was exhibited by FD-83 having mean value 59.777 cm^2 (Table 1). Lowest mean values were observed for advance lines 9708 (31.170 cm2). Coefficient of variability (CV %) is 7.95.

Spike Length
The maximum spike length was observed in
Shahkar-95 having mean values 18 cm. The wheat genotype Watan-93 showed the minimum mean value 10.667 cm (Table 1). Coefficient of variability is 17.02.

Spikelets per spike

Maximum mean value for spikelets per spike was exhibited by Chakwal-86 with mean values 25.267. While, AS-2002 had minimum number of spikelets per spike, 16.300 as shown in table 1. Coefficient of variability is 3.26.

Spike Weight:

Maximum mean value for spike weight was perceived by FD-83 having mean values 4.0840. PB-85 had minimum mean values 1.9653 shown in Table 1. Coefficient of variability is 7.60.

Spike Density:

Chakwal-86 had maximum spike density with mean values 2.0320 (Table 2). Minimum spike density was exhibited by Shahkar-95 having mean value 1.3530. Coefficient of variability (CV %) is 8.68.

Grain weight per spike:

FD-83 had maximum mean values for grain weight per spike with mean values 2.9477 (Table 2). Similarly, PB-85 having mean values 1.4143g had minimum mean value for grain weight per spike. Coefficient of variability (CV %) is 8.68.

Number of grains per spike:

The maximum number of grains per spike was shown by the FD-83 that is 62.967 (Table 2). Rawal-87 had minimum mean value of 31.200. Coefficient of variability (CV %) is 2.43.

1000 grain weight:

Advance wheat line 9708 exhibited maximum mean value 47.145. Minimum mean value was revealed by Chenab-2000 (27.605) showed in table 1. Coefficient of variability (CV %) is 11.08 (Table 2).

Harvest index:

FD-83 exhibited highest thousand grain weight with mean value 48.619 g (Table 2). Wheat variety FD-85 showed minimum average thousand grain weight (28.374g). Coefficient of variability (CV %) is 11.08.

Biological yield (grams/meter)

GA-2002 showed maximum biological yield with mean value 602.93g (Table 2). Minimum mean value for biological yield was exhibited by PB-85 (304.70g). Coefficient of variability (CV %) is 12.74.

Grain yield (grams/meter)

FD-83 showed maximum grain yield with mean value 213.87g (Table 2). Minimum mean value was exhibited by Chakwal-86 (112.77g). Coefficient of variability (CV %) is 15.09.

CORRELATION COEFFICIENT

The estimates of correlation coefficients among various plant morphological traits are used to assess the degree of interrelationship among these characters. Genetic association of two genotypes is estimated through genotypic correlation.

Correlation between Plant height and other characters

There was a positive and significant association of plant height with Flag leaf area, grain filling period, grain yield per meter, Spike length, spikelets per spikes, thousand grain weight, grain weight per spike, number of grains per spike, and peduncle length. Plant height had negative and non-significant correlation with tillers per meter and spike density. Days to heading, spike weight, spike density and biological yield had positive and non-significant correlation with plant height (Table 3). The results were also confirmed by other scientists [8].

Correlation between Peduncle length and other characters

Spike density had positive and highly significant association while days to heading had negative and highly significant correlation with peduncle length. Peduncle length had positive but non-significant correlation with flag leaf area, days to maturity, Spike weight, grain weight, number of grains per spike, harvest index and grain yield. Peduncle length had negative but non-significant correlation with tillers per meter, biological yield and spike length (Table 3).

Correlation between Tillers per meter and other characters

Tillers per meter had positive and significant correlation with biological yield. Grain weight, days to Heading, spike weight, and grain yield per meter had positive but non-significant correlation with tillers per meter. Tillers per meter had negative but non-significant correlation with flag leaf area, spikelets per spike, number of grains per spike. Spike density, spike length, grain filling duration and harvest index (Table 3). Results are consistent with the findings of other scientists [9,10].

Correlation between Flag leaf area and other characters

Flag leaf area had positive and highly significant correlation with spikelet/spike and number of grains per spike while thousand grain weight had negative and significant correlation with flag leaf area. Days to heading, days to maturity and tillers per meter had negative but non-significant correlation with flag leaf area. Grain filling period, spike length, spike density, biological yield, and grain yield per meter had positive but non-significant correlation with flag leaf area (Table 3). These Results are similar as reported earlier [11].

Correlation between Days to 50% heading and other characters

Days to 50% heading had significant positive correlation with biological yield while harvest index showed negative and significant correlation with days to 50% heading. Days to 50% heading had positive but non-significant correlation with Plant height, spike length, spikelets per spike, spike density, thousand grain weight and grain weight per spike. Peduncle length, flag leaf area, grain filling period, days to maturity, spike weight and grain yield per meter had negative but non-significant correlation with days to 50% heading (Table 3).

Correlation between Grain filling period and other characters

Grain filling period had positive and significant correlation with spikelet/spike. Grain filling period had positive but non-significant correlation with plant height, flag leaf area, spike length and spike density. Spike weight, thousand grain weight, grain weight per spike, number of grains per spike, harvest index, biological yield and grain yield per meter and days to 50% heading had negative but non-significant correlation with grain filling period (Table 3).

Correlation between days to maturity and other characters

Days to maturity had no positive and significant correlation with any traits evaluated in this experiment. Peduncle length, spike weight, grain weight per spike and thousand grin

weight had positive but non-significant correlation with days to maturity. Days to maturity had negative but non-significant correlation with spikelet/spike, spike density, plant height, number of grains per spike, grain filling period, biological yield, harvest index and grain yield per meter (Table 3).

Correlation between spike length and other characters

Spike length had positive and highly significant correlation with spike density. Plant height, flag leaf area, days to heading, grain filling period, spikelets per spike, number of grains and biological yield had positive but non-significant correlation with spike length. Spike weight, peduncle length, tillers per meter, grain weight per spike thousand grain weight and harvest index had negative and non-significant correlation with spike length (Table 3).

Correlation between spikelets per spike and other characters

Spikelets per spike had highly significant and positive correlation with flag leaf area, spike density and plant height while biological yield, tillers per meter and days to maturity had negative but non-significant correlation with it. Peduncle length, thousand grain weight, harvest index and grain yield per meter had positive and non-significant correlation with spikelets per spike (Table 3). Results are in accordance with other scientists [12,13].

Correlation between spike density and other characters

Spike density had positive and highly significant correlation with spikelet per spike, peduncle length. Spike density had negative and highly significant correlation, spike length and biological yield. Days to maturity and number of tillers per meter had negative but non-significant correlation with spike density. Spike density had non-significant but positive correlation days to 50% heading, plant height and spike weight (Table 3).

Correlation between spike weight and other characters

Spike weight had positive but highly significant correlation with thousand grain weight, and grain weight per spike. Days to maturity and grain filling duration had negative but non-significant correlation. Peduncle length, days to maturity, biological yield, number of grains per spike, peduncle length, spike density and harvest index had positive but non-significant correlation with spike weight (Table 3).

Correlation between thousand grain weight and other characters

Thousand grain weight had positive and highly significant correlation with spike weight and grain weight per spike while grain filling duration, spike length and spike density had negative but non-significant correlation. Thousand grain weight had positive but non-significant correlation with days to 50% heading, days to maturity, harvest index, biological yield and spikelets per spike (Table 3).

Correlation between grain weight and other characters

Grain weight had positive and highly significant correlation with number of grains per spike, plant height, spike length and thousand grain weight while tillers per meter and spike density had positive but non-significant correlation. Grain filling period and spike length showed negative and non-significant correlation with grain per spike. Days to maturity, harvest index, biological yield and grain yield per meter had non-significant, but positive correlation with grain weight (Table 3).

Correlation between number of grains per spike and other characters

Flag leaf area and harvest index had positive and highly significant correlation with number of grains per spike while days to 50%heading, days to maturity, grain filling duration, thousand grain weight and tillers per meter had negative but non-significant correlation with it (Table 3). Spikelet per spike, spike density, biological yield, number of grains per spike, spike weight and spike length had positive and significant correlation with grains per spike.

Correlation between harvest index and other characters

Harvest index had positive and significant correlation with number of grains per spike while days to 50% heading and biological yield had negative correlation with harvest index. Peduncle length, flag leaf area, spike density, thousand grain weight, grain weight per spike and spike weight had positive but non-significant correlation with harvest index. Harvest index showed negative and non-significant correlation with plant height, grain filling duration, days to maturity and spike length (Table 3).

Correlation between biological yield per meter and other characters

Biological yield per meter had positive and highly significant correlation with plant grain yield per meter while it had positive and significant correlation with days to 50% heading and number of tillers per meter. Spike density and harvest index had negative and significant correlation with biological yield. Plant height, spike length, spike weight, thousand grain weight and number of grains per spike had positive and non-significant correlation with biological yield. Biological yield had negative and non-significant correlation with peduncle length, flag leaf area, grain filling duration, days to maturity and spikelet per spike (Table 3).

Correlation between grain yield per meter and other characters

Grain yield per meter had positive and highly significant correlation with spike weight, thousand grain weight and biological yield per meter. It had negative but non-significant correlation with days to maturity, spikelet per spike, grain filing duration and spike density. Harvest index, spike length, plant height, peduncle length, spike weight, flag leaf area and number of grains had positive but non-significant correlation with grain yield (Table 3).

PATH COEFFICIENT ANALYSIS

The technique of path coefficient analysis was used [3] in plant breeding experiment. It is simply a standardized partial regression coefficient and measures the influence of each variable upon the resultant variable directly as well as indirectly by partitioning the genetic correlation coefficients.

Direct and indirect effects of plant height on grain yield

Direct effect of plant height on grain yield was positive (0.321) as shown in the Table 3. The indirect effect via peduncle length (0.845), tillers per meter (0.378), flag leaf area (0.551), days to 50% heading (0.070), grain filling period (0.123), spike length (0.058), spike density (0.054), spike weight (0.171), grain weight per spike (0.105), harvest index (0.371), biological yield (0.119) were positive. Indirect effects through days to maturity (-0.528), spikelets per spike (-0.038), thousand grain weight (-0.257), number of grains per spike (-0.300) were negative (Table 4). The result

obtained in the present study, therefore, clearly indicated that days to heading through the indirect effects of peduncle length, flag leaf area, tillers per meter and harvest index can enhance the grain yield per meter length in the long run.

Direct and indirect effects of peduncle length on grain yield

Direct effect of peduncle length on grain yield was positive (0.023) as shown in the Table 3. The indirect effects via Plant height (0.364), flag leaf area (0.110), days to maturity (0.302), spikelets per spike (0.020), thousand grain weight (0.208) and biological yield (0.266) were positive. Indirect effects via tillers per meter (-0.444), days to 50% heading (-0.564), grain filling period (-0.203), spike length (-0.032), spike density (-0.035), spike weight (-0.113), grain weight per spike (-0.082), number of grains per spike (-0.048) and harvest index (-0.360) were negative (Table 4). The result obtained in the present study, clearly indicated that peduncle length through the indirect effects of plant height and days to maturity can enhance the grain yield per meter.

Direct and indirect effects of number of tillers per meter on grain yield

Direct effect of number of tillers per meter on grain yield was positive (0.059) as shown in the Table 3. The indirect effects via peduncle length (-0.622), flag leaf area (-0.125), days to 50% heading (-0.568), spikelets per spike (-0.046), spike weight (-0.273), number of grains per spike (-0.204) and harvest index (-0.618) were negative. Indirect effects through plant height (0.228), grain filling period (0.182), days to maturity (0.196), spike length (0.022), spike density (0.024), thousand grain weight (0.420), grain weight per spike (0.106) and biological yield (0.744) were positive (Table 4). These results indicated that biological yield, thousand grain weight and plant height could be used for grain yield improvement.

Direct and indirect effects of flag leaf area on grain yield

Direct effect of flag leaf area on grain yield was negative (-0.004) as indicated in Table 3. Indirect effects through plant height (0.162), peduncle length (0.075), days to maturity (0.263), spikelets per spike (0.019), thousand grain weight (0.128), grain weight per spike (0.020) and number of grains per spike (0.353) were positive. Indirect effects via number of tillers per meter (-0.061), days to 50% heading (-0.398), grain filling period (-0.219), spike length (-0.020), spike density (-0.022), spike weight (-0.062), harvest index (-0.156) and biological yield (-0.017) were negative (Table 4). These results indicated that flag leaf area through indirect effects of number of grains per spike and days to maturity could be used for grain yield improvement.

Direct and indirect effects of spike length on grain yield

Direct effect of spike length on grain yield was negative (-0.007) as indicated in Table 3. Indirect effects of spike length on grain yield through plant height (0.460), tillers per meter (0.937), days to maturity (0.132), spikelets per spike (0.111), spike weight (0.740), number of grains per spike (0.211) and harvest index (0.040) were positive. Indirect effect via peduncle length (-0.900), flag leaf area (-0.697), days to 50% heading (-0.920), grain filling period (-0.215), spike density (-.007), thousand grain weight (-0.454), grain weight per spike (-0.517) and biological yield (-0.802) were negative (Table 4). The results from the current research indicated that number of tillers per meter, spike weight per spike and plant height could be used as an indirect way for grain yield improvement.

Direct and indirect effects of spikelets per spike on grain yield

Direct effect of spikelets per spike on grain yield was positive (0.036) as indicated in Table 3. Indirect effects of spikelets per spike on grain yield through peduncle length (0.930), flag leaf area (0.278), days to 50% heading (0.059), grain filling period (0.611), spike length (0.868), spike density (0.881), thousand grain weight (0.643), grain weight per spike (0.404) and biological yield (0.968) were positive. Indirect effects of spikelets per spike on grain yield through plant height (-0.745), tillers per meter (-0.516), days to maturity (-0.176), spike weight (- 0.861), number of grains per spike (-0.687) and harvest index (-0.248) were negative (Table 4). The results from the current studies indicated that biological yield, peduncle length, spike length and grain filling period could be used as an indirect way for grain yield improvement.

Direct and indirect effects of spike density on grain yield

Direct effect of spike density on grain yield was positive (0.008) as indicated in Table 3. Indirect effects of spike density on grain yield through plant height (0.327), tillers per meter (0.967), days to maturity (0.248), spikelets per spike (0.097), spike weight (0.807), number of grains per spike (0.956) and harvest index (0.764) were positive. Indirect effect via peduncle length (-0.002), flag leaf area (-0.825), days to 50% heading (-0.944), grain filling period (-0.360), spike length (-0.979), thousand grain weight (-0.440), grain weight per spike (-0.713) and biological yield (-0,730) were negative (Table 4). It is concluded from the study that number of tillers per meter, spike weight per spike and number of grains per spike could have indirect effect on grain yield via spike density.

Direct and indirect effects of spike weight on grain yield

Direct effect of spike weight on grain yield was positive (0.168) as indicated in Table 3. Indirect effects of spike density on grain yield through plant height (0.477), grain filling period (0.347), spike length (0.082), spike density (0.092), thousand grain weight (0.153), grain weight per spike (0.167), number of grains per spike (0.353) and biological yield (0.216) were positive. Indirect effects of spike weight on grain yield through peduncle length (-0.736), tillers per meter (-0.264), flag leaf area (-0.594), days to 50% heading (-0.231), days to maturity (-0.470), spikelets per spike (-0.122) and harvest index (-0.098) were negative (Table 4). It is concluded from the current study that plant height, number of grains per spike, grain filling period and biological yield could have indirect effect on grain yield via spike weight.

Direct and indirect effects of thousand grain weight on grain yield

Direct effect of thousand grain weight on grain yield was negative (-0.014) as indicated in Table 3. Indirect effects of thousand grain weight on grain yield via peduncle length (0.669), tillers per meter (0.965), flag leaf area (0.602), days to 50% heading (0.979), days to maturity (0.183), spikelets per spike (0.115), spike weight (0.572) and harvest index (1.320) were positive while plant height (-0.356), grain filling period (-0.069), spike length (-0.080), spike density (-0.081), grain weight per spike (-0.376), number of grains per spike (-

0.028) and biological yield (-0.886) showed negative indirect effects on grain yield via thousand grain weight (Table 4).

Table 1: Mean values for different morphological and phenological traits in spring wheat genotypes

Sr. No	Genotype	Plant height	Peduncle	No of tiller/m	Flag leaf	Spike	Spikelets/	Spike weight
1	FD-83	113.50	45.66	138.33	59.78	11.63	21.23	4.08
2	Kohnoor-83	118.83	41.47	125.00	52.16	15.67	21.93	2.98
3	FD-85	118.07	42.52	97.00	40.92	14.07	21.87	2.64
4	PB-85	116.80	43.40	126.00	53.20	12.33	24.07	1.97
5	Chakwal-86	120.04	44.67	116.00	56.13	12.47	25.27	3.08
6	Rawal-87	113.81	42.13	143.33	48.52	11.57	21.23	2.50
7	Inqlab-91	111.78	46.97	147.00	41.49	12.60	19.63	2.89
8	Watan-93	107.57	43.22	107.00	41.76	10.67	20.23	3.12
9	Parwaz-94	105.93	37.73	178.67	38.89	11.73	19.20	2.85
10	Shahkar-95	105.07	37.53	129.33	41.27	18.00	20.27	2.55
11	Pb-96	103.20	37.91	180.00	50.50	12.77	21.37	2.96
12	MH-97	112.22	43.74	163.33	46.37	12.43	18.87	2.90
13	Uqab-2000	99.83	37.73	140.33	53.11	14.20	21.53	2.85
14	Chenab-2000	109.13	40.48	133.00	42.95	11.97	20.13	3.13
15	GA-2002	129.56	48.12	141.67	45.90	13.57	20.23	3.49
16	AS-2002	98.32	42.53	137.67	38.70	11.37	16.30	2.44
17	Ufaq-2002	112.49	40.98	112.67	45.75	12.50	19.70	2.86
18	SH-2002	101.86	42.76	110.00	36.43	11.47	16.90	2.66
19	9708	112.12	42.10	134.00	31.17	11.77	19.77	3.40
20	9718	110.53	37.36	183.00	38.62	11.50	19.17	3.13
21	9750	110.10	36.54	126.67	31.24	13.93	22.73	3.40
22	9751	114.82	37.58	151.00	33.99	12.70	20.10	3.09
23	9757	117.83	41.89	128.00	42.54	13.13	21.27	3.67
24	9887	110.72	42.94	132	38.57	11.20	19.17	2.94

The results from the current studies indicated that days to 50% heading, tillers per meter, peduncle length and flag leaf area could be used as an indirect way for grain yield improvement.

Direct and indirect effects of grain weight per spike on grain yield

Direct effect of grain weight per spike on grain yield was negative (-0.114) as indicated in Table 3. Indirect effects of thousand grain weight on grain yield via plant height (0.102), tillers per meter (0.170), flag leaf area (0.067), days to 50% heading (0.107), days to maturity (0.666), spikelets per spike (0.069), spike weight (0.404), number of grains per spike (0.070) and harvest index (0.205) while peduncle length (-0.185), grain filling period (-0.626), spike length (-0.058), spike density (-0.067), thousand grain weight (-0.262) and biological yield (-0.306) showed negative indirect effects on grain yield via grain weight per spike (Table 4). The results from the current studies indicated that days to maturity and spike weight per spike could be used as an indirect way for grain yield improvement in wheat.

Direct and indirect effects of number of grain per spike on grain yield

Direct effect of number of grain per spike on grain yield was negative (-0.034) as indicated in Table 3. Indirect effects through flag leaf area (0.291), days to 50% heading (0.078), grain filling period (0.091), days to maturity (0.075), spike length (0.021), spike density (0.019), spike weight (0.031), grain weight per spike (0.018) and biological yield (0.112) were positive. Indirect effects of number of grain per spike on grain yield via plant height (-0.072), peduncle length (-0.027), tillers per meter (-0.082), spikelets per spike (-0.021), thousand grain weight (-0.005) and harvest index (-0.213) were negative (Table 4). It is concluded from the current study that flag leaf area could have indirect effects on grain yield via number of grains per spike.

Table 2: Mean values for different morphological and phenological traits in spring wheat genotypes

Sr. No	Genotype	Spike density	Grain wt/	No of grain	1000 grain	Harvest	Biological	Grain Yield
1	FD-83	1.83	2.95	62.97	44.37	48.62	444.97	213.87
2	Kohnoor-83	1.40	2.25	61.00	35.67	39.53	489.30	193.47
3	FD-85	1.56	2.05	46.60	36.86	28.37	491.70	141.93
4	PB-85	1.96	1.41	53.27	31.62	45.92	304.70	138.97
5	Chakwal-86	2.03	2.28	58.63	36.52	33.13	340.03	112.77
6	Rawal-87	1.83	1.89	31.20	32.87	30.54	470.97	144.45
7	Inqlab-91	1.56	1.89	46.33	40.58	35.93	485.90	174.30
8	Watan-93	1.90	2.40	53.83	41.87	42.61	445.50	189.87
9	Parwaz-94	1.64	2.41	45.77	46.06	29.71	522.90	154.57
10	Shahkar-95	1.36	1.86	52.93	35.91	36.44	485.13	176.73
11	Pb-96	1.67	2.27	61.27	31.93	34.81	533.47	186.27
12	MH-97	1.52	2.08	55.93	32.07	33.73	471.73	160.47
13	Uqab-2000	1.51	1.85	53.53	31.13	32.26	477.87	154.40
14	Chenab-2000	1.68	2.21	56.57	27.61	35.33	416.90	147.57
15	GA-2002	1.49	2.31	55.03	38.20	34.10	602.93	205.57
16	AS-2002	1.44	1.74	50.17	36.24	40.02	426.93	173.30
17	Ufaq-2002	1.57	2.31	57.73	38.68	34.88	453.23	158.20
18	SH-2002	1.47	1.45	45.23	35.22	37.36	368.60	137.40
19	9708	1.68	2.24	47.43	47.15	35.48	516.07	183.27
20	9718	1.67	2.13	48.00	43.70	35.55	530.53	188.27
21	9750	1.63	2.30	47.10	46.38	37.68	396.97	146.50
22	9751	1.58	2.36	49.33	43.03	34.69	533.84	185.07
23	9757	1.62	2.75	56.57	43.79	38.18	523.43	200.00
24	9887	1.72	2.36	47.03	39.80	38.77	359.60	139.70

Direct and indirect effects of harvest index on grain yield

Direct effect of harvest index on grain yield was positive (0.588) as indicated in Table 3. Indirect effects of harvest index on grain yield via plant height (0.137), grain filling period (0.057), spike length (0.045), spike density (0.042), thousand grain weight (0.353), grain weight per spike (0.078) and biological yield (0.280) were positive. Indirect effects of harvest index on grain yield through peduncle length (-0.309), tillers per meter (-0.380), flag leaf area (-0.197), days to 50% heading (-0.434), days to maturity (-0.197), spikelets per spike (-0.061), spike weight (-0.146) and number of grains per spike (-0.326) were negative (Table 4). It is concluded from the current study that harvest index could indirectly be used as selection criteria as it have higher indirect effects on grain yield via thousand grain weight and biological yield.

Direct and indirect effects of biological yield on grain yield

Direct effect of biological yield on grain yield was negative (-0.034) as indicated in Table 3. Indirect effects of biological yield on grain yield through plant height (0.082), peduncle length (0.426), tillers per meter (0.849), days to 50% heading (0.210), spikelets per spike (0.069), spike weight (0.299), number of grains per spike (0.318) and harvest index (1.094) were positive. Indirect effects of biological yield on grain yield via flag leaf area (-0.040), grain filling period (-0.508), days to maturity (-0.016), spike length (-0.049), spike density (-0.048), thousand grain weight (-0.440) and grain weight per spike (-0.218) were negative (Table 4). The results from the current studies indicated that biological yield could indirectly be used as selection criteria as it has higher indirect effects on grain yield via harvest index, number of tillers per meter, peduncle length and number of grains per spike.

Table 3: Correlation between different morphological and phenological traits in spring wheat genotypes

Characters	PH	PL	T	FLA	SL	SS	SD	SW	TGW	GW	NG	HI	BY
PL	0.512*	1	-0.329	0.337	-0.281	0.003	0.217	0.135	-0.074	0.022	0.114	0.275	-0.143
T	-0.201	-0.329	1	-0.017	-0.153	-0.230	-0.082	0.090	0.082	0.120	-0.047	-0.202	0.478*
FLA	0.231	0.337	-0.017	1	0.104	0.523**	0.348	0.012	-0.479*	0.091	0.529**	0.244	-0,168
SL	0.124	-0.281	-0.153	0.104	1	0.307	-0.550**	-0.095	-0.171	-0.101	0.231	-0.167	0.241
SS	0.496*	0.003	-0.230	0.523**	0.307	1	0.556**	0.069	-0.099	0.162	0.269	0.044	-0.237
SD	0.233	0.217	-0.082	0.348	-0.550**	0.556**	1	0.085	0.068	0.200	0.001	0.266	-0.464*
SW	0.307	0.135	0.090	0.012	-0.095	0.069	0.085	1	0.557**	0.857**	0.388	0.194	0.369
TGW	0.145	-0.074	0.082	-0.479*	-0.171	-0.099	0.068	0.557**	1	0.554**	-0.144	0.136	0.275
GW	0.338	0.022	0.120	0.091	-0.101	0.162	0.200	0.857**	0.554**	1	0.413*	0.122	0.364
NG	0.146	0.114	-0.047	0.529**	0.231	0.269	0.001	0.388	-0.144	0.413*	1	0.415*	0.015
HI	-0.025	0.275	-0.202	0.244	-0.167	0.044	0.266	0.194	0.136	0.122	0.415*	1	-0.414*
BY	0.180	-0.143	0.478*	-0.168	0.241	-0.237	-0.464*	0.369	0.275	0.364	0.015	-0.414*	1
GY	0.143	0.083	0.298	0.023	0.116	-0.233	-0.284	0.567**	0.581**	0.498*	0.372	0.360	0.692**

* Significant at the 0.05 level; **. Correlation is significant at the 0.01 level. (PH=Plant height, PL=Peduncle length, T=Tillers/m, FLA= Flag leaf area, DH=Days to 50% heading, GFP=Grain filling period, DM=Days to maturity, SL=Spike length, SS=Spikelets/spike, SD=Spike Density, SW=Spike weight, TGW=Thousand grain weight, GW=Grain weight/spike, NG=Number of grains/spike, HI=Harvest index, BY=Biological yield/m, GY=Grain yield/m)

Table 4: Direct and indirect effects of different characters of wheat on grain yield

Traits	PH	PL	T	FLA	SL	SS	SD	SW	TGW	GW	NG	HI	BY
PH	**0.271**	0.795	0.328	0.501	-0.042	-0.138	-0.046	0.121	-0.207	0.155	-0.250	0.421	0.169
PL	0.314	**-0.050**	-0.494	0.060	-0.132	-0.080	-0.135	-0.163	0.258	-0.032	0.002	-0.310	0.316
T	0.178	-0.672	**0.009**	-0.175	-0.078	-0.146	-0.076	-0.323	0.470	0.156	-0.154	-0.568	0.794
FLA	0.112	0.025	-0.111	**-0.054**	-0.120	-0.081	-0.122	-0.112	0.178	0.070	0.403	-0.106	0.033
SL	0.410	-0.950	0.887	-0.747	**-0.101**	0.011	-0.107	0.690	-0.404	-0.467	0.261	0.090	-0.752
SS	-0.795	0.880	-0.566	0.228	0.768	**-0.064**	0.781	-0.911	0.693	0.454	-0.637	-0.198	.108
SD	0.277	-0.052	0.917	-0.875	-1.079	-0.003	**-0.092**	0.757	-0.390	-0.663	1.006	0.814	-0.680
SW	0.427	-0.786	-0.314	-0.644	-0.018	-0.222	-0.008	**0.118**	0.203	0.217	0.403	-0.048	0.266
TGW	-0.406	0.619	0.915	0.552	-0.180	0.015	-0.181	0.522	**0.036**	-0.326	0.022	1.37	-0.836
GW	0.052	-0.235	0.120	0.017	-0.158	-0.031	-0.167	0.354	-0.212	**-0.064**	0.12	0.255	-0.256
NG	-0.122	-0.077	-0.132	0.241	-0.079	-0.121	-0.081	-0.019	0.045	0.068	**0.016**	-0.163	0.162
HI	0.087	-0.359	-0.43	-0.247	-0.055	-0.161	-0.058	-0.196	0.403	0.128	-0.276	**0.638**	0.330
BY	0.032	0.376	0.799	-0.090	-0.149	-0.031	-0.148	0.249	-0.39	-0.168	0.368	1.144	**0.920**

* Significant at the 0.05 level; **. Correlation is significant at the 0.01 level.
(PH=Plant height, PL=Peduncle length, T=Tillers/m, FLA= Flag leaf area, DH=Days to 50% heading, GFP=Grain filling period, DM=Days to maturity, SL=Spike length, SS=Spikelets/spike, SD=Spike Density, SW=Spike weight, TGW=Thousand grain weight, GW=Grain weight/spike, NG=Number of grains/spike, HI=Harvest index, BY=Biological yield/m, GY=Grain yield/m)

CONCLUSION

These results reveled that characters showing higher positive direct effects could be used for production of high yielding genotypes and selection on the basis of morphological traits proves helpful. Path coefficient analysis revealed that plant height, peduncle length, tillers per meter, spikelets per spike, spike weight, number of grains per spike, harvest index and biological yield had a positive direct effect on grain yield. From mean values, it was revealed that wheat variety FD-83 had maximum grain yield followed by GA-2002 and a wheat advance line 9757. As a whole, three wheat cultivars, FD-83, GA-2002, Inqlab-91 and a wheat advance line 9757 are the best.

Competing Interest

"The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper."

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