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Assessment of correlation and path analysis for yield and yield contributing traits in bread wheat (*Triticum aestivum* L. Em. Thell)

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Abstract
An experiment was conducted to study the correlation and path coefficient analysis for different characters in bread wheat. The investigation comprised of 30 genotypes was carried out in Randomized Complete Block Design (RCBD) with three replications. Data were recorded for days to flowering, days to maturity, plant height, No. of productive tillers per plant, Spike length, No. of spikelet per spike, No. of grains per spike, 1000 seed weight, biological yield per plant, grain yield per plant, harvest index, chlorophyll content, canopy temperature and protein content. Both genotypic and phenotypic correlation coefficient study revealed that grain yield per plant was positively and highly significantly correlated with spike length, 1000 seed weight, biological yield per plant and harvest index but in genotypic correlation, chlorophyll content showing negatively and highly significant correlated with the grain yield. Path analysis results showed that biological yield (0.985) and harvest index (0.927) had the highest positive direct effect on grain yield. While other traits contribute to the grain yield significantly indirectly via biological yield and harvest index. This suggests that biological yield and harvest index having significant positive correlation and high direct effect on grain yield explained the true relationship and the direct selection of the genotypes through these traits is effective for improving yield potentiality.

Keywords: Genotypes, correlation and path coefficient, bread wheat, yield

Introduction
Wheat (*Triticum aestivum* L.) is the most important cereal of the world which belongs to poaceae family and world's leading cereal grain and most important food crop, occupying commanding position in Indian Agriculture, which occupies 28% area under cereals and contributing 33% of the total food grain production in the country (Singh *et al.*, 2022) [17].
Wheat (*Triticum aestivum* L.) is grown widely across almost all around the world, representing about 30% of the cereal cultivation area, providing 20% of the calories for the human population (Rangare *et al.*, 2010 and Khan *et al.*, 2015). Since the advent of Green solution, wheat yields have increased in many reg-ions of the world (Fang *et al.*, 2017).
Wheat (*Triticum aestivum* L.) is the largest growing crop among all other cereal crops. It covers 17% of the total cultivated land in the world. Wheat plays a big role in feeding the human family. Over 1.2 billion resource poor consumers depend on wheat as a staple food (Lumpkin, 2014). Worldwide, wheat is grown on nearly 221 million hectares, with a production of 729 million tonnes and productivity of 3.28 tonnes/ha (FAO, 2014).
Correlation analysis is used as effective tool to determine the relationship among different traits in genetic diverse population for enhancement of crop improvement process (Kandel *et al.*, 2018b; Dhami *et al.*, 2018; Kharel *et al.*, 2018).
Path analysis provides a measure of relative importance of each independent variable to prediction of changes in the dependent one. A path coefficient is a standardized partial regression coefficient and as such measures the direct effect of one trait upon other and permits the separation of correlation coefficient into direct and indirect effects (Dewey and Lu, 1959; Phougat *et al.*, 2017) [3].
The objective of this study was to estimate correlation between grain yield and its component characters and to determine the direct and indirect influences of various yield attributing characters.

Materials and Methods

The field experiment was conducted at during *rabi* season at Agriculture research farm, Department of Genetics and Plant breeding, Lovely Professional University, Punjab during 2018-2019. The experimental design comprised of 30 different genotypes of Wheat grown in Randomized Complete Block Design with three replications. The sowing was done by dibbling seeds in rows with row to row distance 22.5 cm, plant to plant distance 3 cm, row length is 2 m. All genotypes were sown in 5 lines each. The recommended packages of practices were adopted for optimum crop growth.

Observations were recorded on the whole plot basis for days to 50% flowering and days to maturity, whereas the character like plant height, number of productive tillers per plant, spike length, number of spikelet per spike, number of grains per spike, 1000 seed weight, grain yield per plant, biological yield, harvest index, chlorophyll content and canopy temperature were taken over five randomly selected competitive plants from each plot. Harvest index was calculated in percentage by the proportion of total grain yield in comparison to biological yield. For estimation of quality parameter in terms of protein content and sedimentation value samples were analysed with the protein estimation method developed by Bradford, (1976) [2].

Statistical Analysis

Data entry and processing were carried out using Microsoft Office Excel. The correlation coefficients were computed according to the method suggested by Miller *et al*., (1958) [10] while the direct and indirect effects of component traits up on grain yield were measured by path analysis as described by Dewey & Lu (1959) [3].

Results and Discussion

Correlation coefficient analysis: Genotypic and Phenotypic correlations coefficients of different traits are presented in have been presented in Table 1. In general, the estimates of genotypic correlation are higher than phenotypic correlation and the magnitudes are in same direction (+/-).

Yield per plant had highly significant and positive genotypic and phenotypic correlations with spike length, 1000 seed weight, biological yield per plant and harvest index but in genotypic correlation, chlorophyll content showing negatively and highly significant correlated with the grain yield. Canopy temperature observed positive and significant association with grain yield per plant (0.226).

Table 1: Genotypic and phenotypic (upper and lower diagonal, respectively) correlation coefficients between characters in wheat

Characters	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14
X1	1	0.796**	0.383**	-0.094	-0.186	-0.11	-0.202	0.04	-0.028	-0.251*	-0.035	-0.308**	-0.024	-0.193
X2	0.738**	1.000	0.376**	-0.03	-0.006	-0.12	-0.296**	0.126	0.048	-0.254*	-0.049	0.017	-0.207	-0.107
X3	0.356**	0.329**	1.000	0.506**	-0.228*	-0.186	-0.381**	-0.029	0.461**	-0.463**	0.122	0.096	-0.238*	0.099
X4	-0.105	-0.038	0.360**	1.000	0.101	-0.123	-0.18	-0.031	0.422**	-0.344**	0.062	0.019	-0.117	0.164
X5	-0.162	-0.021	-0.222*	0.092	1.000	0.463**	0.484**	0.11	0.244*	0.351**	-0.587**	0.103	-0.205	0.436**
X6	-0.062	-0.093	-0.161	-0.146	0.364**	1.000	0.825**	-0.192	-0.069	0.350**	0.039	0.324**	0.033	0.015
X7	-0.183	-0.270*	-0.330**	-0.152	0.450**	0.687**	1.000	0.024	-0.232*	0.480**	0.052	-0.055	0.03	0.027
X8	0.048	0.152	-0.028	-0.038	0.099	-0.13	0.019	1.000	0.197	-0.012	-0.485**	-0.248*	-0.097	0.332**
X9	-0.034	0.036	0.427**	0.399**	0.204	-0.082	-0.196	0.178	1.000	-0.391**	0.105	0.084	-0.069	0.687**
X10	-0.205	-0.209*	-0.369**	-0.278**	0.285**	0.280**	0.377**	-0.01	-0.395**	1.000	-0.467**	0.214*	0.220*	0.377**
X11	-0.008	-0.05	0.022	-0.018	-0.207	0.049	0.074	-0.213*	0.022	-0.092	1.000	0.885**	0.410**	-0.312**
X12	-0.114	0.017	0.042	0.025	0.032	0.097	0.023	-0.136	0.07	0.088	0.021	1.000	0.403**	0.226*
X13	-0.043	-0.177	-0.237*	-0.07	-0.156	0.003	0.022	-0.094	-0.092	0.183	0.12	0.226*	1.000	0.071
X14	-0.18	-0.118	0.084	0.125	0.351**	0.04	0.032	0.283**	0.588**	0.400**	-0.092	0.062	0.037	1

X1: Days to flowering; **X2:** Days to maturity; **X3:** Plant height(cm); **X4:** Number of productive tillers; **X5:** Spike length(cm); **X6:** Number of spikelet per spike; **X7:** Number of grains per spike; **X8:** 1000 seed weight (g); **X9:** Biological yield per plant(g); **X10:** Harvest index (%); **X11:** Chlorophyll content; **X12:** Canopy temperature; **X13:** Protein content (%); **X14:** Grain yield/plant.

Genotypic correlation coefficient analysis

Days to flowering exhibited positive and highly significant association with days to maturity (0.796), plant height (0.383), while negative and highly significant association with canopy temperature (-0.308). Negative and significant association with harvest index (-0.251).

Days to maturity observed positive and highly significant association with plant height (0.376), while negative and highly significant association with no. of grains per spike (-0.296). Negative and significant association with harvest index (-0.254).

Plant height expressed positive and highly significant association with No. of productive tillers (0.506) and biological yield per plant (0.461) while negative and highly significant association with no. of grains per spike (-0.381) harvest index (-0.463). Negative and significant association with spike length (-0.228) and protein content (-0.238).

Number of productive tillers per plant observed positive and highly significant association with biological yield per plant (0.520) and harvest index (0.232). Spike length expressed positive and highly significant association with No. of spikelet per spike (0.463), No. of grains per spike (0.484), harvest index (0.351) and grain yield per plant (0.436) while positive and significant association with biological yield per plant (0.244) and negative and highly significant association with chlorophyll content (-0.587).

Number of spikelets per spike observed positive and highly significant association with Number of grains per spike (0.825), Harvest index (0.350) and Canopy temperature (0.324).

Number of grains per spike exhibited positive and highly significant association with harvest index (0.480) while negative and significant association with biological yield per plant (-0.232).

1000 seed weight exhibited positive and highly significant with grain yield per plant (0.332). Negative and significant association with chlorophyll content (-0.485) while negative and significant association with Canopy temperature (-0.248).

Biological yield per plant expressed negative and highly significant association with harvest index (-0.391) while

positive and highly significant association with grain yield per plant (0.687).
Harvest index expressed negative and highly significant association with Chlorophyll content (-0.467) while positive and highly significant association with grain yield per plant (0.377) and positive significant association with canopy temperature (0.214) protein content (0.220).
Chlorophyll content observed positive and highly significant association with canopy temperature (0.885) protein content (0.410) while negative and highly significant association with grain yield per plant (-0.312).
Canopy temperature observed positive and highly significant association with protein content (0.403) while positive and significant association with grain yield per plant (0.226).

Phenotypic correlation coefficient analysis
Days to flowering exhibited positive and highly significant association with days to maturity (0.738) and plant height (0.356).
Days to maturity observed positive and highly significant association with plant height (0.329), while negative and significant association with No. of grains per spike (-0.270) and harvest index (-0.209).
Plant height expressed positive and highly significant association with No. of productive tillers (0.360) and biological yield per plant (0.427), while negative and highly significant association with No. of grains per spike (-0.330) and harvest index (-0.369), negative and significant association with spike length (-0.222) and protein content (-0.237).
Number of productive tillers per plant observed positive and highly significant association with biological yield per plant (0.399) while negative and highly significant association with harvest index (-0.278).
Spike length expressed positive and highly significant association with No. of spikelet per spike (0.364), No. of grains per spike (0.450), harvest index (0.285) and grain yield per plant (0.351).
Number of spikelets per spike observed positive and highly significant association with No. of grains per spike (0.687) and harvest index (0.280).
Number of grains per spike exhibited positive and highly significant association with harvest index (0.377).
1000 seed weight observed positive and highly significant association with grain yield per plant (0.283) while negative and significant association with chlorophyll content (-0.213).
Biological yield per plant expressed negative and highly significant association with grain yield per plant (0.588) while negative and highly significant association with harvest index (-0.395).
Harvest index expressed positive highly significant association with grain yield per plant (0.400).
Canopy temperature expressed positive and significant association with protein content (0.226).
The similar results observed in phenotypic and genotypic correlation of grain yield per plant by Rohani *et al.* (2016) [14]; Ismail *et al.* (2012); Roshan *et al.* (2017) [15]; Desheva *et al.* (2016); Gezahegn *et al.* (2015); Berhanu *et al.* (2017).

Path coefficient analysis
Path coefficient analysis reveals that the relative contribution of causal factor towards the grain yield per plant. By partitioning the phenotypic and genotypic correlations, the direct effect of studied traits towards grain yield per plant and its indirect effect through other characters were computed and presented in Table 2.

Table 2: Genotypic path coefficient showing direct and indirect effects of different contributing characters on grain yield per plant in wheat

Characters	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13
X1	0.206	-0.103	-0.043	-0.008	0.001	0.020	0.013	0.007	-0.027	-0.232	-0.004	-0.026	0.004
X2	0.164	-0.129	-0.042	-0.003	0.000	0.022	0.018	0.023	0.047	-0.235	-0.006	0.001	0.033
X3	0.079	-0.049	-0.112	0.043	0.001	0.034	0.024	-0.005	0.454	-0.429	0.014	0.008	0.038
X4	-0.019	0.004	-0.057	0.085	0.000	0.022	0.011	-0.006	0.416	-0.319	0.007	0.002	0.019
X5	-0.038	0.001	0.026	0.009	-0.005	-0.084	-0.030	0.020	0.240	0.325	-0.068	0.009	0.033
X6	-0.023	0.016	0.021	-0.010	-0.002	-0.182	-0.051	-0.036	-0.068	0.324	0.005	0.027	-0.005
X7	-0.042	0.038	0.043	-0.015	-0.002	-0.150	-0.062	0.004	-0.229	0.445	0.006	-0.005	-0.005
X8	0.008	-0.016	0.003	-0.003	-0.001	0.035	-0.001	0.185	0.194	-0.011	-0.056	-0.021	0.015
X9	-0.006	-0.006	-0.052	0.036	-0.001	0.013	0.014	0.036	0.985	-0.362	0.012	0.007	0.011
X10	-0.052	0.033	0.052	-0.029	-0.002	-0.064	-0.030	-0.002	-0.385	0.927	-0.054	0.018	-0.035
X11	-0.007	0.006	-0.014	0.005	0.003	-0.007	-0.003	-0.090	0.104	-0.433	0.116	0.073	-0.065
X12	-0.063	-0.002	-0.011	0.002	-0.001	-0.059	0.003	-0.046	0.083	0.198	0.103	0.083	-0.064
X13	-0.005	0.027	0.027	-0.010	0.001	-0.006	-0.002	-0.018	-0.068	0.204	0.048	0.033	-0.159

X1: Days to flowering; **X2:** Days to maturity; **X3:** Plant height(cm); **X4:** Number of productive tillers; **X5:** Spike length(cm); **X6:** Number of spikelet per spike; **X7:** Number of grains per spike; **X8:** 1000 seed weight (g); **X9:** Biological yield per plant(g); **X10:** Harvest index (%); **X11:** Chlorophyll content; **X12:** Canopy temperature; **X13:** Protein content(%).

Direct effect of various characters on grain yield per plant
Out of thirteen, seven characters had positive and direct effect on grain yield per plant *viz*., days to flowering (0.206), Number of productive tillers (0.085), 1000 seed weight (0.185), biological yield per plant (0.985), harvest index (0.927), chlorophyll content (0.116), canopy temperature (0.083), while rest of six had negative and direct effect on grain yield per plant *viz*., days to maturity (-0.129), plant height (-0.112), spike length (-0.005), number of spikelet per spike (-0.182), number of grains per spike (-0.062), protein content (-0.159).

Indirect effects of various characters on grain yield per plant
Days to flowering revealed positive indirect on grain yield per plant via., spike length (0.001), number of spikelets per spike (0.020), number of grains per spike (0.013), 1000 seed weight (0.007), protein content (0.004). while negative effects via., days to maturity (-0.103), plant height (-0.043), number of productive tillers (-0.008), biological yield per plant (-0.027), harvest index (-0.232), chlorophyll content (-0.004), canopy temperature (-0.026).
Days to maturity showed positive indirect on grain yield per

plant via., days to flowering (0.164), spike length (0.000), number of spikelet per spike (0.022), number of grains per spike (0.018), 1000 seed weight (0.023), biological yield per plant (0.047), canopy temperature (0.001), protein content (0.033) while negative effects via., plant height (-0.042), number of productive tillers (-0.003), harvest index (-0.235), chlorophyll content (-0.006).

Plant height reported positive indirect on grain yield per plant via., days to flowering (0.079), number of productive tillers (0.043), spike length (0.001), number of spikelet per spike (0.034), number of grains per spike (0.024), biological yield per plant (0.454), chlorophyll content (0.014), canopy temperature (0.008), protein content (0.038) while negative indirect effects via., days to maturity (-0.049), 1000 seed weight (-0.005), harvest index (-0.0429).

Number of productive tillers per plant revealed positive indirect on grain yield per plant via., days to maturity (0.004), spike length (0.000), number of spikelet per spike (0.022), number grains per spike (0.011), biological yield per plant (0.416), chlorophyll content (0.007), canopy temperature (0.002), protein content (0.019) while negative indirect effects via., days to flowering (-0.019), plant height (-0.057), 1000 seed weight (-0.006), harvest index (-0.319).

Spike length revealed positive indirect on grain yield per plant via., days to maturity(0.001), plant height (0.026), number of productive tillers (0.009), 1000 seed weight (0.020), biological yield per plant (0.240), harvest index (0.325), canopy temperature (0.009), protein content (0.033) while negative indirect effects via., days to flowering (-0.038), number of spikelet per spike (-0.084), number of grains per spike (-0.030), chlorophyll content (-0.068).

Number of spikelet per spike showed positive indirect on grain yield per plant via., days to maturity (0.016), plant height (0.021), harvest index (0.324), chlorophyll content (0.005), canopy temperature (0.027) while negative indirect effects via., days to flowering (-0.023), number of productive tillers (-0.010), spike length (-0.002), number of grains per spike (-0.051), 1000 seed weight (-0.036), biological yield per plant (-0.068), protein content (-0.005).

Number of grains per spike showed positive indirect on grain yield per plant via., days to maturity (0.038), plant height (0.043), 1000 seed weight (0.004), harvest index (0.445), chlorophyll content (0.006) while negative indirect effects via., days to flowering (-0.042), number of productive tillers (-0.015), spike length (-0.002), number of spikelet per spike (-0.150), biological yield per plant (-0.229), canopy temperature (-0.005), protein content (-0.005).

1000 seed weight showed positive indirect on grain yield per plant via., days to flowering (0.008), plant height (0.003), number of spikelet per spike (0.035), biological yield per plant (0.194), protein content (0.015) while negative indirect effects via., days to maturity (-0.016), number of productive tillers (-0.003), spike length (-0.001), No. of grains per spike (-0.001),harvest index (-0.011), chlorophyll content (-0.056), canopy temperature (-0.021).

Biological yield per plant showed positive indirect on grain yield per plant via., number of productive tillers (0.036), number of spikelet per spike (0.013), number of grains per spike (0.014), 1000 seed weight (0.036), chlorophyll content (0.012), canopy temperature (0.007), protein content (0.011) while negative indirect effects via., days to flowering (-0.006), days to maturity (-0.006), plant height (-0.052), spike length (-0.001), harvest index (-0.362).

Harvest index showed positive indirect on grain yield per plant via., days to maturity (0.033), plant height (0.052), canopy temperature (0.018) while negative indirect effects via., days to flowering (-0.052), number of productive tillers (-0.029), spike length (-0.002), number of spikelet per spike (-0.064), number of grains per spike (-0.030), 1000 seed weight (-0.002), biological yield per plant (-0.385), chlorophyll content (-0.054), protein content (-0.035).

Chlorophyll content showed positive indirect on grain yield per plant via., days to maturity (0.006), number of productive tillers (0.005), spike length (0.003), biological yield per plant (0.104), canopy temperature (0.073) while negative indirect effects via., days to flowering (-0.007), plant height (-0.014), number of spikelet per spike (-0.007), number of grains per spike (-0.003), 1000 seed weight (-0.090), harvest index (-0.433), protein content (-0.065).

Canopy temperature showed positive indirect on grain yield per plant via., number of productive tillers (0.002), number of grains per spike (0.003), biological yield per plant (0.083), harvest index (0.198), chlorophyll content (0.103) while negative indirect effects via., days to flowering (-0.063), days to maturity (-0.002), plant height (-0.011), spike length (-0.001), number of spikelet per spike (0.059), 1000 seed weight (-0.046), protein content (-0.064).

Protein content showed positive indirect on grain yield per plant via., days to maturity (0.027), plant height (0.027), spike length (0.001), harvest index (0.204), chlorophyll content (0.048), canopy temperature (0.033) while negative indirect effects via., days to flowering (-0.005), number of productive tillers (-0.010), number of spikelet per spike (-0.006), number of grains per spike (-0.002), 1000 seed weight (-0.018), biological yield per plant (-0.068).

The similar results observed direct and indirect effect on grain yield per plant on several characters by Thakur *et al*. (2018); Berhanu *et al*. (2017); Gezahegn *et al*. (2015); Suleiman *et al*. (2014); Khokar *et al*. (2010) [6]; Majumder *et al*. (2008) [7]; Zakirullah *et al*. (2017); Desheva *et al*. (2016); Vamshikrishna *et al*. (2013).

Conclusion

The genotypic correlation coefficient was higher in magnitude than their corresponding phenotypic one, indicating there by strong inherent association between different traits studied. The phenotypic expression of correlation was less due to multiple influences of environmental components in the view of correspondence selection on phenotypic basis would be effective. The positive highly significant genotypic correlation and phenotypic correlation of grain yield per plant was found for the characters namely, spike length, 1000 seed weight and harvest index. And in genotypic correlation shows positive significant found in canopy temperature. Thus, these characters revealed as most important association of grain yield per plant in wheat. It showed that the above-mentioned characters must be included in selection criteria during improvement of grain yield in wheat.

Out of thirteen characters, seven characters had positive direct effect on grain yield per plant *viz*., days to flowering, number of productive tillers, 1000 seed weight, biological yield per plant, harvest index, chlorophyll content and canopy temperature. The remaining six characters are negative direct effect on grain yield per plant *viz*., days to maturity, plant height, spike length, number of spikelets per spike, number of grains per spike and protein content. Thus, these characters

need special attention during the time of selection strategy due to their contrasting direct and indirect effects.

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