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Correlation and path coefficient analysis in bread wheat (*Triticum aestivum* L.) under timely and late sown conditions

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Abstract
The present experiment was conducted to identify important yield attributing traits under timely and late sowing conditions by employing correlation and path coefficient analysis at Wheat experimental farm, DRPCAU, Samastipur, Bihar during *rabi* 2020-21. Grain yield plant^{-1} had a significant positive correlation with tillers plant^{-1}, grains spike^{-1}, chlorophyll content, 1000-grain weight and harvest index under both the conditions, however it reported significant negative correlation with canopy temperature and heat susceptibility index. Whereas, canopy temperature reported significant negative alliance with grains spike^{-1} and harvest index under both sown conditions. Analysis of correlations and path coefficients under both sowing conditions indicated that tillers per plant, spike length, grains per spike, chlorophyll content, and harvest index are dependable and efficient traits. These traits not only had a strong positive correlation with grain yield but also showed positive interrelationships and substantial indirect effects on grain yield.

Keywords: Wheat, terminal heat stress, correlation, path analysis

Introduction
Wheat (*Triticum aestivum* L.) has served as a staple food for prominent civilizations since ancient times and is now the most widely cultivated cereal crop globally. The wheat crop is critical to India's food security, and there is a constant need to enhance wheat productivity to meet the needs of rapidly growing population (Singh *et al.*, 2012) [26]. The productivity of wheat has been found to be negatively impacted by the 0.4 °C rise in worldwide temperatures between 1980 and 2000 (Lobell and Field, 2007) [18]. One of the most important abiotic stress that reduces wheat grain production globally is heat stress, which is more prevalent in arid, semi-arid, tropical, and subtropical regions (Okechukwu *et al.*, 2016) [20]. The optimal temperature for wheat throughout the anthesis to grain maturity stage is 22-25 °C; beyond this range causes irreversible loss (Farooq *et al.*, 2011) [11]. During late sowing of wheat genotypes, their anthesis and grain filling stages are influenced by a high temperature of 25-32 °C, resulting in early crop maturity and a significant drop in grain production. Heat stress also impacts accumulation of chlorophyll, which subsequently affects photosynthesis in plants. Thus, in wheat crop improvement programmes, the development of heat-tolerant cultivars is an absolute necessity by identifying tolerant genotypes under normal and stress conditions (Kamrani *et al.*, 2017, Khan *et al.*, 2014) [15, 17].

Choosing selections based on multiple characteristics is preferable to relying solely on yield, given that yield is a complex quantitative trait influenced by many genes. Understanding the relationship between yield and its contributing traits is critical for breeders. It enables them to assess and improve multiple traits simultaneously. While correlation reveals associations between traits, it doesn't explain cause and effect. Path analysis, on the other hand, investigates how traits influence each other. This approach provides more insights into trait interactions, allowing breeders to make better judgements when selecting traits for wheat improvement for terminal heat tolerance.

Materials and Methods

The current experiment comprised twenty-nine wheat genotypes, including one check (Rajendra Ghehu 3). The investigation was carried out at wheat research farm, DRPCAU, Pusa, Bihar, during *rabi* 2020-21. The experiment was performed in Randomised block design with three replications for both normal (15 November, 2020) and late sown conditions (15 December, 2020), with row spacing of 23 cm and 18 cm, respectively. Data was collected on plant height (PH), tillers per plant (TPP), days to 50% flowering (DFF), canopy temperature (CT), spike length (SL), grains per spike (GPS), chlorophyll content (CC), days to maturity (DM), 1000-grain weight (TGW), harvest index (HI), grain yield per plant (GYP), and heat susceptibility index (HSI). The correlation was computed using the methodology described by Al-jibouri *et al*., (1958) [2]. The statistical technique provided by Wright (1921, 1960) [29] and developed by Dewey and Lu (1959) [8] was used to evaluate the direct and indirect contribution of numerous factors to grain yield determined by path coefficient analysis.

Results and Discussion

Correlation analysis

The interactions of the component features resulted in the final outcome, grain yield, which is a complicated trait. Insight of the interactions between different characters and also with the external environment has been extensively used in plant breeding programmes. This is owing to the connection between various plant character that may occur as a result of linkage, pleiotrophy, or may be impacted by certain functional relationship throughout the growth stage. Correlation studies can therefore reveal the degree and range of the relationship between any two sets of quantitative characters. As a result of this, selecting of another pair may result in genetic improvements of one character. In general, the association was shown to be stronger at the genotypic level than at the phenotypic level. Thus, it revealed that strong innate connections at the phenotypic level were slightly distorted as a result of environmental effects, Rajshree and Singh (2016) [23], El-Mohsen *et al*., (2012) [10].

Under normal sown conditions (table 1), grain yield plant^{-1} displayed significantly positive alliance with tillers plant^{-1} (0.497), chlorophyll content (0. 693), harvest index (0. 627) and grains per spike (0. 562) While it reported negative alliance only with trait canopy temperature. Fellahi *et al.* (2013) [12] for chlorophyll content, Verma *et al.* (2019) [28] for harvest index, Shehrawat *et al.* (2021) [25] and Choudhary *et al.* (2020) [7] for tillers plant^{-1}, Parveen *et al.* (2021) [21] and Barman *et al.* (2021) [21] for canopy temperature reported similar observations with grain yield plant^{-1}. Tillers plant^{-1} reported significantly positive association with grains per spike (0.377), chlorophyll content (0.385), 1000-grain weight (0.228) and harvest index (0.462). It was in accordance with Baloch *et al.* (2021) [4] for grains per spike and 1000-grain weight, Hassan *et al.* (2022) [13] for harvest index. It also displayed significant negative association with canopy temperature as observed by Parveen *et al.* (2021) [21]. Days to 50% flowering displayed significantly positive alliance with days to maturity and negatively significant association with thousand grain weight. Raaj *et al.* (2018) [22] reported similar outcome.

Table 1: Phenotypic correlation for eleven traits under timely sown condition

TRAIT	PH	TPP	DFF	CT	SL	GPS	CHL	DM	TGW	HI
PH	1									
TPP	-0.173	1								
DFF	0.045	-0.111	1							
CT	-0.168	-0.43 **	-0.069	1						
SL	0.092	-0.073	0.043	0.064	1					
GPS	0.058	0.377**	-0.017	-0.436**	0.179	1				
CHL	0.124	0.385**	0.045	-0.429**	-0.009	0.359**	1			
DM	-0.095	0.074	0.614**	0.062	0.124	0.087	0.087	1		
TGW	-0.094	0.228 *	-0.370**	-0.028	-0.073	0.040	0.187	0.031	1	
HI	-0.032	0.462**	0.005	-0.456**	0.195	0.248 *	0.424**	0.087	0.257 *	1
GYP	0.033	0.497**	0.066	-0.694**	0.130	0.562**	0.693**	0.088	0.155	0.627**

Whereas under late sown conditions (table 2) grain yield plant^{-1} reported significantly positive alliance with tillers plant^{-1} (0. 718), spike length (0.380), grains spike^{-1} (0. 789), chlorophyll content (0. 769), 1000-grain weight (0. 442), harvest index (0. 721). Above mentioned findings are in line with Bhanu *et al.* (2018) [6] for thousand grain weight in heat stress conditions, Sharma *et al.* (2018) [24] for tillers per plant, grains per spike, Jee *et al.* (2019) [14] for harvest index and Maurya *et al.* (2020) [19] for spike length. Grain yield plant^{-1} reported significantly negative alliance with heat susceptibility index (-0. 649). However, canopy temperature reported significantly negative alliance with grain yield plant^{-1} (-0. 804). Attarbashi *et al.* (2002) [3] and Parveen *et al.* (2021) [21] reported the similar findings. Tillers per plant reported significant positive association with spike length (0. 290), grains spike^{-1} (0. 527), chlorophyll content (0. 649), 1000-grain weight (0. 508), harvest index (0. 547). Shehrawat *et al.* (2021) [25] reported similar findings for 1000-grain weight, harvest index. Tillers plant^{-1} reported significantly negative correlation with HSI (-0. 385). Findings of Raaj *et al.* (2018) [22] supports these results. Days to 50% flowering reported positively significant alliance with canopy temperature (0. 249) and days to maturity (0. 335). While it reported negative association with spike length (-0. 266), thousand grain weight (-0. 279) stated similar findings in relation to grain yield per plant. Canopy temperature reported positive alliance with chlorophyll content (0. 625) and heat susceptibility index (0. 490). Similar outcomes were stated by Raaj *et al.* (2018) [22] and Barman *et al.* (2020) [5]. It was also noted that increasing the canopy temperature reduced the chlorophyll content of leaves, which impacted grain production and other yield contributing traits.

Table 2: Phenotypic correlation for twelve traits under late sown conditions

TRAIT	PH	TPP	DFF	CT	SL	GPS	CHL	DM	TGW	HI	HSI
PH	1100										
TPP	0.057	1									
DFF	0.001	-0.164	1								
CT	0.069	-0.601**	0.249 *	1							
SL	0.166	0.290 **	-0.266 *	-0.278**	1						
GPS	0.210	0.527 **	-0.193	-0.610**	0.381**	1					
CHL	0.080	0.649 **	-0.031	0.625**	0.197	0.720**	1				
DM	-0.071	0.132	0.335 **	-0.039	0.078	-0.091	0.012	1			
TGW	-0.015	0.508**	-0.279 **	-0.470**	0.443**	0.448**	0.543**	0.154	1		
HI	-0.131	0.547**	-0.1761	-0.671**	0.292**	0.570**	0.500**	0.028	0.404**	1	
HSI	0.103	-0.385**	0.0070	0.490**	-0.258*	-0.506**	-0.570**	-0.043	-0.246*	-0.442**	1
GYP	0.086	0.718**	-0.117	-0.804**	0.380**	0.789**	0.769**	0.094	0.442**	0.721**	-0.649**

The study of correlation analysis under timely and late situations shows that, in general, the direction of correlation in both conditions is the same for nearly most of the characters, with the main difference being the magnitude (degree) of relationship across both situations for that pair of characters. As a result, selecting for any of these traits would result in simultaneous improvement of the other traits and ultimately, an enhancement in yield.

Path Coefficient Analysis

Under timely sown conditions, path coefficient analysis (table 3) revealed that Canopy temperature (-0.3532) reported high negative and direct effects on grain yield and further negative association was build up by the indirect effects via other traits. Parveen *et al.* (2021) [21] observed similar findings for canopy temperature. While, traits tillers plant^{-1} (0.0065), days to 50% flowering (0.0361), spike length (0.0829), grains spike^{-1} (0.2039), chlorophyll content (0.3740), thousand grain weight (0.0180) and harvest index (0.0591) reported direct positive effects on grain yield plant^{-1}. Tapaswini *et al.* (2020) [27] observed direct effects of tillers plant^{-1}, grains spike^{-1}, days to flowering on grain yield plant^{-1}. Therefore, it can be stated that selection relying upon these traits, such as tillers plant^{-1}, harvest index, spike length, chlorophyll content and thousand grain weight, would be efficient and dependable because they were positively associated with grain yield per plant, positive inter interrelationship amongst themselves and a positive indirect influence of many of the characters through these characters on grain yield plant^{-1}. Because of its negative indirect influence with many characters on grain production, canopy temperature showed a strongly and negatively correlated with grain yield plant^{-1}, implying the relevance of this character during the selection of breeding programmes for improving bread wheat genotypes.

Table 3: Phenotypic path coefficient analysis under timely sown conditions

Traits	PH	TPP	DFF	CT	SL	GPS	CHL	DM	TGW	HI
PH	-0.0831	0.0144	-0.0038	0.0140	-0.0077	-0.0048	-0.0103	0.0080	0.0079	0.0027
TPP	-0.0011	0.0065	-0.0007	-0.0029	-0.0005	0.0025	0.0025	0.0005	0.0015	0.0030
DFF	0.0017	-0.0040	0.0361	-0.0025	0.0016	-0.0006	0.0016	0.0222	-0.0134	0.0002
CT	0.0593	0.1554	0.0246	-0.3532	-0.0227	0.1541	0.1518	-0.0220	0.0100	0.1613
SL	0.0076	-0.0061	0.0036	0.0053	0.0829	0.0149	-0.0008	0.0103	-0.0061	0.0162
GPS	0.0119	0.0769	-0.0035	-0.0890	0.0366	0.2039	0.0734	0.0179	0.0083	0.0506
CHL	0.0465	0.1440	0.0168	-0.1607	-0.0035	0.1346	0.3740	0.0326	0.0700	0.1586
DM	0.0002	-0.0001	-0.0012	-0.0001	-0.0002	-0.0002	-0.0002	-0.0019	-0.0001	-0.0002
TGW	-0.0017	0.0041	-0.0067	-0.0005	-0.0013	0.0007	0.0034	0.0006	0.0180	0.0046
HI	-0.0075	0.1063	0.0012	-0.1051	0.0450	0.0571	0.0975	0.0202	0.0591	0.2301
GYP	0.0337	0.4974**	0.0665**	-0.6947**	0.1302	0.5622**	0.6930**	0.0882	0.1553	0.6271**

Under late sown conditions (table 4), canopy temperature (-0.3029), heat susceptibility index (-0.1529) and thousand grain weight (-0.1396) reported direct negative effects on grain yield plant^{-1}. Whereas, grains spike^{-1} (0.2447), tillers plant^{-1} (0.1871), harvest index (0.1694), chlorophyll content (0.1649), spike length (0.0806), days to maturity (0.0760), plant height (0.0598) and days to 50% flowering (0.0294), reported direct positive effects over grain yield plant^{-1}. Ehdaie *et al.* (1989) [9] reported direct effects of plant height, days to maturity and harvest index over grain yield plant^{-1}. Ali *et al.* (2008) [1] observed positive direct effects of grains spike^{-1} on grain yield. Raaj *et al.* (2018) [22] observed direct negative effects of heat susceptibility index on grain yield plant^{-1}.

Hence, it is implied that traits such as harvest index, canopy temperature and HSI must be taken into consideration in the selection procedure for breeding programmes, because they reported positive interrelationship with grain yield, a positive inter correlation among themselves and a high direct effects on grain yield and remaining traits reported indirect contribution to grain yield. As a result, selection for yield enhancement in bread wheat under late sown conditions would be more successful if based on these traits.

Table 4: Phenotypic path coefficient analysis under late sown conditions

Traits	PH	TPP	DFF	CT	SL	GPS	CHL	DM	TGW	HI	HSI
PH	0.0598	0.0035	0.0001	0.0042	0.0100	0.0126	0.0048	-0.0043	-0.0009	-0.0079	0.0062
TPP	0.0108	0.1871	-0.0307	-0.1125	0.0543	0.0987	0.1214	0.0247	0.0951	0.1024	-0.0720
DFF	0.0001	-0.0048	0.0294	0.0073	-0.0078	-0.0057	-0.0009	0.0098	-0.0082	-0.0052	0.0002
CT	-0.0211	0.1822	-0.0757	-0.3029	0.0845	0.1848	0.1895	0.0118	0.1424	0.2034	-0.1485
SL	0.0135	0.0234	-0.0215	-0.0225	0.0806	0.0307	0.0159	0.0063	0.0358	0.0236	-0.0208
GPS	0.0515	0.1291	-0.0473	-0.1493	0.0933	0.2447	0.1763	-0.0223	0.1098	0.1397	-0.1239
CHL	0.0132	0.1070	-0.0052	-0.1032	0.0326	0.1188	0.1649	0.0021	0.0896	0.0824	-0.0941
DM	-0.0054	0.0100	0.0255	-0.0030	0.0059	-0.0069	0.0010	0.0760	0.0118	0.0021	-0.0033
TGW	0.0021	-0.0710	0.0390	0.0657	-0.0619	-0.0627	-0.0758	-0.0216	-0.1396	-0.0565	0.0344
HI	-0.0222	0.0927	-0.0298	-0.1137	0.0495	0.0967	0.0847	0.0048	0.0686	0.1694	-0.0749
HSI	-0.0158	0.0589	-0.0011	-0.0750	0.0395	0.0774	0.0872	0.0067	0.0377	0.0676	-0.1529
GYP	0.086	0.718**	-0.117	-0.804**	0.380**	0.789**	0.769**	0.094	0.442**	0.721**	-0.649**

Conclusion

The Grain yield plant^{-1} had a substantial positive alliance with tillers plant^{-1}, grains spike^{-1}, chlorophyll content, 1000-grain weight and harvest index under both circumstances, but it had a substantial negative alliance with canopy temperature and heat susceptibility index. Canopy temperature reported significant negative alliance with grains spike^{-1} and harvest index under both sown conditions implying high canopy temperature leads to decline in yield under heat stress conditions. Grains spike^{-1} and harvest index must be prioritised in the selection process for crop improvement as they are positively correlated with grain yield plant^{-1}and harvest index has a strong direct effect on grain yield plant^{-1}. As a result, selection relying on these traits would be quite successful for increasing production in wheat under terminal heat stress conditions. Correlation and path analysis under both conditions suggested that characters such as tillers plant^{-1}, spike length, grains spike^{-1}, chlorophyll content and harvest index would be dependable and efficient as they illustrated positively strong alliance with grain yield and positive interrelation amongst themselves and also through high indirect effects of many of the traits on grain yield.

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