

## Dissecting Heat Tolerance in Bread Wheat (*Triticum aestivum* L.): A Quantitative Trait Analysis via Correlation and Path Coefficients

Binita Dobariya<sup>1</sup>, Ashwin Pansuriya<sup>2</sup>, Deep Vekaria<sup>2\*</sup>, Chandrakant Singh<sup>2</sup> and Jaysukh Savaliya<sup>3</sup>

<sup>1</sup>Department of Genetics and Plant Breeding, College of Agriculture, Junagadh Agricultural University, Junagadh-362001, Gujarat, India

<sup>2</sup>Wheat Research Station, Junagadh Agricultural University, Junagadh-362001, Gujarat, India

<sup>3</sup>Main Oilseeds Research Station, Junagadh Agricultural University, Junagadh-362001, Gujarat, India

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**\*Corresponding authors:** E-mail: [dmvekaria1991@jau.in](mailto:dmvekaria1991@jau.in)

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Wheat (*Triticum aestivum* L.) is one of the most important food crops in world. Among various food grains, wheat stands next to rice, both in area and production. The share of wheat in total food grain production is around 35.5% and share in area is about 21.8% of the total area under food grains (Joshi *et al.*, 2025). The major wheat producing states are Uttar Pradesh, Punjab, Haryana, Madhya Pradesh, Rajasthan, Bihar, Maharashtra, Gujarat, etc. These states contribute about 87.5% of total wheat production in the country. Climate change and the rapidly growing global population pose significant threats to global food security. Rising temperatures, reduced and erratic rainfall, and shorter winter seasons have intensified abiotic stresses particularly drought and heat stress which are among the most damaging factors affecting crop growth, development, yield potential, and food quality. High temperature stress, already a major limitation to the productivity of crops such as wheat, is expected to worsen with ongoing climatic changes. Climate models predict a temperature increase of 1–4 °C by the end of the twenty-first century, potentially reducing wheat yields by 4.1–6.4%. Excessive heat disrupts plant growth and development by affecting physiological functions, grain formation, and yield, and by impairing metabolic processes such as protein synthesis, enzyme activity, and

cellular integrity, including membrane stability and cell division. In wheat, the optimum temperature during anthesis to grain maturity is 22–25 °C; temperatures beyond this range can cause irreversible damage. Under late-sown conditions, wheat genotypes often experience temperatures of 25–32 °C during anthesis and grain filling, leading to accelerated maturation and substantial yield reduction. Heat tolerance in wheat breeding is increasingly vital as rising global temperatures threaten crop productivity and food security. The correlation coefficient gives a measure of the important poor relationship between traits and provides the degree to which various characters of a crop are associated with productivity. Association of character with yield and among themselves and the extent of environmental influence on the expression of these characters are necessary. In such situations, correlation and path coefficient analysis could be used as an important tool to bring information about appropriate cause and effects relationship between yield and yield contributing traits. Correlation and path-coefficient analysis lead us to a clear understanding of the genetic association of various plant traits and their contribution of various yield and yield contributing traits.

The experimental material consisted of 48 diverse genotypes of wheat (*Triticum aestivum* L.) representing



different geographic origins (Table 1). The pure seeds of these genotypes were obtained from the Research Scientist (Wheat), Wheat Research Station, Junagadh Agricultural University, Junagadh, Gujarat. The selected genotypes consisted of released varieties as well as breeding lines developed at different sources India. Genotypes of wheat were sown at normal and late sowing condition in a Randomized Block Design with three replications during *Rabi* 2017-2018. The observations were recorded on five randomly selected plants from each entry and replication for different characters *viz.*, plant height (cm), number of effective tillers per plant, length of main spike (cm), number of grains per main spike, grain weight per main spike (g), grain yield per plant (g), biological yield per plant

(g), harvest index (%), 1000 grain weight and chlorophyll content ( $CHL_a$  &  $CHL_{21}$ ) while days to 50% flowering, days to maturity and grain filling period (days) was measured on plot basis. The chlorophyll content was measured using Soil Plant Analyzer Development (SPAD) meter. The data recorded for various characters were statistically analysed for various parameters *viz.*, genotypic and phenotypic correlations and path coefficient analysis and heat tolerance. The mean values were used for the statistical analysis. The phenotypic and genotypic correlation coefficients for pair of the characters were worked-out through covariance analysis as per Al-Jibouri *et al.* (1958). The genotypic path coefficient analysis was done as per the method suggested by Dewey and Lu (1959).

**Table 1:** List of genotypes used for study and their source

Sr. No.	Name of genotype	Source
1	AKAW 4842	PDKV, Akola, Maharashtra
2	AKAW 4924	PDKV, Akola, Maharashtra
3	BRW 3775	BAU, Sabour, Bihar
4	BRW 5872	BAU, Sabour, Bihar
5	CG 1014	IGKV, Chhattisgarh
6	DBW 173	IIWBR, Karnal, Haryana
7	DBW 235	IIWBR, Karnal, Haryana
8	DWAP 1530	IIWBR, Karnal, Haryana
9	GW 11	WRS, Vijapur, Gujarat
10	GW 173	WRS, Vijapur, Gujarat
11	GW 451	WRS, Vijapur, Gujarat
12	GW 477	WRS, Junagadh, Gujarat
13	GW 493	WRS, Vijapur, Gujarat
14	GW 495	WRS, Junagadh, Gujarat
15	GW 498	WRS, Junagadh, Gujarat
16	HD 3215	IARI, New Delhi
17	HI 1544	IARI, Indore, Madhya Pradesh
18	HPW 360	CSKHPKV, Malan, Himachal Pradesh
19	HS 592	IARI, RS, Shimla, Himachal Pradesh
20	HUW 675	BHU, Varanasi, Uttar Pradesh
21	HUW 1525	BHU, Varanasi, Uttar Pradesh
22	JWS 152	JNKVV, Jabalpur, Madhya Pradesh
23	JWS 810	JNKVV, Jabalpur, Madhya Pradesh
24	K 1610	CSAUA & T, Kanpur, Uttar Pradesh
25	KBRL 77-1	PAU, Ludhiana, Punjab
26	LBPY 2013-3	IIWBR, Karnal, Haryana
27	LOK 11	Lok Bharti Sanosara, Gujarat
28	MACS 6222	ARI, Pune, Maharashtra
29	MACS 6703	ARI, Pune, Maharashtra



30	MP 1339	JNKVV, Jabalpur, Madhya Pradesh
31	MP 3288	JNKVV, Jabalpur, Madhya Pradesh
32	NIAW 3161	MPKV, Niphad, Maharashtra
33	NW 5054	NDUA & T, Faizabad, Uttar Pradesh
34	PBW 770	PAU, Ludhiana, Punjab
35	PHSL 5	IWPR, Karnal, Haryana
36	QBP-12-9	IWBR, Karnal, Haryana
37	RAJ 3077	SKRAU, Durgapur, Rajasthan
38	RAJ 3765	SKRAU, Durgapur, Rajasthan
39	RAJ 4238	SKRAU, Durgapur, Rajasthan
40	RAJ 4493	SKRAU, Durgapur, Rajasthan
41	RAJ 4500	SKRAU, Durgapur, Rajasthan
42	UAS 391	UAS, Dharwad, Karnataka
43	UP 2672	GBPAU & T, Pantnagar, Uttarakhand
44	UP 2959	GBPAU & T, Pantnagar, Uttarakhand
45	VL 1003	VPKAS, Almora, Uttarakhand
46	WH 147	CCSHAU, Hisar, Haryana
47	WH 730	CCSHAU, Hisar, Haryana
48	WH 1234	CCSHAU, Hisar, Haryana

The study of genotypic correlation gives an idea of the extent of relationship between different variables. This relationship among yield contributing characters as well as their association with yield provides information for exercising selection pressure for bringing genetic improvement in grain yield. In general, the values of genotypic correlation were higher than their corresponding phenotypic correlations in the present study (Table 2&3). It indicated that there was a high degree of association between two respective variables at genotypic level, while its phenotypic expression was deflated by the influence of environment. The phenotypic correlation coefficients in very few cases were higher than their corresponding genotypic correlation coefficients which might be due to the non-genetic causes; probably environment influenced the value of phenotypic correlation (Patel *et al.*, 2025).

Under timely sowing condition ( $D_1$ ), the characters, grain yield per plant exhibited highly significant and positive genotypic and phenotypic correlation with biological yield per plant (Ramanuj, 2018; Borkhatariya *et al.*, 2025; Puri *et al.*, 2025, whereas significant and positive correlations at both levels with harvest index was also found by Patel (2018). Moreover, grain yield per plant also manifested positive, but non-significant genotypic and phenotypic correlation with number of effective tillers per plant, length of main spike and 1000-grain weight. It also manifested the positive but non-significant correlation at phenotypic

level with plant height which was also supported by Bhanu *et al.* (2018) and Karla *et al.* (2024).

Under late sown condition ( $D_2$ ), grain yield per plant had highly significant and positive genotypic and phenotypic correlation with biological yield per plant and harvest index (Patel, 2018). The grain yield per plant had positive but non-significant correlation with grain filling period, number of effective tillers per plant and 1000-grain weight at both levels.

Days to 50% flowering exhibited highly significant and positive correlation both at genotypic and phenotypic levels with days to maturity (Patel, 2018). While, length of main spike exhibited significant and positive association at genotypic level with days to 50% flower under late sowing condition (Patel, 2018). Days to maturity showed highly significant and positive correlation at both the levels with grain filling period under both sowing conditions; significant and positive correlation at both levels with plant height under timely sowing condition; significant and positive correlation at both levels with biological yield per plant under late sowing condition and significant and positive genotypic correlation with length of main spike under late sowing condition. These relationships indicated that the improvement in one character, which in turn automatically lead to increase in grain yield. Days to 50% flowering and days to maturity had significant and





**Table 2:** Genotypic ( $r_g$ ) and phenotypic ( $r_p$ ) correlation coefficients among different characters in 48 genotypes of bread wheat under timely sowing condition ( $D_1$ )

Characters	$r_p$	$r_g$	Days to 50% flowering	Days to maturity	Grain filling period (Days)	Plant height (cm)	Number of effective tillers per plant	Length of main spike (cm)	Number of grains per main spike	Grain weight per main spike (g)	Biological yield per plant (g)	Harvest index (%)	1000-grain weight (g)	CHL <sub>a</sub>	CHL <sub>21</sub>
Grain yield per plant (g)	$r_p$	$r_g$	-0.0481	-0.0427	-0.0093	0.0075	0.0775	0.0952	-0.0406	-0.0773	0.7186**	0.3267*	0.0369	-0.1459	-0.1148
Days to 50% flowering	$r_p$	$r_g$	<b>1.000</b>	-0.0630	-0.0555	-0.0192	0.0878	0.0607	-0.0506	-0.0928	0.7517**	0.3066*	0.0848	-0.1889	-0.1632
	$r_p$	$r_g$	<b>1.000</b>	0.8833**	0.1683	0.1559	0.0662	0.1380	0.0766	0.0187	0.0779	-0.1958	-0.2313	-0.2407	-0.2257
Days to maturity	$r_p$	$r_g$	<b>1.000</b>	0.8903**	0.1824	0.1657	0.0754	0.1607	0.0861	0.0241	0.0844	-0.2255	-0.2961*	-0.2619	-0.2322
	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	0.6107**	0.3128*	0.0781	0.1304	0.0799	0.0058	0.0593	-0.1592	-0.1130	-0.1793	-0.1867
Grain filling period (Days)	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	0.6171**	0.3326*	0.0917	0.1470	0.0821	-0.0017	0.0654	-0.1960	-0.1385	-0.1927	-0.1917
	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	0.3944**	0.0524	0.0410	0.0386	-0.0194	-0.0068	-0.0040	0.1532	0.0295	-0.0113
Plant height (cm)	$r_p$	$r_g$	<b>1.000</b>	0.4308**	<b>1.000</b>	0.4308**	0.0582	0.0490	0.0325	-0.0137	-0.0119	-0.0254	0.2064	0.0367	-0.0084
	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	-0.3362*	0.0996	0.1396	-0.1814	-0.0069	0.0897	0.0371	-0.0546	0.0427
No of effective tillers per plant	$r_p$	$r_g$	<b>1.000</b>	-0.3827**	<b>1.000</b>	<b>1.000</b>	-0.3827**	0.1119	0.1527	-0.1997	-0.0193	0.0901	0.0571	-0.0470	0.0402
	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	0.0476	-0.2840*	0.0370	0.1457	-0.0885	-0.0687	-0.2805	-0.2874*
Length of main spike (cm)	$r_p$	$r_g$	<b>1.000</b>	0.0213	-0.3282*	0.0364	<b>1.000</b>	<b>1.000</b>	-0.3282*	0.0364	0.1661	-0.1244	0.0793	-0.1002	-0.2985*
	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	0.2702	-0.0288	0.0724	0.0410	-0.0572	0.1913	0.1264
Number of grains per main spike (g)	$r_p$	$r_g$	<b>1.000</b>	0.2967*	-0.0605	0.0914	0.0914	0.0914	0.2967*	-0.0605	0.0914	0.0238	-0.0460	0.2366	0.1489
	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	0.1511	-0.1857	0.0747	-0.0277	-0.1965	-0.0805
Grain weight per main spike (g)	$r_p$	$r_g$	<b>1.000</b>	0.1069	-0.0256	-0.2451	-0.0925	-0.0925	0.1069	-0.0256	-0.0925	0.1069	-0.0256	-0.2451	-0.0925
	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>
Biological yield per plant (g)	$r_p$	$r_g$	<b>1.000</b>	0.0068	-0.4112**	0.0543	0.0927	-0.1076	0.0068	-0.4112**	0.0543	0.0927	-0.1076	0.0068	0.0099
	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>
Harvest index (%)	$r_p$	$r_g$	<b>1.000</b>	0.0278	0.1216	0.1216	0.1216	0.1216	0.0278	0.1216	0.1216	0.1216	0.1216	0.1216	0.1216
	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>
1000-grain weight (g)	$r_p$	$r_g$	<b>1.000</b>	0.0141	0.1820	0.1820	0.1820	0.1820	0.0141	0.1820	0.1820	0.1820	0.1820	0.1820	0.1820
	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>
CHL <sub>a</sub>	$r_p$	$r_g$	<b>1.000</b>	0.7466**	0.8418**	0.8418**	0.8418**	0.8418**	0.7466**	0.8418**	0.8418**	0.8418**	0.8418**	0.8418**	0.8418**
	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>
CHL <sub>21</sub>	$r_p$	$r_g$	<b>1.000</b>	0.7466**	0.8418**	0.8418**	0.8418**	0.8418**	0.7466**	0.8418**	0.8418**	0.8418**	0.8418**	0.8418**	0.8418**
	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>

\* \*\*Significant at 5% and 1% levels, respectively

**Table 3:** Genotypic ( $r_g$ ) and phenotypic ( $r_p$ ) correlation coefficients among different characters in 48 genotypes of bread wheat under late sowing condition ( $D_2$ )

Characters	$r_p$	$r_g$	Days to 50% flowering	Days to maturity	Grain filling period (Days)	Plant height (cm)	Number of effective tillers per plant	Length of main spike (cm)	Number of grains per main spike	Grain weight per main spike (g)	Biological yield per plant (g)	Harvest index (%)	1000-grain weight (g)	CHL <sub>a</sub>	CHL <sub>21</sub>
Grain yield per plant (g)	$r_p$	$r_g$	-0.0886	-0.0257	0.0594	-0.1843	0.1857	-0.1441	-0.0007	-0.0993	0.5913**	0.5685**	0.2319	-0.2981*	-0.1015
Days to 50% flowering	$r_p$	$r_g$	-0.0738	0.0269	0.1588	-0.1687	0.2545	-0.0849	-0.0424	-0.1371	0.6021**	0.5584**	0.3079*	-0.3216*	-0.0456
	$r_p$	$r_g$	<b>1.000</b>	0.6573**	-0.2553	-0.0633	-0.1128	0.2374	-0.1620	0.0397	0.2336	-0.3328*	-0.1797	-0.0690	0.1531
Days to maturity	$r_p$	$r_g$	<b>1.000</b>	0.6734**	-0.2494	-0.0635	-0.1194	0.2838*	-0.1751	0.0480	0.2789	-0.4233*	-0.1965	-0.0666	0.1576
	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	0.5182**	0.0465	-0.1917	0.2416	-0.0452	0.1279	0.3694*	-0.3895**	0.0506	0.1935	0.2140
Grain filling period (Days)	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	0.5205**	0.0524	-0.2141	0.3037*	-0.0365	0.1300	0.4298**	-0.4773**	0.0691	0.2129	0.2217
	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	0.1457	-0.0756	0.0268	0.1009	0.1304	0.2062	-0.1447	0.2540	0.3743**	0.1303
Plant height (cm)	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	0.1642	-0.0988	0.0780	0.1278	0.1217	0.2652	-0.1730	0.3030*	0.4045**	0.1436
	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	-0.0238	0.1713	0.0668	0.0474	-0.0758	-0.1585	0.3333*	-0.0652	-0.0351
No of effective tillers per plant	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	-0.0194	0.1874	0.0746	0.0619	-0.0951	-0.1984	0.3453*	-0.0665	-0.0382
	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	0.1012	-0.0900	0.0536	-0.1196	0.3755**	0.2044	0.0168	-0.2928*
Length of main spike (cm)	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	0.1418	-0.1073	0.0395	-0.1892	0.5774**	0.2119	0.0025	-0.3174*
	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	-0.0229	0.0973	-0.1212	-0.0403	-0.0149	0.1754	0.3153*
Number of grains per main spike	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	-0.0496	0.1518	-0.1203	-0.1531	0.0057	0.1883	0.3685**
	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	-0.0639	0.3240*	-0.0402	-0.0728	-0.1771	0.2509
Grain weight per main spike (g)	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	-0.0753	0.3780**	-0.0401	-0.0881	-0.1930	0.2602
	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	-0.0683	-0.0317	0.2928*	0.1175	-0.0739
Biological yield per plant (g)	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	-0.0767	0.3343*	0.1383	-0.0760
	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	-0.3162*	0.1062	-0.1203	0.1060
Harvest index (%)	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	-0.3004*	0.1022	-0.1544	0.1215
	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	0.1358	-0.2234	-0.2491
1000-grain weight (g)	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	0.1996	-0.2782	-0.3039*
	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	-0.1166	-0.1655
CHL <sub>a</sub>	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	0.2991*
CHL <sub>21</sub>	$r_p$	$r_g$	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	0.3040*

\*\*, \*Significant at 5% and 1% levels, respectively



highly significant but negative correlation respectively with harvest index (Patel, 2018). Days to 50% flowering also had significant but negative genotypic correlation with 1000-grain weight (Singh *et al.*, 2003). This result of special significant for trait suggested that selection for flowering and early maturity would likely to provide genotypes with higher harvest index.

The grain filling period exhibited highly significant and positive correlation with plant height and chlorophyll content at anthesis at both levels and significant correlation only at genotypic level with 1000-grain weight (Rathwa *et al.*, 2018). The plant height possessed significant and positive correlation with 1000-grain weight but had exhibited highly significant and negative association with number of effective tillers per plant (Patel, 2018). Number of effective tillers per plant showed highly significant and positive correlation at both levels with harvest index while it had significant but negative association with number of grains per main spike and chlorophyll content at 21 days after anthesis (Patel, 2018). Length of main spike exhibited highly significant and positive correlation with chlorophyll content at 21 days after anthesis at genotypic level while at phenotypic level only significant and found significant and positive correlation with number of grains per main spike only at genotypic level (Table 4 & 5). Number of grains per main spike showed highly significant and positive correlation at genotypic level while significant and positive correlation at phenotypic level with biological yield per plant. The interrelationship between grain weight per main spike and 1000-grain weight was positive and highly significant and significant at genotypic and phenotypic level respectively. Biological yield showed highly significant but negative association with harvest index at both levels (Ramanuj, 2018). Harvest index exhibited highly significant but negative correlation at both levels with 1000-grain weight while negatively significant at genotypic level only with chlorophyll content at 21 days after anthesis (Ramanuj, 2018). Chlorophyll content at anthesis showed significant to highly significant and positive correlation at both levels with chlorophyll content at 21 days after anthesis (Table 4 & 5).

The results on correlation coefficients in the present study revealed that under both conditions, biological yield and harvest index were the most important traits and may contribute considerably towards higher grain

yield (Table 4 & 5). The interrelationship among yield components would help in increasing the yield levels and, therefore, more emphasis should be given to afore said components, while selecting better types in wheat.

The path coefficient analysis revealed that the days to 50% flowering, grain filling period, biological yield per plant and harvest index showed high and positive direct effect on grain yield per plant under timely sowing ( $D_1$ ) condition. While, in case of late sowing condition, days to 50% flowering biological yield per plant and harvest index exhibited high and positive direct effect on grain yield per plant. Similar results has been reported by Rathwa *et al.* (2018) and Patel (2018). Thus, these characters turned to be the major components of grain yield.

The characters like 1000-grain weight and chlorophyll content at anthesis exerted low and positive direct effect on grain yield per plant (Karla *et al.*, 2024). Days to maturity, plant height, number of effective tillers per plant, length of main spike, number of grains per main spike, grain weight per main spike and chlorophyll content at 21 days after anthesis showed low negative direct effect on grain yield per plant. Number of effective tillers had low direct effect but supplemented yield through indirect effect from biological yield per plant. Thus, giving rise to significant and positive associations of these traits with grain yield in timely sowing ( $D_1$ ) condition. Similarly, characters like grain filling period, plant height, length of main spike, number of grains per main spike, 1000-grain weight and chlorophyll content at 21 days after anthesis exhibited low and positive effects on grain yield per plant (Puri *et al.*, 2025). While, days to maturity, number of effective tillers per plant, grain weight per main spike and chlorophyll content at anthesis showed low and negative effects on grain yield per plant. Borkhatariya *et al.* (2025) also reported the low and negative effects on grain yield from chlorophyll content at anthesis. Grain yield was also affected indirectly by biological yield and harvest index *via* effects on days to maturity and number of effective tillers per plant respectively. Thus, giving rise to significant and positive associations of these traits with grain yield in late sowing ( $D_2$ ) condition.

### Conclusion

It was apparent from the path analysis that maximum direct effects as well as appreciable indirect influences was exerted by biological yield per plant and harvest



Table 4: Phenotypic path coefficient analysis showing direct (diagonal and bold) and indirect effects of different characters on grain yield in genotypes of bread wheat under timely sowing (D<sub>1</sub>)

Characters	Days to 50% flowering	Days to maturity	Grain filling period (Days)	Plant height (cm)	Number of effective tillers per plant	Length of main spike (cm)	Number of grains per main spike	Grain weight per main spike (g)	Biological yield per plant (g)	Harvest index (%)	1000 grain weight (g)	CHL <sub>a</sub>	CHL <sub>21</sub>	Phenotypic correlation with grain yield per plant
Days to 50% flowering	<b>0.2279</b>	-0.2034	0.0221	-0.0131	-0.0043	-0.0009	-0.0007	-0.0001	0.0808	-0.1513	-0.008	-0.0192	0.0221	-0.0481
Days to maturity	0.2013	<b>-0.2303</b>	0.0803	-0.0262	-0.005	-0.0009	-0.0007	0.0001	0.0616	-0.123	-0.0039	-0.0143	0.0183	-0.0427
Grain filling period (Days)	0.0383	-0.1406	<b>0.1315</b>	-0.0331	-0.0034	-0.0003	-0.0004	0.0001	-0.007	-0.0031	0.0053	0.0023	0.0011	-0.0093
Plant height (cm)	0.0355	-0.072	0.0519	<b>-0.0838</b>	0.0217	-0.0007	-0.0013	0.0012	-0.0071	0.0693	0.0013	-0.0043	-0.0042	0.0075
Number of effective tillers per plant	0.0151	-0.018	0.0069	0.0282	<b>-0.0645</b>	-0.0003	0.0025	-0.0002	0.1512	-0.0684	0.003	-0.0055	0.0275	0.0775
Length of main spike (cm)	0.0315	-0.0300	0.0054	-0.0083	-0.0031	<b>-0.0066</b>	-0.0015	0.0002	0.0751	0.0317	-0.002	0.0152	-0.0124	0.0952
Number of grains per main spike	0.0175	-0.0184	0.0051	-0.0117	0.0181	-0.0011	<b>-0.0091</b>	-0.001	-0.0889	0.0577	-0.001	-0.0157	0.0079	-0.0406
Grain weight per main spike (g)	0.0043	-0.0013	-0.0026	0.0152	-0.0024	0.0002	-0.0014	<b>-0.0065</b>	-0.09	-0.0008	-0.0047	0.0021	0.0106	-0.0773
Biological yield per plant (g)	0.0177	-0.0137	-0.0009	0.0006	-0.0094	-0.0005	0.0008	0.0006	<b>1.0381</b>	-0.3178	0.0019	-0.0076	0.0088	0.7186**
Harvest index (%)	-0.0446	0.0367	-0.0005	-0.0075	0.0057	-0.0003	-0.0007	0.0001	-0.4269	<b>0.7727</b>	-0.0014	-0.0056	-0.001	0.3267*
1000-grain weight (g)	-0.0527	0.026	0.0201	-0.0031	-0.0055	0.0004	0.0003	0.0009	0.0564	-0.0309	<b>0.0347</b>	0.0022	-0.0119	0.0369
CHL <sub>a</sub>	-0.0548	0.0413	0.0039	0.0046	0.0044	-0.0013	0.0018	-0.0002	-0.0985	-0.0547	0.001	<b>0.0797</b>	-0.0731	-0.1459
CHL <sub>21</sub>	-0.0514	0.043	-0.0015	-0.0036	0.0181	-0.0008	0.0007	0.0007	-0.0935	0.0077	0.0042	0.0595	<b>-0.0979</b>	-0.1148

\*, \*\* Significant at 5 % and 1% levels, respectively

Residual effect, R = 0.0961

N.B.: Values at diagonal indicated direct effects of respective character

CHL<sub>a</sub> = chlorophyll content at anthesis (SPAD unit); CHL<sub>21</sub> = chlorophyll content at 21 days after anthesis (SPAD unit)



Table 5: Phenotypic path coefficient analysis showing direct (diagonal and bold) and indirect effects of different characters on grain yield in 48 genotypes of bread wheat under late sowing (D<sub>2</sub>)

Characters	Days to 50% flowering	Days to maturity	Grain filling period (Days)	Plant height (cm)	Number of effective tillers per plant	Length of main spike (cm)	Number of grains per main spike	Grain weight per main spike (g)	Biological yield per plant (g)	Harvest index (%)	1000 grain weight (g)	CHL <sub>a</sub>	CHL <sub>21</sub>	Phenotypic correlation with grain yield per plant
Days to 50% flowering	<b>0.1086</b>	-0.0908	-0.0228	-0.0003	0.0037	0.0001	-0.0004	-0.0001	0.1999	-0.2833	-0.0072	0.0001	0.0019	-0.0886
Days to maturity	0.0714	<b>-0.1382</b>	0.0462	0.0002	0.0098	0.0001	-0.0001	-0.0002	0.3122	-0.3316	0.002	-0.0002	0.0027	-0.0257
Grain filling period (Days)	-0.0277	-0.0716	<b>0.0893</b>	0.0008	0.0039	0.0001	0.0003	-0.0002	0.1764	-0.1232	0.0102	-0.0005	0.0016	0.0594
Plant height (cm)	-0.0069	-0.0064	0.013	<b>0.0052</b>	0.0012	0.0001	0.0002	-0.0001	-0.0648	-0.1349	0.0094	0.0001	-0.0004	-0.1843
Number of effective tillers per plant	-0.0122	0.0265	-0.0067	-0.0001	<b>-0.0510</b>	0.0001	-0.0002	-0.0001	-0.1023	0.3197	0.0082	0.0001	0.0037	0.1857
Length of main spike (cm)	0.0258	-0.0334	0.0024	0.0009	-0.0052	<b>0.0006</b>	-0.0001	-0.0002	-0.1037	-0.0343	-0.0006	-0.0002	0.0039	-0.1441
Number of grains per main spike	-0.0176	0.0063	0.0090	0.0003	0.0046	0.0001	<b>0.0026</b>	0.0001	0.0277	-0.0342	-0.0029	0.0002	0.0031	-0.0007
Grain weight per main spike (g)	0.0043	-0.0177	0.0116	0.0002	-0.0027	0.0001	-0.0002	<b>-0.0016</b>	-0.0584	-0.027	-0.0069	-0.0001	-0.0009	-0.0993
Biological yield per plant (g)	0.0254	-0.0504	0.0184	-0.0004	0.0061	-0.0001	0.0001	0.0001	<b>0.8555</b>	-0.2692	0.0043	0.0002	0.0013	0.5913**
Harvest index (%)	-0.0361	0.0538	-0.0129	-0.0008	-0.0191	0.0001	-0.0001	0.0001	-0.2705	<b>0.8513</b>	0.0055	0.0003	-0.0031	0.5685**
1000-grain weight (g)	-0.0195	-0.007	0.0227	0.0012	-0.0104	0.0001	-0.0002	0.0003	0.0909	0.1156	<b>0.0402</b>	0.0001	-0.0021	0.2319
CHL <sub>a</sub>	-0.0075	-0.0267	0.0334	-0.0003	-0.0009	0.0001	-0.0005	-0.0002	-0.1030	-0.1902	-0.0047	<b>-0.0013</b>	0.0037	-0.2981*
CHL <sub>21</sub>	0.0166	-0.0296	0.0116	-0.0002	0.0149	0.0002	0.0006	0.0001	0.0907	-0.2120	-0.0067	-0.0004	<b>0.0125</b>	-0.1015

\*, \*\* Significant at 5 % and 1% levels, respectively

Residual effect, R = 0.0961

**N.B.:** Values at diagonal indicated direct effects of respective characterCHL<sub>a</sub> = chlorophyll content at anthesis (SPAD unit); CHL<sub>21</sub> = chlorophyll content at 21 days after anthesis (SPAD unit)

index towards grain yield under both conditions, both these characters also exhibited significant and positive association with grain yield per plant and hence, these may be considered as the most important yield contributing characters and due emphasis should be placed on these components while breeding for high yield in wheat.

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### Author's contribution

Conceptualization of research (BD and AGP); Designing of the experiments (BD, AGP and DMV); Contribution of experimental materials (AGP, DMV and CS); Execution of field/lab experiments and data collection (BD and AGP); Analysis of data and interpretation (BD, AGP and JS); Preparation of the manuscript (BD, AGP, DMV, JS and CS).

### Declaration

The authors declare no conflict of interest.

### Conflict of interest

The authors declare that they have no conflict of interest.

### Ethical Approval

The article doesn't contain any study involving ethical approval.

### Use of Generative AI or AI assisted technologies

Authors declare that no Generative AI or AI assisted technologies have been used in preparation of this manuscript.

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