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Effect of Two Different Dates of Sowing on Genetic Variability of Morpho-Physiological Traits in Advance Lines of Wheat (*Triticum aestivum* L.)

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ABSTRACT: Wheat (*Triticum aestivum* L.) is a staple crop that feeds hundreds of millions of people, but global climate change is predicted to reduce wheat yields by 6% for every 1°C increase in temperature. The estimation of genetic parameters that avail to decide breeding strategies may vary with environmental conditions, so it is critical to conduct studies in various environments. An experiment was conducted to evaluate the performance of 48 genotypes of wheat under two environments i.e. timely and late sown conditions, for assessment of mean performance, variability, correlation, and path analysis of 16 morpho-physiological traits at research area of Wheat and Barley Section, Department of Genetics and Plant Breeding, CCS HAU, Hisar during *Rabi* 2019-20. The results showed that estimates of phenotypic variance were higher than their corresponding genotypic variances, indicating the influence of the environment. High heritability associated with high genetic advance was reflected for CTD 1 and CTD 2 in both environments. Correlation studies showed a significant association of grain yield with spike length, number of spikelets/spike, number of grains/spike, biological yield, harvest index, 1000-grain weight, NDVI 1, NDVI 2, CTD 1 and CTD 2. Path analysis revealed biological yield and harvest index had a true relationship with grain yield and were the main yield determinants in both conditions.

Keywords: Wheat, correlation, path analysis, heat stress, timely sown, late sown, yield.

INTRODUCTION

Wheat (*Triticum aestivum* L. em. Thell) is the most consequential cereal crop for the majority of the world's population and is the staple aliment crop of about two billion people. Bread wheat is hexaploid AABBDD with chromosome number 2n (6x) equals 42. It provides about 20 percent of the total dietary calories and protein (Ninai *et al*., 2019). Wheat is grown on 223.67 million hectares throughout the world, which engenders 735.3 million tons of grain.

Victuals security requires developing high-yielding cultivars with tolerance to abiotic and stresses. Wheat is very sensitive to high temperature and trends in incrementing growing season temperatures have already been reported for major wheat-engendering regions (Hennessy *et al*., 2008). Due to delayed sowing wheat plant consummates its growing degree days earlier and minimizes the life cycle (Aslam *et al*., 2017). The global wheat crops are currently threatened by heat stress in around 40% of the areas. Heat is common in dry and semi-dry regions globally, resulting in severe yield losses (Yashavanthakumar *et al*., 2021). Date of sowing is the most paramount factor that governs the phenological development of crops and the withal efficient conversion of biomass into economic yield. Joshi *et al*., (2016) visually examined up to 45% truncation in wheat yield due to delayed planting mediated heat stress. The canopy temperature depression (CTD), the difference between air temperature (Ta) and canopy temperature (Tc), is utilized to assess plant response to environmental stress (Balota *et al*., 2007). NDVI (Normalized Difference Vegetation Index) variation during heat stress could be a quantification of tolerance. Because NDVI has a positive relationship with grain yield, it could be utilized as an indirect selection criterion for culling physiologically superior genotypes (Hazratkulova *et al*., 2012). Wheat plants evolve several physiological mechanisms to cope with heat stress which include early maturity (Mondal *et al*., 2013) and reduced canopy temperature (Pinto & Reynolds, 2015). Consequently, these physiological traits can be the best coalescence for genetic amendment of wheat genotypes to mitigate heat stress because of their common genetic basis (Pinto *et al*., 2016). Thus, a perpetual cull of high-yielding varieties that can cope with transmuting environmental conditions is compulsory (Tahir *et al*., 2009).

Identification of the morpho-physiological traits which performs well in both normal and stressed conditions should be emphasised in this era of climate change. The present study compared the performance of 48 advance wheat genotypes to identify morpho-physiological traits, the sodality of these traits with grain yield was tenacious for their further use in the cultivar selection. In order to achieve genetic improvement in crops, genetic variability, heritability, and genetic advance of the characters at least across two environments are critical to select the appropriate material and mode of selection. Here, we examine the genetic potential of cultivars for timely sown and late sown conditions. In plant breeding, genetic variability is important because it provides both a source of variation as well as raw material for increasing yields (Gaur *et al*., 2020). For a valid estimation of genetic parameters, we need a method that is highly accurate and does not depend on environmental factors. The genetic potential of different cultivars for the presence of diversity, performance stability is quantified by statistical parameters such as mean, variance, coefficient of variation (%), heritability, and genetic gain (Ali *et al*., 2008). An effective breeding program depends on the degree of variability and heritability in early-generation populations for economic traits (Pal *et al*., 2018). The simple statistical analysis of yield and other important traits cannot clarify cause and effect relationships. An endeavor was also made to analyze grain yield and its attributing traits of wheat by correlation and path coefficient analysis.

MATERIALS AND METHODS

The seed material used in the investigation comprised of 48 advance wheat breeding genotypes. The seed of all genotypes were grown in a Randomized Block Design (RBD) under timely sown (14 November) and late sown (18 December) conditions with three replications during *Rabi* (2019-20) at research area of Wheat & Barley Section, Department of Genetics and Plant Breeding, CCS HAU, Hisar. Following morpho-physiological traits were recorded i.e. days to 50 % heading, days to anthesis, days to maturity, plant height (cm), number of effective tillers/meter, spike length (cm), number of spikelets/spike, number of grains/spike, biological yield/plant (g), harvest index (%), 1000-grain weight (g), grain yield/plant (g), normalized difference vegetation index (NDVI), canopy temperature depression (CTD). The observations were recorded on five randomly selected plants from each genotype in both conditions. Phenotypic and genotypic coefficient of variation, heritability in broad sense and genetic advance by (Burton & Devane, 1953). Correlation coefficient analysis by (Al-Jibouri *et al*., 1958) and path coefficient analysis (Dewey & Lu, 1959).

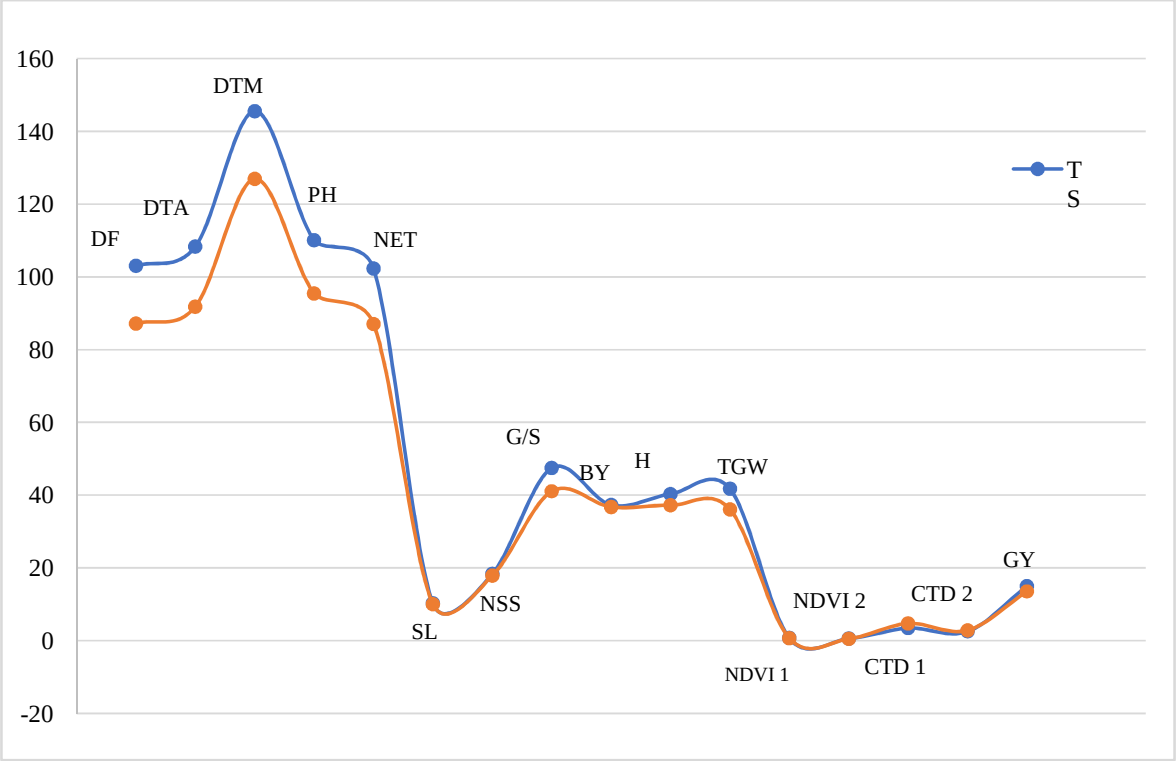
RESULTS AND DISCUSSION

Genetic parameters. The presence of significant diversity in the base material ensures greater possibilities of evolving desired plant kinds, therefore information on genetic variability is quite valuable. This has been shown for various parameters like mean, range, coefficient of variation (GCV and PCV), broad sense heritability, genetic advance as % of mean under both timely and late sown conditions in Table 1 and 2 respectively. The mean values of the traits for both the conditions are given in Fig. 1.

GCV ranged from 0.92 (days to maturity) to 29.58 % (CTD 1) and 1.63 (days to maturity) to 31.51 % (CTD 2) under normal and late sown conditions respectively. The estimates of phenotypic coefficient of variation varied from 1.06 (days to maturity) to 29.90% (CTD 1) and 1.79 (days to maturity) to 31.73 % (CTD 2) under normal and late sown condition respectively. High GCV, PCV, heritability and genetic advance as % of mean was observed for CTD 1, CTD 2, number of grains/spike, under timely sown condition. High PCV, GCV, heritability, genetic advance as per cent of mean was seen for the traits CTD 2, CTD 1, number of grains/spike, grain yield per plant for late sown condition. Similar results were obtained by Thapa *et al*., (2019); Hossain *et al*., (2021) by reporting that GCV, PCV, heritability, genetic advance estimates were highest for canopy temperature depression (CTD) under both (normal and heat stress) environment. Bhushan *et al.*, (2013) reported moderate genotypic coefficient of variation (GCV) for number of grain/spike, number of grains per plant.

Table 1: Genetic parameters for morpho-physiological traits of wheat under timely sown condition.

Trait	Mean±S.E	Range		GCV	PCV	h^2 (bs)	GA as % mean
		Minimum	Maximum				
DFF	103.06 ± 0.447	99.00	106.33	2.05	2.19	88.19	3.97
DTA	108.32 ± 0.33	103.33	112.33	1.79	1.87	92.02	3.54
DTM	145.56 ± 0.436	143.00	148.33	0.92	1.06	75.82	1.65
PH (cm)	110.09 ± 1.647	99.77	129.47	4.78	5.44	77.29	8.66
NET	102.28 ± 1.214	86.00	128.67	7.07	7.36	92.20	13.98
SL (cm)	10.26 ± 0.32	9.13	13.23	6.40	8.38	58.29	10.06
NSS	18.39 ± 0.492	16.33	21.00	5.07	6.87	54.52	7.72
G/S	47.49 ± 1.407	34.00	65.67	16.00	16.81	90.67	31.39
BY (g)	37.31 ± 0.986	29.06	43.70	9.84	10.88	81.82	18.34
HI (%)	40.32 ± 1.445	32.63	44.10	5.13	8.29	38.33	6.55
TGW (g)	41.77 ± 0.776	35.23	48.23	9.87	10.38	90.40	19.33
NDVI 1	0.752 ± 0.014	0.69	0.82	3.09	4.02	59.15	4.89
NDVI 2	0.592 ± 0.013	0.50	0.69	7.26	8.55	72.17	12.71
CTD 1	3.48 ± 0.087	1.13	5.43	29.58	29.90	97.88	60.28
CTD 2	2.542 ± 0.079	1.03	3.77	27.64	28.16	96.38	55.90
GY (g)	15.01 ± 0.741	11.10	17.80	11.20	14.09	63.23	18.35



DFF: Days to 50 % heading, DTA: Days to anthesis, DTM: Days to maturity, PH: Plant height (cm), NET: Number of effective tillers/meter, SL: Spike length (cm), NSS : Number of spikelets/spike, G/S: Number of grains/spike, BY: Biological yield/plant (g), HI: Harvest index (%), TGW: 1000-grain weight (g), NDVI 1: Normalized difference vegetation index at anthesis, NDVI 2: Normalized difference vegetation index at 21 days after anthesis, CTD 1: Canopy temperature depression at anthesis, CTD 2: Canopy temperature depression at 21 days after anthesis, GY: Grain yield /plant (g).

Fig. 1. Mean values of 16 morpho-physiological traits in both timely sown and late sown environments.

Table 2: Genetic parameters for morpho-physiological traits of wheat under late sown condition.

Trait	Mean±S.E	Range		GCV	PCV	h^2 (bs)	GA as % mean
		Minimum	Maximum				
DFF	87.21 ± 0.481	82.33	90.33	2.25	2.44	84.74	4.27
DTA	91.81 ± 0.485	86.67	94.67	2.08	2.27	83.74	3.91
DTM	126.99 ± 0.546	123.33	132.00	1.63	1.79	82.74	3.06
PH (cm)	95.48 ± 2.298	85.40	112.23	4.73	6.30	56.30	7.31
NET	87.08 ± 1.462	72.00	100.67	4.94	5.73	74.28	8.77
SL (cm)	10.05 ± 0.307	8.53	11.17	5.80	7.85	54.59	8.83
NSS	17.90 ± 0.444	15.33	20.33	4.59	6.28	53.30	6.90
G/S	41.08 ± 1.804	28.33	60.67	19.00	20.46	86.29	36.36
BY (g)	36.75 ± 0.973	24.70	46.87	15.93	16.61	91.97	31.48
HI (%)	37.22 ± 1.604	25.70	43.51	11.48	13.72	70.05	19.80
TGW (g)	36.11 ± 0.829	32.63	40.80	5.84	7.07	68.33	9.95
NDVI 1	0.67 ± 0.011	0.62	0.72	3.15	4.23	55.53	4.83
NDVI 2	0.51 ± 0.008	0.47	0.59	4.95	5.68	76.02	8.89
CTD 1	4.73 ± 0.21	3.03	6.57	21.59	22.91	88.78	41.91
CTD 2	2.84 ± 0.061	1.63	4.33	31.51	31.73	98.63	64.46
GY (g)	13.55 ± 0.772	8.50	16.27	13.33	16.59	64.57	22.07

S.E : Standard error, GCV : Genotypic coefficient of variation, PCV : Phenotypic coefficient of variation, h^2 (bs) : heritability in broad sense, GA : Genetic advance, DFF : Days to 50 % heading, DTA : Days to anthesis, DTM : Days to maturity, PH : Plant height (cm), NET : Number of effective tillers/meter, SL : Spike length (cm), NSS : Number of spikelets/spike, G/S : Number of grains/spike, BY : Biological yield/plant (g), HI : Harvest index (%), TGW : 1000-grain weight (g), NDVI 1: Normalized difference vegetation index at anthesis, NDVI 2: Normalized difference vegetation index at 21 days after anthesis, CTD 1: Canopy temperature depression at anthesis, CTD 2: Canopy temperature depression at 21 days after anthesis, GY : Grain yield /plant (g).

Tabassum *et al.*, (2017) reported high heritability for 1000-grain weight and number of grains/spike, high values of genetic advance as per cent of the mean were observed for number of grains/spike. These findings agreed with results of Rajput, 2018; Tilahun *et al*., 2020.

In the studies noted above, late sowing significantly affects the yield and yield component of wheat, since the mean performance of all morpho-physiological traits declined, except for canopy temperature depression, where the values shifted upward with late sowing.

Low GCV, PCV, heritability and genetic advance as % of mean was observed for days to maturity, days to anthesis, days to 50 % heading, 1000-grain weight, NDVI 1 under timely sown condition. Low PCV, GCV, heritability, genetic advance as per cent of mean was seen for the traits days to maturity, days to anthesis, 1000- grain weight, days to 50 % heading, number of spikelets/spike, NDVI 1 for late sown condition. For days to heading, days to anthesis, days to physiological maturity, Negasa & Chauhan, (2016) reported similar results. Similarly, Bhushan *et al*., (2013) obtained the same results for days to maturity, days to heading and 1000-grain weight, these traits showed low PCV, GCV values. Patel *et al.*, (2019) reported lowest GCV and PCV for days to maturity (2.25% & 2.38%, respectively), days to heading (5.94% & 6.16 %, respectively) indicating difficulty of improvement for these traits through selection. These findings were in agreement with those of Kumar *et al*., (2014); Kyosev & Desheva, (2015).

Character association : A correlation coefficient is a numerical measure of a statistical relationship between two variables. It is shown in Table 3 for timely sown (TS) and Table 4 for late sown (LS) condition.

In both timely and late sown wheat, the character, days to 50 % heading exerted significant and positive correlation with days to anthesis [0.901 (TS), 0.920 (LS)], spike length [0.185 (TS), 0.198 (LS)]. Subhani & Chowdhry (2000); Vaishnavi & Bural (1996) agree with my findings. For late sown environment, days to maturity displayed a highly significant interrelationship with days to anthesis and days to 50% heading (0.271, 0.229). Masood *et al*., (2005) found the same thing. Singh *et al*., (2014) observed similar findings. Days to anthesis was negatively correlated with plant height in timely sown wheat (-0.170) but positively with number of effective tillers/meter (0.190). Number of grains/spike (-0.179) and biological yield (0.168) were negatively correlated with days to anthesis for late sown wheat. Days to maturity exhibited positive correlation with plant height (0.164) in timely sown condition, whereas highly significant negative association with plant height, biological yield, grain yield in late sown condition. Majumder *et al*., (2008) reported contrary association between days to maturity and grain yield. It is interesting to note that days to anthesis, days to 50% heading, days to maturity, and plant height had no correlation with grain yield irrespective of the direction, except for late sown condition where days to maturity have negative correlation with grain yield. It indicates that the direct selection for these characters may not help improve the yield and for that indirect selection will have to be followed. In addition, Dabi *et al*., (2016) reported that the days to 50% heading and days to maturity did not show a significant correlation to yield. These findings were similar to reports by Adhikari *et al*., (2018). On contrary, Suleiman *et al*., (2014), obtained significant positive correlation of plant height with grain yield. Number of effective tillers/meter showed high correlation with spike length, number of spikelets/spike in both environments.

Phougat *et al*., (2017); Khames *et al*., (2016) reported the same for this trait. Spike length showed significant correlation under both the conditions with number of spikelets/spike, number of grains/spike, biological yield, CTD 2, grain yield. Sokoto *et al*., (2012) found highly significant positive interrelationship of this character with grain yield. Virk & Anand, (1970) documented the same results. Number of spikelets/spike had a significant positive association with number of grains/spike, biological yield, harvest index, grain yield. The correlation between tillers per plant, spike length, and 1000-grain weight was significant by Khaliq *et al*., (2004). Number of grains/spike showed significant and positive correlation with biological yield, 1000-grain weight, grain yield and also in late sown condition for harvest index. Khan & Dar, (2010) reported significant correlation between grain yield and spike density. Biological yield had significant positive association with all the physiological traits, grain yield, and negative correlation with harvest index for late sown environment. Subhani & Chowdhry, (2000) reported the same results for biological yield and harvest index. According to the study by Fellahi *et al*., (2013) grain yield correlated positively with the number of spikes/plant and biological yield. Singh & Singh, (2001) demonstrated that grain yield had high positive interrelationship with number of grains/spike and spike length. Grain yield was positively and significantly correlated with spike length, kernels per spike and thousand kernels weight (Gerema, 2021). Grain yield/plant showed significant and positive correlation with harvest index, 1000-grain weight, NDVI 1, NDVI 2, CTD 1, CTD 2. Mohsin *et al*., (2009) concluded same results. Alemuet *et al*., (2020) reported same correlation of 1000-grain weight with grain yield.

In timely sown condition, NDVI 1 had significant association with number of grains/spike, harvest index and1000-grain weight. CTD 1 and CTD 2 exhibited positive correlation with number of spikelets/spike, number of grains/spike and 1000-grain weight for both environments. NDVI and CTD at anthesis stage revealed positive correlation with NDVI and CTD at 21 days after anthesis. For late sown environment, NDVI 1 had highly significant positive correlation with spike length, number of spikelets/spike, NDVI 2, CTD 1. CTD 1 exhibited positive correlation with NDVI 2, CTD 2 whereas, negative correlation with days to 50% heading. NDVI at anthesis and after stages has been correlated to final wheat yield (Verhulst & Govaerts, 2010).

Table 3: Phenotypic correlation coefficients (below diagonal values) and genotypic correlation coefficient (above diagonal values) among morpho-physiological traits of wheat under timely sown condition.

	DFF	DTA	DTM	PH	NET	SL	NSS	G/S	BY	HI	TGW	NDVI 1	NDVI 2	CTD 1	CTD 2	GY
DFF		0.962**	0.216**	-0.234**	0.135	0.255**	0.027	-0.109	0.166*	-0.000	0.035	0.225**	-0.155	-0.224**	-0.010	0.197*
DTA	0.920**		0.279**	-0.238**	0.084	0.183*	-0.120	-0.196*	0.185*	-0.081	-0.049	0.188*	-0.097	-0.150	-0.023	0.145
DTM	0.229**	0.271**		-0.531**	-0.046	0.083	-0.081	-0.126	-0.291**	0.055	-0.212*	-0.087	-0.072	-0.137	-0.087	-0.287**
PH	-0.126	-0.136	-0.353**		0.107	0.348**	-0.141	-0.010	0.393**	-0.549**	0.059	0.249**	0.125	0.018	-0.080	-0.020
NET	0.076	0.047	-0.088	0.014		0.455**	0.378**	0.316**	0.174*	0.135	0.131	0.522**	0.433**	0.331**	0.086	0.342**
SL	0.198*	0.145	0.082	0.157	0.261**		0.694**	0.425**	0.374**	-0.059	0.073	0.464**	-0.049	-0.057	-0.283**	0.393**
NSS	0.014	-0.052	-0.107	0.004	0.229**	0.293**		0.691**	0.311**	0.283**	0.266**	0.352**	0.063	0.124	-0.033	0.610**
G/S	-0.095	-0.179*	-0.104	-0.007	0.252**	0.303**	0.489**		0.212*	0.199*	0.272**	0.189*	-0.172*	0.057	0.087	0.436**
BY	0.156	0.168*	-0.249**	0.270**	0.144	0.257**	0.218**	0.184*		-0.561**	0.000	0.591**	0.281**	0.501**	0.315**	0.699**
HI	-0.001	-0.049	0.003	-0.376**	0.147	0.031	0.179*	0.183*	-0.418**		0.239**	-0.273**	-0.185*	-0.180*	-0.054	0.193*
TGW	0.093	0.026	-0.140	0.075	0.078	0.064	0.123	0.229**	0.017	0.178*		0.314**	0.098	0.101	0.212*	0.203*
NDVI 1	0.137	0.128	-0.086	0.131	0.316**	0.280**	0.201*	0.118	0.449**	-0.072	0.146		0.372**	0.562**	0.198*	0.480**
NDVI 2	-0.109	-0.05	-0.069	0.080	0.327**	-0.000	0.043	-0.129	0.268**	-0.070	0.090	0.404**		0.763**	0.178*	0.195*
CTD 1	-0.193*	-0.130	-0.145	0.046	0.289**	-0.042	0.095	0.048	0.459**	-0.157	0.075	0.444**	0.672**		0.534**	0.440**
CTD 2	-0.006	-0.024	-0.077	-0.054	0.074	-0.216**	-0.028	0.076	0.299**	-0.035	0.175*	0.142	0.161	0.500**		0.337**
GY	0.156	0.123	-0.235**	-0.043	0.277**	0.279**	0.367**	0.344**	0.655**	0.405**	0.168*	0.394**	0.230**	0.333**	0.276**	

Table 4: Phenotypic correlation coefficients (below diagonal values) and genotypic correlation coefficient (above diagonal values) among morpho-physiological traits of wheat under late sown condition.

	DFF	DTA	DTM	PH	NET	SL	NSS	G/S	BY	HI	TGW	NDVI 1	NDVI 2	CTD 1	CTD 2	GY
DFF		0.945**	-0.144	-0.149	0.170*	0.226**	-0.037	-0.044	0.032	0.092	-0.161	-0.132	-0.174*	-0.123	-0.162	0.027
DTA	0.901**		-0.163	-0.194*	0.204*	0.157	-0.002	0.007	0.112	0.166*	-0.098	0.009	-0.06	-0.040	-0.118	0.138
DTM	-0.095	-0.134		0.190*	0.108	0.015	0.087	-0.119	-0.001	0.007	-0.088	-0.058	0.138	-0.076	-0.12	0.040
PH	-0.146	-0.170*	0.164*		0.220**	0.224**	0.085	0.172*	0.000	-0.354**	0.059	-0.206*	-0.015	-0.121	-0.04	-0.148
NET	0.161	0.194*	0.093	0.162		0.299**	0.419**	0.082	0.292**	0.207*	0.220**	0.144	-0.017	0.039	-0.034	0.349**
SL	0.185*	0.114	0.016	0.083	0.210*		0.628**	0.365**	0.270**	0.143	0.028	-0.048	-0.229**	0.340**	0.275**	0.302**
NSS	-0.016	-0.025	0.058	0.105	0.265**	0.311**		0.577**	0.340**	0.527**	0.276**	0.011	-0.056	0.373**	0.358**	0.549**
G/S	-0.031	-0.001	-0.088	0.111	0.088	0.301**	0.387**		0.372**	0.159	0.265**	-0.266**	0.080	0.420**	0.412**	0.402**
BY	0.024	0.096	-0.004	0.053	0.252**	0.187*	0.193*	0.323**		-0.011	0.264**	0.385**	0.547**	0.397**	0.239**	0.879**
HI	0.076	0.132	0.024	-0.165*	0.127	0.069	0.248**	0.077	0.104		-0.001	0.242**	0.026	0.235**	0.197*	0.452**
TGW	-0.134	-0.089	-0.064	0.041	0.213*	0.045	0.224**	0.238**	0.235**	0.024		-0.230**	-0.087	0.305**	0.301**	0.199*
NDVI 1	-0.023	0.011	-0.041	-0.130	0.111	-0.035	0.068	-0.190*	0.251**	0.184*	-0.181*		0.833**	0.069	-0.208*	0.466**
NDVI 2	-0.141	-0.042	0.091	0.009	-0.026	-0.164*	-0.041	0.04	0.521**	0.259**	-0.049	0.532**		0.038	-0.174*	0.522**
CTD 1	-0.11	-0.037	-0.066	-0.094	0.038	0.252**	0.269**	0.387**	0.364**	0.165*	0.286**	0.04	0.036		0.870**	0.475**
CTD 2	-0.150	-0.104	-0.107	-0.020	-0.028	0.229**	0.245**	0.394**	0.221**	0.131	0.272**	-0.149	-0.135	0.846**		0.311**
GY	0.039	0.126	0.032	-0.048	0.269	0.188*	0.303**	0.295**	0.820**	0.631**	0.174*	0.322**	0.561**	0.394**	0.255**	

* = Significant P ≤ 0.05 ** = Highly significant P ≤ 0.01; DFF: Days to 50 % heading, DTA : Days to anthesis, DTM : Days to maturity, PH : Plant height (cm), NET : Number of effective tillers/meter, SL : Spike length (cm), NSS : Number of spikelets/spike, G/S : Number of grains/spike, BY : Biological yield/plant (g), HI : Harvest index (%), TGW : 1000-grain weight (g), NDVI 1: Normalized difference vegetation index at anthesis, NDVI 2: Normalized difference vegetation index at 21 days after anthesis, CTD 1: Canopy temperature depression at anthesis, CTD 2: Canopy temperature depression at 21 days after anthesis, GY : Grain yield /plant (g).

Path coefficient analysis: Path analysis is simply a standardized partial regression coefficient partitioning the correlation coefficient into direct and indirect effects of a set of independent variables on the dependent variable. It is shown in Table 5 for timely sown (TS) and Table 6 for late sown (LS) environment. Highest direct and positive effect was seen for biological yield [0.8934 (TS), 1.1456 (LS)], harvest index [0.4425 (TS), 0.8805 (LS)], while NDVI 2 (TS), 1000-grain weight (LS), spike length [(TS), (LS)], showed highest negative direct effects on grain yield. Nukasani *et al*., (2013) reported negative direct effect of 1000-grain weight on grain yield. For timely sown wheat, biological yield and harvest index showed highest positive indirect effect on grain yield via number of traits i.e, days to 50% heading, days to anthesis, number of effective tillers/meter, spike length, number of spikelets/spike, number of grains/spike, NDVI 1, CTD 1, CTD 2. Days to 50 % heading had highest indirect positive effect on grain yield via two traits i.e biological yield, harvest index. Gelalcha & Hanchinal, (2013) concluded that biological yield, harvest index and plant height all had a substantial positive directorial effect. Among all the studied traits, days to anthesis, number of effective tillers/meter, spike length, 1000-grain weight and NDVI 2 negative direct effect was countered by positive indirect effect via other traits. Plant height (0.004) and days to anthesis (0.003) contributed positive effect indirectly to days to maturity followed by 1000 – grain weight, harvest index. In case of plant height, which had positive direct effect, days to maturity (0.011) and number of grains/spike (0.0100) contributed maximally through indirect effect whereas harvest index (-0.1567) and NDVI 1 (-0.0231) had highly negative effect. For number of spikelets/spike and number of grains/spike, their direct effect was positive. Chaudhary *et al*., 2020 reported the same results. Same results were observed by Khan & Naqvi, (2012) based on the number of spikelets, and number of grains. 1000–grain weight negative direct effect was balance countered by number of grains/spike and biological yield. Physiological traits NDVI 1, CTD 1, CTD 2 had positive direct effect on grain yield while NDVI 2 had negative direct effect on grain yield although it is compensated by biological yield and NDVI 1 resulting in significant positive correlation with grain yield. Neeru *et al*., (2017) observed positive direct effect for canopy temperature depression. In the present research, for biological yield correlation coefficient was 0.879 which reveals highly significant positive association with grain yield, and the direct positive effect value was also highly positive and approximately the same with that of 0.893; this suggests that there were little or no indirect effect of these traits on grain yield and correlation explains the true relationship. The same trend was seen for harvest index. Fellahi *et al.,* (2013) reported that biological yield and harvest index should be considered as the main selection criteria.

For late sown condition, days to 50 % heading showed highest indirect positive effect on grain yield via biological yield, days to anthesis, while maximum indirect negative effect via spike length, plant height. Ozukum *et al*., (2019) reported same results for days to 50% heading and number of spikelets per ear. Days to anthesis showed indirect positive effect on grain yield via days to maturity, biological yield, days to 50% heading, number of effective tillers/meter, 1000-grain weight, NDVI 1, CTD 1, while indirect negative effect via remaining traits. Days to maturity and plant height had positive direct effect on grain yield. Ashraf *et al*., (2002) reported the same for plant height which is in agreement with the present study. Contrary, Khaliq *et al.,* (2004) for spike length, reported the highest positive direct effect towards grain yield. 1000-grain weight showed indirect positive effect on grain yield via harvest index, number of spikelets/spike, while indirect negative effect via days to maturity, spike length. Mecha *et al.,* (2017) on the contrary observed positive direct effect for this trait.

CONCLUSION

Ultimately, climate change and sustainable development are intertwined issues that pose a significant threat to humanity. In recent years, high-temperature stress has been a key issue affecting wheat productivity. Wheat production's goal is to figure wheat genotypes that have higher grain yield and tolerance. These physiological attributes, in addition to morphological features, can be combined to develop thermo tolerant cultivars. More research is needed to assess their efficacy in a variety of climates and crop types.

FUTURE SCOPE

The experimental results conclude that both CTD 1 and CTD 2 had high heritability and high genetic advance suggesting an additive gene component is dominant in affecting these traits and providing evidence that selection could take place for both environments. Although a positive correlation of grain yield was seen with a number of traits indicating the simultaneous improvement for these traits but the negative correlation was seen as a major challenge in the future breeding program. Days to maturity in timely sown condition and plant height for both the conditions were showing the negative trade-off with grain yield, so these traits should be kept low or moderate in the wheat breeding programme. Two traits i.e biological yield and harvest index showed a true relationship with grain yield and should be the main traits to be considered because they performed consistently in both environments. NDVI and CTD have substantial positive associations with grain yield, indicating that these traits can be employed as selection criteria or as novel decision-supporting tools in applied breeding research to boost crop output.

Table 5: Direct (diagonal) and indirect (off diagonal) effects of morpho-physiological traits on grain yield under timely sown condition.

	DFF	DTA	DTM	PH	NET	SL	NSS	G/S	BY	HI	TGW	NDVI 1	NDVI 2	CTD 1	CTD 2	GY (rg)
DFF	**0.0003**	-0.0208	-0.0083	-0.0032	-0.0019	-0.0103	-0.0000	-0.0025	0.0285	0.0408	0.0058	-0.0148	0.0169	-0.0010	-0.0021	0.027
DTA	0.0003	**-0.0220**	-0.0094	-0.0041	-0.0023	-0.0071	0	0.0004	0.0997	0.0734	0.0035	0.0009	0.0065	-0.0003	-0.0015	0.138
DTM	-0.0000	0.0035	**0.0580**	0.0041	-0.0012	-0.0007	0.0000	-0.0069	-0.0009	0.0029	0.0031	-0.0064	-0.0135	-0.0006	-0.0016	0.040
PH	-0.0000	0.0042	0.0110	**0.0215**	-0.0025	-0.0102	0.0000	0.0100	0.0001	-0.1567	-0.0021	-0.0231	0.0014	-0.0010	-0.0005	-0.148
NET	0.0000	-0.0044	0.0062	0.0047	**-0.0116**	-0.0136	0.0001	0.0047	0.2609	0.0915	-0.0078	0.0162	0.0016	0.0003	-0.0004	0.349**
SL	0.0000	-0.0034	0.0009	0.0048	-0.0035	**-0.0457**	0.0002	0.0213	0.2413	0.0631	-0.001	-0.0053	0.0223	0.0030	0.0036	0.302**
NSS	-0.0000	0.0000	0.0050	0.0018	-0.0048	-0.0287	**0.0003**	0.0337	0.3034	0.2331	-0.0099	0.0012	0.0055	0.0033	0.0047	0.549**
G/S	-0.0000	-0.0001	-0.0068	0.0037	-0.0009	-0.0166	0.0001	**0.0584**	0.332	0.0703	-0.0095	-0.0299	-0.0078	0.0037	0.0054	0.402**
BY	0.0000	-0.0024	-0.0000	0	-0.0034	-0.0123	0.0001	0.0217	**0.8934**	-0.0047	-0.0094	0.0433	-0.0534	0.0035	0.0031	0.879**
HI	0.0000	-0.0036	0.0003	-0.0076	-0.0024	-0.0065	0.0001	0.0092	-0.0095	**0.4425**	0.0000	0.0272	-0.0025	0.0020	0.0026	0.452**
TGW	-0.0000	0.0021	-0.0051	0.0012	-0.0025	-0.0012	0.0000	0.0154	0.2358	-0.0003	**-0.0359**	-0.0258	0.0085	0.0027	0.0039	0.199*
NDVI 1	-0.0000	-0.0001	-0.0033	-0.0044	-0.0016	0.0021	0	-0.0155	0.3443	0.1069	0.0082	**0.1125**	-0.0813	0.0006	-0.0027	0.466**
NDVI 2	-0.0000	0.0014	0.0080	-0.0003	0.0002	0.0104	-0.0000	0.0046	0.4888	0.0113	0.0031	0.0937	**-0.0976**	0.0003	-0.0022	0.522**
CTD 1	-0.0000	0.0008	-0.0044	-0.0026	-0.0004	-0.0155	0.0001	0.0245	0.354	0.1037	-0.0109	0.0077	-0.0036	**0.0088**	0.0114	0.475**
CTD 2	-0.0000	0.0026	-0.0072	-0.0008	0.0004	-0.0125	0.0001	0.0240	0.2132	0.0872	-0.0108	-0.0233	0.0169	0.0077	**0.0131**	0.311**

Table 6: Direct (diagonal) and indirect (off diagonal) effects of morpho-physiological traits on grain yield under late sown condition.

	DFF	DTA	DTM	PH	NET	SL	NSS	G/S	BY	HI	TGW	NDVI 1	NDVI 2	CTD 1	CTD 2	GY (rg)
DFF	**0.0060**	0.0532	0.02	-0.0374	0.0021	-0.0536	0.0043	-0.0022	0.1900	-0.0002	-0.0016	0.0121	-0.0016	0.0063	-0.0000	0.197*
DTA	0.0058	**0.0553**	0.0257	-0.0380	0.0013	-0.0386	-0.0196	-0.0040	0.2123	-0.0709	0.0022	0.0101	-0.0010	0.0042	-0.0000	0.145
DTM	0.0013	0.0154	**0.0924**	-0.0849	-0.0007	-0.0174	-0.0132	-0.0026	-0.3333	0.0483	0.0098	-0.0046	-0.0007	0.0038	-0.0000	-0.287**
PH	-0.0014	-0.0131	-0.0490	**0.1601**	0.0017	-0.0732	-0.0229	-0.0002	0.4503	-0.4835	-0.0027	0.0134	0.0013	-0.0005	-0.0000	-0.020
NET	0.0008	0.0046	-0.0042	0.0171	**0.0158**	-0.0957	0.0616	0.0065	0.1991	0.1187	-0.0060	0.0281	0.0045	-0.0093	0.0000	0.342**
SL	0.0015	0.0101	0.0076	0.0557	0.0072	**-0.2107**	0.1130	0.0088	0.4290	-0.0523	-0.0033	0.0250	-0.0005	0.0016	-0.0001	0.393**
NSS	0.0001	-0.0066	-0.0074	-0.0225	0.0059	-0.1462	**0.1629**	0.0144	0.3563	0.2492	-0.0123	0.019	0.0006	-0.0034	-0.0000	0.610**
G/S	-0.0006	-0.0108	-0.0116	-0.0015	0.005	-0.0895	0.1126	**0.0208**	0.2424	0.1750	-0.0125	0.0101	-0.0017	-0.0016	0.0000	0.436**
BY	0.001	0.0102	-0.0269	0.0629	0.0027	-0.0789	0.0506	0.0044	**1.1456**	-0.4936	-0.0000	0.0318	0.0029	-0.0141	0.0001	0.699**
HI	0	-0.0044	0.0050	-0.0879	0.0021	0.0125	0.0461	0.0041	-0.6423	**0.8805**	-0.0110	-0.0147	-0.0019	0.0050	-0.0000	0.193*
TGW	0.0002	-0.0027	-0.0196	0.0094	0.0020	-0.0153	0.0433	0.0056	0.0004	0.2105	**-0.0463**	0.0169	0.0010	-0.0028	0.0001	0.203*
NDVI 1	0.0013	0.0104	-0.0080	0.0399	0.0082	-0.0977	0.0574	0.0039	0.6772	-0.2402	-0.0145	**0.0539**	0.0038	-0.0158	0.0001	0.480**
NDVI 2	-0.0009	-0.0053	-0.0066	0.0201	0.0068	0.0103	0.0102	-0.0035	0.3217	-0.1624	-0.0045	0.0200	**0.0104**	-0.0215	0.0001	0.195*
CTD 1	-0.0013	-0.0082	-0.0126	0.0028	0.0052	0.0120	0.0201	0.0011	0.5734	-0.1588	-0.0046	0.0303	0.0079	**-0.0281**	0.0003	0.440**
CTD 2	-0.0000	-0.0012	-0.0080	-0.0128	0.0013	0.0596	-0.0053	0.0018	0.3613	-0.0477	-0.0098	0.0106	0.0018	-0.0150	**0.0005**	0.337**

DFF : Days to 50 % heading, DTA : Days to anthesis, DTM : Days to maturity, PH : Plant height (cm), NET : Number of effective tillers/meter, SL : Spike length (cm), NSS : Number of spikelets/spike, G/S : Number of grains/spike, BY : Biological yield/plant (g), HI : Harvest index (%), TGW : 1000-grain weight (g), NDVI 1: Normalized difference vegetation index at anthesis, NDVI 2: Normalized difference vegetation index at 21 days after anthesis, CTD 1: Canopy temperature depression at anthesis, CTD 2: Canopy temperature depression at 21 days after anthesis, GY : Grain yield /plant (g).

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