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Analysis of genetic variability for terminal heat tolerance in advance lines of bread wheat (*Triticum aestivum* L. Em Thall.)

Lalit Kumar, Naresh, OP Bishnoi, Krishan Kumar, Mehak Nagora, Narender Pal and Rohit

Abstract
Forty advance lines were used in the present study to identify the terminal heat-tolerant lines. The experiments were conducted in *Rabi* 2019-20 using a Randomized Block Design with three replications and two sowing dates (20th November and 20th December, 2019) at the Research Area of Wheat and Barley Section, Department of Genetics & Plant Breeding, CCS-Haryana Agricultural University in Hisar. Various morpho-physiological characteristics were observed and noted. The ANOVA revealed that variance due to genotypes were highly significant for all the traits, under both the conditions. GCV and PCV estimates for grain yield per plant, harvest index, biological yield per plant and CTD were moderate. Moderate to high estimates of heritability were also associated with moderate to high estimates of genetic advance as a percentage of the mean for plant height, spike length, peduncle length, number of spikelets per spike, number of grains per spike, 1000 grain weight, biological yield per plant, harvest index, grain yield per plant, CTD-1, CTD-2, SPAD-1 and SPAD-2 under both the environmental conditions, indicating the existence of additive gene effects and suggesting the effectiveness of the selective breeding approach for improving these traits in wheat.

Keywords: Bread wheat, heritability, genetic advance, genetic variability, GCV, PCV

Introduction

Bread wheat (*Triticum aestivum* L.), a cereal crop belonging to the *Poaceae* family and of the genus *Triticum* with allohexapliod (2n=6x=42) nature with three genomes (AABBDD), is the most widely cultivated cereal crop and serves as a global staple food. It is one of the oldest domesticated food crops in the world and believed to have originated in SW- Asia or more specifically, in the fertile crescent of middle east nearly 8000 to 10000 years ago (Nesbitt, 2002) [16]. Bread wheat (*Triticum aestivum* L.) accounts ~95% of total wheat production, while durum wheat (*T. durum*, AABB) reports the remaining 5%. More than 40 countries of the world, considered bread wheat as staple food which provides basic calories (85%) and protein (82%) of the world's 4.5 billion population (Nahid *et al.*, 2022) [15]. Bread wheat provides essential amino acids, minerals, vitamins, beneficial phytochemicals and dietary fiber to the human diet, with the majority of these nutrients found in whole-grain products. FAO estimates that annual cereal production must increase by nearly one billion tonnes in order to sustain the projected population of 9.1 billion in 2050. (FAO, 2004) [6]. Wheat accounts for approximately 30% of global grain production and 50% of global grain trade. (Karki *et al*., 2021) [11]. In order to satisfy the needs of this growing population, there is a need for increased crop production and productivity. Wheat is grown on 223.67 million hectares worldwide, yielding 735.3 million tonnes of grain; India produced 107.59 million tonnes from 21.45 million hectares with a yield of 3.42 tonnes per hectare. (DESA, 2021).

Climate change is the main cause of both biotic and abiotic stresses on agriculture, so there is a strong relationship between both of them. The impact of adverse environmental conditions on crop production is significant. Variations in atmospheric CO_2 levels, changes in temperature, heat waves, annual precipitation, high wind velocity and changes in the development of microorganisms, pests and vegetation all have an impact on agriculture. Wheat is cultivated in tropical and subtropical regions, which are subject to a variety of abiotic stresses. The most significant abiotic stresses include heat, drought, salinity, cold, chemicals and heavy precipitation. However, heat and drought are the major abiotic stresses impacting global wheat production. (Yadav *et al*., 2020) [29].

It is estimated that nearly half (13.5 million hectares) of India's wheat crop area is heat stressed. (Ahmad and Prakash, 2016) [1]. Heat stress is a significant threat to global crop production. Global average temperature will increase by 0.3 °C per decade above the current ambient temperature, leading to approximately 0.3 and 1°C for the years 2025 and 2100, respectively. Temperatures in the Indian region will rise by 0.7–2.0 °C by the 2030s and by 3.3–4.8 °C by the 2080s. (Palanisami *et al.*, 2019) [17]. There is a likelihood that global wheat yields will decrease by 4.1% to 6.4% by the middle of the 21st century if the average global temperature increases by 1 °C. This temperature increase may alter the growing season and crop maturity period. (Yadav *et al*, 2021) [28].

Wheat is a highly thermosensitive crop that is subject to both early (during germination) and terminal (during reproduction) heat stresses, but terminal heat stress is more prevalent worldwide. Wheat experiences terminal heat stress when the average temperature during grain filling exceeds 31 °C. The effects of thermal stress on crops depend on the intensity, rate, duration and developmental stage of the plant. Wheat's morphological, physiological, biological and biochemical processes are affected by thermal stress. In wheat, high temperatures reduce seed germination, grain filling period, grain number, Rubisco enzyme activity, photosynthetic capacity, assimilate translocation rate, premature leaf senescence, chlorophyll content and yield. (Poudel and Poudel, 2020) [19].

Heat tolerance is a complex phenomenon and heat stress affects the morpho-physiological characteristics of plants. Today, tolerance to heat improvement in wheat is a significant objective for wheat breeders. In comparison to tropical cereal crops, temperate cereal crops are more susceptible to rising temperatures. Numerous morpho-physiological traits contributing to heat tolerance are heritable, additive gene action and show variation, these traits are pinpointing for the scope of wheat improvement programme under heat stress (Chaudhary *et al.*, 2020) [3].

For a successful plant breeding programme existence of genetic variability is highly desired and must. The effectiveness of selection primarily determined by the magnitude of genetic variability present in the plant population. Therefore, the success of genetic improvement in any crop development program depends on the nature of variability present in the genotypes. Furthermore, it is extremely beneficial to investigate germplasm variability estimates. Evaluation of gene action may benefit from genetic advance and heritability analysis. The estimates of heritability, GCV and genetic advance demonstrate the genetic advance that can be made by selection, and they also provide the information a breeder would need (Sharma *et al.*, 2021) [23]. The principle objective of this research was to find potential genotypes and the finest qualities of wheat advance lines that perform well in heat stress conditions in order to boost current breeding programmes by measuring the genetic diversity, heritability and genetic advance for various traits.

Materials and Methods

The experimental material comprised of total 40 wheat advance lines (Table 1) grown in randomized block design (RBD) with three replications at Research Farm of Wheat and Barley Section, Department of Genetics and Plant Breeding CCS HAU, Hisar during *Rabi* 2019-20. The experimental site is located at a latitude of 29.1503° N, longitude of 75.7056° E and altitude of 215.2 m above sea level, comprising semi-tropical region of North-Western zone of India. The sowing of experiment was conducted on 20th Nov, 2019 (normal sowing) and 20th Dec, 2019 (late sowing), to study the effect of terminal heat stress on wheat advance lines. Length of paired rows was 2.5 meter each, row to row and plant to plant distance was maintained 20 cm and 10 cm respectively, for both dates of sowing. For both the environments (timely and late) all the recommended package of practices for wheat crop were followed, so that the genotypes may express their full genetic potential. Data were measured on five randomly selected plants of each genotype from each replication for 15 morpho-physiological traits *viz.* days to heading, days to maturity, plant height, number of effective tillers per meter, spike length, peduncle length, number of spikelet per spike, number of grains per spike, 1000 grain weight, biological yield per plant, harvest index, grain yield per plant, normalized difference vegetation index at initiation of anthesis (NDVI-1), NDVI after 15 days of anthesis (NDVI-2), canopy temperature depression at initiation of anthesis (CTD-1), CTD after 15 days of anthesis (CTD-2), SPAD value at initiation of anthesis (SPAD-1) and SPAD value after 15 days of anthesis (SPAD-2).

Table 1: List of advance lines of bread wheat used in the present study

Sr. No.	Advance lines	Parentage	Developing Institutes
1.	DBW-14	RAJ3765/PBW343	IIWBR, Karnal,
2.	DBW-71	PRINIA/UP2425	
3.	DBW-88	KAUZ//ALTAR84/AOS/3/MILAN/KAUZ/4/HUITES	
4.	DBW-173	KAUZ/AA//KAUZ//PBW602	
5.	DBW-187	AC/TH.AC//3*PVN/3/MIRLO/BUC/4/2*PASTOR/5/KACHU/6/KACHU	
6.	DBW-221	36IBWSN284/22ESWYT28	
7.	DBW-301	SR 39/DPW621-50	
8.	DBW-307	MUNAL*2/CHONTE (22ND SAWYT 334)	
9.	DBW-304	NADI/3/KINGBIRD#1//INQALAB91*2/TUKURU/4/NADI	
10.	DPW-621-50	KAUZ//ALTAR84/AOS/3/MILAN/KAUZ/4/HUITES	IIWBR, Karnal and Ludhiana, PAU
11.	HD-2967	ALD/CUC//URES/HD2160M/HD2278	IARI, New Delhi
12.	HD-3043	PJN/BOW//OPATA*2/3CROC_1/AE.SQ(224)//OPATA	
13.	HD-3059	KAUZ//ALTAR84/AOS/3/MILAN/KAUZ/4/HUITES	
14.	HD-3086	DBW14/HD2733//HUW468	
15.	HD-3226	GRACKLE/HD2894	
16.	HD-3237	HD3016/HD2967	
17.	HD-3271	CHIRIYA7/HD2824	
18.	HD-3317	DBW50/HD2859//HD2307	

19.	HD-3347	HD3086/HD2997	
20.	NW-7049	FRET2/KIRITATI/5/NAC/TH.AC//3*PVN/3/MIRLO/BUC/4/ 2*PASTOR*2/6/PVN	NDUA&T, Faizabad
21.	PBW-544	PBW550//Yr15/6*Avocet/3/2*PBW550	PAU, Ludhiana
22.	PBW-644	PBW175/HD2643	
23.	PBW-757	PBW550/YR15/6*AVOCET/3/2*PBW550/4/PBW568+YR36/3*PBW550	
24.	PBW-771	BWL9246/2*DBW17	
25.	PBW-797	PBW 621/BWL 0772RAJ	
26.	PBW-820	WL711-Ae.ovata/CS(S)//WL711NN/3/ 4*PBW 621	
27.	PBW-821	PBW550//Yr15/6*AVOCET/3/2*PBW550/4/GLUPRO/3*PBW568//3*PBW550	
28.	PBW-824	WAXWING//INQALAB 91*2/KUKUNA/3/WBLL1*2/TUKURU/8/ 2*NG8201/KAUZ/4/ SHA7//PRL/VEE#6/3/FASAN/5/MILAN/ KAUZ/6/ACHYUTA/7/PBW343*2/KUKUNA	
29.	PBW-825	SAUAL/MUTUS*2//PICAFLOR #1	
30.	BRW-3806	NI5439/MACS2496	BAU, Sabour
31.	WH-542	JUP/BJY SIB//URES	CCSHAU, Hisar
32.	WH-711	S308/CHR/KAL	
33.	WH-1021	NYOT95/SONAK	
34.	WH-1080	PRL/*2PASTOR	
35.	WH-1105	MILAN/S87230//BABAX	
36.	WH-1124	MUNIA/CHTO//AMSEL	
37.	WH-1142	OEN/AE.SQ.(TAUS)/FCT/3/2*WEAVER	
38.	WH-1184	HD2850/WH147	
39.	WH-1254	PRL/2*PASTOR//PBW343*2/KUKUNA/WHEAR//INQALAB91*2/TUKURU// SOKO LL*2/4/CHEN/AEGILOPSSQUARROSA(TAUS.)//.	
40.	WH-1270	SHA7//PRL/VEE#6/3/FASAN/4/HAAS8446/2*FASAN/5/CBRD/KAUZ/6/ MILAN/AMSE L/7/FRET2*2/KUKUNA/8/2*WHEAR/SOKOLL	

The data were analyzed by using the OP- Stat software, to the analysis of variance (ANOVA) and further, biometrical procedures were followed to estimate genotypic and phenotypic coefficient of variation, heritability in broad sense and genetic advance as percent mean (GA% mean).

Results and Discussion

Analysis of variance

The analysis of variance (ANOVA) for 15 different morpho-physiological traits is presented in Table 2 and 3. The results revealed highly significant variation for most of the traits under both the environmental study among forty advance lines of wheat. This indicated that there is a genetic difference between the advance lines of wheat. Variability is essential for the success of any breeding programme. In order to achieve self-sufficiency and sustainability, the future breeding programme also depends on the availability of genetic variability to increase grain productivity. It is necessary to develop cultivars with a diverse genetic base. Many traits are known to be negatively impacted by terminal heat stress, resulting a decrease in grain yield.

Table 2: Mean sum of squares for different traits of wheat under timely sown conditions

Source of Variation	d. f.	Mean sum of squares								
		DH	**DM**	**PH**	**ET/m**	**SL**	**PL**	**SL/S**	**G/S**	**TGW**
Replication	2	1.633	4.725	135.187	17.558	0.044	90.557	2.473	36.000	9.997
Treatment	39	30.574**	28.077**	181.715**	240.796**	3.549**	51.239**	8.849**	91.698**	25.182**
Error	78	2.240	2.973	20.992	74.054	0.459	4.994	1.533	21.769	6.73

Source of Variation	d. f.	Mean sum of squares								
		BY/P	**GY/P**	**HI**	**NDVI-1**	**NDVI-2**	**CTD-1**	**CTD-2**	**SPAD-1**	**SPAD-2**
Replication	2	10.963	3.329	1.457	0.001	0.001	0.140	0.320	0.134	1.520
Treatment	39	55.966**	12.024**	47.675**	0.007**	0.003**	1.280**	0.770**	21.540**	18.790**
Error	78	9.731	2.196	12.968	0.001	0.001	0.250	0.220	3.00	2.400

**Significant at 1% level of significance

(DH: Days to heading, DM: Days to maturity, PH: Plant height (cm), ET/m: Number of effective tiller per meter, SL: Spike length (cm), PL: Peduncle length (cm), SL/S: Number of spikelets per spike, G/S: Grains per spike, TGW: 1000-grain weight (g), BY/P: Biological yield per plant (g), GY/P: Grain yield per plant (g), HI: Harvest index (%), NDVI 1: Normalized difference vegetation index at initiation of anthesis, NDVI 2: Normalized difference vegetation index after 15 days of anthesis, CTD 1: Canopy temperature depression at initiation of anthesis, CTD 2: Canopy temperature depression after 15 days of anthesis, SPAD 1: Soil plant analysis development at initiation of anthesis, SPAD 2: Soil plant analysis development after 15 days of anthesis)

Table 3: Mean sum of squares for different traits of wheat under late sown conditions

Source of Variation	d. f.	Mean sum of squares								
		DH	**DM**	**PH**	**ET/m**	**SL**	**PL**	**SL/S**	**G/S**	**TGW**
Replication	2	7.408	5.833	35.210	98.425	0.022	9.700	0.604	50.877	47.549
Treatment	39	18.342**	13.879**	174.987**	492.085**	3.832**	24.035**	9.006**	92.900**	20.749**
Error	78	1.485	1.474	17.806	78.092	0.388	5.867	1.693	15.668	5.162

Source of Variation	d. f.	Mean sum of squares								
		BY/P	**GY/P**	**HI**	**NDVI-1**	**NDVI-2**	**CTD-1**	**CTD-2**	**SPAD-1**	**SPAD-2**
Replication	2	39.323	0.182	31.923	0.001	0.001	0.104	0.089	2.857	2.367
Treatment	39	91.123**	6.797**	68.980**	0.019**	0.026**	3.221**	4.180**	57.996**	52.260**
Error	78	19.397	0.797	18.034	0.002	0.001	0.066	0.100	6.253	5.182

**Significant at 1% level of significance

(DH: Days to heading, DM: Days to maturity, PH: Plant height (cm), ET/m: Number of effective tiller per meter, SL: Spike length (cm), PL: Peduncle length (cm), SL/S: Number of spikelets per spike, G/S: Grains per spike, TGW: 1000-grain weight (g), BY/P: Biological yield per plant (g), GY/P: Grain yield per plant (g), HI: Harvest index (%), NDVI 1: Normalized difference vegetation index at initiation of anthesis, NDVI 2: Normalized difference vegetation index after 15 days of anthesis, CTD 1: Canopy temperature depression at initiation of anthesis, CTD 2: Canopy temperature depression after 15 days of anthesis, SPAD 1: Soil plant analysis development at initiation of anthesis, SPAD 2: Soil plant analysis development after 15 days of anthesis)

Parameters of Genetic variability: The estimates of range, mean, phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability (broad sense) and genetic advance as percent mean (GA % mean) for fifteen characters of wheat advance lines in timely sown (normal) and late sown (heat stress) conditions are presented in Table 4 and Table 5. Genotypic and phenotypic coefficients of variation are clear and concise measures of variability; these measures are frequently employed to evaluate variability. The relative values of these types of coefficient gives an idea about the magnitude of variability present in a genetic population. Thus, variation components such as genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were calculated.

Table 4: Genetic variability parameters for different traits of wheat advance lines under timely sown conditions

Traits	Mean ± $SE_{(m)}$	Range	GCV (%)	PCV (%)	Heritability (%)	Genetic Advance	GA as% mean
DH	96.21 ± 0.86	87.00 – 103.00	3.20	3.55	80.83	5.69	5.92
DM	138.92 ± 0.99	134.00– 146.00	2.08	2.42	73.79	5.12	3.66
PH	99.97 ± 2.64	83.28 – 110.69	7.32	8.64	71.85	12.78	12.79
ET/m	112.78 ± 4.96	94.67 – 132.67	6.61	10.10	62.88	10.06	8.92
SL	10.15 ± 0.35	7.83 – 12.11	9.99	12.02	69.16	1.74	17.13
PL	34.75 ± 1.29	28.63 – 47.68	11.30	13.00	75.53	7.03	20.23
SL/S	19.61 ± 0.71	15.67 – 23.00	7.96	10.16	61.40	2.52	12.85
G/S	51.25 ± 2.69	40.45 – 68.00	9.42	13.10	51.71	7.15	13.96
TGW	39.34 ± 1.40	33.44 – 45.38	6.26	9.06	69.43	3.53	8.92
BY/P	36.34 ± 1.80	29.34- 46.67	10.8	13.80	61.3	6.33	17.42
HI	33.64 ± 2.07	25.23 -41.31	10.11	14.73	47.15	4.81	14.3
GY/P	13.20 ± 0.85	9.33 – 16.81	13.70	17.71	59.86	2.86	21.84
NDVI-1	0.73 ± 0.01	0.65 - 0.81	5.89	7.23	66.31	0.07	9.87
NDVI-2	0.58 ± 0.01	0.50 - 0.64	5.30	6.65	63.61	0.05	8.71
CTD-1	2.99 ± 0.01	1.50 - 4.57	19.56	25.78	67.58	0.92	30.59
CTD-2	3.34 ± 0.01	2.14 - 4.58	12.83	19.24	64.50	0.59	17.63
SPAD-1	43.38 ± 1.00	38.31 - 48.76	5.73	6.99	67.25	4.20	9.68
SPAD-2	39.05 ± 0.89	33.59 - 43.98	5.99	7.18	69.47	4.01	10.28

(DH: Days to heading, DM: Days to maturity, PH: Plant height (cm), ET/m: Number of effective tiller per meter, SL: Spike length (cm), PL: Peduncle length (cm), SP/S: Number of spikelets per spike, G/S: Grains per spike, TGW: 1000-grain weight (g), BY/P: Biological yield per plant (g), GY/P: Grain yield per plant (g), HI: Harvest index (%), NDVI 1: Normalized difference vegetation index at initiation of anthesis, NDVI 2: Normalized difference vegetation index after 15 days of anthesis, CTD 1: Canopy temperature depression at initiation of anthesis, CTD 2: Canopy temperature depression after 15 days of anthesis, SPAD 1: Soil plant analysis development at initiation of anthesis, SPAD 2: Soil plant analysis development after 15 days of anthesis).

Phenotypic coefficient of variation (PCV) values were greater than their respective genotypic coefficient of variation (GCV) values, indicating that these traits are influenced by environmental factors. The traits which shows the high to moderate PCV and GCV values in a timely sown conditions are: CTD-1 (25.78) and (19.56), CTD-2 (19.24) and (12.83), grain yield per plant (17.71) and (13.70), harvest index (14.73) and (10.11), biological yield *per* plant (13.80) and (10.80), peduncle length (13.00) and (11.30) and the traits which have high to moderate PCV and GCV values under sown conditions are: CTD-1 (33.62) and (32.62), CTD-2 (30.12) and (29.07), grain yield/plant (18.00) and (15.22), harvest index (21.60) and (15.04), biological yield/plant (18.94) and (14.08), number of effective tillers per meter (16.36) and (13.07), spike length (13.2) and (11.42), NDVI-2 (19.93) and (18.76), NDVI-1 (13.23) and (11.31), SPAD-2 (12.80) and (11.09), number of grains per spike (13.43) and (10.59), SPAD-1 (12.35) and (10.58). The higher estimates of PCV indicated that sufficient variability exists for these traits; therefore, there is opportunity for improvement through the use of suitable breeding programmes in a heat stress environment. In the timely sown experiment, the estimates of GCV and PCV showed a wide range, with GCV and PCV values ranging from 2.08 to 19.56 for days to heading and from 2.42 to 25.78 for CTD-1, respectively. In the late sown experiment, the GCV and PCV values ranged from 1.78 to 32.62 for days to maturity and from 2.07 to 33.78 for CTD-1. The wide range of GCV and PCV indicates that all the characters exhibit a significant amount of variation.

Table 5: Genetic variability parameters for different traits of wheat advance lines under late sown conditions

Traits	Mean ± $SE_{(m)}$	Range	GCV (%)	PCV (%)	Heritability (%)	Genetic Advance	GA as% mean
DH	85.91 ± 0.70	81.33 – 91.67	2.76	3.10	79.09	4.34	5.06
DM	114.18 ± 0.70	108.67-118.33	1.78	2.07	73.72	3.60	3.15
PH	83.09 ±2.43	78.70 – 107.52	8.71	10.08	74.64	12.88	15.5
ET	89.85 ± 5.10	57.33 – 115.33	13.07	16.36	63.86	19.34	21.52
SL	9.39 ± 0.35	7.33 – 11.61	11.42	13.2	74.77	1.91	20.34
PL	30.19 ± 1.41	24.98 – 35.48	8.15	11.44	50.79	3.61	11.97
SL/S	18.07 ± 0.78	14.44 – 21.00	8.64	11.25	59.01	2.47	13.67
G/S	47.93 ± 2.28	38.44 – 63.56	10.59	13.43	62.17	8.24	17.2
TGW	35.81 ± 1.31	26.70 – 39.33	6.37	8.99	50.16	3.33	9.29
BY/P	34.74 ± 2.54	27.55 – 44.66	14.08	18.94	55.21	7.48	21.55
HI	27.39 ± 2.44	19.12 -34.00	15.04	21.6	48.50	5.91	21.58
GY/P	9.19 ± 0.51	6.53 – 12.31	15.22	18.00	50.30	2.46	26.51
NDVI-1	0.67 ± 0.02	0.50 - 0.76	11.31	13.23	73.04	0.13	19.91
NDVI-2	0.48 ± 0.01	0.27- 0.63	18.76	19.93	88.68	0.18	36.4
CTD-1	3.14 ±.014	1.26- 5.37	32.62	33.62	94.12	2.05	65.19
CTD-2	4.01 ± 0.18	1.87-6.55	29.07	30.12	93.16	2.32	57.80
SPAD-1	39.2 ±1.44	32.60 - 47.75	10.58	12.35	73.39	7.33	18.68
SPAD-2	35.71 ± 1.31	29.49– 40.99	11.09	12.80	75.18	7.08	19.81

(DH: Days to heading, DM: Days to maturity, PH: Plant height (cm), ET/m: Number of effective tiller per meter, SL: Spike length (cm), PL: Peduncle length (cm), SL/S: Number of spiklets per spike, G/S: Grains per spike, TGW: 1000-grain weight (g), BY/P: Biological yield per plant (g), GY/P: Grain yield per plant (g), HI: Harvest index (%), NDVI 1: Normalized difference vegetation index at initiation of anthesis, NDVI 2: Normalized difference vegetation index after 15 days of anthesis, CTD 1: Canopy temperature depression at initiation of anthesis, CTD 2: Canopy temperature depression after 15 days of anthesis, SPAD 1: Soil plant analysis development at initiation of anthesis, SPAD 2: Soil plant analysis development after 15 days of anthesis)

Following the studies of Shehrawat *et al.* (2021) [24], Thapa *et al.* (2019) [27], Suresh *et al.* (2018) [26], Kyosev and Desheva (2015) [14] and Azimi *et al.* (2017), similar results were observed in both environments. CTD had high GCV and PCV values while days to maturity had low GCV and PCV values. We can conclude that the degree of variability present in wheat for various traits and their results follow the same variability pattern, i.e. higher PCV and GCV values for CTD followed by grain yield/plant, harvest index and biological yield/plant, as concluded in our study, and similar results were also in agreement with the work of Gahtyari *et al.* (2017) [8], whose findings were maximum values of GCV and PCV for GY/P and CTD.

Heritability and genetic advance as percent of mean

Heritability and genetic advance are the important selection parameters for crop improvement. Heritability estimates along with genetic advance are normally more helpful in predicting the gain under selection than heritability estimate alone. Heritability is a measure of the phenotypic variance attributable to genetic causes, has predictive function in breeding crops (Songsri *et al.*, 2008). It provides an estimate of the genetic advance a breeder can expect from selection applied to a population under certain environment. The higher the heritability estimates, the simpler are the selection procedures (Khan and Naqvi, 2011) [12]. High heritability (*bs*) associated with high genetic advance reveals strong contribution of additive genetic variance for expression of the traits and the selection based on these traits could play a vital role in improving grain yield. The estimation of heritability helps the plant breeder in selection of elite genotypes from diverse genetic populations. The heritability estimates were classified as low (below 30%), medium (30% to 60%) and high (above 60%) (Johansan *et al.*, 1955) [10].

The estimation of heritability (broad sense) and genetic advance as percent of mean for fifteen morpho-physiological traits of wheat advance lines in timely sowing (normal) and late sowing (heat stress) conditions are shown in Table 4 and Table 5. In both conditions, heritability estimates for most of traits were found higher. Heritability estimates in timely condition were highest for days to heading (80.83%) followed by peduncle length (75.53%), days to maturity (73.79%), plant height (71.85%), SPAD-2 (69.47%), 1000-grain weight (69.43%), spike length (69.16%), CTD-1 (67.58%), SPAD-1 (67.25%), NDVI-1 (66.31%), CTD-2 (64.50%), NDVI-2 (63.61%), number of effective tillers per meter (62.88%), number of spikelets per spike (61.40%) and biological yield per plant (61.30%). In late sown (heat stress) conditions, heritability estimates were highest for CTD-1 (94.12%) followed by CTD-2 (93.16%), NDVI-2 (88.68%), days to heading (79.09%), SPAD-2 (75.18%), spike length (74.77%), plant height (74.64%), days to maturity (73.72%), SPAD-1 (73.39%), NDVI-1 (73.04%), number of effective tillers per meter (63.86%) and number of grains per spike (62.17%).

Characters with high heritability, such as CTD, NDVI, SPAD, number of effective tillers per metre, number of spikelets per spike, 1000-grain weight, days to maturity, plant height, spike length and biological yield per plant, are less influenced by environment, whereas characters with low heritability, such as harvest index, grain yield and peduncle length, are ineffective for selection due to the predominance of non-additive genes. The above finding of heritability were in agreement with the work of Ramanuj *et al.* (2018) [20] and Thapa *et al.* (2019) [27] reported high heritability for tiller per plant and biological yield. Fellahi *et al.* (2013) [7] found high heritability for spike length, number of spikelets per spike and number of grains per spike. Saini *et al.* (2020) [21] observed high heritability for plant height and days to maturity, while moderate for 1000-grain weight. Gupta and Verma, (2000) [9] reported moderate heritability for harvest index and grain yield. Sharma *et al.* (2018) [22] and Shehrawat *et al.* (2021) [24] reported high heritability for NDVI, CTD and SPAD.

For timely sown conditions higher value of genetic advance as percentage of mean (above 20%) was obtained for CTD-1 (30.59%) followed by grain yield per plant (21.84%) and peduncle length (20.23%). Medium genetic advance as a percentage of mean (above 10%) CTD-2 (17.63%), biological yield per plant (17.42%), spike length (17.13%), harvest index (14.30%), number of grains per spike (13.96%), number of spikelets per spike (12.85%), plant height (12.79%) and SPAD-2 (10.28%). Low genetic advance as a percentage of mean (below 10%) was obtained for NDVI-1 (9.87%), SPAD-1 (9.68%), 1000- grain weight (8.92%), number of effective tillers per meter (8.92%), NDVI-2 (8.71%), days to heading (5.92%) and days to maturity (3.66%), while for late sown conditions higher value was for CTD-1 (65.19%), followed by CTD-2 (57.80%), NDVI-2 (36.40%), grain yield per plant (26.51%), harvest index (21.58%), biological yield per plant (21.55%), number of effective tillers per meter (21.52%) and spike length (20.34%). Moderate was observed for NDVI-1 (19.91%), SPAD-2 (19.81%), SPAD-1 (18.68%), number of grains per spike (17.20%), plant height (15.50%), number of spikelets per spike (13.67%) and peduncle length (11.97%). Low was recorded for 1000-grain weight (9.29%), days to heading (5.06%) and days to maturity (3.15%). Suresh *et al.* (2018) [26]; Porte *et al*. (2021) [18]; Kumar and Kumar, (2021) [13] and Emmadishetty and Gurjar, (2022) [5] reported the similar results for morpho-physiological traits.

The present study reveals that there is considerable genetic variability among the forty advance lines of bread wheat. Moderate values of PCV than GCV were observed in grain yield per plant, harvest index, biological yield per plant and CTD under both the environmental conditions. Most of the traits under both the study exhibited moderate to high heritability along with genetic advance as percentage of mean *viz.*, plant height, spike length, peduncle length, number of spikelet per spike, number of grains per spike, 1000 grain weight, biological yield per plant, harvest index, grain yield per plant, CTD-1, CTD-2, SPAD-1 and SPAD-2, which suggests the presence of additive gene effects, showing the better response of selection for improving these traits. The advance lines NW 7049, DBW 14, WH 1021, PBW 825, DBW 304 and PBW 797 were identified as potential genotypes. So, these lines can be further used for development of terminal heat tolerant varieties in future breeding programs.

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