Science Letters ISSN 2345-5463
DOI: https://doi.org/10.47262/SL/11.2.132023800

Research article
2023 | Volume 11 | Issue 2 | Pages 59-66

ARTICLE INFO

Received
January 28, 2023
Revised
March 31, 2023
Accepted
April 05, 2023
Published
May 12, 2023

***Corresponding author**
Darya Khan Akbarzai
E-mail
d.akbarzai@gmail.com

Keywords
Bread wheat
Canopy temperature
Genetic diversity
Grain yield
Terminal heat stress
Chlorophyll content

How to Cite
Akbarzai DK, Singh V, Yashveer S, Nimbal S, Kumar M, Dalal MS, Mor VS, Devi S. Evaluation of genetic diversity of wheat (*Triticum aestivum*) lines under terminal heat stress in the Hisar environment. Science Letters 2023; 11(2):59-66.

Open Access

Evaluation of Genetic Diversity of Wheat (*Triticum aestivum*) Lines Under Terminal Heat Stress in the Hisar Environment

Darya Khan Akbarzai*, Vikram Singh, Shikha Yashveer, Somveer Nimbal, Mukesh Kumar, Mohinder Singh Dalal, Virender Singh Mor, Suman Devi

Department of Genetics and Plant Breeding, Chaudhary Charan Singh Haryana Agricultural University, Hisar-125004, Haryana, India

Abstract

Various environmental stresses affect plant development and growth globally and restrict agricultural output and productivity. Wheat plants are negatively impacted by terminal heat stress, which lowers productivity. The correlation between grain yield and other qualities may determine the plant material's ability to minimize the effects of heat stress on yield, and a trait variance aids in the identification of attractive genotypes in a breeding program. To accomplish this, the genetic variability, heritability, correlation and path coefficient analyses of 64 bread wheat genotypes were conducted. As a result, all 15 morpho-physiological traits revealed highly significant genotypic variations. Total chlorophyll content and main spike weight were both higher than 42% and 16%, respectively, for the genotypic coefficient of variation and the phenotypic coefficient of variation. The grain yield per plot indicated a significant and positive correlation with spike length, spike weight, number of grains per spike, number of spikelets per spike, 1000-grain weight, biological yield per plot, grain growth rate, total chlorophyll content and number of productive tillers per meter. As a result, five genotypes, P13833, P13828, P13031, P13723, and P13726, had higher yields and should be utilized as parents in breeding programs. The results revealed that the selection of key physiological and morphological characteristics associated with grain production significantly raises wheat productivity in situations like heat stress.

SCAN ME

Introduction

Wheat (*Triticum aestivum* L., 2n = 6× = 42, AABBDD) is a self-pollinated, and most popular cereal crop for human food and livestock feed globally. Wheat is an ancestor of the subtribe Triticinae of the tribe Triticeae (hordaceae) of the Poaceae family. Wheat can be grown in a variety of climates, such as temperate, irrigated areas, tropical regions with abundant rainfall, and cold, dry climates. Wheat can be grown at latitudes of 30°-60° N and 27°-40° S and 3000 to 4570 mean sea level [1, 2]. Wheat is the second-largest cereal crop in the globe after maize, having area, production, and productivity in the amount of 214.29 million hectares, 734.05 million tons and 3.43 tons per hectare globally, respectively [3]. Wheat is utilized by more than one-third (40%) of the world's population and occupies more than 17% of all cropland. After China, India is the second-largest producer of wheat, consistently producing more than 100 million tons per year. According to the latest estimate, India's total wheat production is 109.52 million tons from 31.35 m/ha of cultivated area with productivity of 34.4 q/ha, while, Haryana produced 11.87 million tons of wheat from 2.53 m/ha of cultivated area and productivity of 4.68 tons per hectare [4.5].

It is anticipated that to fulfill the demands of the expanding population, wheat production must be boosted by 60% [6]. Along with tolerance to abiotic and biotic stresses, the yield must be improved by at least 1.6% per year [7]. Multiple environmental stresses have an impact on plant growth and development, which globally restricts agricultural productivity and output. Heat stress is a key abiotic stress that lowers wheat grain production worldwide, especially in arid, semi-arid, tropical, and sub-tropical environments [8]. The damage to plant growth and development that occurs when the temperature increases beyond a certain threshold level is irreversible [9]. Under controlled environments, high temperature reduces yields by 3% to 5% for each degree above 15°C [10]. The impacts of terminal heat on crops include reduced crop stand, shortened life cycles, lower tillering, decreased biomass production, smaller seeds, fewer spikes per plant, fewer grains per spike, and decreased grain weight, all of which led to decreased grain yield [11] and also affects photosynthetic activity during grain filling period and grain weight [7]. Heat stress also affects chlorophyll accumulation which further affects photosynthesis in plants. Therefore, developing heat-tolerant genotypes is of the highest priority in wheat breeding programs. Breeding for heat tolerance in wheat is an important worldwide challenge. The suitable plant type should be selected from a sundry gene pool for utilization in the hybridization program. Furthermore, the level of genetic variability and the degree to which the desired traits are heritable and associated with grain yield can have a significant impact on the effectiveness of crop development. To further comprehend the genetic diversity of yield and yield-contributing traits in wheat under extreme heat stress, this research was carried out utilizing genetic material from the gene bank at CCSHAU, Hisar, India.

Materials and Methods

The current investigation was executed at Chaudhary Charan Singh Haryana Agricultural University, Hisar, India during the Rabi season of 2019-20 under late sowing conditions for exposing genotypes to high temperatures. The maximum temperature during crop season ranged from 15^{o}C (December) to 39^{o}C (April) while the minimum temperature varied from 2^{o}C (January and February) to 18^{o}C (April) (Fig. 1). A total of 64 genotypes were grown in a randomized complete block design (RCBD) with three replications in plots sized 6.48 m^2 and recommended packages of practices were followed to raise the healthy crop (Table S1). Observations were recorded on grain yield (GY) and its related traits, *viz.*, days to heading (DH), number of productive tillers per meter (NPTM), main spike length (MSL), number of spikelets per spike (NSPS), main spike weight (MSW), number of grains per spike (NGPS), days to maturity (DM), 1000-grain weight (TGW), biological yield (BY), grain yield per plot (GY), grain growth rate (GGR), canopy temperature (CT) and total chlorophyll content (TCC). The grain growth rate was measured at 14, 21, and 28 days after anthesis by weighing the kernel from main spikes and expressed as g/grain/day. Canopy temperature was recorded at 7 days after anthesis (DAA) with the help of a handheld infrared thermometer. Chlorophyll 'a' and chlorophyll 'b' and total chlorophyll content were extracted (10ml of dimethyl sulfoxide (DMSO) as per the standard procedure described elsewhere [34] at 28 DAA. By measuring its absorbance at 663 and 645 nm, respectively, and using the subsequent estimation, the amount of extracted chlorophyll in DMSO was calculated as follows:

$$\text{Chl 'a'} = \frac{(12.3A_{663} - 0.86A_{645})}{\text{a} \times 1000 \times W} \times V$$

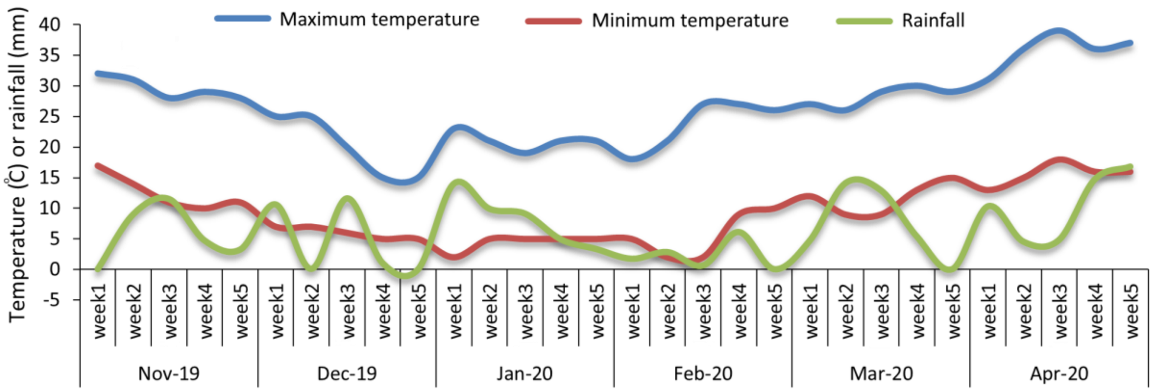

Fig. 1 Weekly weather data for Rabi crop season 2019-2020.

$$\text{Chl 'b'} = \frac{(19.3A_{645} - 3.6A_{663})}{\text{a} \times 1000 \times W} \times V$$

Statistical analysis was carried out on the mean values of individual genotypes. Analysis of variance was carried out for individual characters as per the standard procedure [13]; computing the genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) using the formula provided by Burton [12]; heritability (h^2) as suggested by Burton and De [14] and genetic advance as per the method designated by Johnson et al. [15]. The phenotypic correlations were computed using the formula of Al-Jibouri et al. [16]. Path coefficient analysis was employed to evaluate the proportion of the direct and indirect contributions of various characteristics to the total correlation coefficients to yield [17] as illustrated by Dewey and Lu [18]. The data was analyzed using OPSTAT (software available at http: //www.hau.ernet.in.), INDOSTAT (version 8.0), SPSS (version 24.0), and STAR (Statistical Tool for Agricultural Research) software.

Results and Discussion

Wheat breeding for resistance to terminal heat stress is becoming more and more crucial due to a result of global warming. Owing to its complex characteristics, which cannot be measured on its own, breeding for heat tolerance is more difficult than breeding for other biotic stresses. It needs to be evaluated in terms of how it affects the genotype's ability to perform differently for a particular trait knowing that stress quickens the plant's phonological development, which then affects all of the plant's characteristics. In this study, some key characteristics that are crucial in the selection of genotypes that are resistant to heat stress are evaluated. The results showed that variations due to genotypes were highly significant (p<0.01, F=5.291) for all the traits indicating highly diverse genotypes used for the study (Tables 1 and 2). The mean values for the 15 morpho-physiological traits are given in Table 3. Genotypes mean ranged from 74-88 days for days to heading, 35 to 65 for the number of grains per spike and 15 to 23 for the number of spikelets per spike, 119 to 127 days for days to maturity, 4.27 to 8.21 for GGR14, 8.19 to 16.67 for GGR21, 12.61 to 21.08 for GGR28, 19 to 31 for canopy temperature and 14.30 to 44.10 for total chlorophyll content (TTC). Grain yield/plot ranged from 2.37 to 3.60 kg/plot with an overall mean of 2.94 kg/plot. Top five high yielding (highest 3.53 to 3.60 kg per plot) genotypes *viz.,* P13726 (3.53 kg/plot), P13723 (3.57 kg/plot), P13833 (3.60 kg/plot), P13828 (3.60 kg/plot) and P13031 (3.60 kg/plot) performed better than the best check HD 3059 (3.13 kg/plot).

Estimation of variability components

Phenotypic and genotypic coefficient parameters have been assessed for all characters under late-sown conditions (Table 3). Across all the traits (20), the genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) varied from 1.64% to 42.07% and from 1.95% to 42.63%, respectively. The less difference between PCV and GCV for nearly all of the traits indicated that environmental influences had little impact on how those traits were expressed. Total chlorophyll content has been shown to have high phenotypic and genotypic coefficients of variation (42.07 and 42.63%) followed by main spike weight (19.54 and 16.70%), number of grains per spike (15.20 and 10.97%), main spike length (11.62 and 10.47%), grain yield (12.23 and 9.31%) and number of productive tillers per meter (10.92 and 9.90%). For

Table 1 Analysis of variance for different traits of wheat under late sown conditions.

Traits	DF	Mean Sum Square (MSS)								
		FE	DH	PH	NPTP	PL	MSL	MSW	NGPS	NSPS
Genotypes	63	2.64**	16.20**	84.88**	658.20**	22.29**	3.83**	0.66**	122.03**	7.36**
Replication	2	1.05	2.54	26.69	305.43	5.82	1.41	0.24	1.31	1.05
Error	211	0.13	0.79	34.88	44.38	1.72	0.29	0.08	27.31	1.04
CV (%)		3.07	1.06	6.32	4.61	9.18	5.15	10.65	10.45	5.57
CD		0.59	1.44	9.55	10.78	2.12	0.88	0.46	8.46	1.65

** Significant at (P< 0.01) level of significance; CV = coefficient of variation of experimental error at general mean level; CD = critical difference; DF= degrees of freedom.

FE: field emergence, DH: days to heading, PH: plant height (cm), NPTP: number of productive tillers/meter, PL: peduncle length (cm), MSL: main spike length (cm), MSW: main spike weight (g), NGPS: number of grains/spike, NSPS: number of spikelets/spike

Table 2 Analysis of variance for different traits of wheat under late sown conditions.

Traits	DF	Mean Sum Square (MSS)									
		GGR14	GGR21	GGR28	CT	TCC	DM	TGW	BY	GY	HI
Genotypes	63	0.02**	0.02**	0.04**	14.99**	176.99**	11.72**	25.61**	1.68**	0.28**	46.34**
Replication	2	0.01	0.01	0	2.94	8.04	0.8	0.76	0.44	0.12	7.99
Error	211	0.01	0	0.01	2.25	1.57	1.64	0.24	0.32	0.06	14.79
CV (%)		8.87	4.7	5.68	5.9	6.89	1.12	1.3	7.26	7.94	10.04
CD		0.11	0.09	0.11	2.43	2.03	2.07	0.79	0.91	0.38	6.22

** Significant at (P< 0.01) level of significance; CV = coefficient of variation of experimental error at general mean level; CD = critical difference; DF= degrees of freedom.

GGR14: grain growth rate at 14th days after anthesis, GGR21: grain growth rate at 21st days after anthesis, GGR28: grain growth rate at 28th days after anthesis, CT: canopy temperature (˚C), TCC: total chlorophyll content (%), DM: days to maturity, BY: biological yield /plot (kg), GY: grain yield /plot (kg), HI: harvest index (%), TGW: 1000-grain weight (g)

these characteristics, the selection will be successful and effective in the breeding program. Earlier researchers also reported significant GCA and SCA for grain yield/plant, length of the main spike, 1000-grain weight, number of effective tillers/plant, chlorophyll [19], main spike length, number of grains per spike [20] and grain weight per spike [21]. The significance of GCA and SCA variances recommended both additive and non-additive types of gene action played an important role in the inheritance of the traits and highly responded to selection [22]. Breeding programs for heat resistance can greatly benefit from the genetic diversity of various traits found in wheat germplasm.

Heritability and genetic advance (%)

The heritability (bs) measures ranged from 27.82% (GGR21) to 98.47% (1000-grain weight). Heritability is quite effective in deciding the traits while selecting, these traits could be directly enhanced by selection as they are least affected by the environment and would have a high degree of genotype-phenotype correlation. High (>60%) heritability was observed for 1000-grain weight (98.47%), TTC (97.39%), days to heading (86.49%), number of productive tillers/meter (82.17%), main spike length (81.19%), main spike weight (73.06%), days to maturity (71.25%), number of spikelets/spike (66.20%) and canopy temperature (65.35%). Other researchers also declare a high degree of heritability (>60%) for days to heading, physiological maturity and the number of spikelets/spike [23], for spike length, chlorophyll content and 1000-grain weight [24], for canopy temperature depression [28], and plant height and spike length [25].

Grain yield (57.91%), GGR28 (44.55%), GGR14 (32.2%), and GGR21 (21.82), on the other hand, exhibited moderate heritability. The findings for grain yield/plant, biological yield/plant and number of seeds/spike were consistent with those of previous research [19, 24, 26,]. Therefore, the high heritable traits are highly responsive to selection. Due to the inclusion of additive and non-additive effects, broad sense heritability has some drawbacks. High heritability in the presence of genetic advance indicates an additive gene effect, whereas high heritability with low genetic advance suggests dominance and epistatic effect. High heritability was found together with high genetic advance as a percent of the mean for total chlorophyll content (85.52%), and main spike length (29.40%). Due to the preponderance of additive gene effects, these characteristics will respond significantly to selection. A similar result was reported by Wahidy et al. [27] for spike length; Raaj et al. [24] for chlorophyll content and Thapa et al. [28] for grain weight per spike. The other traits had low to moderate levels of genetic advance, demonstrating a limited window for improvement by selection under conditions of extreme heat stress.

Table 3 Range, genotypic and phenotypic coefficient of variance, heritability and genetic advance for morpho-physiological traits under late sown conditions.

Traits	Genetic parameters					
	Mean	Range	GCV (%)	PCV (%)	h^2 (bs) (%)	Genetic advance (%) *
Days to heading	84.26	74.00 - 88.00	2.69	2.89	86.49	5.14
Number of productive tillers/meters	144.47	77.00 - 159.00	9.90	10.92	82.17	18.49
Main spike length (cm)	10.49	8.00 - 14.00	10.47	11.62	81.19	19.43
Main spike weight (g)	2.65	2.11 - 3.90	16.70	19.54	73.06	29.40
Number of grains/spikes	49.87	35.00 - 65.00	10.97	15.20	52.09	16.31
Number of spikelets/spike	18.53	15.00 - 23.00	8.31	10.21	66.20	13.93
Grain growth rate at 14 DAA (g/gr $\times 10^{-4}$)	0.79	4.27 - 8.21	7.92	13.96	32.20	9.26
Grain growth rate at 21 DAA (g/gr $\times 10^{-4}$)	1.11	8.19 - 16.67	10.34	19.60	27.82	11.23
Grain growth rate at 28 DAA (g/gr $\times 10^{-4}$)	1.23	12.61 - 21.08	9.45	14.15	44.55	12.99
Canopy temperature (˚C)	25.43	19.00 - 31.00	8.10	10.02	65.35	13.49
Total chlorophyll content (%)	18.17	14.30 - 44.10	42.07	42.63	97.38	85.52
Days to maturity	114.80	119.00 - 127.00	1.64	1.95	71.25	2.86
1000-grain weight (g)	37.37	29.90 - 45.45	7.83	7.89	98.47	16.01
Biological yield /plot (kg)	7.75	6.13 - 9.70	8.70	11.32	58.99	13.76
Grain yield/plot (kg)	2.94	2.37 - 3.60	9.31	12.23	57.91	14.59

PCV: phenotypic coefficient of variation; GCV: genotypic coefficient of variation; h^2 (bs): heritability (broad sense); DDA = days after anthesis
*Genetic advance is given over mean at 5% intensity of selection.

Table 4 Phenotypic correlation coefficient among grain yield and component traits in wheat under late sown conditions.

Traits	DH	NPTP	MSL	MSW	NGPS	NSPS	GGR14	GGR21	GGR28	CT	TTC	DM	TGW	BY	GY
FE															
NPTP	0.018														
MSL	-0.084	0.177*													
MSW	-0.120	0.147*	0.593**												
NGPS	-0.073	0.111	0.505**	0.618**											
NSPS	-0.015	0.257**	0.558**	0.537**	0.473**										
GGR14	-0.283**	0.190**	0.511**	0.461**	0.368**	0.542**									
GGR21	-0.265**	0.179*	0.572**	0.525**	0.404**	0.568**	0.955**								
GGR28	-0.273**	0.185*	0.568**	0.516**	0.399**	0.569**	0.979**	0.993**							
CT	0.199**	-0.234**	-0.604**	-0.572**	-0.474**	-0.572**	-0.661**	-0.728**	-0.719**						
TTC	-0.214**	0.201**	0.663**	0.604**	0.518**	0.607**	0.724**	0.805**	0.792**	-0.794**					
DM	0.101	0.330**	0.181*	0.112	0.153*	0.178*	0.187*	0.158*	0.168*	-0.097	0.084				
TGW	-0.129	0.121	0.687**	0.636**	-0.599**	0.599**	0.614**	0.676**	0.672**	-0.693**	0.757**	0.143*			
BY	-0.193**	0.134	0.234**	0.247**	0.202**	0.284**	0.347**	0.382**	0.374**	-0.326**	0.348**	0.121	0.350**		
GY	-0.250**	0.162*	0.533**	0.470**	0.393**	0.537**	0.832**	0.865**	0.867**	-0.642**	0.748**	0.098	0.638**	0.379**	

FE : field emergence, NPTP: number of productive tillers/meter, MSL: main spike length (cm), MSW: main spike weight (g), NGPS: number of grains/spike, NSPS: number of spikelets/spike, DM: days to maturity, BY: biological yield /plot (kg), GY: grain yield /plot (kg), TGW: 1000-grain weight (g), GGR14: grain growth rate at 14th days after anthesis, GGR21: grain growth rate at 21st days after anthesis, GGR28: grain growth rate at 28th days after anthesis, CT: canopy temperature (˚C), TCC: total chlorophyll content (%).

Traits association

The grain yield/plot had a positive and significant (P<0.01) correlation at the phenotypic level with GGR28 (0.867), GGR21 (0.865), GGR14 (0.832), total chlorophyll content (0.748), 1000-grain weight (0.638), main spike weight (0.470), number of grains/spike (0.393), biological yield (0.379), number of productive tillers/meter (0.162) and days to maturity (0.098) (Table 4). The favorable correlation between the aforementioned characters suggests the possibility of increasing grain yield by direct selection of these characters. Similar findings of grain yield association were also reported for the number of spikelets/spike, spike length, and the number of grains/spike [23]; for spike weight; [29] for chlorophyll content [30]; for GGR14, GRR21 and GGR28 and canopy temperature depression [33]. Important features like heading and maturity have an impact on how well wheat cultivars adapt to the normal field conditions in a particular region. Furthermore, heat-stressed environments are better suited for early maturing genotypes, while heat-favorable environments are better suited for late maturing genotypes. The correlation indicates that early maturing genotypes are best for heat-stressed environments while late maturing genotypes do well in the heat-favorable environments. This suggests that days to maturity may be advantageously chosen for increased grain yield, except for extreme and prolonged heat stress, particularly in the late growing season. Fast-maturing genotypes, especially in the tropics and subtropics, will perform efficiently under intense heat stress by exploiting escape mechanisms to avoid the extended terminal heat stress that frequently happens. Days to heading and grain filling rate both influence grain growth rate. It is best to select medium days to heading (79-88 days) and medium days to maturity (120 days) when creating high-yielding genotypes for the heat-stress environment. Grain yield/plot had a negative and significant association with days to heading (-0.250) and canopy temperature (-0.642). It is indicated that the low canopy temperature has an effect on grain yield in a stressful environment and increases the grain yield.

Path coefficient analysis

Path analysis for morphological traits

The path coefficient analysis exhibited (Table 5) that the highest and positive direct effect on grain yield/plot was revealed by biological yield (0.9287), while the traits such as 1000-grain weight (0.0293), main spike weight (0.0167), number of spikelets/spike (0.0110), days to heading (0.0094), number of productive tillers/meter (0.0082), number of grains per spike (0.0066), main spike length (0.0061) revealed low positive direct effects. Days to maturity (-0.0199) demonstrated the negative direct effect on grain yield per pot (-0.0199).

Path analysis for physiological traits

According to physiological traits (Table 6), total chlorophyll content (0.5912), GGR21 (0.0853), GGR14 (0.0451), and GGR28 (0.0147) had the highest and most favorable direct effects on grain yield per plot. The canopy temperature had a negative direct effect (-0.1209) while favoring grain yield per plant indirectly through total chlorophyll content (0.0961), GGR14 (0.0592), GGR28 (0.0562), and GGR21 (0.0328). Path coefficient analysis showed that the residual effect is very low (0.02489). The results are consistent with past reports where direct positive effects for biological yield/plant, grain growth rate, grains/splike and spikelets/spike [35]; days to heading, plant height and chlorophyll [19]; number of effective tillers per plant and harvest index [31]; hundred-grain weight [29]; protein content and days to flowering [32, 34, 35] have been researched so far in bread wheat. The results suggest that physiological traits such as total chlorophyll content and GGR genes play a crucial role in determining grain yield/plot, while canopy temperature has a negative direct effect on grain yield/plot but can indirectly influence it through other physiological

Table 5 Path coefficient analysis showing direct (diagonal and bold) and indirect (off-diagonal) effects of different morphological traits on grain yield per plot under late sowing conditions.

Traits	DH	NPTP	MSL	MSW	NGPS	NSPS	DM	TGW	BY	r with GY
DH	**0.0127**	0.0001	0.0005	-0.0025	0.0007	0.0001	-0.0019	-0.0015	-0.1448	-0.250**
NPTP	0.0002	**0.0070**	-0.0011	0.0030	-0.0011	-0.0017	-0.0063	0.0014	0.1004	0.162*
MSL	-0.0011	0.0012	**-0.0064**	0.0122	-0.0052	-0.0036	-0.0035	0.0077	0.1754	0.533**
MSW	-0.0015	0.0010	-0.0038	**0.0206**	-0.0063	-0.0035	-0.0021	0.0072	0.1849	0.470**
NGPS	-0.0009	0.0008	-0.0032	0.0127	**-0.0103**	-0.0031	-0.0029	0.0068	0.1513	0.393**
NSPS	-0.0002	0.0018	-0.0035	0.0111	-0.0049	**-0.0065**	-0.0034	0.0063	0.2126	0.537**
DM	0.0013	0.0023	-0.0012	0.0023	-0.0016	-0.0012	**-0.0190**	0.0016	0.0906	0.098
TGW	-0.0016	0.0009	-0.0044	0.0131	-0.0061	-0.0036	-0.0027	**0.0113**	0.2621	0.638**
BY	**-0.0025**	**0.0009**	**-0.0015**	**0.0051**	**-0.0021**	**-0.0019**	**-0.0023**	**0.0039**	**0.7490**	**0.379****

Residual effect: 0.02489

FE: field emergence, DH: days to heading, PH: plant height (cm), NPTP: number of productive tillers/meter, PL: peduncle length (cm), MSL: main spike length (cm), MSW: main spike weight (g), NGPS: number of grains/spike, NSPS: number of spikelets/spike; DM: days to maturity, BY: biological yield /plot (kg), TGW: 1000-grain weight (g)

Table 6 Path coefficient analysis showing direct (diagonal and bold) and indirect (off-diagonal) effects of different physiological traits on grain yield per plot under late sowing conditions.

Traits	GGR14	GGR21	GGR28	CT	TTC	r with GY
GGR14	**-0.2027**	0.1701	0.1427	0.0083	-0.0008	**0.832****
GGR21	-0.1935	**0.1782**	0.1447	0.0092	-0.0009	**0.865****
GGR28	-0.1984	0.1768	**0.1458**	0.0090	-0.0009	**0.867****
CT	0.1341	-0.1297	-0.1048	**-0.0126**	0.0009	**-0.642****
TTC	**-0.1469**	**0.1435**	**0.1155**	**0.0100**	**-0.0011**	**0.748****

Residual effect: 0.02489

GGR14: grain growth rate at 14th days after anthesis, GGR21: grain growth rate at 21st days after anthesis, GGR28: grain growth rate at 28th days after anthesis, CT: canopy temperature (˚C), TCC: total chlorophyll content (%).

traits. These findings highlight the importance of understanding the complex interactions between different physiological traits in improving crop productivity.

Conclusions

According to the study, there is a significant amount of variation in bread wheat genotypes for each trait. High GCV and PCV were observed for total chlorophyll content and peduncle length and moderate GCV and PCV were observed for main spike weight, number of grains/spike and main spike length. Total chlorophyll content and main spike weight showed high heritability along with high genetic advance as a percentage of the mean. Grain yield/plot was significantly and positively correlated with main spike length, main spike weight, number of grains/spike, number of spikelets/spike, days to maturity, 1000-grain weight, biological yield/plot, GGR14, GGR21, GGR28, total chlorophyll content, and number of productive tillers/meter under stress environments. The direct selection of the aforementioned traits can increase grain yield in heat stressed environment. The grain yield/plot directly and positively effecting by biological yield/plot followed by the harvest index, GGR21, field emergence, GGR28, main spike weight, days to heading, 1000-grain weight and number of productive tillers/meter. Through biological yield/plot and harvest index, the majority of the characters contributed to the grain yield/plot in this research. Therefore, these traits must be given high importance during breeding for heat tolerance in wheat.

Conflict of interest

The authors declare no conflict of interest.

Reference

[1] Nuttonson MY. Wheat-climatic relationships and the use of phenology in ascertaining the thermal and photo thermal requirements of wheat. Washington, DC, American Institute of Crop Ecology; 1955.
[2] Percival J. The Wheat Plant. A monograph. New York, NY, USA, E.P. Dutton & Company; 1921.
[3] FAO. FAOSTAT. Food and Agriculture Organization of the United Nations, Rome, Italy; 2018.
[4] Anonymous. Progress report of the All India: Ministry of Agriculture and Farmer Welfare, Govt. of India; 2021.
[5] Irfan M, Abbas M, Shah JA, Akram MA, Depar N, Memon MY. Field study aiming at higher grain yield and nutrient use efficiency in wheat grown in alkaline calcareous soil. Sci Lett 2019; 7(1):1-9
[6] Rosegrant MW, Agcaoili M. Global food demand, supply, and price prospects to 2010. Washington, DC: International Food Policy Research Institute; 2010.
[7] Narayanan S. Effects of high temperature stress and traits associated with tolerance in wheat. Open Access J Sci 2018; 2(3):177–186.
[8] Okechukwu EC, Agbo CU, Uguru MI, Ogbonnaya FC. Germplasm evaluation of heat tolerance in bread wheat in Tel Hadya, Syria. Chiilleeaan J Agric Res 2016; 76:9-17.
[9] Wahid A, Gelani S, Ashraf M, Foolad MR. Heat tolerance in plants: An overview. Environ Exp Bot 2007; 61:199-223.
[10] Elbashier EM, Elbashier EME, Idris SE, Tadesse W, Tahir ISA, Ibrahim AES, et al. Genetic variations, heritability, heat tolerance indices and correlations studies for traits of bread wheat genotypes under high temperature. Int J Clim Chang Strateg Manag 2019; 11(5):672-686.
[11] Saha NR, Islam MT, Islam MM, Haque MS. Morpho-molecular screening of wheat genotypes for heat tolerance. Afr J Biotechnol 2020; 19(2):71-83.
[12] Burton GW. Quantitative inheritance in grasses. Proced. 6th Int. Grassland Cong. 1952; 1:127-183.16.
[13] Fisher RA. Statistical methods for research workers. Oliver & Boyd. Edinburgh; 1925.
[14] Burton GW, De V. Estimating heritability in tall Fescue from replicated clonal material. Agron J 1953; 45:475-481.
[15] Johnson HW, Robinson HF, Comstock RE. Estimates of genetic and environmental variability in wheat. Agron J 1955; 47:314-318.
[16] Al-Jibouri HA, Miller PA, Robinson H.F. Genetic and environmental variances and co-variances in upland cotton cross of interspecific origin. Agron J 1958; 50: 633-37.
[17] Wright S. Correlation and causation. J Agric Res 1921; 20: 557-585.
[18] Dewey DR, Lu KH. A correlation and path coefficient analysis of components crested wheat grass and seed production. Agron J 1959; 52:515–518.
[19] Ramanuj BD, Delvadiya IR, Patel NB, Ginoya AV. Evaluation of bread wheat (*Triticum aestivum* L.) genotypes for heat tolerance under timely and late sown conditions. Ind J Pure Apl Biosci 2018; 6(1):225-233.
[20] Chimdesa O, Mohammed W, Eticha F. Analysis of genetic variability among bread wheat (*Triticum aestivum* L.) genotypes for growth, yield and yield components in Bore District, Oromia Regional State. Gric For Fish 2017; 6(6):188-199.
[21] Balkan A. Genetic variability, heritability and genetic advance for yield and quality traits in M2-4 generations of bread wheat (*Triticum aestivum* L.) genotypes. Turkish J Field Crop 2018; 23(2):173-179.
[22] Ram M, Singh M, Agrawal RK. Genetic analysis for terminal heat stress in bread wheat (*Triticum Aestivum L.* EM THELL). Supp Genet Plant Breed 2014; 9(2):771-776,
[23] Zeeshan M, Arshad W, Khan MI, Ali S, Tariq M. Character association and casual effect of polygenic traits in spring wheat (Triticum aestivum L.) genotypes. Int J Agric For Fish 2014; 2(1): 16-22.
[24] Raaj N, Singh SK, Kumar A, Kumar A. Assessment of variability parameters in wheat in relation to terminal heat

tolerance. J Pharmacogn Phytochem 2018; 7(6): 2155-2160.
[25] Haydar FMA, Ahamed MS, Siddique AB, Uddin GM, Biswas KL, Alam MF. Estimation of genetic variability, heritability and correlation for some quantitative traits in wheat (*Triticum aestivum* L.). J Biosci 2020; 28: 81-86.
[26] Iqbal A, Khalil IH, Shah SMA, Kakar MS. Estimation of heritability, genetic advance and correlation for morphological traits in spring wheat. Sarhad J Agric 2017; 33(4):674-679.
[27] Wahidy S, Suresh BG, Lavanya GR. Genetic variability, correlation and path analysis in wheat germplasm (*Triticum aestivum* L.). Int J Multidiscip Des Dev 2016; 3(7):24-27.
[28] Thapa RS, Sharma PK, Pratap D, Singh T, Kumar A. Assessment of genetic variability, heritability and genetic advance in wheat (*Triticum aestivum* L.) genotypes under normal and heat stress environment. Indian J Agric Res 2019; 53(1): 51-56.
[29] Sharma P, Kamboj MC, Singh N, Chand M, Yadava RK. Path coefficient and correlation studies of yield and yield associated traits in advanced homozygous lines of bread wheat germplasm. Int J Curr Microbiol App Sci 2018; 7(2):51-63.
[30] Bhanu AN, Arun B, Mishra VK. Genetic variability, heritability and correlation study of physiological and yield traits in relation to heat tolerance in wheat (*Triticum aestivum* L.). Food Science and Technology Research 2018; 2(1):2112-2116.
[31] Nagar SS, Kumar P, Vishwakarma SR, Singh G, Tyagi BS. Assessment of genetic variability and character association for grain yield and its component traits in bread wheat (*Triticum aestivum* L.). J Appl Nat Sci 2018; 10(2):797 – 804.
[32] Kumari P, De N, Kumar A, Kumari A. Genetic variability, correlation and path coefficient analysis for yield and quality traits in wheat (*Triticum aestivum* L.). Int J Curr Microbiol App Sci 2020; 9(1):1281-1293.
[33] Baral S, Chhabra AK, Behl RK, Sikka VK, Bishnoi OP, Munjal R. Grain growth rate, canopy temperature depression, chlorophyll content and AGPase activity in relation to grain yield in spring wheat genotypes under late sown condition. J wheat res 2013; 5 (1): 50-54.
[34] Sawhney V, Singh DP. Effect of chemical desiccation at the post-anthesis stage on some physiological and biochemical changes in the flag leaf of contrasting wheat genotypes. Field Crops Res 2002; 77(1):1-6.
[35] Shenarvar A, Golparvar AR. Determination of best indirect selection criteria to improve seed yield in bread wheat (*Triticum aestivum* L.) genotypes. Res Crops 2015; 16(4): 719-721.