ISSN 2518–2021 (Print) 2415–4474 (Electronic)

Fundamental and Applied Agriculture

Journal home page: https://www.f2ffoundation.org/faa/index.php/home

Vol. 9(2), pp. 65 – 71: 2024, doi: https://doi.org/10.5455/faa.187752

Plant Breeding | ORIGINAL ARTICLE

Genetic variability, correlation and path analysis of yield and yield contributing characters in wheat (*Triticum aestivum* L.) under normal and terminal heat stress condition

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ARTICLE INFO

Article history
Received: 24 Jan 2024
Accepted: 24 Mar 2024
Published online: 30 June 2024

Keywords
Wheat (*Triticum aestivum* L.), Yield contributing character, Terminal heat stress, Genetic variability, Path analysis

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ABSTRACT

Genetic variability and characters association studies play a pivotal role in enhancing selection efficiency under stress condition in plants. Therefore, the study was aimed at assessing the impact of terminal heat stress on various morpho-physiological traits and their association in wheat under control and terminal heat stress condition. The experiment was conducted using thirty-five wheat genotypes in a Randomized Complete Block design (RCBD) plots on three different sowing dates to induce terminal heat stress. A range of 11 morpho-physiological parameters were assessed. All of the traits showed significant variations under studied conditions. Estimates of the genotypic and phenotypic coefficients of variation (GCV and PCV) showed that PCV was higher than GCV indicating large environmental influence on the expression of the traits under study. High GCV and PCV were observed in grain per plant and yield per plant in both normal and heat stress conditions. Chlorophyll content, grain per plant and yield per plant showed highest heritability with high genetic advance (GA) under both normal and terminal heat stress condition. According to the results of the path co-efficient analysis, grain per plant had a strong positive connection with grain yield and plant height and days to 50% flowering had a negative correlation with grain yield per plant under both normal and stress condition. Canopy temperature has direct negative effect on yield in stress condition. The identified traits can be used as effective selection criteria under terminal heat stress condition to develop high yielding heat tolerant wheat variety.

1. Introduction

Wheat is the most widely consumed type of grain around the world. FAO's prediction for world wheat production in 2023 has been boosted somewhat from early estimates in March to 786 million tonnes, which would be the second-highest output on record and just 1.3 percent lower than the 2022 level (Ajansi, 2023). Wheat alone plays a vital role in ensuring global food and nutrition security, accounting for one-fifth of global protein and food calories (Erenstein et al., 2022). The growth, development and output of a crop can be significantly impacted by a wide range of environmental factors. Two of the most significant of these are heat and drought stress. Consequently, increasing heat tolerance in wheat is a challenge for wheat breeders. Early senescence and slowing down grain-filling in wheat are two ways in which terminal heat stress affects grain yield during crop growth (Paulsen, 1994), as well as a reduction in the rate of carbon absorption and a corresponding shortening of the grain-filling duration. After anthesis, on the third day, a temperature increases from 15 to 20 degrees Celsius (day/night) to 40 to 15 degrees Celsius (day/night) resulted in a kernel weight loss of up to 23 percent. The temperature range was day/night (Stone and Nicolas, 1994). It is an alarming fact that the global population is growing at a very high rate, the number of crops that are grown needs to be increased to feed the rising population. During anthesis, high temperatures can lead to the production of pollen sterility, as well as impede the development of embryos, which leads to a decrease in grain number. The rate at which grains are filled out following anthesis is affected by high-temperature stress, which in turn leads to a drop in grain yield (Tashiro and Wardlaw, 1990). Increases in biomass, 1000-grain weight, stomatal conductance, canopy temperature, mobilization of stem reserve, growth rate of

Cite This Article

Das A, Das A, Muntaha S, Akhter S, Sagor GHM. 2024. Genetic variability, correlation and path analysis of yield and yield contributing characters in wheat (*Triticum aestivum* L.) under normal and terminal heat stress condition. *Fundamental and Applied Agriculture*, 9(2): 65–71. https://doi.org/10.5455/faa.187752

grain, and stay-green habit under heat stress conditions are all essential traits that can be easily included in a breeding program for heat tolerance (Joshi et al., 2017). Aside from the traits above-mentioned, some physiological traits like membrane stability index, greenness index, chlorophyll content, photosystem II efficiency etc. play an important role in heat tolerance in any crop (Cornish et al., 1991). One strategy that is commonly used to select heat stress tolerant plants is to grow breeding materials in an environment having high temperature and find individuals or lines with increased yield potential (Joshi et al., 2017). Traditional breeding programs have been used to improve wheat's heat tolerance; however, very little research has used both molecular characterization and physiological parameters in order to characterize the genetic diversity of wheat. Plant breeders can be benefited from information on late sowing, grain yield, and its constituent parts by boosting the effectiveness of selection in breeding programs. In this connection, the research was carried out with several genotypes to study on genetic variability of different traits and their association with yield under terminal heat stress conditions.

2. Materials and Methods

2.1. Plant materials

Thirty-five wheat genotypes were collected from Genetics and Plant Breeding department, Bangladesh Agricultural University (BAU) and Bangladesh Agricultural Research Institute (BARI). The name of genotypes used in the study were Sourav, Gourav, Sabia, Kheri, Kalyan sona, Wuhan, Opata, Sufi, Barkat, Sohora, Sonalika, Ananda, Swaghat, Pavan, Ning 3517, BL 1020, BAW 457, Shatabdi, BAW1027, DSN76, SADH 12, SADH 14, SADH 22, SADH 24, NK 5, KT-1-40, PV 79, KAV-2, DSN-117, SA 2, BARI Gom 25, BARI Gom 26, BARI Gom 30, BARI Gom 32 and BARI Gom 33.

2.2. Experimental site, duration, and design

The experiment was conducted at the Farm Laboratory of the Department of Genetics and Plant Breeding, BAU, Mymensingh. The field is situated at 24°75′ N latitude and 90°50′ E longitude, 18m above sea level. The farmland is part of the Old Brahmaputra floodplain Agro-ecological Zone and has non-calcareous dark grey floodplain soil. Sandy loam soil with a pH of 6.5 best describes the soil texture. The study was conducted during the Rabi season, from November 2022 to April 2023, using a randomized complete block design (RCBD) with three sowing dates *viz* 23rd Nov (optimum), 25st Dec, and 5th Jan. Terminal heat stress was imposed by manipulating sowing dates. Seeds were planted in 4 m x 1.25 m rows, with 25 cm and 5 cm spacings between rows and plants respectively, and 35 cm gaps between plots. Weeding was done on each 30 plots 30 days after sowing. Other agronomic practices were taken in standard dose to give high yield potential. Air temperature and humidity during the experimental period are presented in Table 1.

2.3. Observation recorded

Five plants were selected from each plot and data on plant height (PH), no. of spikelets per spike (NSPS), no. of tiller per plant (NTPP), spike length (SL), grain per spike (GPS), grain per plant (GPP), thousand grain weight (TGW), chlorophyll content (CC), canopy temperature (CT), days to 50% flowering (DFF) were recorded in each replication.

Table 1. Air Temperature and humidity data during the experiment period (2022-23)

Date	Air Temperature (°C)	Humidity (%)
10th November	24.7	81
20h November	23.3	83
30th November	21.9	79
10th December	23.1	77
20th December	19	78
30th December	19.3	84
10th January	20.6	84
20th January	17.7	85
30th January	16.7	78
10th February	17.3	91
20th February	20.8	70
28th February	23.8	79
10th March	26.3	69
20th March	27.0	69
30th March	27.9	84

2.4. Statistical analysis

Statistical analysis was performed using R-software, MS office excel program as done by Tithi and Sagor (2023).

3. Results

3.1. Analysis of variance and estimation of genetic parameters for morpho-physiological traits

To determine the importance of variations in the genotypes and treatments, an analysis of variance (ANOVA) was carried out. According to the analysis of variance, genotype mean squares were significant at the 5% level of probability (Table 2) for all the studied traits. All the traits were under the effects of terminal heat stress in a major way. Estimation of different genetic parameters *viz.* the mean, range, genotypic variances, phenotypic variances, phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability estimates in percentage, and predicted genetic advance as a percentage of the mean under both normal and stress condition were estimated and presented in Table 3 & 4. PCV value is higher than GCV value for the number of tiller per plant, number of spikelet per spike, grain per plant, thousand grain weight and yield per plant under both studied conditions. The highest heritability was observed for plant height, chlorophyll content, grains per plant and yield per plant in terminal heat stress condition. The highest percentage of genetic advance was also observed for chlorophyll content, grain per plant and yield per plant in stress condition, whereas, grain per spike in normal condition.

3.2. Correlation coefficient of the characters studied

The correlation analysis provides information regarding the strength and direction of the relationship between two variables in the experiment. Breeders get enough information for the selection of traits for their breeding program from this analysis. The correlation coefficients of the selected 11 morphological and physiological traits for the normal condition and the terminal heat stress condition are presented in Table 5 and Table 6, respectively. Yield per plant showed positive and significant correlation with the number of NSPS, NTPP, GPS, GPP, TGW, CC, and significant negative correlation with PH and DFF at both levels. Highest positive correlation was observed for GPP, CC and negative for days to 50% flowering. Upon terminal heat stress condition, CT shows negative correlation with yield in stress condition. Under heat stress condition, canopy temperature always showed negative correlation with all the studied traits except plant height. Days to 50% flowering was negatively correlated with all of the traits.

Table 2. Mean sum of squares for different quantitative characters of thirty-five wheat genotypes under study

Traits	Mean Sum of Squares					
	Replication (df=2)		Treatment (df=34)		Error (df=68)	
	Normal	Terminal heat stress	Normal	Terminal heat stress	Normal	Terminal heat stress
PH	0.012	0.574	272.253***	192.659***	0.425	0.7
NSPS	0.0024	0.0266	3.842***	7.6549***	0.2524	0.2651
NTPP	0.02073	0.03725	1.4548***	1.69155***	0.03482	0.05699
SL	0.00239	0.33616	1.6131***	1.5786***	0.02459	0.10761
GPS	0.383	1.2348	81.275***	10.7179***	0.829	1.1467
GPP	36.2	0.3	4911.2***	335.71***	19.1	0.91
TGW	0.03384	0.13831	0.88207***	1.05139***	0.01365	0.2459
CC	0.076	0.595	168.55***	185.62***	0.025	0.251
CT	0.7161	0.02695	4.0697***	2.04375***	0.3348	0.11009
DFF	1.2095	1.8667	28.2734***	16.0073***	0.4154	0.8569
YPP	0.03	0.04611	33.904***	2.8724***	0.011	0.01871

*, ** and *** Indicates significance at 5%, 1% and 0.1% level of significance. **Legend**: **PH**= Plant height, **NSPS**= No. of spikelets per spike, **NTPP**=No. of tiller per plant, , **SL**= Spike length, **GPS** = Grain per spike, **GPP** = Grain per plant, **TGW**= Thousand grain weight, **CC**= Chlorophyll content, **CT**= Canopy temperature, **DFF**= Days to 50% Flowering, **YPP**= Yield per plant

Table 3. Estimation of genetic parameters for 11 traits studied in 35 wheat genotypes under normal condition

Traits	Max	Min	Mean	Genotypic variation	Phenotypic variation	GCV (%)	PCV (%)	Heritability (%)	GA	GA%
PH	120.60	81.47	95.11	90.61	91.03	10.01	10.03	99.53	19.56	20.57
NSPS	18.83	14.00	15.99	1.20	1.45	6.84	7.53	82.58	2.05	12.80
NTPP	7.00	3.50	5.05	0.47	0.51	13.63	14.12	93.15	1.37	27.10
SL	12.33	9.21	10.75	0.53	0.55	6.77	6.92	95.56	1.47	13.63
GPS	41.66	16.57	23.88	26.82	27.65	21.68	22.01	97.00	10.51	10.51
GPP	210.00	65.00	103.95	1630.71	1649.78	38.85	39.08	98.84	72.71	79.57
TGW	5.90	3.45	4.52	0.29	0.30	11.91	12.19	95.51	1.08	23.98
CC	50.80	20.30	34.26	56.18	56.20	21.88	21.88	99.95	15.44	45.06
CT	25.80	19.50	21.91	1.25	1.58	5.09	5.74	78.81	2.04	9.31
DFF	68.00	53.00	59.98	9.29	9.70	5.08	5.19	95.72	6.14	10.24
YPP	14.35	2.33	5.24	11.30	11.31	64.16	64.19	99.91	6.92	132.10

Legend: **PH**= Plant height, **NSPS**= No. of spikelet per spike, **NTPP**=No. of tiller per plant, **SL**= Spike length, **GPS** = Grain per spike, **GPP** = Grain per plant, **TGW**=Thousand grain weight, **CC**= Chlorophyll content, **CT**= Canopy temperature, **DFF**= Days to 50% Flowering, **YPP**= Yield per plant

Table 4. Estimation of genetic parameters for 11 traits studied in 35 wheat genotypes under terminal heat stress

Traits	Max	Min	Mean	Genotypic variation	Phenotypic variation	GCV (%)	PCV (%)	Heritability (%)	GA	GA%
PH	105.7	66.00	82.95	63.99	64.69	9.64	9.70	98.92	16.39	19.76
NSPS	17.00	9.07	12.79	2.46	2.73	12.27	12.92	90.28	3.07	24.02
NTPP	5.33	1.67	3.19	0.54	0.60	23.14	24.32	90.53	1.45	45.36
SL	10.47	5.54	8.78	0.49	0.60	7.98	8.81	82.00	1.31	14.88
GPS	15.35	0.85	2.66	3.19	4.34	67.11	78.24	73.56	3.16	118.56
GPP	45.00	4.33	14.08	111.60	112.51	75.04	75.34	99.19	21.67	153.95
TGW	8.82	3.02	4.03	0.27	0.51	12.87	17.82	52.20	0.77	19.16
CC	44.00	13.5	25.33	61.79	62.04	31.03	31.10	99.60	16.16	63.80
CT	28.3	25.00	26.60	0.64	0.75	3.02	3.27	85.41	1.53	5.75
DFF	73.00	60.00	63.84	5.05	5.91	3.52	3.81	85.49	4.28	6.71
YPP	4.63	0.03	1.10	0.95	0.97	88.60	89.47	98.07	1.99	80.75

Legend: **PH**= Plant height, **NSPS**= No. of spikelet per spike, **NTPP**=No. of tiller per plant, **SL**= Spike length, **GPS** = Grain per spike, **GPP** = Grain per plant, **TGW**= Thousand grain weight, **CC**= Chlorophyll content, **CT**= Canopy temperature, **DFF**= Days to 50% Flowering, **YPP**= Yield per plant

Table 5. Correlation between the 11 traits of wheat genotypes under normal condition

	NSPS	NTPP	SL	GPS	GPP	TGW	CC	CT	DFF	YPP
PH	-0.251	-0.042	0.291*	-0.229	-0.206	0.022	-0.206	0.001	0.322*	-0.261
NSPS		0.429*	0.354*	0.385*	0.460**	0.440**	0.520**	-0.127	-0.415*	0.399*
NTPP			0.375*	0.381*	0.615***	0.524**	0.398*	-0.287*	-0.296*	0.586***
SL				0.247	0.158	0.337*	0.230	0.030	-0.142	0.206
GPS					0.612***	0.434**	0.543**	-0.356*	-0.424*	0.598***
GPP						0.783***	0.752***	0.038	-0.642***	0.934***
TGW							0.743***	0.115*	-0.467**	0.686***
CC								0.045	-0.519**	0.686***
CT									-0.045	0.102
DFF										-0.682***

*, ** and *** Indicates significance at 5%, 1% and 0.1% level of significance. **Legend**: **PH**= Plant height, **NSPS**= No. of spikelet per spike, **NTPP**=No. of tiller per plant, **SL**= Spike length, **GPS** = Grain per spike, **GPP** = Grain per plant, **TGW**= Thousand grain weight, **CC**= Chlorophyll content, **CT**= Canopy temperature, **DFF**= Days to 50% Flowering, **YPP**= Yield per plant

Table 6. Correlation between the 11 traits of wheat genotypes at genetic level under terminal heat stress condition

	NSPS	NTPP	SL	GPS	GPP	TGW	CC	CT	DFF	YPP
PH	-0.144	0.087	-0.117	0.034	0.102	0.176	-0.022	0.157	0.174	-0.104
NSPS		0.349*	0.446**	0.549**	0.642***	0.514**	0.465**	-0.193	-0.337*	0.627***
NTPP			0.387*	0.496**	0.476**	0.356*	0.432*	-0.476**	-0.041	0.417*
SL				0.485**	0.547**	0.519**	0.387*	-0.438**	-0.090	0.576***
GPS					0.805***	0.565***	0.746***	-0.593***	-0.020	0.573***
GPP						0.710***	0.830***	-0.368*	-0.209	0.832***
TGW							0.701***	-0.181	-0.100	0.628***
CC								-0.368*	-0.130	0.707***
CT									-0.046	-0.186*
DFF										-0.410*

*, ** and *** Indicates significance at 5%, 1% and 0.1% level of significance.

3.3. Path coefficient analysis

Path coefficient analysis effectively identifies direct and indirect relationships among plant traits using correlation coefficients. Table 7 and Table 8 show path analysis for grain yield under the normal condition and under the terminal heat stress condition, conducted using 10 independent characters, respectively. In normal condition, NTPP, SL, GPS, GPP and CT exhibited positive direct, and PH, NSPS, TGW, DFF exhibited negative direct effect on yield per plant. Considering heat stress condition, DFF, PH, GPS, TGW showed direct negative and NSPS, NTPP, SL, GPP, CC, CT showed direct positive effect on yield.

Table 7. Path coefficient analysis of wheat genotypes at genetic level under normal condition.

	PH	NSPS	NTPP	SL	GPS	GPP	TGW	CC	CT	DFF	YPP
PH	-0.063	0.026	-0.005	0.025	-0.022	-0.175	-0.003	-0.001	0.001	-0.043	-0.261
NSPS	0.017	-0.099	0.054	0.032	0.039	0.402	-0.069	0.003	-0.022	0.057	0.399*
NTPP	0.003	-0.045	0.117	0.032	0.038	0.529	-0.080	0.002	-0.042	0.040	0.586***
SL	-0.019	-0.037	0.044	0.086	0.024	0.132	-0.051	0.001	0.005	0.019	0.206
GPS	0.015	-0.039	0.046	0.021	0.097	0.522	-0.06	0.003	-0.053	0.057	0.598***
GPP	0.013	-0.047	0.073	0.014	0.060	0.847	-0.119	0.004	0.006	0.086	0.934***
TGW	-0.001	-0.045	0.062	0.029	0.043	0.670	-0.151	0.004	0.018	0.063	0.686***
CC	0.013	-0.053	0.047	0.020	0.053	0.638	-0.113	0.005	0.006	0.069	0.686***
CT	-0.0003	0.016	-0.035	0.003	-0.037	0.034	-0.019	0.0002	0.140	0.006	0.102
DFF	-0.021	0.042	-0.035	-0.012	-0.042	-0.550	0.072	-0.003	-0.006	-0.132	-0.68***

Bold values are indicating the direct effect and the others are showing indirect effects. *, ** and *** Indicates significance at 5%, 1% and 0.1% level of significance. Residual= 0.0028

Table 8. Path coefficient analysis of wheat genotypes at genetic level under terminal heat stress condition

	PH	NSPS	NTPP	SL	GPS	GPP	TGW	CC	CT	DFF	YPP
PH	**-0.134**	-0.004	0.009	-0.031	-0.010	0.079	-0.014	-0.005	0.033	-0.028	-0.104
NSPS	0.020	**0.031**	0.039	0.125	-0.160	0.510	-0.043	0.101	-0.039	0.052	0.627***
NTPP	-0.011	0.011	**0.109**	0.104	-0.145	0.378	-0.028	0.093	-0.098	0.006	0.417*
SL	0.016	0.015	0.043	**0.260**	-0.147	0.444	-0.044	0.086	-0.091	0.017	0.576***
GPS	-0.005	0.018	0.058	0.141	**-0.272**	0.664	-0.049	0.169	-0.127	0.001	0.573***
GPP	-0.013	0.020	0.052	0.148	-0.231	**0.781**	-0.058	0.178	-0.075	0.033	0.832***
TGW	-0.027	0.019	0.043	0.159	-0.186	0.633	**-0.071**	0.171	-0.042	0.019	0.628***
CC	0.003	0.014	0.047	0.104	-0.214	0.649	-0.057	**0.214**	-0.074	0.020	0.707***
CT	-0.022	-0.006	-0.054	-0.120	0.175	-0.295	0.015	-0.080	**0.198**	0.007	-0.186
DFF	-0.024	-0.010	-0.004	-0.028	0.001	-0.167	0.009	-0.028	-0.009	**-0.155**	-0.410*

Bold values are indicating the direct effect and the others are showing indirect effects. *, ** and *** Indicates significance at 5%, 1% and 0.1% level of significance. Residual= 0.003. Legend: PH= Plant height, NSPS= No. of spikelet per spike, NTPP=No. of tiller per plant, SL= Spike length, GPS = Grain per spike, GPP = Grain per plant, TGW= Thousand grain weight, CC= Chlorophyll content, CT= Canopy temperature, DFF= Days to 50% Flowering, YPP= Yield per plant

4. Discussion

4.1. Analysis of variance for morpho-physiological traits

High heritability estimates and genetic progress are mostly effective in cases of selection (Lal et al., 2001). Under both normal and terminal heat stress conditions, GCV was lower than the PCV, which signifies the impact of the environment on these traits' expressions (Gaikwad et al., 2011). Characters with the highest heritability under the normal condition, according to estimates (Table 3), included chlorophyll content (99.95%) and yield per plant (99.91%). Meanwhile, in the terminal heat stress condition (Table 4), the highest heritability was found in chlorophyll content (99.60%) and grain per plant (99.19%). (Lal et al., 2001) found strong heritability, modest genetic progress, and low GCV and PCV values for genotype selection. High GCV and PCV were observed in yield per plant and grain per panicle under the normal condition, but apart from these two characters, under terminal heat stress, high values were also observed in grain per spike and chlorophyll content. This suggests sufficient variability is present in the germplasm, additive gene action predominance and the high transmission ability of these characters. A similar result was also reported by Santosh and Jaiswal, 2019. A high difference between GCV and PCV was observed in grain per panicle under terminal heat stress conditions. High heritability with high genetic advance is suitable in cases of selection. Since high heritability with high GA accumulates more additive genes, this leads to further improvement in their performance. Among the traits under study, yield per plant (under normal condition) and grain per panicle (under heat stress condition) had a high GA%. Thus, the selection of these traits is effective for maximizing genetic gain.

4.2. Correlation coefficient of the characters studied

The study examines the correlation coefficients between various morphological and physiological traits associated with both the normal condition and the terminal heat stress condition. Improving yield is the ultimate goal of any breeding program. As yield is a complex trait, it is dependent on many factors. In the present investigation, yield per plant was observed to have a significant positive correlation with no. of spikelets per spike, no. of tiller per plant, spike length, grain per spike, grain per plant, thousand grain weight, chlorophyll content in both the normal and heat stress conditions (Table 5 and Table 6). Though canopy temperature had a positive correlation with yield in the normal condition, it showed a negative correlation under terminal heat stress. Plant height and days to 50% flowering showed a negative correlation in both conditions, which is supported by Mohanty et al., (2016). Thousand grain weight showed a negative correlation with days to 50% flowering but was positive with all other traits. This observation is supported by Khan et al., (2014) and AbdulHamid et al., (2017). Days to 50% flowering attained a negative correlation with yield per plant, which was in accordance with Mohammadi et al., (2012); Zafarnaderi et al., (2013). Chlorophyll content showed a negative correlation with plant height and days to 50% flowering under heat stress conditions; this finding aligns with Tithi and Sagor, (2023). No. of spikes per spikelet showed a positive correlation with all other traits except for canopy temperature and days to 50% flowering. The present finding was similar to Kumar et al., (2010), where it was noted that there was a positive correlation with plant height, no. of grains per spike and grain yield.

4.3. Path coefficient analysis

Path coefficient analysis was done using yield per plant as the dependent factor (effect) and other quantitative characters under study as independent factors (causes). The path coefficient analysis revealed that no. of spikelets per spike, no. of tillers per plant, spike length, grain per spike, grain per plant; total grain weight and chlorophyll content have a direct positive effect on grain yield per plant (Table 7 and Table 8). In both the normal and terminal heat stress conditions, grain per plant has the highest direct effect and a positive correlation with yield per plant. It means a slight increase in grain per plant will increase the yield significantly. The positive correlation between them is mainly due to the high positive direct effect of grain per plant on yield per plant. So, the direct selection of this trait will contribute to an increase in yield per plant. Plant height, thousand grain weight and days to 50% flowering showed a negative direct effect in both conditions. However, the correlation between grain weight and yield per plant is observed to be positive. Poudel et al. (2021) found plant height and thousand grain weight have a positive direct effect on grain yield in both the normal and terminal heat stress conditions, which is the opposite of our finding. But while the number of spikes per spikelet showed a negative direct effect in the normal condition, and it showed a positive direct effect in the terminal heat stress condition. Similar findings of Khaliq et al., (2004), Khokhar et al., (2010) and Zeeshan et al., (2014) supported this result. Again, grain per spike showed a positive direct effect in the normal condition, as found in Khan and Dar, (2010) but a negative direct effect in the terminal heat stress condition, with yield per plant showing a positive correlation in both.

5. Conclusion

The performance of 35 wheat genotypes with respect to terminal heat stress, yield, and factors that contribute to yield was analyzed. Significant variations were seen across genotypes for every trait, indicating genotype variability that would be useful in future breeding programs. The treatment effect was likewise significant for every characteristic. The direct selection of several yield-enhancing features will increase the genetic potential of wheat genotypes for grain output. No. of spikelets per spike, no. of tillers per plant, spike length, grain per spike, grain per plant, total grain weight and chlorophyll content are genotypic characteristics that have a direct positive effect on grain yield per plant. The higher value of the PCV than the GCV under both normal and terminal heat stress conditions indicates the influence of the environment on the expression of the selected traits. Under normal conditions, grain per plant showed higher GCV and PCV than any other traits. Whereas, under the terminal heat stress condition, yield per plant showed high GCV and PCV along with high heritability. As grain per panicle has the highest direct positive effect and positive correlation with yield per plant under both conditions, this criterion can be utilized for selection in heat tolerant genotypes.

Acknowledgements

Ministry of Education, Government of the People's Republic of Bangladesh, for funding through the BANBEIS and Bangladesh Agricultural University Research System (BAURES) for their outstanding financial management of the project.

Conflict of interest

The authors have declared that no competing interests exist.

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