Research Article

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Ekin
Journal of Crop Breeding and Genetics

7(1):34-42, 2021

Ekin International biannual peer-reviewed journal

Genetic Architecture of Morpho-Physiological Traits in Wheat Accessions under Terminal Heat Stress

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Citation:
Shehrawat S., Kumar Y., 2021. Genetic Architecture of Morpho-Physiological Traits in Wheat Accessions under Terminal Heat Stress. Ekin J. 7(1):34-42, 2021.

Received: 05.08.2020 ***Accepted: 18.10.2020*** ***Published Online: 29.01.2021*** ***Printed: 30.01.2021***

ABSTRACT

This study investigated genetic variability, character association and path analysis for 12 morphological and 6 physiological traits in fourty wheat accessions at CCS Haryana Agricultural University, Hisar during *rabi* 2018-19 growing season. The mean sum of squares due to genotypes were highly significant for all the morpho-physiological characters studied hereby indicates enough variability for selection of heat tolerant genotypes for further crop improvement. Phenotypic and genotypic coefficients of variation were recorded highest for grain yield followed by biological yield, peduncle length and 1000 grain weight, signifying scope for genetic improvement through selection. High heritability coupled with high genetic advance was reflected for grain yield, peduncle length, biological yield, 1000 grain weight and plant height. Correlation studies showed significant and positive association of grain yield with biological yield, 1000 grain weight, harvest index, SPAD 1, SPAD 2, grains per spike, spike length, peduncle length, NDVI 2, NDVI 1 and tillers per plant. Biological yield exerted the highest positive direct effect on grain yield followed by harvest index, SPAD1 and peduncle length. Hence, due emphasis should be given to these attributes for genetic improvement in wheat under heat stress condition.

***Keywords*: ** Genetic variability, correlation, path analysis, wheat, heat stress.

Introduction

Wheat (*Triticum aestivum* L), a self-pollinating annual plant in the true grass family Poaceae, is the largest cereal crop extensively grown as staple food in the world. It is one of the most important export and strategic cool-season cereal crop in the world in terms of production and utilization (Guin et al. 2019). Globally, India has the largest area under wheat cultivation and is the second largest producer after China. (USDA, 2017). Nationally, wheat is the second most important food crop after rice (Dey, 2020). It is cultivated extensively in North-Western and Central Zones. India has reported a record production of 101.20 million tonnes wheat from an area of 29.55 million hectare with a productivity of 3424 kg/ha during the crop season 2018-19. In Haryana, 11.65 million tonnes wheat was produced on an area of 2.51 million hectare with average productivity of 4643 kg/ha (ICAR-IIWBR, 2019).

In India, rice-wheat cropping system is spread over 11 million hectares in the Indo-Gangetic Plains and is important for national food security, but due to the long duration of basmati rice, sowing time of wheat in this region is pushed beyond the month of November. Wheat delayed sowing causes supra-optimal thermal stress at the reproductive phase (Preeti et al. 2016a). The prevalence of reproductive stage at heat stress has been found to be more detrimental in wheat production as compared to early heat stress due to its direct effect on grain number and grain weight (Nawaz et al. 2013). Low latitude zones, where around 100 million hectares of wheat is cultivated, are predominantly heat prone areas worldwide (Braun et al. 2010). In India the most significant impacts of high temperature are being experienced in the Gangetic plains zone in the form of shorter winters and the onset of significantly higher temperatures much earlier than normal (Chandra et al. 2017).

Therefore, heat can influence the different stages of crop growth during crop cultivation in Indo-Gangetic Plains (Preeti et al. 2016b).

To adapt new wheat varieties to the future climate change, we need to understand how they respond to elevated temperatures and how tolerance to heat can be improved (Halford 2009). Therefore, there is need to exploit the existing genetic variability in wheat for developing high yielding and good quality varieties under changing climatic scenario (Kant et al. 2014). Identification of genetically superior parents is an important pre-requisite for developing promising genotypes for effective transfer of targeted genes controlling both quantitative and qualitative traits in the resultant progenies. Thus, the estimation of genetic parameters like heritability and genetic advance is essential for a breeder which helps in understanding the magnitude, nature and interaction of genotype and environmental variation of the traits.

Correlation studies provide better understanding of yield component which helps the plant breeder during selection (Johnson et al. 1955). Path coefficient analysis measures the direct and indirect contribution of independent variables on dependent variables and thus helps breeder in determining the yield components and understanding cause of association between two variables. The information obtains by path coefficient analysis also helps in indirect selection for genetic improvement of yield because direct selection is not effective for low heritable trait like yield. Hence, the present investigation was carried out to evaluate genetic variability and to determine correlation coefficient and path analysis among morpho-physiological traits in wheat accessions under terminal heat stress conditions.

Materials and Methods

The present study was conducted at Research Area of Wheat and Barley Section of Department of Genetics & Plant Breeding, Chaudhary Charan Singh Haryana Agricultural University, Hisar located at an altitude of 215.2 meters above mean sea, latitude of 29º 10' N and at longitude of 75º 46' E. The experimental material consisted of 40 wheat accessions (Table 1) along with four check varieties namely WH 711, WH 542, WH 1124 and HD 3059 raised under optimum input conditions (150 kg N, 60 kg P_2O_5 and 25 kg $ZnSO_4$ per hectare based on soil testing reports). These wheat accessions were received from National Bureau of Plant Genetic Resources (NBPGR), New Delhi for screening against terminal heat stress tolerance. The experiment was planted on 24th December under late sown condition in randomized block design (RBD) with 3 replications during *rabi* season of 2018-19. Each accession was sown in paired rows of 2.5 m length with inter-row and inter-plant distances of 20 and 10 cm, respectively. Observations were recorded at specific stage on five randomly selected plants per accession per replication for 12 morphological traits *viz*., 1) days to heading, 2) days to maturity, 3) grain filling duration, 4) plant height (cm), 5) peduncle length (cm), 6) tillers per plant, 7) spike length (cm), 8) grains per spike, 9) 1000 grain weight (g), 10) grain yield per plant (g), 11) biological yield per plant (g) and 12) harvest index (%) and 6 physiological traits *viz.,* 1) normalized difference vegetation index at anthesis (NDVI 1), 2) normalized difference vegetation index at 15 days after anthesis (NDVI 2), 3) canopy temperature at anthesis (CT 1), 4) canopy temperature at 15 days after anthesis (CT 2), 5) soil plant chlorophyll development at anthesis (SPAD 1) and 6) soil plant chlorophyll development at 15 days after anthesis (SPAD 2).

The mean performance of each accession was recorded and employed for statistical analysis. Analysis of variance to test the significance for each character was carried out as per methodology advocated by Fisher (1925) and described by Panse and Sukhatme (1967). Phenotypic coefficient of variability (PCV) and genotypic coefficient of variability (GCV) were calculated by the formula given by Burton (1952), heritability in broad sense (h^2) was calculated by using the formula suggested by Hanson et al. (1956) and genetic advance that is the expected genetic gain was calculated by using the procedure given by (Johnson et al. 1955). Correlation and path coefficients were worked out as per method suggested by Al-Jibouri et al. (1958) and Dewey and Lu (1959), respectively.

Results and Discussion

The mean sum of squares due to genotypes were highly significant for all the morphological and physiological characters studied hereby indicating a wide range of allelic variability, which could be used for selection of heat tolerant genotypes for further crop improvement. The presence of significant variability has also been reported by Mansouri et al. (2018) and Suresh et al. (2018) for various morphological traits and for physiological traits by Sharma et al. (2018) and Sangwan et al. (2018).

Table 2 depicts the estimates of genetic variability parameters for all the characters. In general, the results revealed wide range for all the traits under investigation. Less difference in the estimates of genotypic and phenotypic variances depicted little influence of environment on the expression of traits studied. The estimates of genotypic and phenotypic coefficient of variation ranged from 2.99 to 24.42% and 3.63 to 26.20%, respectively. The perusal of data revealed highest phenotypic and genotypic coefficients of variation for grain yield followed by biological yield, peduncle length and 1000 grain weight, indicating availability of enough genetic variability and thus exhibited scope for genetic improvement through selection. However, days to heading and maturity exhibited least phenotypic and genotypic coefficients of variation. Similar findings were also reported by Veeresha and Naik (2016), Neeru et al. (2017), Mansouri et al. (2018) and Rathwa et al. (2018) in wheat.

Heritability determines the extent of genetic control of a given trait and its transmission to progeny and, hence has bearing on the selection efficiency of trait concerned. Heritability in broad sense was found to be maximum for 1000 grain weight (94.78%) followed by plant height (93.26%) and was recorded minimum for harvest index (62.32%). The estimates of heritability are more advantageous when expressed in terms of genetic advance. (Johnson et al. 1955) advocated consideration of heritability and genetic advance together for effective selection. High heritability coupled with high genetic advance reflected for grain yield, peduncle length, biological yield, 1000 grain weight and plant height, therefore, the variability present in these traits was of additive nature, which can be better utilized for crop improvement. These findings confirm with the results obtained by Kant et al. (2011), Neeru et al. (2017), Rathwa et al. (2018) and Suresh et al. (2018).

Correlation analysis was done separately for morphological and physiological traits, whose results have been presented in Table 3 and 4, respectively. The results of correlation analysis under heat stress condition revealed significant and positive association of grain yield with biological yield, 1000 grain weight, harvest index, grains per spike, spike length, peduncle length and tillers per plant; and significant negative association with days to heading and days to maturity. Significant positive correlation was also observed for days to heading with days to maturity; grain filling duration with days to maturity, plant height, peduncle length and biological yield; plant height with peduncle length, 1000 grain weight and biological yield; peduncle length with 1000 grain weight and biological yield; spike length with grains per spike and biological yield; grains per spike with 1000 grain weight, biological yield and harvest index; and 1000 grain weight with biological yield. Similar results were also obtained by Mohanty et al. (2016), Islam et al. (2017), Parihar et al. (2018), Suresh et al. (2018) and Sareen et al. (2020) in their studies. Likewise, significant negative correlation was recorded for days to heading with grain filling duration, plant height, peduncle length, tillers per plant and biological yield; days to maturity with spike length, tillers per plant; plant height with harvest index; and peduncle length with grains per spike and harvest index.

The estimates of correlation coefficients among different physiological traits and with grain yield are depicted in Table 4. The results showed significant positive correlation of grain yield with physiological traits *viz.,* NDVI 1, NDVI 2, SPAD 1 and SPAD 2, however CT 1 and CT 2 exhibited significant negative correlation with grain yield. Similar results were also obtained by Lopes and Reynolds (2012) and Kumar et al. (2018). Mohammadi et al. (2012) and Mansouri et al. (2018) also recorded negative correlation between grain yield and canopy temperature. Significant positive correlation was observed for NDVI 1 with NDVI 2, SPAD 1 and SPAD 2; NDVI 2 with SPAD 1 and SPAD 2; CT 1 with CT 2; and SPAD 1 with SPAD 2. Similarly, significant negative correlation was recorded for NDVI 1 and NDVI 2 with CT 2 and CT 1; and CT 2 with SPAD 1 and SPAD 2.

The results of path coefficient analysis for morphological traits are presented in Table 5 and for physiological traits in Table 6. Biological yield (0.856) exerted the highest positive direct effect on grain yield followed by harvest index (0.459) and peduncle length (0.222). Similar results were also reported by (Islam et al. 2017) and (Suresh et al. 2018). The highest negative direct effect on grain yield was recorded for plant height (-0.287). Mohanty et al. (2016) and Suresh et al. (2018) also reported negative direct effect of plant height on grain yield, which support our finding. The results also showed maximum positive indirect effect of 1000 grain weight on grain yield through biological yield, whereas, plant height exhibited highest negative indirect effect *via* harvest index. The low residual effect (0.013) indicated that most of the variability in grain yield for the genotypes under study has been explained by the independent variables included in the analysis.

The path analysis for physiological characters revealed that the traits SPAD 1 had maximum direct effect on grain yield, followed by SPAD 2 and NDVI 1. These results are similar to the findings of Mądry et al. (2015), Neeru et al. (2017) and Khanal et al. (2020). The trait SPAD 2 had highest positive, while CT 2 recorded highest negative indirect effect on grain yield through SPAD 1. A residual factor of 0.749 depicted that six physiological parameters used in the study were unable to account for a major portion of the variability present in grain yield. It also denotes that other possible independent variables which were not included in the study had a significant effect on grain yield. No value of direct effect exceeded one indicating that inflation due to multicollinearity was minimal. The traits *viz.,* biological yield, harvest index, peduncle length and SPAD 1 exhibited true positive association, while canopy temperature exhibited true negative association with grain yield as the values of their genotypic correlation coefficients and direct effect on grain yield are fairly close to each other. Consequently, it is suggested that these parameters can be considered as key components for wheat improvement under heat stress.

Table 1. List of wheat genotypes used in the study.

Sr. No.	Accessions	Accession No.	Sr. No.	Accessions	Accession No.
1	DT 5	IC 335583	21	DT 139	IC 335968
2	DT 25	IC 335966	22	DT 142	IC 111844
3	DT 46	EC 609336	23	DT 147	IC 445528
4	DT 54	EC 276983	24	DT 150	IC 535772
5	DT 83	IC 296756	25	DT 151	IC 535518
6	DT 101	IC 543401	26	DT 153	EC 276814
7	DT 102	EC 277323	27	DT 154	IC 543364
8	DT 104	EC 276920	28	DT 168	EC 276864
9	DT 106	IC 534137	29	DT 169	IC 547701
10	DT 109	IC 402058	30	DT 171	EC 295392
11	DT 110	IC 276717	31	DT 175	EC 478016
12	DT 113	IC 542124	32	DT 176	EC 299085
13	DT 114	EC 313735	33	DT 177	EC 573837
14	DT 116	EC 519498	34	DT 178	IC 128664
15	DT 122	EC 577722	35	DT 181	EC 577619
16	DT 124	IC 47337	36	DT 183	IC 535848
17	DT 125	EC 609337	37	DT 187	IC 445522
18	DT 126	EC 445157	38	DT 190	IC 335932
19	DT 127	EC 609574	39	DT 191	EC 519501
20	DT 137	IC 35143	40	DT 192	EC 13263
Check Variety 1	WH 711		Check Variety 3	WH 1124	
Check Variety 2	WH 542		Check Variety 4	HD 3059	

Table 2. Genetic variability parameters for different morpho-physiological traits.

Traits	Mean ± SE	Range	GCV (%)	PCV (%)	Heritability (bs) (%)	Genetic Advance (% of mean)
DH+	83.93 ± 1.77	75.00 - 93.33	4.99	6.18	65.23	8.30
DM	120.72 ± 1.44	115.00 - 129.67	2.99	3.63	67.76	5.06
GFD	30.77 ± 1.08	22.67 - 37.67	8.81	10.70	67.79	14.95
PH	104.59 ± 2.71	75.07 - 145.27	16.70	17.29	93.26	33.22
PL	36.47 ± 1.11	21.90 - 49.90	18.70	19.43	92.59	37.06
SL	10.81 ± 0.33	8.63 - 13.37	9.07	10.53	74.26	16.10
TIL	7.25 ± 0.27	5.27 - 9.20	10.10	12.02	70.68	17.50
GPS	53.68 ± 1.35	43.67 - 62.73	8.95	9.95	80.76	16.56
TGW	32.98 ± 0.78	20.91 - 43.76	17.37	17.84	94.78	34.83
BY	27.74 ± 1.61	16.97 - 36.90	19.51	21.94	79.09	35.75
GY	8.59 ± 0.47	5.10 - 14.10	24.42	26.20	86.83	46.87
HI	31.27 ± 2.10	18.13 - 41.95	14.96	18.95	62.32	24.33
NDVI 1	0.75 ± 0.02	0.63 - 0.83	6.44	7.87	67.08	10.87
NDVI 2	0.67 ± 0.02	0.50 - 0.74	7.36	8.47	75.55	13.18
CT 1	24.65 ± 0.67	22.47 - 28.37	6.58	8.11	65.83	10.99
CT 2	28.48 ± 0.72	25.03 - 31.23	5.68	7.18	62.41	9.24
SPAD 1	44.55 ± 1.93	32.73 - 55.6	10.62	13.01	66.74	17.88
SPAD 2	40.25 ± 1.34	30.30 - 49.13	9.09	10.77	71.24	15.81

+**DH:** Days to heading (day), **DM:** Days to maturity (day), **GFD:** Grain filling duration (day), **PH:** Plant height (cm), **PL:** Peduncle length (cm), **SL:** Spike length (cm), **TIL:** Tillers per plant, **GPS:** Grains per spike (%), **TGW:** 1000-grain weight (g), **BY:** Biological yield per plant (g), **GY:** Grain yield per plant (g), **HI:** Harvest index (%), **NDVI1:** Normalized difference vegetation index at anthesis, **NDVI 2:** Normalized difference vegetation index at 15 days after anthesis, **CT 1:** Canopy temperature at anthesis, **CT 2:** Canopy temperature at 15 days after anthesis, **SPAD 1:** Soil plant chlorophyll development at anthesis, **SPAD 2:** Soil plant chlorophyll development at 15 days after anthesis

Table 3. Genotypic correlation coefficients among different morphological traits in wheat genotypes.

Traits	DH	DM	GFD	PH	PL	SL	TIL	GPS	TGW	BY	HI	GY
DH⁺	1.000	0.630**	-0.402**	-0.307**	-0.431**	-0.077	-0.211*	0.092	-0.097	-0.297**	0.001	-0.274**
DM		1.000	0.544**	-0.068	-0.045	-0.172*	-0.291**	0.002	-0.008	-0.170	-0.029	-0.188*
GFD			1.000	0.239**	0.327**	-0.068	0.066	-0.060	0.134	0.225**	-0.049	0.135
PH				1.000	0.824**	-0.106	0.086	-0.120	0.491**	0.583**	-0.667**	0.088
PL					1.000	0.075	0.003	-0.257**	0.526**	0.537**	-0.282**	0.288**
SL						1.000	-0.118	0.503**	0.160	0.296**	0.046	0.323**
TIL							1.000	-0.102	0.042	0.163	0.143	0.213*
GPS								1.000	0.291**	0.322**	0.217*	0.414**
TGW									1.000	0.784**	0.100	0.719**
BY										1.000	-0.106	0.789**
HI											1.000	0.517**
GY												1.000

*, ** Significant at 5% and 1% level, respectively

⁺**DH**: Days to heading (day), **DM:** Days to maturity (day), **GFD:** Grain filling duration (day), **PH:** Plant height (cm), **PL:** Peduncle length (cm), **SL:** Spike length (cm), **TIL:** Tillers per plant, **GPS:** Grains per spike (%), **TGW:** 1000-grain weight (g), **BY:** Biological yield per plant (g), **GY:** Grain yield per plant (g), **HI:** Harvest index (%)

Table 4. Genotypic correlation coefficients among different physiological traits and grain yield in wheat genotypes.

Physiological Traits	NDVI 1	NDVI 2	CT 1	CT 2	SPAD 1	SPAD 2	GY
NDVI 1⁺	1.000	0.698**	-0.07	-0.561**	0.369**	0.427**	**0.274****
NDVI 2		1.0001	-0.157	-0.316**	0.514**	0.421**	**0.285****
CT 1			1.000	0.214*	-0.265**	-0.221*	**-0.200***
CT 2				1.000	-0.478**	-0.418**	**-0.364****
SPAD 1					1.000	0.862**	**0.467****
SPAD 2						1.000	**0.415****

*, **Significant at 5% and 1% level, respectively

⁺**NDVI 1:** Normalized difference vegetation index at anthesis, **NDVI 2:** Normalized difference vegetation index at 15 days after anthesis, **CT 1:** Canopy temperature at anthesis, **CT 2:** Canopy temperature at 15 days after anthesis, **SPAD 1:** Soil plant chlorophyll development at anthesis, **SPAD 2:** Soil plant chlorophyll development at 15 days after anthesis

Table 5. Direct (diagonal values) and indirect effects of different morphological traits on grain yield in wheat genotypes.

Traits	DH	DM	GFD	PH	PL	SL	TIL	GPS	TGW	BY	HI	Correlation with GY
DH+	**0.057**	-0.062	-0.015	0.088	-0.096	0.004	-0.003	0.008	-0.001	-0.254	0.000	**-0.274****
DM	0.036	**-0.098**	0.020	0.020	-0.010	0.009	-0.004	0.000	0.000	-0.146	-0.013	**-0.188***
GFD	-0.023	-0.054	**0.036**	-0.069	0.073	0.003	0.001	-0.005	0.001	0.193	-0.023	**0.135**
PH	-0.017	0.007	0.009	**-0.287**	0.183	0.005	0.001	-0.010	0.004	0.499	-0.306	**0.088**
PL	-0.024	0.005	0.012	-0.236	**0.222**	-0.004	0.000	-0.021	0.005	0.460	-0.130	**0.288****
SL	-0.004	0.017	-0.002	0.031	0.017	**-0.049**	-0.002	0.041	0.001	0.253	0.021	**0.323****
TIL	-0.012	0.029	0.002	-0.025	0.001	0.006	**0.014**	-0.008	0.000	0.140	0.066	**0.213***
GPS	0.005	0.000	-0.002	0.034	-0.057	-0.025	-0.001	**0.081**	0.003	0.276	0.100	**0.414****
TGW	-0.006	0.001	0.005	-0.141	0.117	-0.008	0.001	0.024	**0.009**	0.672	0.046	**0.719****
BY	-0.017	0.017	0.008	-0.167	0.119	-0.015	0.002	0.026	0.007	**0.856**	-0.049	**0.789****
HI	0.000	0.003	-0.002	0.191	-0.063	-0.002	0.002	0.018	0.001	-0.091	**0.459**	**0.517****

Residual factor = 0.0135

*, ** Significant at 5% and 1% level, respectively

+**DH:** Days to heading (day), **DM:** Days to maturity (day), **GFD:** Grain filling duration (day), **PH:** Plant height (cm), **PL:** Peduncle length (cm), **SL:** Spike length (cm), **TIL:** Tillers per plant, **GPS:** Grains per spike (%), **TGW:** 1000-grain weight (g), **BY:** Biological yield per plant (g), **GY:** Grain yield per plant (g), **HI:** Harvest index (%)

Table 6. Direct (diagonal values) and indirect effects of different physiological traits on grain yield in wheat genotypes.

Physiological Traits	NDVI 1	NDVI 2	CT 1	CT 2	SPAD 1	SPAD 2	Correlation with GY
NDVI 1+	**0.032**	0.016	0.005	0.088	0.119	0.015	**0.274****
NDVI 2	0.022	**0.023**	0.011	0.049	0.165	0.014	**0.285****
CT 1	-0.002	-0.004	**-0.068**	-0.033	-0.085	-0.008	**-0.148**
CT 2	-0.018	-0.007	-0.015	**-0.156**	-0.154	-0.014	**-0.364****
SPAD 1	0.012	0.012	0.018	0.075	**0.322**	0.030	**0.467****
SPAD 2	0.014	0.010	0.015	0.065	0.277	**0.034**	**0.415****

Residual factor = 0.7499

*, ** Significant at 5% and 1% level, respectively

+**NDVI 1:** Normalized difference vegetation index at anthesis, **NDVI 2:** Normalized difference vegetation index at 15 days after anthesis, **CT 1:** Canopy temperature at anthesis, **CT 2:** Canopy temperature at 15 days after anthesis, **SPAD 1:** Soil plant chlorophyll development at anthesis, **SPAD 2:** Soil plant chlorophyll development at 15 days after anthesis

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