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Selection parameters for improving grain yield of bread wheat under terminal heat stress

VIJAY KAMAL MEENA[1], R K SHARMA[1]*, SURESH YADAV[1], NARESH KUMAR[1], RAHUL GAJGHATE[2] and ATTAR SINGH[1]

Division of Genetics, ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India

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ABSTRACT

Improving terminal heat tolerance is an issue of top priority in wheat breeding in the present era of climate change. Present study was carried out to identify the association among traits of economic importance under terminal heat stress environment. The grain yield/sq. meter under terminal heat stress environment recorded highly significant positive correlation both at genotypic and phenotypic level with grain weight/spike, number of spike/sq. meter, harvest index and 1000-grain weight in both the crop seasons. Path coefficient analysis carried out using genotypic correlation coefficients revealed that days to heading contributing maximum positive direct effect towards grain yield under terminal heat stress environment followed by grain filling duration. Other characters contributing positive direct effects towards grain yield were grain weight/spike, number of spike/sq. meter, harvest index and biological yield/sq. meter under both the crop season. Thus, for improving the wheat grain yield under terminal heat stresses conditions, breeder should aim for selecting genotypes with bold grains or high grain weight /spike, more number of tillers/sq. meter, higher harvest index and longer grain filling duration.

Keywords: Bread Wheat, Correlation, Path Analysis, Terminal Heat Stress, Yield Components

Bread wheat (*Triticum aestivum* L. em. Thell) is an important temperate cereal crop of crucial importance for national food security. The crop has been under cultivation in about 30 million hectares (14% of global area) to produce the all time highest output of 99.70 million tonnes of wheat (13.64% of world production) with a record average productivity of 3371 kg/ha (Mo A & FW, 2018).Wheat and barley are relatively well adapted to cooler environments and sensitive to increased temperature (Raza *et al.* 2019). Temperature is one of the main natural factors which played an important role in development of crop as different growth stages of a particular crop required a specific or optimum range of temperature (Akter and Rafiqul Islam 2017). Heat stress is a complex function of intensity (temperature in degrees), duration and rate of increase in temperature (Farooq *et al.* 2011, Hasanuzzaman *et al.* 2013). Wheat experiences heat stress to varying degrees at different growth stages, but heat stress or high temperature during the reproductive phase was found to be more harmful than during the vegetative phase due to the direct effect on grain number and dry weight (Fan *et al*. 2018).The optimum temperature for wheat anthesis and grain filling ranges from 12–22^{0}C and rise in temperature above this range is harmful to grain yield. Therefore, improving the grain yield under terminal heat stress is of utmost priority. Unlike the biotic stress, heat stress is more complex in nature as it could not be measured on its own. It has to be measured in terms of its manifestation towards changing performance of a genotype for a given trait (Ram *et al.* 2015). To get the maximum grain yield under particular stress environment needs a specific set of desirable characters in the crop plants. The association studies among the grain and yield component traits under terminal heat stress conditions led to identification of selection criteria to be used for selecting high yielding genotypes. Therefore, the present investigation was undertaken to examine the inter relationships among grain yield components and some physiological characters under terminal heat stress conditions.

MATERIALS AND METHODS

The experimental material for the present investigation is consisted of 36 diverse bread wheat genotypes including released varieties of different zones of the country and pre-released advance lines developed at wheat breeding programme of ICAR-IARI, New Delhi. These genotypes were sown at the Experimental Farm, Division of Genetics,

Present address: [1]Division of Genetics, ICAR-Indian Agricultural Research Institute, New Delhi; [2]Crop Improvement Division, ICAR-Indian Grassland and Fodder Research Institute, Jhansi. *Corresponding author e-mail: sharma.rk.rk@gmail.com.

ICAR-IARI, New Delhi during *Rabi* 2016–17 and 2017–18 under very late sown (9th Jan 2017 and 8th Jan 2018) conditions using Randomized Block Design with three replications. Each genotype was sown in a six-row plot having a gross area of 5 m × 1.20 m with a row spacing of 20 cm using self-propelled Norwegian Seed Drill in a well prepared field. Recommended package of practices were followed to raise the healthy crop. The observations were recorded on 13 quantitative characters, viz. days to 50% flowering (HDNG), days to maturity (DTM), number of spike per square meter (SPMS), number of grains/spike (GNPS), ear length (cm) (SL), plant height (cm) (PH), grain filling period (GFD), Grain weight per spike (GWPS)(g), 1000 grain weight (TGW)(g), grain yield per square meter (YPMS)(g), biological yield per square meter (BYPMS)(g) and harvest index (HI). The canopy temperature depression (CTD) was measured at anthesis stage of the unirrigated crop using a portable infrared thermometer (Model AG-42, Teletemp Corporation, Fullerton, CA) with a view of 2.5^0C. The mean performance of each genotype was subjected to analysis of variance. Phenotypic and genotypic correlation coefficients were calculated as per the Al-Jibouri *et al.* (1958) and path coefficient analysis carried out as suggested by Wright (1921) and elaborated by Dewey and Lu (1959).

RESULTS AND DISCUSSION

The weather data of the both the crop seasons (Fig 1) (2016-17) and (Fig 2) (2017-18) which reflected the maximum and mean temperature during the crop season is high. The analysis of variance for all the traits during both the crop seasons revealed highly significant difference among the genotypes suggested the wide range of variability present in the set of genotypes. The grain yield of the wheat crop is a complex quantitative trait and the results of interaction of various yield components, physiological processes and environmental conditions.

Correlation coefficient analysis statistically measured the degree and direction of relationship between two traits. The knowledge of association among the various component traits with grain yield under terminal heat stress environment is of prime importance for the plant breeders to make effective selection to improve the grain yield. The phenotypic correlation represented both genotypic and environmental association while genotypic correlation represented the heritable association between the traits and it may be due to effect of either pleiotropic or linkage effects or due to both (Falconer 1960, Cheverudi 1982) (Table 1). The perusal of phenotypic and genotypic correlation coefficients in both the crop seasons revealed that in general, phenotypic and genotypic correlation had same sign but the magnitude of genotypic or heritable correlations were higher than that of phenotypic correlations, indicating that the elimination of environmental effects led to further strengthen the genetic association. During crop season 2016-17, YPMS under terminal stress environment recorded highly significant positive correlation both at Phenotypic and genotypic level with GWPS (0.884** and 0.874**), SPMS (0.829**and 0.826**), HI (0. 821** and 0.820**), GNPS (0.603** and 0.589**), PH (0.446** and 0.442**), DTM (0.463** and 0.453**), TGW (0.776** and 0.773**), DTH (0.371** and 0.367**) and SL (0.256* and 0.247*). During crop season 2017-18, grain yield/square meter under terminal stress environment recorded highly significant positive correlation both at phenotypic and genotypic level with BYPMS (0.698**, 0.673**), number of spike /sq meter (0.694**, 0.670**), GWPS (0.675** and 0.696**), HI (0.

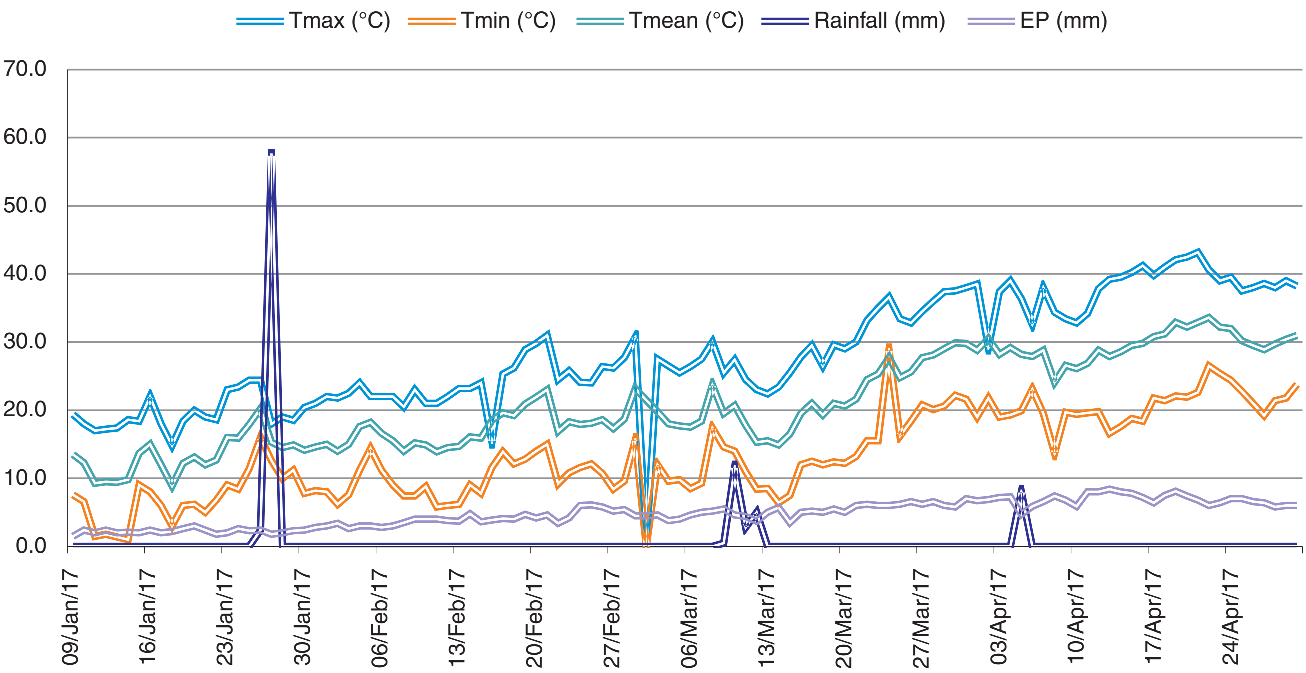

Fig 1 Weather data during growing seasons 2016-17.

Table 1 Phenotypic and Genotypic correlation coefficients among 13 characters for 2016-2017 (Lower diagonal) and 2017-2018 (upper diagonal)

	Phenotypic Correlation													
	2017-18													
	Traits	HDNG	DTM	GFD	PH	SL	GWPS	GNPS	SPMS	YPMS	BYPMS	HI	TGW	CTD
	HDNG	-	0.912**	-0.27**	-0.21*	-0.082	0.170	0.280**	-0.64**	-0.34**	-0.52**	0.116	-0.138	0.117
	DTM	0.731**	-	0.151	-0.204*	-0.061	0.087	0.272**	-0.59**	-0.36**	-0.47**	0.013	-0.196*	0.182
	GFD	-0.64**	0.055	-	0.032	0.051	-0.205*	-0.041	0.172	-0.019	0.157	-0.25**	-0.124	0.143
	PH	0.048	0.161	0.113	-	-0.099	-0.005	-0.28**	0.21*	0.134	0.444**	-0.3**	0.195*	0.111
	SL	0.240*	0.156	-0.175	-0.006	-	-0.25**	0.124	-0.127	-0.25**	-0.087	-0.236*	-0.212*	0.072
2016-17	GWPS	0.496**	0.488**	-0.176	0.413**	0.209*	-	0.119	-0.057	0.696**	0.147	0.749**	0.585**	0.285**
	GNPS	0.369**	0.237*	-0.28**	0.196*	0.385**	0.655**	-	-0.132	-0.020	-0.081	0.091	-0.72**	-0.113
	SPMS	0.088	0.294**	0.203*	0.309**	0.237*	0.486**	0.334**	-	0.670**	0.799**	0.026	0.089	0.000
	YPMS	0.367**	0.453**	-0.026	0.442**	0.247**	0.884**	0.589**	0.826**	-	0.673**	0.578**	0.508**	0.232*
	BYPMS	0.064	0.200*	0.130	0.182	-0.069	0.105	-0.036	0.149	0.182	-	-0.203*	0.182	0.199*
	HI	0.331**	0.282**	-0.165	0.327**	0.258**	0.774**	0.632**	0.652**	0.820**	-0.37**	-	0.441**	0.009
	TGW	0.445**	0.499**	-0.090	0.391**	0.060	0.906**	0.292**	0.393**	0.773**	0.139	0.623**	-	0.300**
	CTD	0.102	0.356**	0.252**	0.049	0.019	0.069	0.052	0.075	0.091	0.030	0.011	0.057	-
	Genotypic Correlation													
	2017-18													
	Traits	HDNG	DTM	GFD	PH	SL	GWPS	GNPS	SPMS	YPMS	BYPMS	HI	TGW	CTD
	HDNG	-	0.914**	-0.27**	-0.211*	-0.083	0.185	0.282**	-0.65**	-0.36**	-0.53**	0.130	-0.141	0.118
	DTM	0.736**	-	0.148	-0.205*	-0.061	0.099	0.275**	-0.60**	-0.38**	-0.48**	0.020	-0.201*	0.184
	GFD	0.652**	0.034	-	0.033	0.054	-0.212*	-0.040	0.170	-0.018	0.158	-0.28**	-0.128	0.146
	PH	0.047	0.163	0.113	-	-0.097	0.007	-0.28**	0.221*	0.147	0.450**	-0.32**	0.210*	0.118
	SL	0.241*	0.159	0.177	-0.007	-	-0.29**	0.124	-0.121	-0.26**	-0.084	-0.27**	-0.224*	0.077
2016-17	GWPS	0.502**	0.500**	-0.180	0.419**	0.220*	-	0.133	-0.054	0.675**	0.155	0.727**	0.552**	0.302**
	GNPS	0.376**	0.240*	-0.29**	0.203*	0.392**	0.673**	-	-0.132	-0.017	-0.086	0.113	-0.74**	0.115
	SPMS	0.090	0.299**	0.204*	0.311**	0.243*	0.491**	0.341**	-	0.694**	0.806**	0.019	0.097	0.002
	YPMS	0.371**	0.463**	-0.028	0.446**	0.256**	0.884**	0.603**	0.829**	-	0.698**	0.540**	0.480**	0.237*
	BYPMS	0.064	0.201*	0.128	0.184	-0.073	0.106	-0.042	0.150	0.183	-	-0.216*	0.191*	0.200*
	HI	0.335**	0.291**	-0.166	0.330**	0.268**	0.775**	0.653**	0.655**	0.821**	-0.37**	-	0.395**	0.005
	TGW	0.455**	0.520**	-0.089	0.399**	0.072	0.909**	0.321**	0.400**	0.776**	0.144	0.624**	-	0.312**
	CTD	0.104	0.363**	0.253**	0.049	0.018	0.071	0.049	0.076	0.093	0.030	0.010	0.063	-

540**, 0.578**), TGW (0.480** and 0.508**) and CTD (0.237*, 0.232*). Highly significant correlation coefficient was exhibited by YPMS with DTH (-0.357**, -0.346**), DTM (-0.373**, -0.473**) and SL (-0.266**, -0.252**) both at genotypic and phenotypic level. Likewise, we have found significant phenotypic and genotypic positive correlation between other traits also. Negatively genotypic and phenotypic significant correlation were found between DTH and GFD (-0.267**, 0.266**) and between DTH with PH (-0.211*, -0.210*). PH recorded negatively significant correlation with DTM (-0.205*, -0.204*) and GNPS (-0.281**, 0.275**) both at genotypic and phenotypic level. Among all the physiological traits, CTD showed significant genotypic and phenotypic correlation in positive direction with GWPS (0.302**, 0.285**), YPMS (0.237*, 0.232*), BYPMS (0.200*, 0.199*) and TGW (0.312**, 0.300**).

The comparative correlation coefficients for both crop seasons revealed that grain YPMS under terminal heat stress environment recorded highly significant positive correlation both at genotypic and phenotypic levels with GWPS, number of spike/sq. meter, HI and TGW in both the crop seasons. Therefore, degree of relationship between these attributes and YPMS appeared to be more meaningful or stable. These findings are in conformity with the findings of earlier researchers. Maintaining grain weight under heat stress during grain filling is a measure of heat tolerance (Tyagi *et al.* 2003, Singha *et al.* 2006). In this regard, Dias and Lidon (2009) proposed that high grain-filling rate and

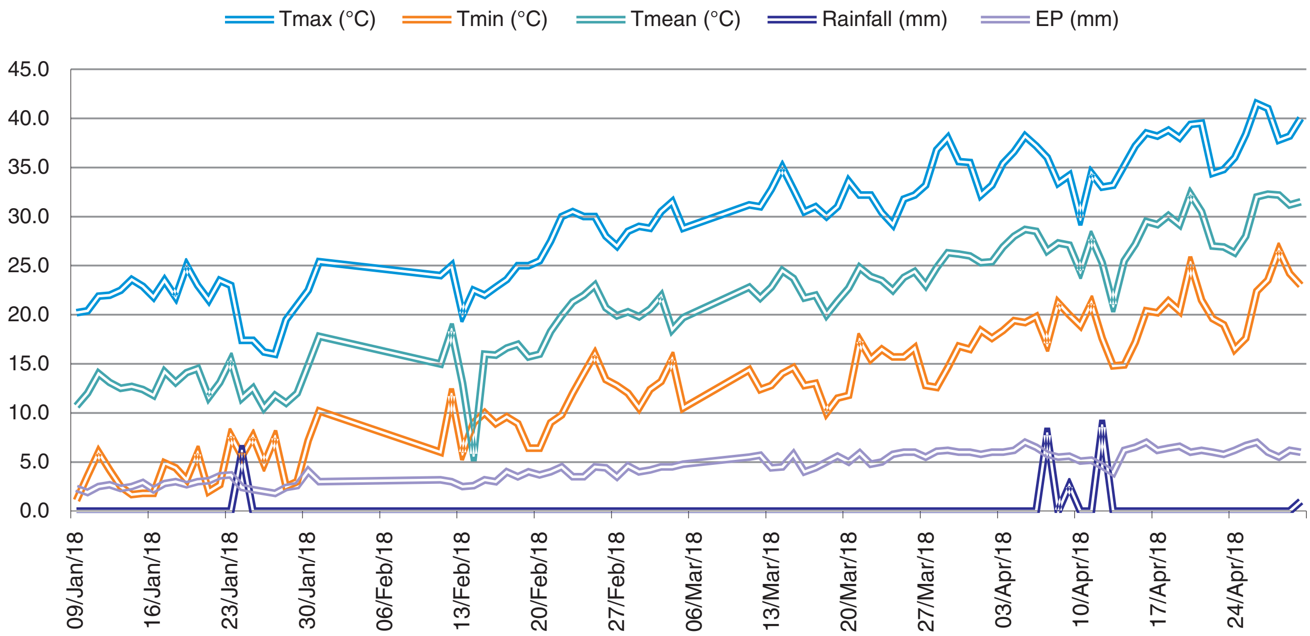

Fig 2 Weather data during growing seasons 2017-18.

Table 2 Genotypic path coefficient analysis showing direct (diagonal) and indirect (off-diagonal) effects of 12 characters on grain yield during 2016-17 and 2017-18

2016-17												
Trait	HDNG	DTM	GFD	PH	SL	GWPS	GNPS	SPMS	BYPMS	HI	TGW	CTD
HDNG	**2.960**	-1.656	-1.306	0.000	-0.001	0.306	-0.025	0.039	0.009	0.072	-0.036	0.003
DTM	2.177	**-2.251**	0.067	0.000	-0.001	0.305	-0.016	0.129	0.030	0.062	-0.041	-0.010
GFD	-1.930	-0.076	**2.003**	0.000	0.001	-0.110	0.019	0.088	0.019	-0.036	0.007	-0.007
PH	0.140	-0.367	0.227	**0.002**	0.000	0.256	-0.014	0.134	0.027	0.071	-0.032	-0.001
SL	0.713	-0.358	-0.355	0.000	**-0.004**	0.134	-0.026	0.104	-0.011	0.057	-0.006	-0.001
GWPS	1.485	-1.126	-0.360	0.001	-0.001	**0.609**	-0.045	0.211	0.016	0.166	-0.072	-0.002
GNPS	1.114	-0.541	-0.572	0.000	-0.002	0.410	**-0.067**	0.147	-0.006	0.140	-0.025	-0.001
SPMS	0.266	-0.674	0.409	0.001	-0.001	0.299	-0.023	**0.430**	0.022	0.140	-0.032	-0.002
BYPMS	0.190	-0.453	0.257	0.000	0.000	0.064	0.003	0.064	**0.148**	-0.079	-0.011	-0.001
HI	0.991	-0.654	-0.332	0.001	-0.001	0.472	-0.044	0.282	-0.054	**0.214**	-0.049	0.000
TGW	1.346	-1.170	-0.179	0.001	0.000	0.554	-0.022	0.172	0.021	0.134	**-0.079**	-0.002
CTD	-0.309	0.816	-0.506	0.000	0.000	-0.044	0.003	-0.033	-0.004	0.002	0.005	**0.028**
2017-2018												
Traits	HDNG	DTM	GFD	PH	SL	GWPS	GNPS	SPMS	BYPMS	HI	TGW	CTD
HDNG	**2.010**	-1.810	-0.233	0.008	-0.002	0.060	0.004	-0.237	-0.232	0.050	-0.004	-0.001
DTM	1.836	**-1.982**	0.129	0.008	-0.001	0.032	0.003	-0.216	-0.209	0.007	-0.005	-0.001
GFD	-0.536	-0.293	**0.874**	-0.001	0.001	-0.069	-0.001	0.062	0.069	-0.104	-0.003	-0.001
PH	-0.425	0.407	0.029	**-0.037**	-0.002	0.002	-0.004	0.081	0.198	-0.124	0.005	-0.001
SL	-0.167	0.121	0.047	0.004	**0.022**	-0.093	0.002	-0.044	-0.037	-0.103	-0.006	0.000
GWPS	0.371	-0.195	-0.186	0.000	-0.006	**0.327**	0.002	-0.020	0.068	0.278	0.014	-0.001
GNPS	0.568	-0.545	-0.035	0.010	0.003	0.043	**0.013**	-0.048	-0.038	0.043	-0.019	0.001
SPMS	-1.302	1.172	0.148	-0.008	-0.003	-0.018	-0.002	**0.366**	0.354	0.007	0.002	0.000
BYPMS	-1.063	0.943	0.138	-0.017	-0.002	0.051	-0.001	0.295	**0.439**	-0.082	0.005	-0.001
HI	0.261	-0.039	-0.237	0.012	-0.006	0.237	0.001	0.007	-0.095	**0.382**	0.010	0.000
TGW	-0.284	0.398	-0.112	-0.008	-0.005	0.180	-0.009	0.036	0.084	0.151	**0.026**	-0.001
CTD	0.237	-0.365	0.128	-0.004	0.002	0.099	-0.001	-0.001	0.088	0.002	0.008	-0.005

Residual are 0.0059 and 0.0056 for 2016-17 and 2017-18 respectively high potential grain weight can be useful selection criteria for improving heat tolerance. Munjal and Dhanda (2004), Semeena *et al.* (2001) reported positive correlation with of grain yield with TGW and HI under heat stress conditions. Monu *et al.* (2017) reported that BYPMS and HI positively and significantly correlated with YPMS under terminal heat stress condition. For rest of traits, no consistency was observed during both the years and hence their relationship should not be considered as strong or stable. However, GNPS, PH, DTH and DTM and SL in crop season 2016-17 and BYPMS, CTD showed positive association in crop season 2017-18 only. Therefore, there is no consistency in these relationships over the years and should not be considered as strong or stable and may be due to the changes in environmental conditions in different years.

Path coefficient analysis splits the correlation coefficient into direct and indirect effects. It measures the direct and indirect contribution of independent variables on dependent variable i.e. grain yield in the present study. The path coefficient analysis based on genotypic correlation in crop season 2016-17 (Table 2) revealed that the magnitude of direct effects ranged from -2.251 to 2.960. Similarly, path analysis based on genotypic correlations in crop season 2017-18 (Table 2) revealed that magnitude of direct effects ranged from -1.982 to 2.010 while magnitude of indirect effects varied from -1.063 to 1.836.

Comparison of path analysis for both the years revealed that DTH, GFD, GWPS, SPMS, HI and BYPMS contributing positive direct effects towards grain yield. GWPS, SPMS, HI and TGW had positively significant correlation and had high positive direct effects, it revealed strong and true relationship between them and direct selection for these traits will be rewarding for improving the yield under terminal heat stress conditions. On the contrary, DTM showed maximum direct effect in negative direction and GNPS. DTM showed positively significant correlation but had negative direct effect suggesting that it was influenced indirectly by DTH in positive direction. Indirect selection through such trait will be rewarding in improving the yield. GFD although showed positive and high direct effect, but had negligible or non-significant correlation with grain yield. This trait is being influenced indirectly in negative direction by DTH, YPMS, HITGW. Direct selection for such traits should be practiced to reduce the undesirable indirect effect. The value of residual factor is very low in both the crop season indicated that the set of characters included to carry out path analysis is adequate to explain the contribution of these traits towards yield. These findings are in conformity with the findings of other researchers Like Munjal and Dhanda (2004) and Monu *et al*. (2017) studied the path analysis for heat tolerance in bread wheat and found TGW had the highest positive and direct effect on grain yield and HI, effective tillers/sq meter, TGW and photosynthetic pigments mainly chlorophyll b and carotenoid as the major contributing traits towards grain yield under terminal heat stressed environment.

The present study on interrelationship of yield and yield components revealed that more GWPS or heavier spike, SPMS, HI and TGW emerged out the major contributing traits towards grain yield under heat stressed environment. Therefore, for improving the grain yield under terminal heat stress environment breeder should aim for selecting genotypes with bold grains or high GWPS, a greater number of effective tillers/sq. meter, higher HI and longer GFD in bread wheat.

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