Available online at www.ijpab.com

DOI: http://dx.doi.org/10.18782/2320-7051.6170

ISSN: 2320 – 7051

Int. J. Pure App. Biosci. **6 (1):** 225-233 (2018)

Research Article

International Journal of Pure & Applied Bioscience

OPEN ACCESS

Evalution of Bread Wheat (*Triticum aestivum* L.) Genotypes for Heat Tolerance under Timely and Late Sown Conditions

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Received: 06.01.2018 | Revised: 3.02.2018 | Accepted: 8.02.2018

ABSTRACT

The present study was carried out to assess genetic variability, correlation coefficient and path coefficient analysis with respect to heat tolerance in 50 genotypes of aestivum wheat grown in a Randomized Block Design with three replications under normal and late sowing conditions at the Wheat Research Station, Junagadh Agricultural University, Junagadh during rabi 2015-16. The observations were recorded on 13 characters viz., days to heading, days to maturity, grain filling period (day), plant height (cm), number of effective tillers per plant, length of main spike (cm), number of grains per main spike, number of spikelets per main spike (g), grain yield per plant (g), biological yield per plant (g), harvest index (%), 100 grain weight (g), chlorophyll content (CHL_a & CHL_{21}), canopy temperature depression (CTD_{vg} & CTD_{gf}) (°C) and heat sensitivity index. The final conclusion that can be reached from variability, correlations and path coefficient analysis with respect to heat tolerance is that under normal sowing condition with harvest index, biological yield per plant, 100-grain weight, length of main spike and plant height, while under late sowing condition with harvest index, biological yield per plant, plant height and length of main spike found the most important component characters. Hence, these traits should be considered as selection criteria for yield improvement in wheat.

Key words: *Heat tolerance, Correlation, Path analysis, Variability parameters, Triticum*

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the leading food crops of the world farming and occupies second most important place in staple food next to rice, consumed by nearly 35% of the world population and providing 20% of the total food calories among the cultivated cereals. Cultivation of wheat has been the symbolic of green revolution the played pivotal role in making the nation a food surplus nation. Grain weight is affected by high temperatures, especially above 34 °C, that reduces the duration of grain filling owing to the limited photosynthesis, and inhibit starch biosynthesis in the endosperm[3]. Yield loss of 33.6% was observed in major wheat cultivars due to heat stress in late sown conditions indicating that there is a need to incorporate heat tolerance in wheat cultivars to achieve sustainable production[1,2].

Cite this article: Ramanuj, B.D., Delvadiya, I.R., Patel, N.B. and Ginoya, A.V., Evalution of Bread Wheat (*Triticum aestivum* L.) Genotypes for Heat Tolerance under Timely and Late Sown Conditions, *Int. J. Pure App. Biosci.* **6(1):** 225-233 (2018). doi: http://dx.doi.org/10.18782/2320-7051.6170

Availability of sufficient genetic variability is very important in a crop improvement programme.

It is essential for a plant breeder to measure the variability with the help of parameters like phenotypic coefficient of variation, genotypic coefficient of variation, heritability and genetic advance. The wheat crop requires favorable winter for about 100-110 days for producing its potential yield. Therefore, the heat tolerant wheat variety is still one of the priority of agricultural research, because above the optimum temperature (22-24^{0}C) wheat yield is drastically affected. Different components of yield very often exhibit varying degree of associations with grain yield as well as among themselves. In order to accumulate optimum combination of yield contributing characters in a single genotype, it is essential to know the inter-relationships among the component traits. Further, the grain yield is influenced by its various components directly and/or indirectly via other traits, which create a complex situation before a breeder for making effective selection. Therefore, path coefficient analysis could provide a more realistic picture of the interrelationship, as it partitions the correlation coefficient in direct and indirect effects of the variables.

MATERIALS AND METHODS

The present study was at the Wheat Research Station, Junagadh Agricultural University, Junagadh during *rabi* 2015-16. There were 50 genotypes (Table 1) of aestivum wheat grown in a Randomized Block Design with three replications under normal and late sowing conditions. Observations were recorded for thirteen characters on previously tagged ten plants selected randomly from middle row before ear emergence. Days to heading was counted from the date of sowing to 50% emergence of main spike in each row.

Grain filling period was recorded as days taken from date of anthesis to date of physiological maturity and physiological maturity was judged when 75% of the glumes in main spike turned yellow. Other agronomic characters were also recorded on plant basis. The heat sensitivity index (HSI) calculated according to formula of Fisher and Maurer[4]. The genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV) were calculated according to Burton[5]. While heritability (h2) in broad sense and genetic advance (GA) as percentage of mean were calculated according to Allard[6]. The phenotypic and genotypic correlation coefficients of all the characters were worked-out as per Al-Jibouri *et al*[7]. The path coefficient analysis was carried-out as per the method suggested by Dewey and Lu[8]. Genotypic correlation coefficients of 12 variables with yield were used to estimate the path coefficient for the direct effects of various independent characters on yield.

RESULTS AND DISCUSSION

The analysis of variance (Table 2) revealed the presence of sufficient variability under both normal and late sowing conditions among the genotypes studied.

The values of phenotypic coefficient of variation in both sowing conditions were slightly higher than that of genotypic coefficient of variation for all the traits studied, indicating less effect of environment on the expression of characters studied. The high values of GCV were observed under normal sowing condition (Table 3) for biological yield per plant (15.814), length of main spike (15.676), number of grain per main spike (12.530), harvest index (14.466), number of effective tillers per plant (14.403), 100-grain weight (15.217) and plant height (10.730), While, under late sowing condition (Table 4) for grain yield per plant (24.698), biological yield per plant (20.627), harvest index (17.820), length of main spike (15.367), 100-grain weight (13.173), number of effective tillers per plant (13.313), chlorophyll

content at anthesis (10.402) and grain filling period (10.077).

The genetic advance at 5% selection intensity (k=2.06) was found high under normal sowing condition (Table 3) for number of grains per main spike (14.532), plant height (11.013) and days to maturity (9.950). Under late sowing condition (Table 4) genetic advance at 5% selection intensity (k=2.06) was found high under for harvest index (9.514), chlorophyll content at anthesis (9.448) and biological yield per plant (8.165).

High heritability coupled with high genetic advance expressed as percentage of mean were observed for all characters except under normal sowing condition for days to maturity, plant height and length of main spike, while, under late sowing condition for days to maturity, grain filling period, length of main spike and 100-grain weight. These may be attributed to the preponderance of additive gene action and possessed high selective value and thus, selection pressure could profitably be applied on these characters for their rationale improvement.

The values of genotypic correlation in both sowing conditions were higher as compared to the corresponding phenotypic correlation. This indicated that though there was high degree of association between two variables at genotypic level, its phenotypic expression was deflated by the influence of environment.

The character, grain yield per plant (r_g=0.457, r_p=0.304) exhibited highly significant and positive genotypic as well as phenotypic correlation under normal sowing condition (Table 5)with harvest index, biological yield per plant and number of grain per main spike, while, it also manifested the highly significant positive correlation days to heading at genotypic level. The character, grain yield per plant under late sowing condition exhibited significant and positive genotypic and phenotypic correlation with biological yield per plant, while it also manifested the significant positive correlation with length of main spike and number of grains per main spike at genotypic level. The yield components exhibited varying trends of association among themselves. Thus, revealed that under normal sowing condition, harvest index, biological yield per plant, 100-grain, length of main spike and plant height, while, under late sowing condition, harvest index, biological yield per plant, plant height length of main spike and number of grains per main spike were the most important traits and may contribute considerably towards higher grain yield. The interrelationship among yield components would help in increasing the yield levels and, therefore, more emphasis should be given to these components, while selecting better types in wheat.

The path coefficient analysis revealed high and positive direct effects under normal sowing condition (Table 7) of harvest index and biological yield, while, under late sowing condition of days to heading, plant height, length of main spike and chlorophyll content at 21 days after anthesis. Thus, these characters turned-out to be the major components of grain yield.

Heat sensitivity index (HIS) (Table 8) had been used for screening heat tolerance genotypes of wheat. According to estimation of HSI, the genotypes GW-2011-347, GW-2011-362, LBPY 2011-9, NIAW 2844, RAJ 4445, HS-557, K-1006, GW-366 and RAJ-3077 had been highly heat tolerant for grain yield per plant. Chlorophyll content at 21 days after anthesis also used as desirable heat tolerance parameter and the result revealed that genotypes under normal sowing condition with high yield than late sowing condition had also high chlorophyll content at anthesis and high CTD means low canopies temperature than late sowing condition. Thus, high CTD favours the grain yield and chlorophyll content at anthesis (Table 9).

Table 1: List of genotypes used for study

Sr. No.	Genotypes	Sr. No.	Genotypes	Sr. No.	Genotypes
1	GW-2011-347	18	GW2013-478	35	PHSL-1104
2	GW-2011-361	19	GW2013-482	36	DBW-88
3	GW-2011-362	20	GW2013-489	37	K-1006
4	JS 6-1	21	LBPY-2014-1	38	AKAW-4731
5	LBPY 2011-2	22	LBPY-2014-2	39	VW-20145
6	LBPY 2011-8	23	LBPY-2014-3	40	GW-11
7	LBPY 2011-9	24	LBPY-2014-8	41	GW-173
8	LBPY 2011-10	25	NIAW 2064	42	GW-322
9	HD-2009	26	NIAW 2809	43	GW-366
10	NIAW 2268	27	NIAW 2844	44	GW-496
11	RAJ 4304	28	RAJ 4441	45	RAJ-3077
12	HI 1588	29	RAJ 4442	46	LOK-1
13	HI 1600	30	RAJ 4444	47	$F_6A_{DALANG}95$
14	KB 2013-05	31	RAJ 4445	48	$F_6A_{DALANG}107$
15	DBW-147	32	MP 1259	49	F_6ADALANG120
16	RAJ 4396	33	HS-557	50	F_6ADALANG126
17	GW2013-471	34	NW-5013		

Table 2: Analysis of variance showing mean squares for various characters in 50 genotypes of bread wheat under different dates of sowing

Source of variation	df	Mean squares							
		Days to heading	Days to maturity	Grain filling period (Days)	Plant height (cm)	Number of effective tillers per plant	Length of main spike (cm)	Number of spikelets per main spike	Number of grain per main spike (g)
Normal date sowing (D_0)									
Replications	02	83.0105**	105.863**	118.235**	50.7081*	5.5832**	5.7412**	21.1489**	26.881*
Genotypes	49	80.6081**	103.7168**	43.6953**	121.6424**	3.967**	4.3918**	3.5913**	172.137**
Error	98	12.65	10.38	7.78	10.70	0.56	0.49	1.74	6.17
Late date sowing (D_1)									
Replications	02	50.1348**	82.2162*	17.2733*	41.5922*	4.5742**	2.1303**	7.2597**	37.8841*
Genotypes	49	59.3661**	73.652**	40.5221**	64.7315**	3.0994**	4.3728**	3.1424**	21.4197**
Error	98	7.60	19.69	3.86	10.32	0.61	0.42	1.30	11.05

***, ** Significant at 1% levels**

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Source of variation	df	Mean squares							
		Grain yield per plant (g)	Biological yield per plant (g)	Harvest index (HI) (%)	100-grain weight (g)	CHL_a (Spad unit)	CHL_{21} (Spad unit)	CTD_{vg} (°C)	CTD_{gf} (°C)
Normal date sowing (D_0)									
Replications	02	12.6383**	12.8521*	46.3055*	4.2239**	33.7244*	7.4591**	73.84**	54.20**
Genotypes	49	15.165**	61.1416**	90.4591**	1.4547**	49.0401**	8.7341**	1.67**	1.44**
Error	98	0.82	3.46	12.81	0.46	10.39	1.42	0.39	0.31
Late date sowing (D_1)									
Replications	02	30.2764**	73.0446**	150.1043**	13.0071**	190.0342**	34.3722**	56.35**	17.09**
Genotypes	49	11.9063**	56.1219**	112.0479**	1.2029**	84.789**	16.3509**	2.62**	3.09**
Error	98	0.56	2.47	16.01	0.14	6.35	1.91	0.39	0.39

*, ** Significant at 5% and 1% levels

CHL_a = Chlorophyll Content at anthesis; CHL_{21} = Chlorophyll Content at 21 days after anthesis; CTD_{vg} = Canopy Temperature Depression at vegetative stage; CTD_{gf} = Canopy Temperature Depression at Grain filling stage.

Table 3: Range of variation, mean, phenotypic and genotypic coefficients of variation, heritability (broad Sense), genetic advance and genetic advance expressed as percentage of mean for various characters in 50 genotypes of durum wheat under normal date of sowing

Character	Range	Mean	Genotypic coefficient of variation (%)	Phenotypic coefficient of variation (%)	Heritability (Broad Sense)(%)	Genetic advance	Genetic advance expressed as percentage of mean
Days to heading	47.336-64.230	56.666	10.485	8.399	64.170	7.853	13.859
Days to maturity	92.990-118.943	106.147	6.068	5.254	74.990	9.950	9.373
Grain filling period (Days)	42.293-56.393	50.144	8.863	6.899	60.590	5.547	11.063
Plant height (cm)	50.733-81.173	64.352	10.730	9.449	77.550	11.013	17.142
Number of effective tillers per plant	5.533-11.730	9.039	14.403	11.791	67.020	1.797	19.886
Length of main spike (cm)	6.933-12.276	8.532	15.676	13.370	72.750	2.004	23.493
Number of spikelets per main spike	11.216-16.290	14.565	10.545	5.388	26.110	0.826	5.671
Number of grain per main spike	36.250-69.016	62.581	12.530	11.885	89.960	14.532	23.221
Grain yield per plant (g)	6.810-16.403	12.863	18.395	17.000	85.400	4.163	32.363
Biological yield per plant (g)	17.260-37.566	30.119	15.814	14.558	84.740	8.314	27.607
Harvest index (%)	29.693-50.550	43.001	14.466	11.831	66.880	8.570	19.931
100-grain weight (g)	3.370-7.433	5.840	15.217	9.872	42.090	0.770	13.194
Character	**Range**	**Mean**	**Genotypic coefficient of variation (%)**	**Phenotypic coefficient of variation (%)**	**Heritability (Broad Sense) (%)**	**Genetic advance**	**Genetic advance expressed as percentage of mean**
Chlorophyll content at anthesis (Spad unit)	52.233-68.266	63.137	7.640	5.685	55.360	5.501	8.713
Chlorophyll content at 21 days after anthesis (Spad unit)	24.887-33.513	28.795	6.819	5.423	63.280	2.558	8.886
Canopy Temperature Depression at vegetative stage (°C)	2.04 to 5.53	3.93	31.55	35.33	79.75	2.28	58.03
Canopy Temperature Depression at Grain filling stage (°C)	0.90 to 3.90	2.52	45.80	50.84	81.16	2.14	85.00

Table 4: Range of variation, mean, phenotypic and genotypic coefficients of variation, heritability (broad Sense), genetic advance and genetic advance expressed as percentage of mean for various characters in 50 genotypes of durum wheat under late date of sowing

Character	Range	Mean	GCV (%)	PCV (%)	Heritability (Broad Sense)(%)	Genetic advance	Genetic advance expressed as percentage of mean
Days to heading	44.676-63.316	54.251	9.189	7.656	69.420	7.129	13.142
Days to maturity	92.583-112.163	100.645	6.098	4.214	47.740	6.036	5.998
Grain Filling Period (Days)	33.393-47.660	39.793	10.077	8.784	75.980	6.277	15.773
Plant height (cm)	54.926-81.453	65.243	8.176	6.527	63.740	7.004	10.735
Number of effective tillers per plant	6.666-10.896	9.011	13.313	10.109	57.650	1.425	15.812
Length of main spike (cm)	6.796-12.153	8.577	15.367	13.383	75.840	2.059	24.009
Number of spikelets per main spike	12.156-18.353	14.829	9.334	5.279	31.990	0.912	6.152
Number of Grain per main spike	59..496-75.413	66.371	5.738	2.800	23.820	1.869	2.816
Grain yield per plant (g)	4.350-12.753	8.436	24.698	23.050	87.100	3.738	44.315
Biological yield per plant (g)	11.146-29.673	21.871	20.627	19.335	87.860	8.165	37.334
Harvest index (%)	22.790-48.030	38.887	17.820	14.548	66.650	9.514	24.468
100-grain weight (g)	4.020-6.833	5.350	13.173	11.104	71.050	1.031	19.281

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Character	Range	Mean	GCV (%)	PCV (%)	Heritability (Broad Sense) (%)	Genetic advance	Genetic advance expressed as percentage of mean
Chlorophyll Content at anthesis (Spad unit)	42.673-66.606	54.802	10.402	9.330	80.860	9.448	17.240
Chlorophyll Content at 21 days after anthesis (Spad unit)	21.900-32.146	27.077	9.577	8.102	71.560	3.823	14.119
Canopy Temperature Depression at vegetative stage (°C)	-0.83 to 5.17	3.51	44.96	48.35	86.46	3.02	86.13
Canopy Temperature Depression at Grain filling stage (°C)	0.57 to 4.74	2.41	71.31	75.87	88.33	3.33	138.06

Table 5: Genotypic (r_g) and phenotypic (r_p) correlation coefficients among 14 characters in wheat under normal sowing condition

Characters		Days to heading	Days to maturity	Grain filling period	Plant height (cm)	Number of effective tillers per plant	Length of main spike (cm)	Number of spikelets per main spike	Number of grain per main spike	Biological yield per plant (g)	Harvest index (%)	100-grain weight(g)	Chlorophyll content at anthesis	Chlorophyll content at 21 days after anthesis
Grain yield per plant	**rg**	0.454*	0.187	0.021	-0.171	0.250	0.146	0.129	0.635**	0.666**	0.555**	0.335*	0.029	-0.167
	rp	0.307*	0.145	0.042	-0.113	0.211	0.112	0.077	0.556**	0.588**	0.576**	0.193	-0.022	-0.126
Days to heading	r_g		0.284*	-0.113	0.134	0.138	0.179	0.470*	0.350*	0.315*	0.217	0.119	0.045	-0.050
	r_p		-0.012	-0.090	0.105	0.082	0.130	0.265	0.253	0.208	0.142	0.077	0.085	-0.059
Days to maturity	r_g			-0.018	-0.063	0.077	0.113	0.348*	0.284*	0.203	0.044	0.039	-0.410	-0.075
	r_p			-0.049	0.001	0.142	0.077	0.290*	0.250	0.017	0.017	-0.007	-0.244	-0.022
Grain filling period	r_g				0.081	-0.121	-0.024	-0.043	-0.077	-0.232	0.290*	-0.377	-0.019	-0.285*
	r_p				0.025	-0.107	-0.044	-0.084	-0.079	-0.168	0.216	-0.180	0.002	-0.162
Plant height	r_g					-0.221	-0.009	-0.026	-0.310	-0.210	0.001	-0.265	-0.008	0.033
	r_p					-0.111	0.010	0.104	-0.239	-0.174	0.031	-0.175	-0.012	0.093
Number of effective tillers per plant	r_g						0.289*	0.342*	0.490*	0.291*	0.017	0.087	0.125	-0.033
	r_p						0.243	0.283*	0.381*	0.246	0.011	0.145	0.090	-0.190
Length of main spike (cm)	r_g							0.218	0.179	0.236	-0.093	-0.216	-0.063	0.033
	r_p							0.173	0.160	0.151	-0.002	-0.104	-0.078	0.080
Number of spikelets per main spike	r_g								0.279	0.147	0.028	-0.240	-0.202	-0.430
	r_p								0.137	0.059	0.041	-0.129	-0.002	-0.056
Number of grain per main spike	r_g									0.768**	-0.023	0.491*	-0.278*	-0.164
	r_p									0.663**	-0.0145	0.317*	-0.192	-0.110
Biological yield per plant	r_g										-0.239	0.673**	-0.069	0.057
	r_p										-0.312	0.388**	-0.043	0.016
Harvest index(%)	r_g											-0.321*	0.105	-0.265
	r_p											-0.169	0.002	-0.144
100 grain weight(g)	r_g												-0.166	0.157
	r_p												-0.052	0.077
Chlorophyll content at anthesis	r_g													-0.183
	r_p													-0.081

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

Table 6: Genotypic (r_g) and phenotypic (r_p) correlation coefficients among 14 characters in wheat late sowing condition

Characters		Days to heading	Days to maturity	Grain filling period	Plant height (cm)	Number of effective tillers per plant	Length of main spike (cm)	Number of spikelets per main spike	Number of grain per main spike	Biological yield per plant (g)	Harvest index (%)	100-grain weight(g)	Chlorophyll content at anthesis	Chlorophyll content at 21 days after anthesis
Grain yield per plant	**rg**	-0.097	-0.017	0.128	0.066	-0.090	0.071	0.021	-0.137	0.777**	-0.108	0.087	-0.046	0.236
	rp	-0.064	-0.059	0.104	0.083	-0.087	0.044	0.005	-0.047	0.709**	-0.080	0.064	-0.071	0.174
Days to heading	r_g		-0.140	0.034	0.097	0.042	0.016	0.052	0.256	-0.109	0.013	-0.039	-0.171	0.157
	r_p		-0.029	0.039	0.036	0.044	0.019	-0.028	-0.055	-0.115	-0.002	-0.062	-0.112	0.152
Days to maturity	r_g			-0.408*	-0.080	-0.159	-0.068	0.052	-0.418*	-0.098	-0.076	-0.120	0.076	0.116
	r_p			-0.229	-0.065	-0.052	-0.039	0.219	-0.177	-0.106	-0.040	-0.127	0.126	0.136
Grain filling period	r_g				0.325	-0.209	-0.284*	0.155	0.173	0.104	0.095	0.116	0.141	-0.437*
	r_p				0.214	-0.182	-0.210	0.070	0.072	0.111	0.112	0.108	0.129	0.300*
Plant height (cm)	r_g					-0.190	-0.162	0.059	0.268	-0.071	-0.143	-0.262*	0.174	0.143
	r_p					-0.073	-0.121	0.061	0.045	-0.078	-0.064	-0.203	0.084	0.059
Number of effective tillers per plant	r_g						0.192	-0.010	-0.256	-0.003	-0.212	0.262	0.195	-0.278*
	r_p						0.152	-0.019	-0.131	-0.074	-0.115	0.165	0.088	-0.151
Length of main spike (cm)	r_g							0.294*	0.039	0.004	-0.023	0.177	-0.031	-0.088
	r_p							0.056	0.055	0.031	-0.044	0.147	-0.030	-0.057
Number of spikelets per main spike	r_g								-0.254	-0.170	0.111	0.154	-0.197	-0.155
	r_p								-0.003	-0.123	0.103	-0.059	0.003	-0.064
Number of grain per main spike	r_g									-0.351*	0.328*	-0.436*	-0.359*	0.099
	r_p									-0.134	0.145	-0.167	-0.181	-0.012
Biological yield per plant	r_g										-0.106	0.307*	0.063	0.186
	r_p										-0.094	0.251*	0.047	0.156
Harvest index(%)	r_g											-0.170	-0.339*	0.320*
	r_p											-0.094	-0.267*	0.194
100 grain weight(g)	r_g												0.017	-0.201
	r_p												0.007	-0.196
Chlorophyll content at anthesis	r_g													-0.279*
	r_p													-0.182

Table 7: Genotypic path coefficient analysis showing direct (diagonal and bold) and indirect effects of different characters on grain yield in 50 genotypes of bread wheat under normal date of sowing

Characters		Days to heading	Days to maturity	Grain filling period	Plant height	No. of effective tillers plant^{-1}	Length of main spike	No. of spikelets main spike^{-1}	No. of grain main spike^{-1}	Biological yield plant^{-1}	Harvest index	100-grain weight (g)	Chlorophyll content at anthesis	Chlorophyll content 21 days after anthesis	Genotypic and Phenotypic correlation with grain yield per plant
Days to heading	r_g	**0.126**	-0.001	0.004	-0.005	0.003	-0.011	-0.080	-0.027	0.309	0.153	-0.018	-0.004	0.005	0.454
	r_p	**0.007**	0.001	0.001	0.001	-0.001	-0.001	-0.001	0.003	0.176	0.119	0.001	0.001	0.001	0.307
Days to maturity	r_g	0.003	**-0.002**	0.001	0.002	0.002	-0.007	-0.059	-0.022	0.197	0.031	-0.006	0.039	0.008	0.187
	r_p	-0.001	**-0.015**	0.001	0.001	-0.001	-0.001	-0.001	0.003	0.148	0.014	0.001	-0.002	0.001	0.145
Grain filling period	r_g	-0.014	0.001	**-0.041**	-0.003	-0.003	0.001	0.007	0.006	-0.226	0.205	0.057	0.001	0.031	0.021
	r_p	-0.001	0.001	**0.001**	0.001	0.001	0.001	0.001	-0.001	-0.142	0.181	-0.001	0.001	0.003	0.042
Plant height	r_g	0.017	0.001	-0.003	**-0.042**	-0.006	0.001	0.004	0.024	-0.204	0.001	0.040	0.001	-0.003	-0.171
	r_p	0.001	0.001	0.001	**0.012**	0.001	-0.001	0.001	-0.003	-0.147	0.026	-0.001	-0.001	-0.001	-0.113
No. of effective tillers per plant	r_g	0.017	-0.001	0.005	0.009	**0.027**	-0.018	-0.058	-0.038	0.283	0.012	-0.013	-0.012	0.036	0.250
	r_p	0.001	-0.002	0.001	-0.001	**-0.011**	-0.002	-0.001	0.005	0.208	0.009	0.001	0.001	0.003	0.211
Length of main spike (cm)	r_g	0.022	-0.001	0.001	0.001	0.008	**-0.064**	-0.037	-0.014	0.230	-0.066	0.032	0.006	-0.003	0.114
	r_p	0.001	-0.001	0.001	0.001	-0.002	**-0.009**	-0.001	0.002	0.128	-0.002	-0.001	-0.001	-0.001	0.112
No. of spikelets per main spike	r_g	0.059	-0.001	0.001	0.001	0.009	-0.014	**-0.171**	-0.022	0.143	0.020	0.036	0.019	0.047	0.129
	r_p	0.002	-0.004	0.001	0.001	-0.003	-0.001	**-0.004**	0.002	0.050	0.034	-0.001	0.001	0.001	0.076
Number of grain per main spike	r_g	0.044	-0.001	0.003	0.013	0.013	-0.011	-0.048	**-0.078**	0.747	-0.016	-0.074	0.026	0.018	0.635
	r_p	0.002	-0.003	0.001	-0.003	-0.004	-0.001	-0.001	**0.014**	0.562	-0.012	0.001	-0.02	0.002	0.556
Biological yield per plant	r_g	0.040	-0.001	0.009	0.008	0.008	-0.015	-0.025	-0.060	**0.973**	-0.169	-0.102	0.006	-0.006	0.666
	r_p	0.001	-0.002	0.001	-0.002	-0.002	-0.001	-0.001	0.009	**0.847**	-0.262	0.002	-0.001	-0.001	0.588
Harvest index	r_g	0.027	-0.001	-0.012	0.001	0.001	0.006	-0.004	0.001	-0.233	**0.706**	0.048	-0.010	0.029	0.559
	r_p	0.001	-0.001	0.001	0.001	-0.001	0.001	-0.001	-0.001	-0.265	**0.839**	-0.001	0.001	0.002	0.576
100 grain weight	r_g	0.015	-0.001	0.015	0.011	0.002	0.014	0.041	-0.038	0.655	-0.227	**-0.151**	0.015	-0.017	0.335
	r_p	0.001	0.001	0.001	-0.002	-0.001	0.001	0.001	0.004	0.329	-0.142	**0.005**	-0.001	-0.001	0.193
Chlorophyll content at anthesis	r_g	0.005	0.001	0.001	0.001	0.003	0.004	0.034	0.021	-0.067	0.074	0.025	**-0.095**	0.020	0.029
	r_p	0.001	0.003	0.001	-0.001	-0.001	0.001	0.001	-0.002	-0.036	0.002	-0.001	**0.010**	0.001	-0.022
Chlorophyll content 21 days after anthesis	r_g	-0.006	0.001	0.011	-0.001	-0.009	-0.002	0.074	0.013	0.056	-0.187	-0.023	0.017	**-0.109**	-0.167
	Rp	-0.001	0.001	0.001	0.001	0.002	-0.001	0.001	-0.001	0.013	-0.121	0.001	-0.001	**-0.019**	-0.126

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

Residual effect, R = 0.0153 N.B.: Values at diagonal indicated direct effects of respective character

CHL_a = Chlorophyll Content at anthesis (spad unit); CHL_{21} = Chlorophyll Content at 21 days after anthesis (spad unit)

Table 8: Classification of 50 genotypes of bread wheat in highly heat tolerance (HHT), heat tolerance (HT), moderately heat tolerance (MHT) and heat susceptible (HS) based on

Sr. No.	Genotype	Heat Sensitivity Index	Heat Tolerance	Sr. No.	Genotype	Heat Sensitivity Index	Heat Tolerance
1	GW-2011-347	0.335	HHT	26	NIWA 2809	0.691	HT
2	GW-2011-361	0.867	MHT	27	NIAW 2844	0.124	HHT
3	GW-2011-362	0.323	HHT	28	RAJ 4441	1.508	HS
4	JS 6-1	0.697	HT	29	RAJ 4442	1.043	HS
5	LBPY 2011-2	0.558	HT	30	RAJ 4444	1.380	HS
6	LBPY 2011-8	0.813	MHT	31	RAJ 4445	0.327	HHT
7	LBPY 2011-9	0.242	HHT	32	MP 1259	1.482	HS
8	LBPY 2011-10	0.872	MHT	33	HS-557	0.325	HHT
9	HD-2009	1.470	HS	34	NW-5013	0.791	MHT
10	NIAW 2268	2.008	HS	35	PHSL-1104	0.931	MHT
11	RAJ 4304	1.009	HS	36	DBW-88	1.135	HS
12	HI 1588	1.474	HS	37	K-1006	0.253	HHT
13	HI 1600	1.339	HS	38	AKAW-4731	1.103	HS
14	KB 2013-05	0.999	MHT	39	VW-20145	1.172	HS
15	DBW-147	1.527	HS	40	GW-11	1.166	HS
16	RAJ 4396	0.526	HT	41	GW-173	1.282	HS
17	GW2013-471	1.434	HS	42	GW-322	1.247	HS
18	GW2013-478	0.515	HT	43	GW-366	-1.506	HHT
19	GW2013-482	1.303	MHT	44	GW-496	0.994	MHT
20	GW2013-489	0.948	HS	45	RAJ-3077	0.231	HHT
21	LBPY-2014-1	1.471	HS	46	LOK-1	1.348	HS
22	LBPY-2014-2	2.125	HS	47	$F_6A_{DALANG}(95)$	0.516	HT
23	LBPY-2014-3	1.829	HS	48	$F_6A_{DALANG}107$	1.082	HS
24	LBPY-2014-8	0.801	MHT	49	F_6A DALANG120	1.139	HS
25	NIAW 2064	0.826	MHT	50	F_6A DALANG126	1.175	HS

Table 9: Canopy temperature depression (CTD) value along with grain yield per plant for normal (D_0) and late sowing (D_1) conditions for 50 genotypes of bread wheat

Sr. No.	Genotype	Canopy Temperature Depression (CTD) (°C)		Grain yield per plant (g)		Sr. No.	Genotype	Canopy Temperature Depression (CTD) (°C)		Grain yield per plant (g)	
		Normal	Late	Normal	Late			Normal	Late	Normal	Late
1	GW-2011-347	4.34	4.10	14.33	10.65	**26**	NIWA 2809	2.12	1.77	19.00	12.12
2	GW-2011-361	3.14	3.04	14.33	9.31	**27**	NIAW 2844	3.75	3.40	20.33	15.24
3	GW-2011-362	2.54	2.44	14.33	10.41	**28**	RAJ 4441	2.92	2.57	13.67	11.17
4	JS 6-1	1.94	1.84	15.67	8.59	**29**	RAJ 4442	3.05	2.70	17.00	15.63
5	LBPY 2011-2	2.54	2.44	10.33	7.24	**30**	RAJ 4444	3.39	3.04	13.67	11.29
6	LBPY 2011-8	3.40	3.30	9.67	6.87	**31**	RAJ 4445	4.12	3.77	12.33	10.01
7	LBPY 2011-9	3.40	3.30	14.33	11.73	**32**	MP 1259	4.45	4.10	15.00	12.81
8	LBPY 2011-10	3.40	3.30	13.00	8.02	**33**	HS-557	4.25	3.90	15.67	11.65
9	HD-2009	2.80	2.70	13.00	9.22	**34**	NW-5013	3.65	3.30	18.33	13.16
10	NIAW 2268	2.20	2.10	11.67	8.04	**35**	PHSL-1104	3.42	2.67	17.00	13.67
11	RAJ 4304	2.87	2.77	11.00	10.66	**36**	DBW-88	3.42	2.67	15.00	12.08
12	HI 1588	2.74	2.64	9.67	8.34	**37**	K-1006	2.89	2.14	12.33	11.81
13	HI 1600	2.54	2.19	14.33	12.90	**38**	AKAW-4731	3.55	2.80	10.33	8.12
14	KB 2013-05	2.54	2.19	11.00	7.39	**39**	VW-20145	3.82	3.07	20.00	12.40
15	DBW-147	1.47	-0.13	14.33	11.63	**40**	GW-11	3.42	2.67	11.00	8.48
16	RAJ 4396	3.05	2.70	13.00	11.37	**41**	GW-173	3.75	3.00	13.67	10.75
17	GW2013-471	2.25	1.90	17.00	15.55	**42**	GW-322	3.42	2.67	11.00	10.57
18	GW2013-478	3.12	2.77	17.67	13.73	**43**	GW-366	3.82	4.22	10.33	7.01
19	GW2013-482	2.85	2.50	17.00	13.14	**44**	GW-496	4.29	4.69	12.33	9.70
20	GW2013-489	3.45	3.10	13.00	10.15	**45**	RAJ-3077	3.84	4.24	17.00	12.98
21	LBPY-2014-1	2.65	2.30	15.67	14.21	**46**	LOK-1	3.44	3.84	9.67	7.83
22	LBPY-2014-2	4.72	4.37	13.00	12.03	**47**	$F_6A_{DALANG}(95)$	3.17	3.57	15.00	12.81
23	LBPY-2014-3	1.85	1.50	14.33	11.32	**48**	$F_6A_{DALANG}107$	3.17	3.57	10.33	9.44
24	LBPY-2014-8	4.05	3.70	17.67	14.58	**49**	$F_6A_{DALANG}120$	2.84	3.24	15.67	12.74
25	NIAW 2064	3.52	3.17	18.33	12.63	**50**	$F_6A_{DALANG}126$	4.04	4.44	16.33	13.94

The final conclusion that can be reached from variability, correlations and path coefficient analysis with respect to heat tolerance is that under normal sowing condition with harvest index, biological yield per plant, 100-grain weight, length of main spike and plant height, while under late sowing condition with harvest index, biological yield per plant, plant height and length of main spike found the most important component characters. Hence, these traits should be considered as selection criteria for yield improvement in wheat.

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