Received: 05 Mar 2024 | Accepted: 23 Aug 2024 | Online: 02 Sep 2024

Electronic Journal of Plant Breeding

Research Article

Assessment of genetic variability, heritability and correlation in advanced breeding lines of bread wheat (*Triticum aestivum*) under heat stress condition

D. M. Kiranakumara[1*], Suma S. Biradar[2], B. Aishwarya[1], M. Akshaya[1] and K. O. Swaroop[1]

[1]Department of Genetics and Plant Breeding, College of Agriculture, DharwadUniversity of Agricultural Sciences, Dharwad-580005, Karnataka, India
[2] ICAR-AICRP on Wheat, MARS, University of Agricultural Sciences, Dharwad-580005, Karnataka, India.
***E-Mail:** dmkiranreddy@gmail.com

Abstract
An experiment was conducted under normal (with six irrigation during crop period) and stressed condition during *Rabi* 2019 in All India Coordinated Research Project (AICRP) on Wheat, MARS, Dharwad, Karnataka with the view of assessing genetic variability, heritability and expected genetic advance in 104 F_4 families of the cross HD2864 × DBW14. The progenies exhibited wide range of variation for all the traits indicating the presence of enough genetic variability in the material under study. Under timely sown condition, the traits like leaf waxyness, NDVI at different stages, SPAD at different stages, number of productive tillers per plant, seeds per spike, grain filling duration, spike length, thousand grains weight and seed set percentage showed high variability. The traits like plant height, canopy temperature at different stages and membrane stability index showed low variability. Under late sown condition, the traits like leaf waxyness, plant height, NDVI at different stages, SPAD at different stages, number of productive tillers per plant, seeds per spike, yield per plant, row bulk yield and seed set percentage showed high variability. The traits like days to maturity, spike length and membrane stability index showed low variability. The findings shows that all traits related to crop yield are positively linked, except for canopy temperature at different growth stages. Promising lines identified through Heat susceptibility index (HSI) and Heat tolerance index (HTI) can be utilized in future breeding programs to enhance crop productivity.

Keywords: Variability, Coefficient of variation, Heritability, Genetic advance.

INTRODUCTION

Wheat (*Triticum aestivum*) is a self-pollinated crop belonging to the family Poaceae and one of the leading cereals in many countries, including India. In India, wheat ranks as the second most significant food crop in terms of both cultivation area and production, following rice. Due to the acreage it occupies, high productivity and the prominent role it holds in the international food grain trade, it has been described as the 'King of cereals.' It is consumed in a number of forms, including bread, chapatti, flour, suji etc.

Abiotic stress such as heat, cold, drought, salinity and nutrient stress, have a significant effect on world agriculture, and it has been reported that most major crop plants reduce their average yields by > 50 percent (Wang *et al.*, 2003). Wheat is no exception to this as well. One of the major abiotic stresses facing wheat today is heat stress. High temperature effects include decreased grain weight, early senescence, shriveled grains, decreased accumulation of starch and altered grain starch-lipid composition, decreased germination of seeds and loss of vigour (Balla *et al*., 2012). Heat stress tolerance could be achieved in plants by various morphological characteristics such as presence of leaf waxyness and physiological adaptations such as maintaining low canopy temperature, changes in physiological process, such as decreased photosynthesis (Blum *et al*., 1994), photosystem II photochemical efficiency (Pradhan *et al*., 2012), increased degradation of chlorophyll (Ristic *et al*., 2007), lipid peroxidation and damage to the membrane (Sairam and Saxena, 2000). The impact of heat stress on physiology, grain yield and quality characteristics in wheat has been documented earlier (Wheeler *et al.,* 1996). Methodologies ranging from visual observations to novel phenotyping techniques such as the use of infrared thermometers, Soil Plant Analysis Development (SPAD) meters and the taking of Normalized Difference Vegetation Index (NDVI) observations along with the different agronomic parameters are applied for assessment of heat stress tolerance.

Awareness of genetic variability, heritability, coefficients of correlation and other parameters helps to further boost grain yield by directly selecting component characteristics and their interrelationship with yield. Genetic variability measures the variance between individual genotypes in a progeny for various characteristics under consideration that result from different causes. The importance of studying genetic diversity has been suggested by Kumar *et al.* (2013) as it indicates the existence of difference in their genetic makeup and helps in effective selection. Keeping all these in view a study was carried out to identify the heat tolerant lines in F_4 generation of the cross HD2864 × DBW14, to forward for subsequent generations.

MATERIALS AND METHODS

The present investigation was carried out at All India Coordinated Wheat Improvement Project, Main Agricultural Research Station (MARS), University of Agricultural Sciences, Dharwad, which is situated in northern transitional tract (Zone 8) of Karnataka with 15° 26' N latitude and 76° 07' E longitude, an altitude of 678 m above mean sea level (AMSL), with silty-clay-loam to clayey soil type. The climatic parameters, such as maximum and minimum temperature, rainfall and relative humidity recorded during the crop growth period are furnished in **Fig. 1**. A total of 104 F_4 families (selected from F_3 population) of the cross HD2864 × DBW14 were used in the study, along with the parents and five drought tolerant and two susceptible checks. HD 2864 is a wheat variety having good grain quality parameters and suitable for late sown condition (Birla *et al.,* 2012) and DBW 14 is a heat tolerant line suitable for late sown condition (Mitra, 2013). List of bread wheat genotypes used in the study are presented in **Table 1**.

The field experiment was conducted under normal (timely sown) and stressed (late sown) condition separately. Evaluation of the F_4 population was done by raising the progenies along with parents and checks during *Rabi* 2019 in Augmented Block Design II (ABD II) with four blocks to estimate the variability. Each progeny was planted in single row with plot size of 6.0 x 0.3 meters. Observations recorded on five randomly selected plants in each row for

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

S. No	Genotypes	Pedigree	Source	Traits	Seasonal condition
Parents					
01	HD 2864	DL 509-2/DL 377-8	IARI, New Delhi	Low canopy temperature and high spikelets per spike	Irrigated, timely sown
02	DBW14	RAJ-3765/PBW-343	IIWBR, Karnal	Heat tolerant based on HSI	Late sown
Tolerant checks					
01	HD 3090	SFW-16/VAISHA61//UP-2425	IARI, New Delhi	Higher leaf waxyness	Irrigated, late sown
02	NI 5439	RFPM-80/3*NP-710	MPKV, Wheat zonal coordinating unit, Niphad	Heat tolerant based on HSI	Released variety , timely sown
03	RAJ 3765	HD-2402/VL-639	RARI, Durgapura	Heat tolerant, high yielding	Released variety for late sown condition
04	WH 730	CPAN 2092/Improved Lok-1	CCS HAU, Hisar	Heat tolerant, high yielding	Released variety for late sown condition
05	HD 2932	KAUZ/STAR//HD2643	IARI, New Delhi	Heat tolerant based on HSI	Released variety for late sown
Susceptible checks					
06	QCSN 35	Not revealed	IIWBR, Karnal	Heat susceptible, high yielding	Released variety for Timely sown condition
07	QUAIU	BABAX/Lr42//BABAX*2/ VIVITSI	CIMMYT, Mexico	Heat susceptible, high yielding	Released variety for Timely sown condition

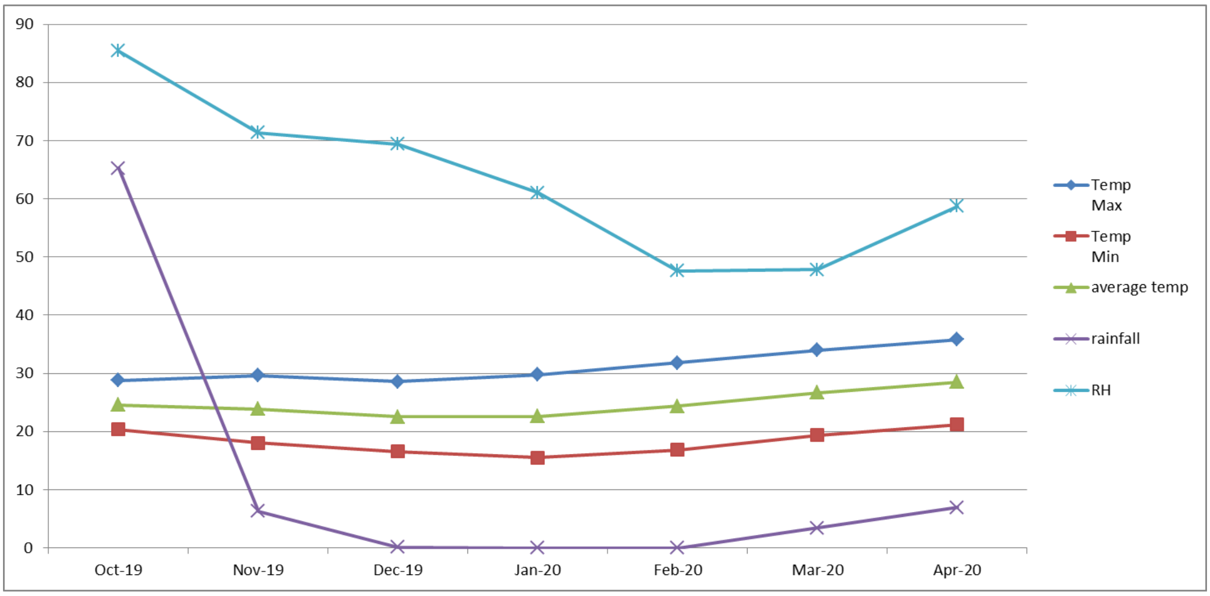

Fig.1. Monthly meteorological data 2018-19

characters such as days to fifty percent flowering, days to maturity, plant height, number of productive tillers per plant, spike length, number of spikelets per spike, number of seeds per spike, thousand grain weight, grain filling duration, grain yield per plant, seed set percentage, leaf waxyness and membrane stability index (MSI). Canopy temperatures (°C), SPAD, NDVI were recorded in three different (booting, anthesis and grain filling) stages. Variability, heritability analysis and correlation studies was carried out by computer generated program, WINDOSTAT (edition 9.1). The promising progenies were selected based on Heat susceptibility index (HSI) as reported by Fischer and Maurer (1978) and Heat tolerance index (HTI) as reported by Fernandez (1992).

Heat susceptibility index (HSI) (Fischer and Maurer , 1978)

$$HSI = \frac{1-(Ys / Yp)}{1-(Ys / Yp)}$$

Where,

Ys = yield under stress condition
Yp = yield under non-stress condition
Ys = Average yield under stress condition
Yp = Average yield under non-stress condition

The genotypes with HSI <0.5 were categorized as tolerant, those with HSI $\geq$ 0.5 to $\leq$ 1.0 were grouped as moderately tolerant and those with value > 1.0 were grouped as susceptible.

Heat tolerance index (HTI) (Fernandez ,1992)

$$HTI = \frac{(Ys \times Yp)}{(Yp)^2}$$

Ys = yield under stress condition
Yp = yield under non-stress condition
Yp = Average yield under non-stress condition

The genotypes with HTI >0.9 were categorized as tolerant, those with HTI 0.8–0.9 were grouped as moderately tolerant and those with value <0.8 were grouped as susceptible.

RESULTS AND DISCUSSION

Analysis of Variance (ANOVA) is an essential approach to classify the total variability into known and unknown causes. Significant differences among the treatments indicate the presence of sufficient variability among the treatments (**Table 2 and 3)**. The present study was aimed to assess genetic variability existing among families of F_4 progenies under timely sown and late sown conditions. The ANOVA for the 23 traits indicated that the treatments showed significant difference for all the characters suggesting the presence of vast variability (**Table 2 and 3)**. Significant differences were observed in case of checks for most of the traits under study. The mean performance of parents, F_4 progenies of the cross HD2864 × DBW14 and checks were studied under normal (timely sown) and stress (late sown) conditions (**Table 4**). It was observed that the trait means were higher in timely sown condition as compared to that of the late sown condition except for leaf waxiness and canopy temperatures in all the stages. That is because canopy temperature tends to increase due to heat stress and leaf waxiness also increases in response to heat experienced by plant.

Knowledge on the estimates of variability in respect of yield, its component traits is essential for formulating selection strategies. The assessment of heritable and non-heritable components in the total variability observed

Table 2. ANOVA of augmented RBD for yield and yield attributing traits in families of HD2864 × DBW14 under timely sown condition

Source of variation	DF	DFF	SPAD I	SPAD II	SPAD III	NDVI I	NDVI II	NDVI III	CT I	CT II	CT III	LW	MSI
Block	3	0.848	0.419	0.918	0.388	0.006	0.007	0.029	0.104	0.231	0.352	0.412	0.380
Treatment	109	7.640**	10.957**	7.736**	7.734**	0.005**	0.005**	0.010**	3.558**	1.262**	6.146**	1.072**	3.568**
Checks	9	2.803**	6.023**	5.858**	11.709**	0.006**	0.013**	0.010**	0.464	0.251	4.489**	2.614**	2.218**
Varieties	99	8.685**	10.347**	8.119**	7.171**	0.005**	0.005**	0.009**	3.925**	1.379**	6.847**	0.346**	3.828**
Checks vs. Varieties	1	3.206**	143.386**	18.081**	77.296**	0.003**	0.022**	0.136**	34.202**	8.135**	12.493**	60.274**	14.966**
Error	27	0.321	0.408	0.372	0.464	0.000	0.000	0.000	0.364	0.215	0.366	0.019	0.432

Source of variation	PH	SL	NSS	NPT	DM	SPS	TGW	YPP	GFD	SSP	RB
Block	0.889	0.531	0.174	0.170	0.674	0.350	0.812	0.248	0.836	0.086	1.510
Treatment	32.673**	1.899**	3.442**	2.158**	19.498**	17.584**	72.411**	5.353**	16.996**	1.527**	809.325**
Checks	57.486**	1.166**	4.042**	0.903**	9.025**	27.942**	56.699**	6.909**	11.569**	0.756	233.425**
Varieties	32.241**	1.652**	3.673**	2.350**	25.554**	17.506**	70.671**	5.817**	20.657**	1.608**	3039.612**
Checks vs. Varieties	168.455**	39.446**	11.630**	0.021	0.006	66.229**	614.429**	7.423**	105.875**	12.127**	4088.51**
Error	0.370	0.102	0.587	0.124	0.426	0.575	0.715	0.320	1.488	0.674	1.258

* Significant at 5% **Significant at 1%

Table 3. ANOVA of augmented RBD for yield and yield attributing traits in families of HD2864 × DBW14 under late sown condition

Source of variation	DF	DFF	SPAD I	SPAD II	SPAD III	NDVI I	NDVI II	NDVI III	CT I	CT II	CT III	LW	MSI
Block	3	0.53	0.0262	0.372	0.875	0.003	0.006	0.003	0.276	0.670	0.280	0.396	0.132
Treatment	109	11.117*	11.214**	8.74**	8.690**	0.006**	0.007**	0.005**	1.057**	1.151**	1.423**	1.299**	3.192**
Checks	9	6.247**	8.338**	13.466**	7.389**	0.010**	0.018**	0.015**	0.210	0.577*	0.398	3.686**	2.151**
Varieties	99	12.712**	11.517**	8.722**	8.895**	0.005**	0.005**	0.004**	1.051**	1.161**	1.475**	0.662**	3.225**
Checks vs. Varieties	1	2.835*	124.970**	55.413**	80.439**	0.045**	0.096**	0.026**	11.311**	9.798**	8.696**	44.002**	5.769*
Error	27	0.662	0.626	0.615	0.781	0.000	0.000	0.000	0.158	0.226	0.430	0.014	0.597

Source of variation	PH	SL	NSS	NPT	DM	SPS	TGW	YPP	GFD	SSP	RB
Block	1.694	0.908	0.118	0.034	1.419	0.068	1.311	0.081	1.926	0.246	2.317
Treatment	27.474**	1.462**	6.139**	1.737**	19.109**	26.760**	48.152**	8.876**	15.620**	17.701**	1212.610**
Checks	47.044**	0.714**	2.440*	0.704**	15.169**	11.544**	81.154**	1.349*	10.400**	3.460**	220.729**
Varieties	25.289**	1.365**	6.881**	1.959**	23.326**	30.111**	43.712**	10.401**	18.719**	20.001**	2210.701**
Checks vs. Varieties	324.676**	23.362**	29.203**	0.983*	0.086	59.328**	327.349**	2.747*	129.626**	18.400**	32410.17**
Error	0.458	0.040	0.825	0.096	0.666	0.620	0.714	0.511	0.570	0.584	1.207

* Significant at 5% **Significant at 1%

TS- Timely sown, LS- Late sown, DFF- Days to 50 per cent flowering, DM-Days to Maturity, PH- Plant Height (cm), LW-Leaf waxyness, NDVI I- NDVI at booting, NDVI II- NDVI at anthesis, NDVI III- NDVI at grain filling, SPAD I- Chlorophyll content at booting, SPAD II- Chlorophyll content at anthesis, SPAD III- Chlorophyll content at grain filling stage, CT I- Canopy Temperature at booting, CT II- Canopy Temperature at anthesis , CT III- Canopy Temperature at grain filling stage, MSI- Membrane Stability Index (%), GFD- Grain filling Duration, NPT- Number of productive tillers per plant, SL- Spike Length (cm), NSS- Number of Spikelets per Spike, SPS- Seeds per Spike, TGW- Thousand Grain Weight (g), YPP- Yield per plant (g), RB- Row bulk yield (g).

Table 4. Genetic variability parameters for morpho-physiological characters among F_4 progenies of cross HD2864 × DBW14

Characters		DFF		SPAD I		SPAD II		SPAD III		NDVI I		NDVI II		NDVI III	
Genetic parameters		TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS
Range	Min	49.00	47.00	41.40	40.42	45.86	41.88	42.80	40.40	0.37	0.40	0.39	0.41	0.32	0.40
	Max	61.00	60.00	56.86	55.94	58.34	55.48	55.68	53.68	0.74	0.72	0.75	0.74	0.69	0.70
Mean		54.11	51.66	49.96	46.74	51.10	47.25	49.95	45.97	0.64	0.59	0.66	0.62	0.53	0.57
GCV %		17.00	19.94	11.58	11.79	36.20	13.26	33.58	11.03	61.27	32.25	20.39	29.28	24.54	26.69
PCV %		19.42	22.47	13.28	13.2	45.86	14.29	45.29	13.04	77.80	37.25	44.91	35.58	52.79	30.28
h²(bs)%		86.84	90.67	88.35	88.81	78.18	91.92	73.27	84.8	79.52	86.76	47.73	83.61	46.51	87.05
G.A.M		10.35	11.29	8.22	9.76	16.81	10.91	14.27	9.12	78.01	91.90	82.29	89.81	92.33	88.63

Characters		CT I		CT II		CT III		LW		MSI		PH		SL		NSS	
Genetic parameters		TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS
Range	Min	18.06	20.66	23.00	24.26	21.74	27.30	3.00	3.00	32.41	45.43	53.60	54.00	7.20	5.00	9.20	7.80
	Max	24.92	24.64	28.00	29.12	36.32	32.44	5.40	7.00	53.39	62.42	81.80	82.00	12.60	10.80	25.40	26.00
Mean		22.22	23.00	25.50	26.80	27.11	29.70	4.03	4.82	48.24	47.92	68.47	64.27	9.95	7.76	15.39	13.55
GCV %		19.59	8.45	5.42	12.80	3.91	9.56	29.82	20.72	7.25	8.71	6.63	20.26	64.64	3.91	11.10	11.02
PCV %		46.47	9.63	5.94	13.90	4.21	12.30	40.10	27.49	8.24	9.28	9.75	23.40	75.90	4.66	15.25	12.78
h²(bs)%		41.29	91.12	90.39	92.92	77.63	80.13	73.71	72.55	86.91	83.81	66.15	89.84	85.48	68.24	70.29	87.50
G.A.M		8.18	12.31	9.94	14.61	6.83	11.73	12.86	45.71	9.76	7.27	4.32	10.59	62.59	9.74	19.49	15.45

Characters		NPT		DM		SPS		TGW		YPP		GFD		SSP		RB	
Genetic parameters		TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS
Range	Min	5.40	2.20	87.00	84.00	28.40	21.60	25.80	24.15	3.93	0.98	22.00	20.00	75.33	70.77	2.50	6.69
	Max	12.40	10.00	109.00	105.00	57.40	65.60	61.00	54.30	14.79	19.56	40.00	37.00	83.11	94.31	231.52	210.58
Mean		8.92	6.59	97.04	94.13	37.09	31.87	44.16	40.15	7.68	7.28	31.70	29.22	80.26	78.87	93.16	84.64
GCV %		29.18	38.15	15.35	4.62	41.90	22.62	56.97	11.01	10.82	61.69	21.24	16.64	31.90	23.51	11.82	50.23
PCV %		38.60	71.45	18.31	5.85	50.30	87.67	67.31	13.29	12.85	79.48	28.93	22.76	40.30	82.8	15.86	68.52
h²(bs)%		76.65	68.24	84.36	72.07	82.41	25.37	84.53	79.67	81.37	77.06	75.54	72.95	86.25	26.72	78.21	78.32
G.A.M		19.50	60.17	10.60	3.85	29.89	7.74	22.42	10.01	10.21	50.96	15.45	12.79	31.2	8.84	9.62	15.23

TS- Timely sown, LS- Late sown, DFF- Days to 50 per cent flowering, DM-Days to Maturity, PH- Plant Height (cm), LW-Leaf waxyness, NDVI I- NDVI at booting, NDVI II- NDVI at anthesis, NDVI III- NDVI at grain filling, SPAD I- Chlorophyll content at booting, SPAD II- Chlorophyll content at anthesis, SPAD III- Chlorophyll content at grain filling stage, CT I- Canopy Temperature at booting, CT II- Canopy Temperature at anthesis , CT III- Canopy Temperature at grain filling stage, MSI- Membrane Stability Index (%), GFD- Grain filling Duration, NPT- Number of productive tillers per plant, SL- Spike Length (cm), NSS- Number of Spikelets per Spike, SPS- Seeds per Spike, TGW- Thousand Grain Weight (g), YPP- Yield per plant (g), RB- Row bulk yield (g).

is indispensable in adapting suitable breeding procedure. In this context, various morpho-physiological characters were studied in F_4 progenies of the cross HD2864 × DBW14 for variability parameters such as PCV, GCV, heritability and genetic advance as percent mean (GAM). These parameters were estimated under experimental situation of heat stress as well as normal condition and presented in **Table 4.**

Under timely sown condition, the traits like leaf waxyness, normalized differential vegetative index at different stages, SPAD at different stages, number of productive tillers per plant, seeds per spike, grain filling duration, spike length, thousand grains weight and seed set percentage showed high GCV and PCV. This could be attributed to the diversity between the parents. High heritability indicates the significant role of additive gene action in the inheritance of the trait. Classical selection methods would be effective for improvement of these traits. These results are in agreement with Shankarrao *et al.* (2010), Yadawad *et al*. (2015), Mondal *et al*. (2015), Jaya (2016) and Vinod (2018). Traits like days to fifty percent flowering, days to maturity, number of spikelets per spike, yield per plant and row bulk yield showed moderate GCV and PCV. The traits like plant height, canopy temperature at different stages and membrane stability index showed low GCV and PCV indicating the presence of non-additive gene action and selection based on these traits can be postponed to later generations. These results are similar to the findings of Mohammed *et al.* (2011), Kant *et al.* (2011), Yadawad *et al*. (2015).

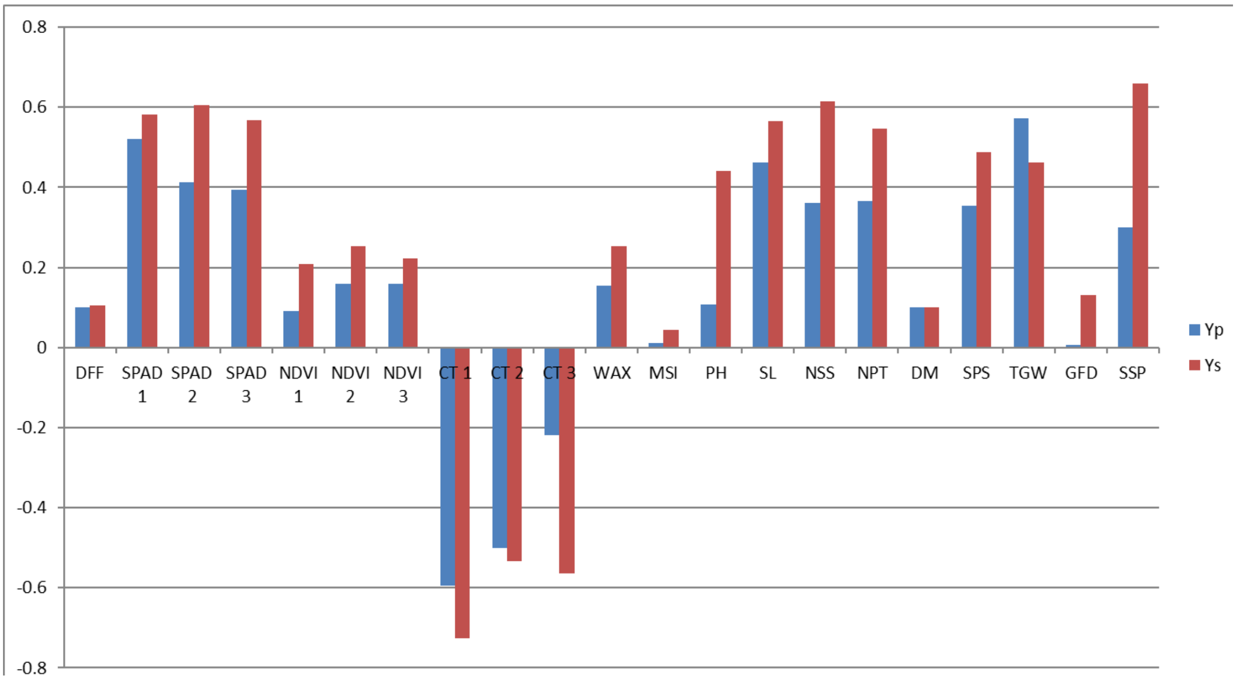

Fig. 2. Correlation pattern of yield attributing characters with yield in cross HD2864 X DBW14

Y_P-Yield per plant under non stress condition, Y_S-Yield per plant under heat stress condition, TS- Timely sown, LS- Late sown, DFF- Days to 50 per cent flowering, DM-Days to Maturity, PH- Plant Height (cm), LW-Leaf waxyness, NDVI I- NDVI at booting, NDVI II- NDVI at anthesis, NDVI III- NDVI at grain filling, SPAD I- Chlorophyll content at booting, SPAD II- Chlorophyll content at anthesis, SPAD III- Chlorophyll content at grain filling stage, CT I- Canopy Temperature at booting, CT II- Canopy Temperature at anthesis , CT III- Canopy Temperature at grain filling stage, MSI- Membrane Stability Index (%), GFD- Grain filling Duration, NPT- Number of productive tillers per plant, SL- Spike Length (cm), NSS- Number of Spikelets per Spike, SPS- Seeds per Spike, TGW- Thousand Grain Weight (g).

Table 5. Heat stress indices of parents and checks.

Genotypes	Y_P	Y_S	HSI	Description	HTI	Description
HD2864	8.15	6.68	1.35	Susceptible	0.88	Susceptible
DBW14	8.97	8.31	0.40	Tolerant	1.20	Tolerant
HD3090	7.45	6.72	0.53	Moderate	0.81	Moderate
NI5439	7.22	7.06	0.12	Tolerant	0.82	Moderate
RAJ3765	7.39	7.24	0.11	Tolerant	0.86	Moderate
WH730	9.01	7.92	0.65	Moderate	1.15	Tolerant
HD2932	6.11	5.89	0.19	Tolerant	0.58	Susceptible
QCSN 35	7.34	4.36	2.20	Susceptible	0.52	Susceptible
QUAIU	7.35	4.71	1.94	Susceptible	0.56	Susceptible

Y_P-Yield per plant under non stress condition, Y_S-Yield per plant under heat stress condition, HSI-Heat susceptibility index, HTI-Heat tolerance index

Table 6. Heat stress indices of the promising families of the cross HD2864 X DBW14 based on HSI

S.No.	Genotypes	Y_P	Y_S	HSI	Description
1	HD2864 × DBW14-F4-1	4.15	9.4	-1.4	Tolerant
2	HD2864 × DBW14-F4-10	4.39	10.35	-1.51	Tolerant
3	HD2864 × DBW14-F4-11	5.43	13.02	-1.56	Tolerant
4	HD2864 × DBW14-F4-13	8.47	8.98	-0.07	Tolerant
5	HD2864 × DBW14-F4-17	7.04	12.01	-0.78	Tolerant
6	HD2864 × DBW14-F4-18	7.74	8.4	-0.09	Tolerant
7	HD2864 × DBW14-F4-19	4.55	12.66	-1.98	Tolerant
8	HD2864 × DBW14-F4-25	10.4	9.54	0.09	Tolerant
9	HD2864 × DBW14-F4-27	8.9	9.78	-0.11	Tolerant
10	HD2864 × DBW14-F4-33	6.12	9.8	-0.67	Tolerant
11	HD2864 × DBW14-F4-41	7.16	8.83	-0.26	Tolerant
12	HD2864 × DBW14-F4-44	9.66	5.53	0.47	Tolerant
13	HD2864 × DBW14-F4-45	6.11	10.28	-0.76	Tolerant
14	HD2864 × DBW14-F4-46	5.56	6.08	-0.1	Tolerant
15	HD2864 × DBW14-F4-47	10.88	7.66	0.33	Tolerant
16	HD2864 × DBW14-F4-48	10.82	6.22	0.47	Tolerant
17	HD2864 × DBW14-F4-52	8.31	12.69	-0.59	Tolerant
18	HD2864 × DBW14-F4-54	12.01	6.81	0.48	Tolerant
19	HD2864 × DBW14-F4-56	11.63	9.44	0.21	Tolerant
20	HD2864 × DBW14-F4-57	11.3	9.54	0.17	Tolerant
21	HD2864 × DBW14-F4-58	12.31	15.08	-0.25	Tolerant
22	HD2864 × DBW14-F4-60	13.82	8.37	0.44	Tolerant
23	HD2864 × DBW14-F4-61	6.36	4.13	0.39	Tolerant
24	HD2864 × DBW14-F4-62	11.66	9.6	0.2	Tolerant
25	HD2864 × DBW14-F4-63	5.94	4.69	0.23	Tolerant
26	HD2864 × DBW14-F4-66	8.78	8.63	0.02	Tolerant
27	HD2864 × DBW14-F4-68	9.64	19.56	-1.14	Tolerant
28	HD2864 × DBW14-F4-70	7.26	13.73	-0.99	Tolerant
29	HD2864 × DBW14-F4-71	9.18	13.61	-0.54	Tolerant
30	HD2864 × DBW14-F4-72	7.86	13.07	-0.74	Tolerant
31	HD2864 × DBW14-F4-73	6.38	11.43	-0.88	Tolerant
32	HD2864 × DBW14-F4-76	9.19	6.07	0.38	Tolerant
33	HD2864 × DBW14-F4-79	9.23	7.97	0.15	Tolerant
34	HD2864 × DBW14-F4-81	7.08	9.3	-0.35	Tolerant
35	HD2864 × DBW14-F4-82	10.77	11.03	-0.03	Tolerant
36	HD2864 × DBW14-F4-89	5.32	6.29	-0.2	Tolerant
37	HD2864 × DBW14-F4-90	7.6	6.04	0.23	Tolerant
38	HD2864 × DBW14-F4-91	4.38	9.42	-1.28	Tolerant
39	HD2864 × DBW14-F4-92	6.64	9.71	-0.51	Tolerant
40	HD2864 × DBW14-F4-93	5.26	8.65	-0.72	Tolerant
41	HD2864 × DBW14-F4-95	9.03	5.79	0.4	Tolerant
42	HD2864 × DBW14-F4-100	9.1	8.88	0.03	Tolerant
43	HD2864 × DBW14-F4-102	6.46	9.46	-0.52	Tolerant
44	HD2864 × DBW14-F4-103	7.71	8.29	-0.08	Tolerant
45	HD2864 × DBW14-F4-104	7.13	11.67	-0.71	Tolerant

Y_P-Yield per plant under non stress condition, Y_S-Yield per plant under heat stress condition, HSI-Heat susceptibility index, HTI-Heat tolerance index

Table 7. Heat stress indices of the promising families of the cross HD2864 X DBW14 based on HTI

S. No.	Genotypes	Y_P	Y_S	HTI	Description
1	HD2864 × DBW14-F4-11	5.43	13.02	0.99	Tolerant
2	HD2864 × DBW14-F4-13	8.47	8.98	1.06	Tolerant
3	HD2864 × DBW14-F4-17	7.04	12.01	1.18	Tolerant
4	HD2864 × DBW14-F4-18	7.74	8.4	0.91	Tolerant
5	HD2864 × DBW14-F4-23	14.79	5.83	1.21	Tolerant
6	HD2864 × DBW14-F4-25	10.4	9.54	1.39	Tolerant
7	HD2864 × DBW14-F4-27	8.9	9.78	1.22	Tolerant
8	HD2864 × DBW14-F4-47	10.88	7.66	1.17	Tolerant
9	HD2864 × DBW14-F4-48	10.82	6.22	0.94	Tolerant
10	HD2864 × DBW14-F4-52	8.31	12.69	1.48	Tolerant
11	HD2864 × DBW14-F4-54	12.01	6.81	1.15	Tolerant
12	HD2864 × DBW14-F4-56	11.63	9.44	1.54	Tolerant
13	HD2864 × DBW14-F4-57	11.3	9.54	1.51	Tolerant
14	HD2864 × DBW14-F4-58	12.31	15.08	2.6	Tolerant
15	HD2864 × DBW14-F4-60	13.82	8.37	1.62	Tolerant
16	HD2864 × DBW14-F4-62	11.66	9.6	1.57	Tolerant
17	HD2864 × DBW14-F4-66	8.78	8.63	1.06	Tolerant
18	HD2864 × DBW14-F4-68	9.64	19.56	2.64	Tolerant
19	HD2864 × DBW14-F4-70	7.26	13.73	1.4	Tolerant
20	HD2864 × DBW14-F4-71	9.18	13.61	1.75	Tolerant
21	HD2864 × DBW14-F4-72	7.86	13.07	1.44	Tolerant
22	HD2864 × DBW14-F4-73	6.38	11.43	1.02	Tolerant
23	HD2864 × DBW14-F4-79	9.23	7.97	1.03	Tolerant
24	HD2864 × DBW14-F4-81	7.08	9.3	0.92	Tolerant
25	HD2864 × DBW14-F4-82	10.77	11.03	1.66	Tolerant
26	HD2864 × DBW14-F4-92	6.64	9.71	0.9	Tolerant
27	HD2864 × DBW14-F4-100	9.1	8.88	1.13	Tolerant
28	HD2864 × DBW14-F4-103	7.71	8.29	0.9	Tolerant
29	HD2864 × DBW14-F4-104	7.13	11.67	1.17	Tolerant

Y_P-Yield per plant under non stress condition, Y_S-Yield per plant under heat stress condition, HSI-Heat susceptibility index, HTI-Heat tolerance index

Under late sown condition, the traits like leaf waxiness, plant height, normalized differential vegetative index at different stages, SPAD at different stages, number of productive tillers per plant, seeds per spike, yield per plant, row bulk yield and seed set percentage showed high GCV and PCV. These results were in accordance with the reports of Prakash and Kerketta (2000), Said *et al.* (2014), Yadawad *et al*. (2015) and Rahman *et al.* (2016). This suggests that there is a lot of scope for improvement of yield under heat stress condition through selection for the above mentioned traits. High heritability indicates the significant role of additive gene action in the inheritance of the trait. Classical selection methods would be effective for improvement of these traits. Traits like days to fifty percent flowering, canopy temperature at different stages, number of spikelets per spike, grain filling duration and thousand grains weight showed moderate GCV and PCV. The traits like days to maturity, spike length and membrane stability index show GCV and PCV indicating the presence of non-additive gene action and selection based on these traits is not recommended in early generation, it can be postponed to further generation. These results were in agreement with the results of Ali *et al*. (2008), Shankarrao *et al*. (2010), Abinasa *et al.* (2011), Kant *et al.* (2011), Mohammed *et al.* (2011), Kalimullah *et al*. (2012), Prabha *et al*. 2022 and Fikre *et al*. (2015).

In the present investigation, parameters such as plant height (0.4), chlorophyll content (SPAD) at booting (0.58), anthesis (0.60) and grain filling (0.57), NDVI values at booting (0.2), anthesis (0.25) and grain filling (0.22), spikelets per spike (0.61), seeds per spike (0.48) and productive tillers per plant (0.54) were positively associated with yield under heat stress. These results agreed with Khan *et al.* (2014). Also, it showed negative association with canopy temperature at anthesis (-0.72), flowering (-0.53) and grain filling (-0.56) stages (**Fig 2**). These results were similar to the findings of Mohammadi *et al*. (2012). Under timely sown condition, all the yield attributing traits such as plant height (0.1), chlorophyll content at (SPAD) at booting (0.52), anthesis (0.41) and grain filling (0.39), NDVI values at booting (0.09), anthesis (0.16) and grain filling (0.16), spikelets per spike (0.36), seeds per spike (0.35) and productive tillers per plant (0.36) showed significant positive association with yield per plant. The trait like canopy temperature at anthesis (-0.59) flowering (-0.50) and grain filling (-0.21) stages showed negative association. Similar results were reported by Ramanuj *et al*. (2017) and Rahman *et al.* (2016).

Study of heat stress indices such as HSI and HTI have shown that among the parents, HD2864 was a heat susceptible genotype while DBW14 was heat tolerant genotype. Among the checks QCSN35 and QUAIU were heat susceptible genotypes whereas, HD3090, NI5439, RAJ3765, WH730 and HD2932 were heat tolerant (**table 5**). In case of the F_4 promising progenies of HD2864 × DBW14, 45 families were classified as tolerant and 10 families were classified under moderately tolerant based on HSI. Based on HTI 29 families were found tolerant, 19 families were classified as susceptible while seven families were categorized as moderately tolerant. The tolerant progenies based on HTI and HSI are listed in **table 6 and 7**.

The genetic variability studies in the F_4 progenies of the cross HD2864 × DBW14 under control and stressed conditions shows there was significant variability among the progenies. The wide range of variation for traits such as leaf waxiness, NDVI, SPAD, productive tillers, seeds per spike, grain filling duration, spike length, thousand grains weight, and seed set percentage indicated substantial genetic diversity. Notably, certain traits exhibited high variability under timely sown conditions, while others showed greater variability under late sown conditions. However, traits such as plant height, canopy temperature, days to maturity, spike length, and membrane stability index displayed lower variability across both conditions. Correlation studies indicate a positive correlation between yield and all yield-related traits, except for canopy temperature at various stages. The promising lines chosen based on HSI and HTI could be used in generation advancement breeding programs after stabilization.

REFERENCES

Abinasa, M., Ayana, A. and Bultosa, G. 2011. Genetic variability, heritability and trait associations in durum wheat (*Triticum turgidum* L. var. *durum*) genotypes. *African Journal of Agricultural Research,* **6**: 3972-3979.

Ali, Y., Atta, B.M., Akhter, J., Monneveux, P. and Lateef, Z. 2008. Genetic variability, association and diversity studies in wheat (*Triticum aestivum* L.) germplasm. *Pak. J. Bot*, **40**(5):2087-2097.

Balla, K., Karsai, I., Bencze, S. and Veisz, O. 2012. Germination ability and seedling vigour in the progeny of heat-stressed wheat plants. *Acta Agronomica Hungarica*, **60**(4): 299-308. [Cross Ref]

Birla, S., Shukla, R.S. and Mishra, D.K. 2012. Screening wheat genotypes suitable for late and very late sown condition using stability analysis. *JNKVV*, **46**(3):301.

Blum, A., Sinmena, B., Mayer, J., Golan, G. and Shpiler, L. 1994. Stem reserve mobilisation supports wheat-grain filling under heat stress. *Functional Plant Biology*, **21**(6):771-781. [Cross Ref]

Fernandez, G. C. J. 1992. Effective selection criteria for assessing plant stress tolerance. *Proc. Int. Symp. Adapt. Veg. Food Crop. Temp. Water Stress.* Tainan (Taiwan), pp. 257-270.

Fikre, G., Alamerew, S. and Tadesse, Z. 2015. Genetic variability studies in bread wheat (*Triticum aestivum* L.) genotypes at kulumsa agricultural research center, south east Ethiopia. *Journal of Biology, Agriculture and Healthcare*, **5**(7):89-98.

Fischer, R.A. and Maurer, R. 1978. Drought resistance in spring wheat cultivars. I. Grain yield responses. *Australian Journal of Agricultural Research*, **29**(5):897-912. [Cross Ref]

Jaya, 2016. Genetic investigations on heat adaptive traits in bread wheat by using molecular markers. *M. Sc. Thesis, University of Agricultural Sciences, Dharwad* (India).

Kalimullah, S., Khan, J., Irfaq, M. and Rahman, H.U. 2012. Genetic variability, correlation and diversity studies in bread wheat (*Triticum aestivum* L.) germplasm. *J. Anim. Plant Sci*, **22**(2):330-333.

Khan, J. A., Afroz, S., Arshad, H. M. I., Sarwar, N., Anwar, H. S., Saleem, K., Babar, M. M. and Jamil, F. F. 2014. Biochemical basis of resistance in rice against bacterial leaf blight disease caused by *Xanthomonas oryzae* pv. oryzae. *Adv. Life. Sci.,* 1(3): 181-190.

Kumar, S., Sairam, R.K. and Prabhu, K.V. 2013. Physiological traits for high temperature stress tolerance in *Brassica juncea*. *Indian Journal of Plant Physiology*, **18:**89-93. [Cross Ref]

Mitra, B. 2013. Performance of wheat genotypes under late and very late sowing in sub-Himalayan plains of West Bengal. *Crop Research*, **46**(3):32-35.

Mohammed, A., Amsalu, A. and Bultosa, G. 2011. Genetic variability, heritability and trait associations in durum wheat (*Triticum turgidum* L. var. *durum*) genotypes. *Afr. J. Agric. Res.,* **6**(17): 3972-3979. [Cross Ref]

Mondal, S., Mason, R.E., Huggins, T. and Hays, D.B. 2015. QTL on wheat (*Triticum aestivum* L.) chromosomes 1B, 3D and 5A are associated with constitutive production of leaf cuticular wax and may contribute to lower leaf temperatures under heat stress. *Euphytica*, **201:**123-130. [Cross Ref]

Prabha, A.A, Avinashe, H., Dubey, N., Reddy, J.P. and Reddy, B.T. 2022. Genetic studies on F3 population of bread wheat [*Triticum aestivum* L.] for yield and its components traits. *Electronic Journal of Plant Breeding*, **13**(2):369-76. [Cross Ref]

Pradhan, G.P., Prasad, P.V.V., Fritz, A.K., Kirkham, M.B. and Gill, B.S. 2012. High temperature tolerance in Aegilops species and its potential transfer to wheat. *Crop Science*, **52**(1): 292-304. [Cross Ref]

Prakash, S. and Kerketta, V. 2000. Estimates of genetic parameter in bread wheat (*Triticum aestivum* L.). *Madras Agricultural Journal*, **86**(Jul-Sep.):1. [Cross Ref]

Ramanuj, B. D., Delvadiya, I. R., Patel, N. B. and Ginoya, A. V. 2017. 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.

Rahman, M.A., Kabir, M.L., Hasanuzzaman, M., Rahman, M.A., Rumi, R.H. and Afrose, M.T. 2016. Study of variability in bread wheat (*Triticum aestivum* L.). *International Journal of Agronomy and Agricultural Research*, **8**(5):66-76.

Ristic, Z., Bukovnik, U. and Prasad, P.V. 2007. Correlation between heat stability of thylakoid membranes and loss of chlorophyll in winter wheat under heat stress. *Crop Science*, **47**(5):2067-2073. [Cross Ref]

Sairam, R.K. and Saxena, D.C. 2000. Oxidative stress and antioxidants in wheat genotypes: possible mechanism of water stress tolerance. *Journal of Agronomy and Crop Science*, **184**(1):55-61. [Cross Ref]

Said Salman, S.S., Khan, S.J., Javed Khan, J.K., Khan, R.U. and Imran Khan, I.K. 2014. Genetic variability studies in bread wheat (*Triticum aestivum* L.) accessions. Pakistan agricultural research council. 1-7

Shankarrao, B.S., Mukherjee, S., Pal, A.K. and De, D.K. 2010. Estimation of variability for yield parameters in bread wheat (*Triticum aestivum* L.) grown in Gangetic West Bengal. *Electronic Journal of Plant Breeding*, **1**(4):764-768.

Kant, S., Lamba, R.A.S., Panwar, I.S. and Arya, R.K., 2011. Variability and inter-relationship among yield and quality parameters in bread wheat. *J. Wheat Res*, **3**(2):50-60.

Vinod, K. 2018. Molecular breeding for heat tolerance in bread wheat. *M. Sc. (Agri.) Thesis, University of Agricultural Sciences,* Dharwad (India).

Wang, W., Vinocur, B. and Altman, A. 2003. Plant responses to drought, salinity and extreme temperatures: towards genetic engineering for stress tolerance. *Planta*, **218**:1-14. [Cross Ref]

Wheeler, T.R., Batts, G.R., Ellis, R.H., Hadley, P. and Morison, J.I.L. 1996. Growth and yield of winter wheat (*Triticum aestivum*) crops in response to CO2 and temperature. *The Journal of Agricultural Science*, **127**(1): 37-48. [Cross Ref]

Yadawad, A., Hanchinal, R.R., Nadaf, H.L., Desai, S.A., Suma, B. and Naik, V.R. 2015. Genetic variability for yield parameters and rust resistance in F2 population of wheat (*Triticum aestivum* L.). *The Bioscan*, **10**(2 Supplement): 707-710.