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Assessment of wheat genotypes based on various indices under different heat stress conditions

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Abstract

The objective of this study was to assess heat tolerance of spring wheat genotypes. For this purpose, a panel of 25 heat-responsive wheat genotypes was evaluated under optimum field conditions and two heat-stress conditions (HSC) *viz*., HSC1 and HSC2 during two crop seasons. Combined analysis of variance showed significant differences among genotypes for HSIs and grain yield. Heat stress indices (HSIs) were estimated using grain yield under optimum and stress conditions. Correlation coefficients and principal component analysis revealed the importance of mean productivity, geometric mean productivity, stress tolerance index and stress susceptibility index in selecting heat tolerant genotypes. Genotypes DBW 71, DBW 107, AKW 2862-1 and KKR 1043 were found more tolerant with good yield potential under HSC1 whereas WH730, DBW 173, DBW 71 and WR 544 performed best under HSC2 along with optimum field condition. Identified genotypes can be used in wheat improvement programs developing heat stress-tolerant genotypes.

Key words: Heat stress, heat susceptibility index, principal component analysis, biplot, correlation

Introduction

The last three decades have witnessed much rise in temperature than overall warming observed in the northern hemisphere during the past millennium (Driedonks et al. 2016). Changing climate is significant environmental issue which affects the growth and productivity of wheat crop. Liu et al. (2016) reported reduction in grain yield (GY) by 4.1 to 6.4 percent with each degree rise in temperature during grain-flling duration (GFD). Increase in temperature during anthesis to grain maturity beyond 22°C, shortens GFD causing reduction in the GY (Dias and Lidon 2009). This poses a challenge to the breeders for developing cultivars which can resist high temperature stress. Growing breeding material under high temperature conditions and its comparative performance for yield *vis-a-vis* optimum condition has often been a most common method in selecting heat stress tolerant genotypes (Ehlers and Hall, 1998). Heat stress indices (HSIs) are valuable tools for selection of genotypes possessing both high yield as well as tolerance to heat stress. There are several physiological and statistical parameters used to determine the performance of the genotypes under heat stress conditions that include, heat stress tolerance index (STI), stress susceptibility index (SSI), stress conditions under which the material is screened, geometric mean of yield under contrasting field conditions to make relative comparisons between the genotypes. Kamrani et al. (2018) have reported a positive correlation between yield under heat stress conditions (Y_h) and mean productivity (MP) and geometric mean productivity (GMP) whereas Chakherchaman et al. (2009) found the same between GMP and stress tolerance index (STI). Therefore, these indices can be used for selecting genotypes with moderate yield under both optimum field conditions (OFC) and heat stress conditions (HSCs). It has been suggested earlier that stress resistant wheat genotypes can be selected based on the values of STI, GMP and MP under optimum and drought stress conditions (Nouri et al. 2011). In a study of common bean, a combination of GMP and SSI was reported to be important criteria for enhancing drought resistance

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(Ramirez-Vallejo and Kelly 1998). Therefore, the present study was conducted to investigate the accuracy of various stress indices in identifying high yielding and heat tolerant wheat genotypes.

Materials and methods

Plant material and experimental site

The research was conducted at the experimental field of ICAR-Indian Institute of Wheat and Barley Research, Karnal, (29°422 N, 77°022 E), India during two successive crop seasons (2017-2018 and 2018-2019). A set of heat responsive genotypic panel (HRGP) consisting of 25 wheat genotypes viz., AKAW 4842, AKW 2862-1, DBW 14, DBW 71, DBW 107, DBW 150, DBW 173, GW 477, HD 2932, HINDI 62, HTW 6, HTW 11, HTW 66, HTW 67, K 7903, KKR 1043, PBW 343, RAJ 3765, RIL 39, RIL 97, RIL 119, RIL 182, WCF8-W12, WH 730, WR 544 was evaluated under three conditions viz., OFC and two heat-stress conditions; HSC1 and HSC2. Genotypes (DBW14, K7903, DBW107, RAJ3765, DBW173, GW477, WR544, DBW71 and HD2932) were selected as their performance was good against heat tolerance under late sown conditions (Gupta et al. 2018a). Another genotype PBW343 is known to have a greater adaptability under diverse sowing regimes, and it formerly inhabited a 10 million hectare (hec) region in India's Indo-Gangetic plains. Other entries viz., WH730, HTW6, DBW150, AKW2862-1, HTW11, HTW66, HTW67, WCF8-W12 and HINDI62 are the registered genetic stocks for heat stress tolerance with ICAR-National Bureau of Plant Genetic Resources, New Delhi and majority of them displayed a stress susceptibility index (SSI) of <1.0 (Gupta et al. 2018b). Mutant line (KKR1043) known for high grain yield under gradual stress condition while other promising RILs like RIL182, RIL39, RIL119 and RIL97 (developed by the crossing of Dharwar Dry/DPW621-50) identified for drought- cum-heat tolerance. Dharwar dry is a traditional variety that thrives in warm, low-moisture environments (Kirigwi et al. 2007).

Experiment design and Sowing conditions

During both years, genotypes were planted in alpha lattice experimental design with two replications in each condition, with a uniform plot size (0.64 m^2) consisting of 24 plants in four rows with a 10 cm spacing between them and a 10 cm plant to plant distance. Sowing was done with the help of "IIWBR Dibbler" (Sharma et al. 2016) to ensure precise planting on two different sowing times: in third week of November under OFC and HSC2. Under HSC2, once the facility is closed, it may maintain a temperature of 1°C to 10°C greater than the ambient temperature (Sharma et al. 2019). In this investigation, the facility was closed at the time of anthesis, and the temperature within was kept at a 5°C higher from the outside temperature during the diurnal cycle. Planting was done in third week of December under HSC1 to coincide with high temperature stress on GFD naturally by way of delayed planting. The grain yield was measured at crop maturity by harvesting of inner eight plants from each plot. Daily temperature (maximum & minimum) and rainfall were recorded under all three conditions throughout the crop season (Watchdog weather station Spectrum Tech. 2000 series). Mean maximum, minimum temperatures and average rainfall from heading to anthesis stages are presented in Supplementary Table S1.

Statistical analysis

Various heat stress indices viz., TOL, SSI, MP, GMP, STI, YI and YSI were calculated to measure heat tolerance or susceptibility of the test genotypes using inter-relationships of various indices (Supplementary Table S2). Stress intensity (SI) was calculated using formula ($1-X_h/X_o$) given by Fischer and Maurer, (1978). Stress tolerance (TOL) is calculated as the yield differences between optimum field condition (OFC) and heat stress conditions (HSCs) whereas yield average of two conditions is defined as mean productivity (MP). Geometric mean productivity (GMP) was used for evaluating relative performance of stress-tolerant genotypes while stress susceptibility index (SSI) was estimated as the ratio of individual genotypic yield performance under OFC and HSCs. Stress tolerance index (STI) is an effective index for selecting genotypes having high yield under stress and non-stress conditions based on Y_o (yield under OFC) Y_h (yield under HSCs) and X_o (average of total Y_o).

Analysis of variance (ANOVA) was carried out for GY and HSIs using Agricolae package of R (version 3.4.2). To indicate relationship among various HSIs and GY, Pearson's correlation coefficient (r) was used. In addition to it, 3-D graphs, multivariate Principal component analysis (PCA) and biplot diagrams were utilized to identify heat tolerant and susceptible genotypes using Stat Graphics software.

Result and discussion

Stress intensity

Nearly 4^0C to 5^0C higher minimum and maximum temperatures were observed under HSC1 and HSC2 conditions compared to timely sowing during grain filling (Supplemetary Table S1.)

High value of stress intensity indicates higher stress severity (Dodig et al. 2008) indicating more yield reduction under stress conditions and vice-versa. Overall stress intensity significantly varied between two HSCs. Based on the values of stress intensity, reduction in yield was observed about 40% and 60% under HSC1 and HSC2 conditions respectively. High reduction under HSC2 condition indicates that if plants get instant shock of high temperature at GFD, it causes higher reduction in yield as against if they receive high temperature from the initial stages as in HSC1 condition. Hoshikawa (1962) showed that a sudden increase in temperature causes a greater loss in grain yield in wheat than a steady increase in temperature. As a result, it is clear that these two forms of stresses have quite different adaptive mechanisms, as seen by the different values of stress intensity under these two scenarios.

Combined analysis of variance

The combined analyses of variance for GY and various HSIs are presented in Table 1. The results revealed significant influence of high temperature on GY of genotypes under both stress conditions. Highly significant differences at P < 0.01 were noticed for grain yield and most of the HSIs among genotypes and sowing conditions. Variation among conditions and genotypes enables us to select condition specific tolerant genotypes.

Heat tolerance/susceptible indices

A lower SSI (<1.0) and TOL value is desirable for heat-tolerant genotypes grown under stress conditions (Zangi, 1998). These are found to be positively correlated with each other. Lowest value of TOL occurred in the genotypes DBW 14 (under HSC1) and RIL 97 (under HSC2 conditions), but this can be attributed to low yield differences of these genotypes in test conditions by virtue of low yielding ability per-se in them. Therefore, lowest TOL value does not alone signify high yield performance under stress and thus yield per-se should also be considered as important criteria. Similar observations were made by Dorostkar et al. (2015) in wheat. SSI is a useful indicator to quantify the magnitude of heat stress which has been also used in previous study to identify tolerant genotypes (El Hassouni et al. 2019). A total of 12 genotypes were found tolerant on the basis of SSI under both stress conditions. Out of them, DBW 173, DBW 71, WH730, KKR 1043 and WR 544 simultaneously showed high yields as well. Genotypes with higher STI value exhibited more tolerance to stress with higher yield potential (Rosielle and Hamblin, 1981). Genotypes DBW 71, AKW 2862-1, KKR 1043 and DBW 107 under HSCI while DBW 173, DBW 71, WH730 and WR 544 under HSC2 favoured high STI value with good yield. In addition to above indices, a combination of higher values of MP, GMP and YI was found to be useful for selecting genotypes with higher heat tolerance and vice-versa (Jahan et al. 2018). On the basis of MP, GMP and YI combination, genotypes DBW 71, AKW 2862-1, DBW 107 and KKR 1043 were found tolerant under HSC1 conditions, whereas under HSC2 conditions, it was DBW 173, DBW 71, WH730 and WR 544. These genotypes were also found under heat tolerant category on the basis of SSI and STI values (Supplementary Table 3). Hence, these genotypes can be recommended as the most stable and productive genotypes under different conditions for further utilization. Therefore, a combination of SSI, STI, MP, GMP and YI found useful to identify high yielding cum heat tolerant genotypes which is in harmony with the observation made by Meena et al. (2015).

Table 1. Analysis of variance (pooled over years) for grain yield and heat stress indices of 25 spring wheat genotypes

Grain yield			Stress indices (P- value)							
Source	DF	P-Value	DF	TOL	SSI	MP	GMP	STI	YI	YSI
Condition	2	0.000**	1	0.000**	0.713 ns	0.000**	0.000**	0.000**	1.000 ns	0.000**
Genotype	24	0.000**	24	0.006**	0.067 ns	0.000**	0.000**	0.000**	0.001**	0.667 ns
Cond*Gen	48	0.354 ns	24	0.985 ns	0.572 ns	0.985 ns	0.930 ns	0.688 ns	0.568 ns	0.939 ns

"**"Significant at P $\leq$ 1%, ns = non-significant

Correlation coefficients among stress indices

Estimation of correlation coefficient between yield and HSIs are considered to be useful for screening stress tolerant genotypes. In the present study, GY was significantly positively correlated with MP, GMP, STI, YI and YSI in both HSCs, suggesting that higher the value of indices are, greater is the tolerance of genotypes with better GY under HSCs. Jahan et al. (2018) opined that there is a positive correlation between GMP, MP, YI, and STI and GY under stress. On the other hand, GY was found to be negatively correlated with SSI in both stress conditions indicating that genotypes with higher index gave lower yield and vice-versa. Khan and Kabir, (2015) also reported negative correlation between SSI and GY. Furthermore, MP, GMP, STI and YI were found negatively correlated with SSI and positively correlated with each other in both stress conditions (Fig. 1).

graphs enabling us to classify genotypes on the basis of stability. Group A included only those genotypes which had stable yield performance under OFC and stress conditions. Genotypes viz., AKW 2862-1, DBW 71, KKR 1043 and DBW 107 under HSC1 whereas DBW 173, WH 730, DBW 71 and WR 544 in HSC2 condition were placed in group A. Group B and Group C included genotypes showing moderate tolerance to heat stress. However, genotypes placed in group D gave poor performance under both OFC and stress conditions. Genotypes namely RIL 39, RIL 97 and HTW 67 under HSC1 while genotypes HTW 6 and HTW 67 under HSC2 were placed in group D, which is the indicator of low yielders. Similar approach to categorize genotypes into four groups was followed by Fernandez (1992).

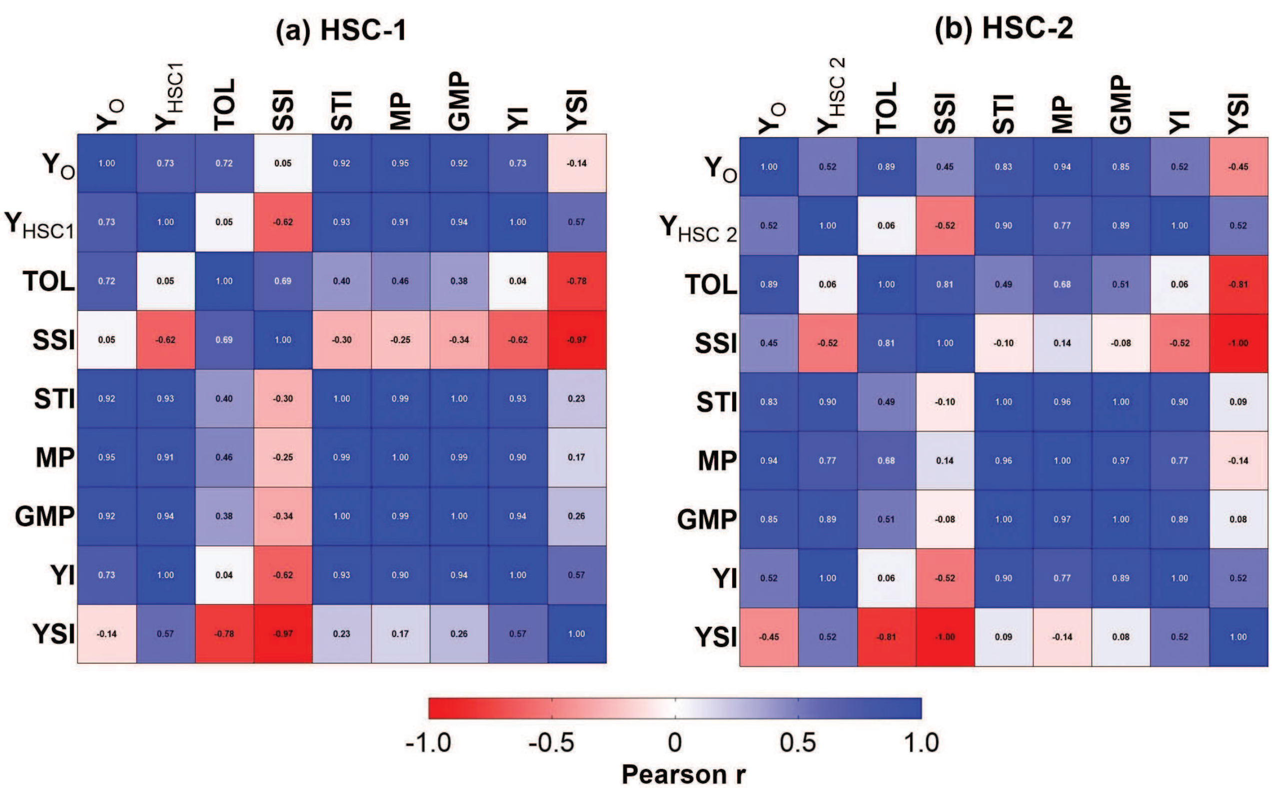

Fig. 1. Correlation coefficients between yield under OFC (Y_o) and stressed conditions (a) heat stress condition 1 (Y_{HSC1}); (b) heat stress condition 2 (Y_{HSC2}) with heat stress indices

In view of high significant correlation between STI and grain yield under OFC and both HSCs, three-dimensional graphs were designed to classify the 25 genotypes based on their yield performance (Figure 2). There are four groups in these three-dimensional

Principal component analysis

There is a comparative advantage of depicting Principal component analysis (PCA) and Biplots as against simply showing a 3D graph as it shows

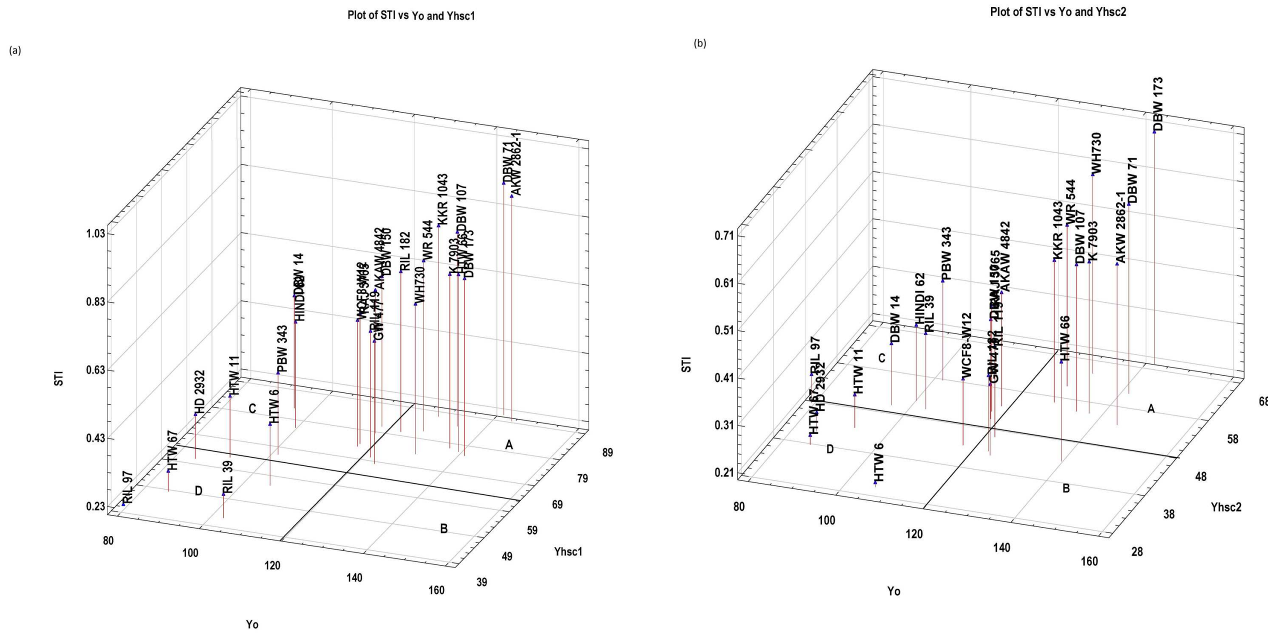

Fig. 2. 3-D representation to identify tolerant genotypes based on stress tolerance index (STI) and grain yield under OFC (Y_o) & stress conditions (a) HSC1 and (b) HSC2

relationship among various stress indices along with categorization of genotypes. PCA was carried out using GY and HSIs resulted in a number of linear combinations responsible for maximum variability in the data. Out of nine principal components (PCs), the first two components having eigen value >1.0 explained about 99% of total variation under both HSCs. PC1 accounts for the maximum variation i.e. 66.2% and 61.3% while PC2 explained 32.9% and 38.2% of the total variation under HSC1 and HSC2 respectively (supplementary table 4). PC1 regarded as stress tolerant component as it showed strong positive correlation with Y_h, GMP, YSI, STI and MP whereas PC2 exhibited strong correlation with Y_o, SSI and TOL therefore, considered as heat susceptibility component. Dorostkar et al. (2015) also used this kind of approach to classify the components. A biplot was generated by making use of first two components to compare relationship between genotypes and various stress indices (Fig. 3).

In another study, it was observed that selection of stable genotypes on the basis of higher PC1 and lower PC2 values and vice-versa is the most favourable

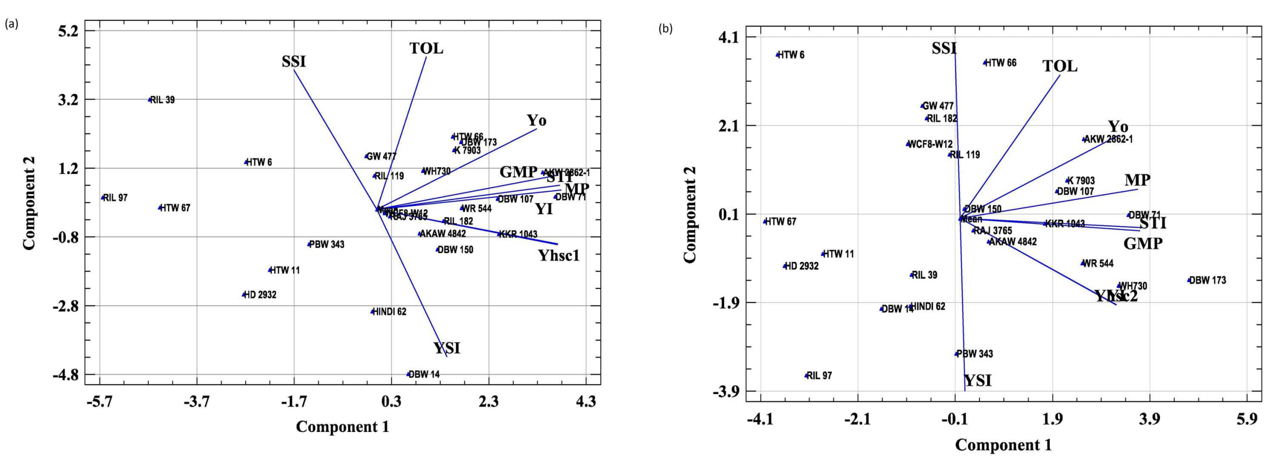

Fig. 3. Biplot of the first two components created from multivariate principal component analysis showing relationship among various heat stress indices of 25 genotypes under heat stress conditions (a) HSC1 and (b) HSC2

criteria (Kaya et al. 2002). Consequently, genotypes DBW71, AKW 2862-1, DBW 107 and KKR 1043 were found with high PC1 and lower PC2 values therefore, regarded as superior genotypes both under OFC and HSC1 conditions. Genotypes WH 730, DBW 173, DBW 71 and WR 544 were found stable and tolerant under both OFC and HSC2 conditions. In this biplot, indices are considered to be positively correlated when the angle between their vectors is less than 90 degrees, negatively linked when the angle is greater than 90 degrees, and independent when the angle is greater than 90 degrees (Yan and Kang 2002). As evidenced by the acute angles between their vectors, yield was positively correlated with the GMP, MP and STI indices. Yield under stress conditions (Yhsc1 and Yhsc2) displayed a high negative correlation with TOL and SSI as their vector showed obtuse angle.

Author's contribution

Conceptualization of research (RT, KD); Designing of the experiments (SC, MHM); Contribution of experimental materials (MHM); Execution of field/lab experiments and data collection (KD,NR,SS); Analysis of data and interpretation (KV,KD); Preparation of manuscript (KD,RT,GS,GPS).

Conflict of Interest

The authors declare no conflict of interest.

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Supplementary Table S1. Weekly mean temperature (°C) and rainfall (mm) details (from heading to anthesis) in 2017-18 and 2018-19 planting seasons

Julian weeks	2017-18 crop season			2018-2019 crop season		
	Temperature (C°)		Rainfall (mm)	Temperature (C°)		Rainfall (mm)
	Min.	Max.		Min.	Max.	
Optimum field condition (OFC)						
5	6.9	21.7	0	5.8	17.3	0.0
6	6.2	21.1	4.1	8.4	18.8	5.4
7	8.2	23.1	0	9.0	20.4	2.4
8	12.4	25.4	0	8.1	21.2	2.8
9	12.2	26.8	0	7.5	22.0	10.2
Avg.	9.18	23.62	0.82	7.76	19.94	4.16
Heat stress condition 2 (HSC2)						
5	6.2	21.3	0	6.6	17.5	0.0
6	8.2	23.2	4.1	7.9	19.2	5.4
7	14.6	28.5	0	10.5	25.7	0.0
8	16.4	30.9	0	11.1	27.8	0.0
9	15.2	32.3	0	12.9	29.1	10.2
Avg.	12.12	27.24	0.82	9.8	23.86	3.1
Heat stress condition 1 (HSC1)						
9	12.2	26.8	0	7.5	22.0	10.2
10	12.1	29.2	0	9.3	21.8	5.4
11	12.8	29.6	0	9.6	23.4	2.0
12	14.1	30.2	0	11.9	26.8	0.0
13	16.7	32.9	0	13.4	28.7	0.0
Avg.	**13.58**	**29.74**	**0**	**10.34**	**24.54**	**3.52**

Supplementary Table S2. Various Heat stress indices (HSIs) analysed to measure stress tolerance in heat responsive genotypic panel (HRGP) of wheat

Heat stress Indices (HSIs)	HSIs of GY	Correlation with stress/yield	References
Stress Susceptibility Index (SSI)	SSI = $(1–Y_b/Y_0)/(1–X_b/X_0)$	Negatively correlated with heat stress. Genotypes said to be highly stress tolerant, moderately tolerant and intolerant when HSI value is <0.5, 0.5-1.0 and >1.0 respectively	(Fischer and Maurer 1978)
Tolerance Index (TOL)	TOL = $Y_o–Y_h$	Negatively correlated with heat tolerance indicating that those genotypes having lower value are said to be highly stress tolerant	(Rosielle and Hamblin 1981)
Mean Productivity (MP)	MP = $(Y_o–Y_h)/2$	Genotypes having positive correlation with yield and MP said to be highly stress tolerant.	(Rosielle and Hamblin 1981)
Geometric Mean Productivity (GMP)	GMP = $\sqrt{Y_o \times Y_h}$	Positively correlated i.e. Genotypes with a high GMP value said to be more heat stress tolerant	(Fernandez, 1992)
Yield Index (YI)		Positive correlation with heat stress and yield	(Gavuzzi et al.1997)
Yield Stability Index (YSI)	$YSI = \frac{Y_h}{Y_h}$	Negatively correlated with TOL and SSI. Genotypes having higher YSI, more tolerant to stress.	(Bouslama and Schapaugh Jr 1984)
Stress Tolerance Index (STI)	STI = $(Y_o \times Y_h)/(X_o)^2$	Positively correlated with yield under stress. $YI = \frac{Y_h}{X_h}$	(Fernandez 1992)

Whereas,Yh and Yo denotes grain yield of each genotype individually under heat stressand optimum field condition; Xh and Xo represents mean grain yield for all genotypes under heat stressand optimum field condition.

Supplementary Table S3. Grain yield (mean over the years), per cent yield reduction (%red) and stress tolerance indices under optimum field condition (OFC) and heat-stressed conditions, HSC1 and HSC2.

Genotypes	Yield (Y o)	Yield (Yh)		%red		TOL		SSI		STI		MP		GMP		YI		YSI	
	OFC	HSC1	HSC2	HSC1	HSC2	HSC1	HSC2	HSC1	HSC2	HSC1	HSC2	HSC1	HSC2	HSC1	HSC2	HSC1	HSC2	HSC1	HSC2
DBW 71	142.9	88.5	59.8	38.09	58.20	54.44	83.20	0.92	0.99	0.91	0.61	115.73	101.35	112.48	92.42	1.28	1.22	0.62	0.42
AKW 2862-1	145.9	86.8	52.0	41.90	64.37	61.13	93.92	0.96	1.10	0.89	0.55	115.34	98.94	111.21	87.09	1.22	1.07	0.58	0.36
KKR 1043	129.4	84.6	55.0	34.63	57.53	44.83	74.47	0.84	0.98	0.79	0.51	107.02	92.21	104.65	84.35	1.22	1.13	0.65	0.42
DBW 107	135.4	82.3	53.7	39.24	60.32	53.13	81.66	0.95	1.03	0.80	0.52	108.82	94.56	105.53	85.28	1.19	1.10	0.61	0.40
DBW 14	97.0	80.1	48.4	17.43	50.07	16.90	48.54	0.42	0.85	0.56	0.34	88.51	72.68	88.10	68.51	1.16	0.99	0.83	0.50
WR 544	129.2	79.0	59.3	38.86	54.10	50.20	69.89	0.94	0.92	0.73	0.55	104.07	99.23	101.00	87.51	1.14	1.21	0.61	0.46
DBW 150	119.4	78.4	48.8	34.28	59.15	40.92	70.60	0.83	1.01	0.67	0.42	98.91	84.07	96.77	76.30	1.13	1.00	0.66	0.41
RIL 182	124.5	77.6	41.1	37.71	66.98	46.97	83.42	0.91	1.14	0.70	0.37	101.07	82.84	98.30	71.57	1.12	0.84	0.62	0.33
AKAW 4842	119.4	75.8	52.2	36.52	56.30	43.59	67.20	0.89	0.96	0.65	0.45	97.57	85.77	95.10	78.91	1.09	1.07	0.63	0.44
K 7903	138.3	74.6	53.7	46.07	61.19	63.70	84.62	1.12	1.04	0.74	0.53	106.43	95.98	101.56	86.15	1.08	1.10	0.54	0.39
HTW 66	140.9	73.8	41.4	47.64	70.63	67.11	99.50	1.15	1.21	0.75	0.42	105.33	91.14	101.95	76.36	1.07	0.85	0.52	0.29
HINDI 62	101.3	73.6	50.3	27.31	50.35	27.67	51.01	0.66	0.86	0.54	0.37	87.47	75.80	86.37	71.38	1.06	1.03	0.73	0.50
DBW 173	143.0	72.8	67.7	49.08	52.65	70.16	75.26	0.98	0.90	0.75	0.70	106.88	105.32	102.01	98.37	1.05	1.39	0.51	0.47
RAJ 3765	118.3	71.5	50.6	39.51	57.20	46.72	67.65	0.96	0.98	0.61	0.43	94.91	84.44	91.99	77.37	1.03	1.04	0.60	0.43
WH730	132.2	70.9	63.2	46.38	52.22	61.32	69.05	0.96	0.89	0.67	0.60	101.56	100.70	96.82	91.39	1.02	1.29	0.54	0.48
WCF8-W12	118.3	70.5	41.6	40.37	64.88	47.77	76.76	0.98	1.11	0.60	0.35	94.43	79.93	91.36	70.11	1.02	0.85	0.60	0.35
RIL 119	123.3	67.5	44.7	45.23	63.71	55.75	78.53	1.10	1.09	0.60	0.40	95.39	84.00	91.22	74.26	0.97	0.92	0.55	0.36
GW 477	125.5	65.5	40.2	47.80	67.94	59.97	85.24	1.16	1.16	0.59	0.36	95.47	82.84	90.64	71.04	0.95	0.82	0.52	0.32
PBW 343	103.1	63.7	56.1	38.22	45.61	39.40	47.02	0.93	0.78	0.47	0.42	83.38	79.57	81.02	76.02	0.92	1.15	0.62	0.54
HTW 11	93.5	60.3	41.7	35.50	55.39	33.18	51.77	0.86	0.95	0.41	0.28	76.87	67.58	75.06	62.42	0.87	0.85	0.64	0.45
HD 2932	86.4	58.1	39.5	32.80	54.33	28.35	46.96	0.79	0.93	0.36	0.25	72.25	62.95	70.85	58.41	0.84	0.81	0.67	0.46
HTW 6	107.8	52.9	28.5	50.96	73.58	54.94	79.33	1.23	1.26	0.41	0.22	80.35	68.16	75.51	55.42	0.76	0.58	0.49	0.26
HTW 67	87.4	45.7	36.1	47.68	58.65	41.67	51.26	1.16	1.00	0.29	0.23	66.56	61.77	63.22	56.20	0.66	0.74	0.52	0.41
RIL 39	104.6	39.6	48.7	62.13	53.40	64.99	55.86	1.51	0.91	0.30	0.37	72.10	76.67	64.36	71.40	0.57	1.00	0.38	0.47
RIL 97	80.5	39.1	46.0	51.39	42.81	41.36	34.45	1.25	0.73	0.23	0.27	59.79	63.24	56.10	60.85	0.56	0.94	0.49	0.57
Mean	118	69.3	48.8	41.1	58.06	48.6	69.1	0.98	0.99	0.6	0.42	93.45	83.67	90.13	75.6	1.00	1.00	0.59	0.42

Supplementary Table S 4. Analysis of Principal components (PCs), Eigen values, percent of variance and cumulative percentage for heat stress indices under both stress conditions (HSC1 and HSC2)

Principal component	Eigen values	Percent of variance	Cumu-lative %age	Yo	Yh	GMP	MP	SSI	STI	TOL	YI	YSI
HSC1 condition												
PC1	5.964	66.271	66.271	0.353	0.399	0.406	0.400	-0.184	0.403	-0.109	0.399	0.155
PC2	2.963	32.924	99.195	0.293	-0.125	0.070	0.124	0.507	0.088	0.555	-0.129	-0.537
HSC2 condition												
PC1	5.524	61.378	61.378	0.373	0.368	0.425	0.418	-0.012	0.423	-0.204	0.368	0.011
PC2	3.442	38.248	99.626	0.258	-0.270	0.028	0.091	0.538	0.038	0.447	-0.269	-0.536

Yo = yield under OFC, Yh = Yield and respective heat stress condition, TOL = Tolerance, SSI =Stress susceptibility index, STI = Stress tolerance index, MP = Mean productivity, GMP = Geometric mean productivity, YI = Yield index and YSI = Yield stability index