GMR
The Original

COMPARATIVE EVALUATION OF YIELD-BASED STRESS INDICES TO IDENTIFY TERMINAL HEAT-TOLERANT BREAD WHEAT (*TRITICUM AESTIVUM L.*) GENOTYPES

Vishal Saini[1], Divya Phougat[2], Yogender Kumar[3], Vinkal Saini[4*], Ishwar Das[5], Prakhar Singla[6], Meenakshi[7] , Hitesh Kashyap[8]

[1]Ph.D. Scholar, Dept of Genetics & Plant Breeding, CCSHAU Hisar. Email id: vishal108saini@gmail.com. ORCID ID: https://orcid.org/0009-0002-1723-2740
[2]Assistant Scientist, Dept of Genetics & Plant Breeding, CCSHAU Hisar. Email id: divyaphougat786@gmail.com
[3]Senior Scientist, Dept of Genetics & Plant Breeding, CCSHAU Hisar. Email id: yogenderkgulia@gmail.com . ORCID ID: https://orcid.org/0009-0008-2190-6078
[4*]Ph.D. Scholar, Dept of Genetics & Plant Breeding, CCSHAU Hisar. Email id: vinkalsaini830@gmail.com . ORCID ID: https://orcid.org/0009-0001-2255-1626
[5]Ph.D. Scholar, Dept of Genetics & Plant Breeding, CCSHAU Hisar. Email id: vinkalsaini830@gmail.com . ORCID ID: https://orcid.org/0009-0001-2255-1626
[6]Ph.D. Scholar, Dept of Genetics & Plant Breeding, CCSHAU Hisar. Email id: prakhar001@hau.ac.in . ORCID ID: https://orcid.org/0009-0004-1755-9000
[7]Ph.D. Scholar, Dept of Genetics & Plant Breeding, CCSHAU Hisar. Email id: meenakshisanwaria001@gmail.com . ORCID ID: https://orcid.org/0009-0000-1453-6840
[8]Ph.D. Scholar, ICAR-IIWBR, Karnal, Dept of Genetics & Plant Breeding, CCSHAU Hisar. Email: drkashyap.hitesh@gmail.com . ORCID: https://orcid.org/0009-0005-8893-2017

Abstract

Heat stress is a significant limiting factor in wheat productivity, especially during anthesis and grain filling. The objective of this study was to evaluate genetic variability for terminal heat tolerance and to identify some potentially useful bread wheat genotypes based on yield-based stress tolerance indices. A total of 100 bread wheat genotypes were tested in 2022–23, during the *Rabi* season, under timely (2 November 2022) and late (15 December 2022) sowing environments at CCS Haryana Agricultural University, Hisar, India, in a randomized complete block design with three replications. Grain yield was observed to have significant genotypic variation under both environments and all evaluated stress indices, with the increase in maximum temperature at anthesis from 25.3 °C to 28.1 °C. A significant positive correlation was observed between the grain yield of timely and late sowing environment (r = 0.491). Stress tolerance index (STI), mean productivity (MP), geometric mean productivity (GMP), harmonic mean (HM), and mean relative performance (MRP) showed positive correlation with grain yield in both environments and proved to be useful tools for selection of productive genotypes under heat stress. The first two principal components accounted for 99.3% of total variance: PC1 (56.2%) was mainly related to yield-related indices, while PC2 (43.1%) was mainly related to yield-loss and stress-response indices. Based on the overall performance on the indices, DBW 252, DBW 327, HPW 368, HI 8805, and PBW 822 were considered as promising genotypes. DBW 252 gave excellent performance in various productivity indices, and HPW 368 gave high grain yield with late sowing. The genotypes need to be tested under various environmental conditions and are considered as genetic resources for developing wheat cultivars that are more heat tolerant at the terminal stage.

Keywords: *Triticum aestivum* L.; terminal heat stress; grain yield; stress tolerance index; principal component analysis.

Introduction

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops in the world and a significant part of food and nutritional security. India is a major producer of wheat with production reaching 117.51 million tons during 2024-2025, highlighting the importance of maintaining wheat production in the context of fluctuating climate patterns. However, the occurrence of high temperatures associated with climate change has become a significant constraint on wheat production, especially in the later stages of the crop cycle. Terminal heat stress is of particular concern in wheat, which occurs when heat stress has occurred during the anthesis stage or grain development and filling stage, when wheat plants have little ability to recover from damage caused by subsequent development.

Temperature during reproductive and post-anthesis stages influences number of grains, grain-filling duration and final grain weight. Heat stress at anthesis can impair pollen development, fertilization and grain setting, whereas exposure during grain filling accelerates senescence, shortens grain-filling duration and disrupts photosynthesis, assimilate translocation and starch accumulation. This disrupts the equilibrium between source activity and sink demand, ultimately reducing grain size and overall yield. High temperatures at anthesis and the early stages of grain filling cause a significant reduction in grain weight, the magnitude of which is mainly dependent on the severity and duration of the heat stress (Ullah et al., 2024). However, several morphological, physiological and biochemical changes are induced under heat stress that adversely affect photosynthesis, membrane stability, water relations, antioxidant defence mechanisms and stress-responsive molecular pathways (Zheng et al., 2025; Khanzada et al., 2025). This is especially important in wheat-

producing areas of South Asian countries, where the reproductive stage occurs during hot weather, causing significant yield loss. In the field, late sowing is a common practice to expose wheat genotypes to naturally increasing temperatures at the heading stage, anthesis, and grain filling stage and is thus popular for screening for terminal heat tolerance. Some field research has recently shown high genetic diversity between wheat genotypes in response to late-sown heat stress. For instance, Sharma et al. (2024) tested 184 wheat genotypes under different sowing dates and found that there are significant variations in physiological and spectral responses to high temperature that are useful for large-scale phenotyping of wheat under high-temperature conditions at a later sowing date. In the same way, Kumar et al. (2024) evaluated wheat genotypes with various heat stress tolerance indices during terminal heat stress and found that from greater to less, wheat genotypes differed significantly in their yield loss and response to heat stress. These results demonstrate the presence of genetic variability in wheat germplasm for terminal heat adaptation, and this can be harnessed by systematic phenotyping and selection.

While a number of morphological and physiological characteristics have been suggested as markers of heat tolerance, grain yield will always be used to assess the agronomic value of a genotype. However, it is not possible to use yield under a single environment to properly differentiate high-yield potential from true stress tolerance. A small decrease in yield may be due to a genotype with inherent low yield potential, while a large absolute decrease may be due to a genotype with relatively greater inherent yield potential. Thus, it is important to evaluate yield in both favorable and heat-stressed conditions simultaneously to identify genotypes with both yield and stress adaptation. Stress tolerance indices based on yield are quantitative ways of comparing genotypic performance under contrasting environments. There are several indices developed for describing different components of stress responses, such as tolerance (TOL), stress susceptibility or susceptibility-related indices, yield stability index (YSI), yield index (YI), relative stress index (RSI), mean productivity (MP), geometric mean productivity (GMP), harmonic mean (HM), stress tolerance index (STI), mean relative productivity (MRP), and percentage yield reduction (PYR). The indices vary in the aspects of the stress response that are emphasized biologically. For instance, MP, GMP, HM, and STI tend to prefer those genotypes that are highly productive in many environments; TOL and yield-loss measures are used to measure the size of the loss under stress. Thus, use of a single index may not be sufficient to represent genotype performance.

Recent studies have further confirmed the value of multiple indices and correlation/multivariate analyses. Bhandari et al. (2024) showed a difference in stress tolerance indices with varying intensities of heat and heat–drought stress and also showed that the discriminating ability of the indices varied with the stress intensity. They found a strong correlation of MP, GMP, HM, STI and MRP with grain yield which were found valid in the various environments tested, and found that the other indices provided more information under certain stress levels. The results suggest that stress tolerance is a multidimensional trait and that using complementary indices can provide a stronger basis for genotype discrimination. In this scenario, principal component analysis (PCA) is very effective because it can reduce the dimensionality of correlated indices and highlight the main components driving variation between the genotypes. PCA and other multivariate techniques have also been used in recent wheat phenotyping tests to sort heat-tolerant and susceptible wheat varieties from several phenotypic and physiological traits. While a range of physiological, molecular, and high-throughput phenotyping methods are available, conventional yield-based evaluation continues to be important, as it can be performed in the field with relatively simple measurements and can link a response to stress with agronomic yield. The multiple stress tolerance indices and multivariate analysis in conjunction with sowing effects on yield performance can thus offer a practical basis for selecting breeding material with good terminal heat adaptation. This is especially true for wheat improvement programmes in environments, where high temperatures are occurring at the same time the crop is maturing.

In the present study, a hundred bread wheat genotypes were tested in different sowing dates viz. timely and late during *Rabi* season 2022-23 at CCS Haryana Agricultural University, Hisar, India. Timely sowing environment was the relatively cool environment, and late sowing environment was the environment that exposed the genotypes to terminal heat stress during reproductive and grain-filling stages. The objectives of this study were to (i) characterize genotypic variation in grain yield under timely and late-sowing environment and determine the discriminatory ability of yield-based heat tolerance indices; (ii) elucidate the relationships among grain yield, heat tolerance, and identify high-yielding, heat-tolerant genotypes with relatively stable performance under terminal heat stress using principal component analysis; and (iii) determine the ability of yield-based heat tolerance indices to discriminate among the genotypic differences in grain yield under timely and late-sowing environment and identify high-yielding and heat-tolerant genotypes with comparatively stable heat stress performance using principal component analysis.

Materials and methods:

Experimental material: One hundred bread wheat genotypes were grown during the *Rabi* cropping season of 2022-23. The planting material used in the present investigation consisted of randomly selected hundred diverse bread wheat genotypes. The seeds of all the genotypes were obtained from the Wheat and Barley Section, Department of Genetics and Plant Breeding, CCSHAU, Hisar.

Experimental site, location and environments: The research was carried out at the Research Area of Wheat and Barley Section, Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar during the *Rabi* season of 2022-23. The site is located at a latitude of 29.1503° N, a longitude of 75.7056° E and an altitude of 215.2 meters above mean sea level. It falls within the sub-tropical region of the North-Western Plains Zone (NWPZ) of India. The region belongs to the alluvial plain of Ghaggar-Yamuna and its southern and western portions mark a gradual transition to the desert.

The experiment was conducted in two environments: E1 (timely sown irrigated) and E2 (late sown irrigated). The effect of heat stress was compared by considering the late sown environment as the heat stress condition and the timely sown

environment as the control. Each genotype was grown in three rows, with each row measuring 3 meters in length. The experiment was conducted with three replications under both timely and late sowing conditions. The date of sowing for the timely sown environment was November 2, 2022, while for the late sown environment it was December 15, 2022. The experiment was arranged in a randomized block design (RBD). A row-to-row distance of 20 cm and a plant-to-plant distance of 10 cm were maintained for sowing in both environments.

Environmental evaluation: The weather parameters were collected from the Department of Agricultural Meteorological, CCS HAU, Hisar for 2022-23 year during crop growing season (November to May) (Fig 1). The maximum temperature observed was 25.3 °C for normal sown genotypes during anthesis stage while genotypes of late sown conditions faced a temperature of 28.1 °C during 2022–2023. There was a ~3 °C rise in temperature at stressed conditions, this high temperature at anthesis and grain filling stage causes early maturation and reduction in grain yield. During this year at anthesis stage the maximum relative humidity was 95%, bright sun shine hours were 7.2 and no rainfall, but the plants of stressed conditions had a maximum relative humidity of 89%, bright sun shine hours 6.0 and no rainfall at anthesis stage. The relative humidity (RH) at anthesis stage during 2022–2023 was high for normal sown genotypes, while it was low for late sown genotypes at same stage. So late sown genotypes have experienced heat stress during anthesis to grain filling stage. When encountered anthesis and post-anthesis stage, high temperatures [>28–30 °C] can dramatically shrink mature grain weight in wheat, lowering yields.

At maturity, harvested the genotypes from each plot separately and measured their grain yield (g). This grain yield (Yp and Ys) of genotype and mean yield (Xp and Xs) of all genotypes under timely and late sown respectively, was used to calculate all stress indices. Weekly minimum and maximum temperature (°C), relative humidity (morning and evening), bright sun shine hours and rainfall (mm) during wheat growing season at research farm are demonstrated in Fig 1. The temperature higher than 25 °C during March adversely affects the anthesis and post anthesis stages of late sown genotypes.

Statistical Analysis: Statistical analysis was conducted using Microsoft Excel, R statistical software, and the General R-based Analysis Platform Empowered by Statistics (GRAPES).

The following calculations were used to compute heat tolerance indices:

Stress tolerance (TOL)=Yp − Ys (Rosielle and Hamblin, 1981)
Stress tolerance index (STI)=(Yp × Ys)/Xp2 (Fernandez, 1992)
Stress susceptibility percentage index (SSPI)=Yp − Ys/ 2(Xp)×100 (Moosavi et al., 2008)
Yield index (YI)=Ys/Xs (Gavuzzi et al., 1997)
Yield stability index (YSI)=Ys/Yp (Bouslama and Schapaugh, 1984)
Relative stress index (RSI)=(Yp/Ys)/(Xs/Xp) (Fischer and Wood, 1979)
Mean productivity (MP)=(Yp+Ys)/2 (Rosielle and Hamblin, 1981)
Geometric mean productivity (GMP)=√(Ys × Yp) (Fernandez, 1992)
Harmonic mean (HM)=2(Yp × Ys)/(Yp+Ys) (Bidinger et al., 1987)
Mean relative performance (MRP)=(Ys/Xs)+(Yp/Xp) (Ramirez and Kelly, 1998)
Percent yield Reduction (PYR)=(Yp − Ys)/Yp×100 (Farshadfar and Javadinia, 2011)

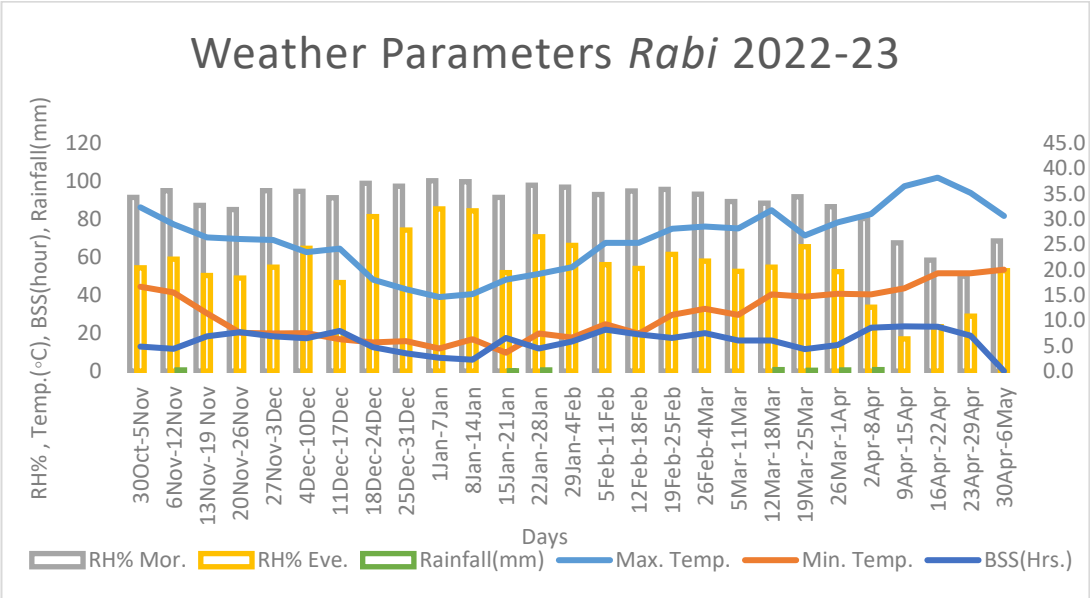

Fig 1: Weekly weather parameter during Rabi crop season 2022-23

Results:

Analysis of Variance: The data collected in this study were analysed by Analysis of Variance (ANOVA) to identify the sources of variance namely treatment, replication and error components. The significance of mean sum of square for each of the characters which were taken in the study, was assessed in this analysis. For all the heat tolerance indices, the mean sum of squares due to treatments were significant at the 1% level of significance for the grain yield under normal (Yp)

and stress (Ys) environments. This indicates the presence of substantial amount of genetic variation among the hundred bread wheat genotypes chosen for study of these traits.

Stress tolerance indices: Tolerance to stress was estimated using the grain yield obtained from the timely and late sowing experiments, as given in table 3, and the following stress tolerance indices were calculated. There was wide variation in the genotypes in all indices, which indicates variation in their response to terminal heat stress. The highest TOL (685.00) and SSPI (36.97) were observed in DBW 187, while grain yield decreased from 1395.00 gm/plot with a timely sowing environment to 710.00 gm/plot with a late sowing environment, showing significant loss of yield under heat stress. In contrast, HD 2851 had the lowest TOL (19.67), SSPI (1.06), and PYR (3.43%), as its grain yield differed only slightly between timely (573.00 gm/plot) and late sowing environments (553.33 gm/plot). On the other hand, the moderate yield in both the environments indicates that low values of these indices do not necessarily mean high heat tolerance and should be used in conjunction with the yield.

DBW 252 recorded the highest STI (1.37), GMP (1085.90), HM (1085.03), and MRP (2.73), while DBW 327 showed the highest MP (1087.84), indicating good yield potential across both sowing environments. YI of HPW 368 was the highest (1.52), and grain yield was also high (1055.00) and showed only a 3.80% decrease as compared to the timely sowing environment. On the other hand, CG 1029 had the lowest figures for all the parameters, indicating poor productivity in both the environments. The highest PYR (57.34%) and the lowest YSI (0.43) were observed for WH 1159, indicating it is more heat stress sensitive. The combination of yield and stress indices suggests that the following eight genotypes (DBW 252, DBW 327, DBW 88, HI 8802, HI 8805, HI 8808, and HPW 368) have a desirable combination of productivity and heat tolerance and may be considered to be good potential material for terminal heat stress conditions.

Table 1. Analysis of variance (ANOVA) for heat tolerance indices, grain yield under normal (Yp) and stress (Ys) conditions of bread wheat genotypes.

	Source of variation	Replication	Genotype	Error
Mean Sum of Squares	DF	2	99	198
	TOL	118577.72	92903.94**	11273.5
	STI	0.073	0.19**	0.01
	SSPI	376.68	295.12**	35.81
	YI	0.160	0.09**	0.014
	YSI	0.140	0.08**	0.013
	RSI	0.491	0.40**	0.067
	MP	11223.30	51785.29**	2108.49
	GMP	14751.03	48646.86**	2381.61
	HM	18876.91	46632.06**	2798.69
	MRP	0.107	0.32**	0.016
	PYR	1396.05	887.92**	132.56
	YS	76113.56	45567.9**	6612.54
	YP	5621.90	104454.9**	3241.24

** Significant at 1 % (P=0.01)

DF: degree of freedom; TOL: Tolerance; STI: Stress tolerance index; SSPI: stress susceptibility; YI: Yield index; YSI: Yield stability index; RSI: Relative stress index; MP: Mean productivity; GMP: Geometric mean productivity; HM: Harmonic mean; MRP: Mean relative performance; PYR: Percent yield index; Yp: Grain yield under normal condition; Ys: Grain yield under stress condition.

Correlation coefficient between grain yield and stress indices: The correlation coefficient between grain yield under timely sown (Yp) and late sown (Ys) and heat-tolerant indices is calculated to estimate the appropriate criteria for heat tolerance. Correlation analysis revealed a significant positive association between grain yield under timely (Yp) and late sowing (Ys) conditions (r = 0.491**), showing that genotypes with good yield potential under normal conditions generally maintained better performance when exposed to terminal heat stress. TOL and SSPI were positively correlated with Yp (r = 0.689** for both), but showed negative associations with Ys (r = −0.293**), indicating that genotypes yielding well under timely sowing environment tended to suffer greater yield losses under late sowing environment. A similar relationship was observed for PYR, which was positively associated with Yp (r = 0.493**) and negatively associated with Ys (r = −0.498**). In contrast, YSI showed a positive correlation with Ys (r = 0.498**) and a negative correlation with Yp (r = −0.492**), highlighting its relevance for evaluating yield stability under heat stress.

STI, MP, GMP, HM and MRP exhibited significant positive correlations with grain yield under both sowing conditions. Among these, MP showed a particularly strong association with Yp (r = 0.901**) and Ys (r = 0.820**). GMP, HM and MRP also showed strong relationships with Yp and Ys, with correlation coefficients of 0.853** and 0.873**, 0.796** and 0.915**, and 0.862** and 0.865**, respectively. STI was similarly associated with both Yp (r = 0.843**) and Ys (r = 0.875**). YI showed a perfect positive correlation with Ys (r = 1.000**) and a moderate positive correlation with Yp (r = 0.490**). Among the stress tolerance indices, STI, MP, GMP, HM, and MRP were the most effective for identifying genotypes with superior yield potential under timely sowing environment, while maintaining stable performance under late-sown heat stress environment. These indices consistently identified DBW 252 as the best-performing genotype, followed by DBW 327, HPW 368, HI 8805, and PBW 822. The consistently high rankings of these genotypes across

multiple indices indicate their broad adaptability and enhanced tolerance to terminal heat stress. Therefore, these genotypes represent valuable genetic resources for developing high-yielding, heat-resilient wheat cultivars and can be considered promising candidates for cultivation in heat-prone environments.

Based on the combined performance of the Yield Stability Index (YSI) and Yield Index (YI), genotypes HPW 368 and DBW 327 were identified as the most promising heat-tolerant genotypes. Their high YSI (>0.92) and YI (>1.50) values indicate superior yield stability and productivity under late-sown heat stress.

Table 2: Correlation coefficient between grain yield (Yp and Ys) of wheat genotypes and stress tolerance indices.

*, ** Significant at 0.05 and 0.01 levels of probability, respectively;

TOL: Tolerance; STI: Stress tolerance index; SSPI: stress susceptibility; YI: Yield index; YSI: Yield stability index; RSI: Relative stress index; MP: Mean productivity; GMP: Geometric mean productivity; HM: Harmonic mean; MRP: Mean relative performance; PYR: Percent yield index; Yp: Grain yield under normal condition; Ys: Grain yield under stress condition.

Principal Component Analysis: Principal component analysis (PCA) was performed using grain yield under timely (Yp) and late sowing (Ys), together with the heat stress tolerance indices, to characterize the major sources of variation among the genotypes. Out of ten principal components, two had eigenvalues >1 and jointly account for 99.3% of the total variation. PC1 explained 56.2% of the variation, while PC2 accounted for a further 43.1% (Fig 2). The first principal component was strongly associated with Yp, Ys, MP, GMP, STI, HM, and YI, indicating that yield potential and indices integrating performance across the two environments were the major contributors to genotype discrimination along PC1. In contrast, PC2 was primarily defined by PYR, RSI, SSPI, and TOL, which represented variation related to the magnitude of yield reduction and stress response.

	TOL	STI	SSPI	YI	YSI	RSI	MP	GMP	HM	MRP	PYR	Ys	Yp
TOL	1												
STI	0.197*	1											
SSPI	1.000**	0.197*	1										
YI	-0.295**	0.874**	-0.295**	1									
YSI	-0.955**	0.032	-0.955**	0.500**	1								
RSI	0.958**	-0.012	0.958**	-0.478**	-0.974**	1							
MP	0.306**	0.989**	0.306**	0.819**	-0.075	0.098	1						
GMP	0.209*	0.996**	0.209*	0.872**	0.021	-0.004	0.994**	1					
HM	0.112	0.991**	0.112	0.914**	0.114	-0.103	0.979**	0.995**	1				
MRP	0.227*	0.995**	0.227*	0.864**	0.006	0.018	0.997**	0.999**	0.991**	1			
PYR	0.956**	-0.032	0.956**	-0.500**	-1.000**	0.974**	0.076	-0.020	-0.113	-0.005	1		
Ys	-0.293**	0.875**	-0.293**	1.000**	0.498**	-0.477**	0.820**	0.873**	0.915**	0.865**	-0.498**	1	
Yp	0.622**	0.854**	0.622**	0.513**	-0.435**	0.438**	0.905**	0.853**	0.801**	0.865**	0.436**	0.519**	1

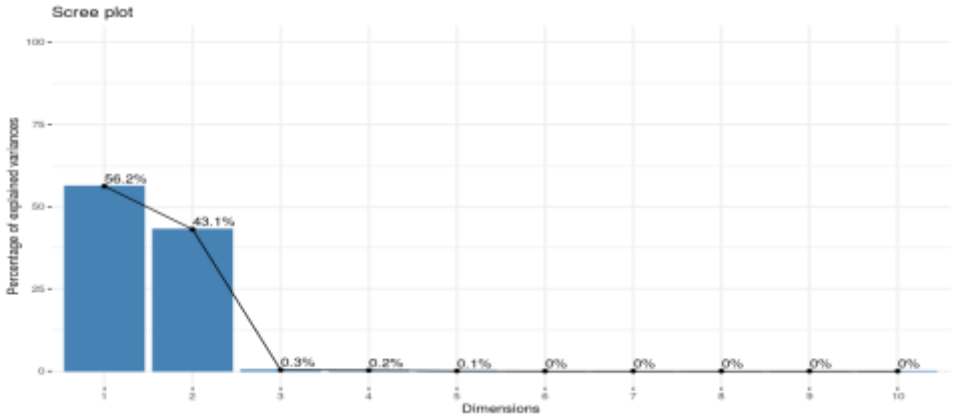

Fig 2: Scree plot of principal components for heat-tolerance indices in wheat genotypes.

The PC1–PC2 biplot provided further insight into the relationships between genotypes and the stress tolerance indices. Genotypes HPW 368, DBW 252, DBW 327, and HI 8805 were positioned on the positive side of PC1 and negative side of PC2, with close association with Ys and YI. Their position indicated comparatively favourable performance under late-sown conditions. In contrast, WH 1159, WH 730, and AKAW 4842 occurred on the negative side of PC1 and positive side of PC2 and were aligned more closely with PYR, RSI, SSPI, and TOL, reflecting a greater stress-associated reduction in yield. PBW 709, RWP 32, PBW 822, and PBW 475 were located on the positive side of PC1 and near the Yp and MP vectors, indicating greater yield potential under timely sowing.

Notably, HPW 368 and DBW 252 were positioned in the direction of STI, MP, GMP, and HM, while also exhibiting high PC1 and comparatively low PC2 scores. The combined association of these genotypes with indices favouring productivity across environments suggests their potential for maintaining high yield under timely sowing, while performing comparatively well under terminal heat stress. Thus, the PCA effectively differentiated genotypes according to their yield potential and stress response and identified HPW 368 and DBW 252 as particularly promising material for further evaluation under heat-prone environments.

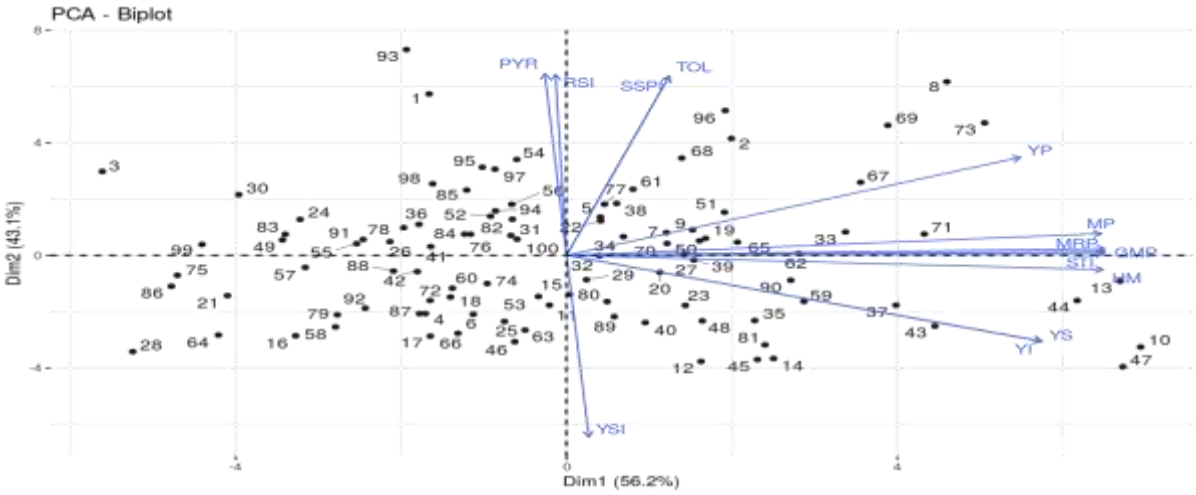

Fig 3: Principal component biplot showing the association among heat-tolerance indices and wheat genotypes.

Table 3 : Grain yield/plot (g), Yp and Ys under normal and stress conditions and stress tolerance indices of different wheat genotypes.

	Genotypes	Yp	Ys	TOL	STI	SSPI	YI	YSI	RSI	MP	GMP	HM	MRP	PYR
1	AKAW-4842	1045.00	506.67	538.33	0.617	29.06	0.73	0.48	2.76	775.84	727.65	682.45	1.86	51.51
2	BRW-3806	1178.33	668.33	510.00	0.918	27.53	0.96	0.57	2.36	923.33	887.42	852.91	2.24	43.28
3	CG-1029	732.33	420.00	312.33	0.358	16.86	0.61	0.57	2.33	576.17	554.60	533.84	1.40	42.65
4	DBW-107	777.00	673.33	103.67	0.610	5.60	0.97	0.87	1.54	725.17	723.31	721.46	1.81	13.34
5	DBW-110	992.00	676.67	315.33	0.782	17.02	0.98	0.68	1.96	834.34	819.30	804.54	2.05	31.79
6	DBW-168	803.33	696.67	106.66	0.652	5.76	1.01	0.87	1.54	750.00	748.10	746.21	1.87	13.28
7	DBW-173	1011.67	720.00	291.67	0.849	15.74	1.04	0.71	1.88	865.84	853.46	841.27	2.13	28.83
8	DBW-187	1395.00	710.00	685.00	1.154	36.97	1.02	0.51	2.63	1052.50	995.21	941.05	2.53	49.10
9	DBW-222	1031.00	729.00	302.00	0.876	16.30	1.05	0.71	1.89	880.00	866.95	854.09	2.17	29.29
10	DBW-252	1130.20	1043.33	86.87	1.374	4.69	1.51	0.92	1.45	1086.77	1085.90	1085.03	2.73	7.69
11	DBW-278	856.67	726.67	130.00	0.725	7.02	1.05	0.85	1.58	791.67	789.00	786.33	1.97	15.18
12	DBW-302	878.33	847.67	30.66	0.868	1.65	1.22	0.97	1.39	863.00	862.86	862.73	2.17	3.49
13	DBW-327	1205.67	970.00	235.67	1.363	12.72	1.40	0.80	1.66	1087.84	1081.43	1075.07	2.70	19.55
14	DBW-88	921.00	880.00	41.00	0.945	2.21	1.27	0.96	1.40	900.50	900.27	900.03	2.26	4.45
15	DBWH-221	880.67	726.67	154.00	0.746	8.31	1.05	0.83	1.62	803.67	799.97	796.29	2.00	17.49

16	DDW-47	679.67	626.67	53.00	0.496	2.86	0.90	0.92	1.45	653.17	652.63	652.09	1.64	7.80
17	DDW-48	755.33	693.33	62.00	0.610	3.35	1.00	0.92	1.46	724.33	723.67	723.00	1.82	8.21
18	DWAP-1108	808.67	673.33	135.34	0.635	7.31	0.97	0.83	1.61	741.00	737.90	734.82	1.84	16.74
19	DWAP-1608	1027.33	743.33	284.00	0.890	15.33	1.07	0.72	1.85	885.33	873.87	862.55	2.18	27.64
20	DWAP-1925	958.33	751.67	206.66	0.839	11.15	1.08	0.78	1.70	855.00	848.73	842.51	2.12	21.56
21	GW-1339	680.33	563.33	117.00	0.447	6.32	0.81	0.83	1.61	621.83	619.07	616.33	1.55	17.20
22	GW-1348	988.33	680.00	308.33	0.783	16.64	0.98	0.69	1.94	834.17	819.80	805.67	2.05	31.20
23	GW-2010-288	933.33	791.67	141.66	0.861	7.65	1.14	0.85	1.58	862.50	859.59	856.68	2.15	15.18
24	GW-499	806.67	543.33	263.34	0.511	14.21	0.78	0.67	1.98	675.00	662.03	649.32	1.65	32.65
25	GW-509	812.67	718.33	94.34	0.680	5.09	1.04	0.88	1.51	765.50	764.05	762.59	1.91	11.61
26	HD-2009	835.67	600.00	235.67	0.584	12.72	0.87	0.72	1.86	717.84	708.10	698.49	1.77	28.20
27	HD-2687	995.00	746.67	248.33	0.866	13.40	1.08	0.75	1.78	870.84	861.94	853.13	2.15	24.96
28	HD-2851	573.00	553.33	19.67	0.369	1.06	0.80	0.97	1.38	563.17	563.08	562.99	1.42	3.43
29	HD-2888	908.00	723.33	184.67	0.765	9.97	1.04	0.80	1.68	815.67	810.42	805.21	2.02	20.34
30	HD-2894	795.00	496.67	298.33	0.460	16.10	0.72	0.62	2.14	645.84	628.37	611.38	1.58	37.53
31	HD-2967	936.67	640.00	296.67	0.699	16.01	0.92	0.68	1.96	788.34	774.25	760.42	1.93	31.67
32	HD-2968	943.67	710.00	233.67	0.781	12.61	1.02	0.75	1.78	826.84	818.54	810.33	2.04	24.76
33	HD-3059	1118.33	800.00	318.33	1.043	17.18	1.15	0.72	1.87	959.17	945.87	932.75	2.36	28.46
34	HD-3086	981.67	703.33	278.34	0.805	15.02	1.02	0.72	1.87	842.50	830.93	819.51	2.07	28.35
35	HD-3182	954.33	836.67	117.66	0.931	6.35	1.21	0.88	1.52	895.50	893.57	891.64	2.24	12.33
36	HD-3288	873.67	600.00	273.67	0.611	14.77	0.87	0.69	1.95	736.84	724.02	711.42	1.81	31.32
37	HD-3298	1051.67	890.00	161.67	1.091	8.73	1.28	0.85	1.58	970.84	967.46	964.10	2.42	15.37
38	HD-3334	1020.00	673.33	346.67	0.800	18.71	0.97	0.66	2.03	846.67	828.73	811.18	2.07	33.99
39	HD-3373	993.33	756.67	236.66	0.876	12.77	1.09	0.76	1.76	875.00	866.96	859.00	2.16	23.82
40	HI-1617	890.00	786.67	103.33	0.816	5.58	1.14	0.88	1.51	838.34	836.74	835.15	2.10	11.61
41	HI-1636	855.00	623.33	231.67	0.621	12.50	0.90	0.73	1.83	739.17	730.03	721.01	1.82	27.10
42	HI-3823	818.00	636.67	181.33	0.607	9.79	0.92	0.78	1.72	727.34	721.66	716.03	1.80	22.17
43	HI-8802	1046.67	926.67	120.00	1.130	6.48	1.34	0.89	1.51	986.67	984.84	983.02	2.47	11.46
44	HI-8805	1156.67	968.33	188.34	1.305	10.17	1.40	0.84	1.60	1062.50	1058.32	1054.15	2.65	16.28
45	HI-8808	911.00	873.33	37.67	0.927	2.03	1.26	0.96	1.39	892.17	891.97	891.77	2.24	4.14

46	HPW-360	796.67	738.67	58.00	0.686	3.13	1.07	0.93	1.44	767.67	767.12	766.57	1.93	7.28
47	HPW-368	1096.67	1055.00	41.67	1.348	2.25	1.52	0.96	1.39	1075.84	1075.63	1075.43	2.71	3.80
48	HPW-373	925.00	813.33	111.67	0.877	6.03	1.17	0.88	1.52	869.17	867.37	865.58	2.17	12.07
49	HS-628	771.67	550.00	221.67	0.495	11.96	0.79	0.71	1.88	660.84	651.47	642.25	1.63	28.73
50	HUW-838	1021.67	741.67	280.00	0.883	15.11	1.07	0.73	1.84	881.67	870.48	859.44	2.17	27.41
51	JKW-261	1073.00	728.33	344.67	0.911	18.60	1.05	0.68	1.97	900.67	884.02	867.69	2.21	32.12
52	KHTW-1	927.67	626.67	301.00	0.677	16.25	0.90	0.68	1.98	777.17	762.46	748.03	1.91	32.45
53	KRL-283	860.00	714.33	145.67	0.716	7.86	1.03	0.83	1.61	787.17	783.79	780.43	1.96	16.94
54	LBP-2017-2	1015.00	593.33	421.67	0.702	22.76	0.86	0.58	2.29	804.17	776.03	748.89	1.95	41.54
55	MACS-9058	813.33	586.67	226.66	0.556	12.23	0.85	0.72	1.85	700.00	690.77	681.65	1.72	27.87
56	MP-1358	955.33	626.67	328.66	0.698	17.74	0.90	0.66	2.04	791.00	773.74	756.86	1.94	34.40
57	NPWW-3465	756.33	580.00	176.33	0.511	9.52	0.84	0.77	1.74	668.17	662.32	656.53	1.65	23.31
58	PBW-123	711.33	640.00	71.33	0.531	3.85	0.92	0.90	1.49	675.67	674.72	673.78	1.69	10.03
59	PBW-302	1004.67	843.33	161.34	0.987	8.71	1.22	0.84	1.59	924.00	920.47	916.96	2.30	16.06
60	PBW-343	819.33	666.67	152.66	0.637	8.24	0.96	0.81	1.64	743.00	739.07	735.16	1.85	18.63
61	PBW-475	1048.67	668.33	380.34	0.817	20.53	0.96	0.64	2.10	858.50	837.17	816.37	2.10	36.27
62	PBW-502	1061.67	798.33	263.34	0.988	14.21	1.15	0.75	1.78	930.00	920.63	911.36	2.30	24.80
63	PBW-528	815.00	735.67	79.33	0.699	4.28	1.06	0.90	1.48	775.34	774.32	773.31	1.94	9.73
64	PBW-550	636.33	586.67	49.66	0.435	2.68	0.85	0.92	1.45	611.50	611.00	610.49	1.53	7.80
65	PBW-676	1041.33	760.00	281.33	0.922	15.19	1.10	0.73	1.83	900.67	889.61	878.70	2.22	27.02
66	PBW-681	773.67	705.00	68.67	0.636	3.71	1.02	0.91	1.47	739.34	738.54	737.74	1.85	8.88
67	PBW-709	1194.67	761.67	433.00	1.060	23.37	1.10	0.64	2.10	978.17	953.91	930.25	2.39	36.24
68	PBW-723	1119.33	663.33	456.00	0.865	24.61	0.96	0.59	2.26	891.33	861.68	833.01	2.17	40.74
69	PBW-752	1293.33	723.33	570.00	1.090	30.77	1.04	0.56	2.39	1008.33	967.21	927.78	2.44	44.07
70	PBW-771	998.67	730.00	268.67	0.850	14.50	1.05	0.73	1.83	864.34	853.83	843.46	2.13	26.90
71	PBW-793	1160.00	836.67	323.33	1.131	17.45	1.21	0.72	1.85	998.34	985.16	972.16	2.46	27.87
72	PBW-821	793.33	665.00	128.33	0.615	6.93	0.96	0.84	1.59	729.17	726.34	723.52	1.82	16.18
73	PBW-822	1355.00	761.67	593.33	1.203	32.03	1.10	0.56	2.38	1058.34	1015.90	975.18	2.56	43.79
74	RAJ-3765	845.00	680.00	165.00	0.670	8.91	0.98	0.80	1.66	762.50	758.02	753.57	1.89	19.53
75	RAJ-4238	670.00	525.00	145.00	0.410	7.83	0.76	0.78	1.71	597.50	593.09	588.70	1.48	21.64
76	RWP-2019-32	893.33	631.67	261.66	0.658	14.12	0.91	0.71	1.89	762.50	751.19	740.05	1.88	29.29

77	RWP-2019-38	1011.67	668.33	343.34	0.788	18.53	0.96	0.66	2.02	840.00	822.27	804.92	2.06	33.94
78	RWP-2019-41	860.00	596.67	263.33	0.598	14.21	0.86	0.69	1.93	728.34	716.34	704.53	1.79	30.62
79	RWP-32	725.00	631.67	93.33	0.534	5.04	0.91	0.87	1.53	678.34	676.73	675.12	1.69	12.87
80	SCG-1023	893.33	751.67	141.66	0.783	7.65	1.08	0.84	1.59	822.50	819.44	816.40	2.05	15.86
81	UP-2903	931.67	863.33	68.34	0.937	3.69	1.25	0.93	1.44	897.50	896.85	896.20	2.25	7.34
82	UP-2938	915.67	651.67	264.00	0.695	14.25	0.94	0.71	1.88	783.67	772.47	761.44	1.93	28.83
83	UP-2944	780.00	546.67	233.33	0.497	12.59	0.79	0.70	1.91	663.34	653.00	642.82	1.63	29.91
84	UP-3043	890.00	628.33	261.67	0.652	14.12	0.91	0.71	1.89	759.17	747.81	736.62	1.87	29.40
85	VL-2015	945.33	595.00	350.33	0.655	18.91	0.86	0.63	2.12	770.17	749.98	730.33	1.88	37.06
86	VL-3020	656.67	530.00	126.67	0.406	6.84	0.76	0.81	1.66	593.34	589.94	586.57	1.47	19.29
87	VL-3022	773.33	670.00	103.33	0.604	5.58	0.97	0.87	1.54	721.67	719.81	717.97	1.80	13.36
88	WH-1021	805.00	625.00	180.00	0.586	9.72	0.90	0.78	1.72	715.00	709.31	703.67	1.77	22.36
89	WH-1124	879.67	766.67	113.00	0.786	6.10	1.11	0.87	1.53	823.17	821.23	819.29	2.06	12.85
90	WH-1133	1023.33	818.33	205.00	0.976	11.07	1.18	0.80	1.67	920.83	915.11	909.42	2.29	20.03
91	WH-1140	821.67	586.67	235.00	0.562	12.68	0.85	0.71	1.87	704.17	694.30	684.56	1.73	28.60
92	WH-1142	748.33	640.00	108.33	0.558	5.85	0.92	0.86	1.56	694.17	692.05	689.94	1.73	14.48
93	WH-1159	1090.00	465.00	625.00	0.591	33.74	0.67	0.43	3.13	777.50	711.93	651.90	1.85	57.34
94	WH-1165	937.33	625.00	312.33	0.683	16.86	0.90	0.67	2.01	781.17	765.40	749.95	1.91	33.32
95	WH-1218	983.33	585.00	398.33	0.670	21.50	0.84	0.59	2.25	784.17	758.45	733.58	1.91	40.51
96	WH-1252	1213.67	641.67	572.00	0.908	30.87	0.93	0.53	2.53	927.67	882.48	839.50	2.24	47.13
97	WH-1270	990.00	591.67	398.33	0.683	21.50	0.85	0.60	2.24	790.84	765.35	740.68	1.92	40.24
98	WH-730	931.67	575.00	356.67	0.624	19.25	0.83	0.62	2.17	753.34	731.92	711.12	1.84	38.28
99	WH-787	718.33	515.00	203.33	0.431	10.98	0.74	0.72	1.86	616.67	608.23	599.90	1.52	28.31
100	WSM-138	915.00	656.67	258.33	0.700	13.94	0.95	0.72	1.86	785.84	775.15	764.60	1.94	28.23
	MEAN	926.33	692.87	233.46	0.76	12.60	1.00	0.76	1.81	809.60	798.35	787.43	2.00	24.22
	MIN	573.00	420.00	19.67	0.36	1.06	0.61	0.43	1.38	563.17	554.60	533.84	1.40	3.43
	MAX	1395.00	1055.00	685.00	1.37	36.97	1.52	0.97	3.13	1087.84	1085.90	1085.03	2.73	57.34

Discussion: There was significant genotypic variation for grain yield under timely (Yp) and late sowing environments (Ys) of wheat and significant differences for all heat-tolerance indices which indicated a high genetic variation for terminal heat response among the 100 bread wheat genotypes. The variability is a key tool for selection and utilization of heat-resistant germplasm in breeding programs. Timely-sowing environment had a lower maximum temperature at anthesis (25.3 °C) than late sowing environment (28.1 °C) which imposed higher thermal stress on the plants during anthesis and grain filling stages. Exposure to heat stress during these stages may affect reproduction, hasten leaf senescence and decrease assimilate availability for grain filling, which can lead to lower grain yield. However, due to the multiple

environmental changes on sowing date this response can be viewed as a late-sowing or terminal-heat environment rather than as a temperature response.

Performance of heat-tolerance indices: The heat-tolerance indices were evaluated in terms of their performance. TOL, SSPI and PYR showed quite a variation, indicating that the magnitude of the yield loss due to late sowing differed among the genotypes. Under timely sowing environment, DBW 187 had the highest TOL and SSPI while under late sowing environment, it had the lowest yield of 710.00 gm/plot compared to 1395.00 gm/plot under timely sowing environment. This points to a weakness of yield loss indices because a high yield potential genotype can also have a large absolute yield loss when faced with stress. However, HD 2851 had the lowest TOL, SSPI and PYR and relatively low yield under both environments. Consequently, a reduction in yield alone is not yet a satisfactory basis for considering a plant, or variety of plants, to have useful heat tolerance. Such indices would be more informative if they are used in conjunction with the yield under favourable and stress conditions (Bhandari et al., 2024). The productivity-oriented indices were complimentary. DBW 252 had the highest STI, GMP, HM and MRP, and DBW 327 had the highest MP suggesting their potential for combining productivity from both timely and late sowing environments. The collaboration between STI, GMP and HM and MR were particularly strong and enhanced the evidence on the overall performance of DBW 252. These relationships among these indices and grain yield have been found to be similar in wheat grown under various environments (Poudel et al., 2021; Bhandari et al., 2024). Similarly, HPW 368 gave a response which was not quite the same, but was equally relevant, and recorded the highest YI and also grain yield of 1055.00 gm/plot under late sowing environment with only a 3.80% decrease from the timely sowing environment. This shows good performance in the stress environment, not just low yield losses due to low yield potential. The PYR was the highest and YSI the lowest in WH 1159, which were the plants that were most sensitive to the late-sown environment. These contrasting responses among the different genotypes highlight the value of using indices that are both a measure of productivity and a measure of yield reduction for genotype discrimination.

Correlations between yield and stress parameters: The discriminatory ability of the indices was also clarified by correlation analysis. There was a moderate positive association ($r = 0.491^{**}$) between grain yield under timely sowing environment and grain yield under late sowing environment, signifying that good yield potential under good conditions was associated with good yield under late sowing, but the relationship was not strong enough to secure resilience to heat. This highlights the need to compare the performance of different genotypes in both environments. TOL and SSPI were positively correlated with Yp and negatively correlated with Ys, meaning that they were dependent on the magnitude of yield lost and productivity of the genotypes at timely sowing environment. STI, MP, GMP, HM and MRP, on the contrary, had good positive correlations with both Yp and Ys. MP exhibited particularly strong correlations with Yp ($r = 0.901^{**}$) and Ys ($r = 0.820^{**}$), while STI was strongly correlated with Yp ($r = 0.843^{**}$) and Ys ($r = 0.875^{**}$). These findings agree with Lamba et al. (2023) and Bhandari et al. (2024), who demonstrated the usefulness of productivity-based indices for identifying wheat genotypes performing well under contrasting stress environments. These relationships showed that productivity-based indices were able to successfully distinguish between the genotypes with good performance in both environments. Also, the intercorrelations between STI, MP, GMP and HM and MRP, respectively, are very high, suggesting a high degree of redundancy among these indices. However, their co-occurrence of similar genotypes increases the certainty of choosing productive material that performs reasonably well in a variety of environments.

Principal component analysis and promising genotypes: PCA was used to give an integrated assessment about the relationship between the grain yield and the heat-tolerant indices. The first two main components accounted for 99.3% of the total variation, PC1 56.2% and PC2 43.1%. PC1 was mainly associated with Yp, Ys, MP, GMP, STI, HM and YI that translate to overall productivity across the various environments, while PC2 was related to PYR, RSI, SSPI and TOL that translate to yield reduction and stress-response behaviour. This separation is indicative of two different aspects of productivity and yield loss in the context of terminal heat response. The PCA biplot was used to support the classification based on the index. The hybrids HPW 368, DBW 252, DBW 327 and HI 8805 had a positive PC1 association with both Ys and YI, suggesting fairly good performance under late sowing. The combined productivity and stress performance of DBW252 and HPW368 were also supported by STI and MP, GMP and HM respectively. In contrast, WH 1159, WH 730 and AKAW 4842 showed a direction towards PYR, RSI, SSPI and TOL, indicating higher reduction in yield under late sowing. Therefore, in addition to the correlation analysis, PCA was used to sort out the genotypes based on the productivity and stress-response dimensions.

Implications for wheat breeding: Considering grain yield, stress indices, correlations and PCA collectively, DBW 252, DBW 327, DBW 88, HI 8802, HI 8805, HI 8808 and HPW 368 emerged as promising materials for further evaluation under terminal heat stress. DBW 252 performed consistently across STI, GMP, HM and MRP, whereas DBW 327 was distinguished by its high MP. HPW 368 showed favourable late-sown performance and the highest YI. The value of combining yield-based indices with multivariate analysis is supported by Lamba et al. (2023) and Poudel et al. (2024), who demonstrated that index-based correlations and PCA can jointly assist in identifying promising wheat genotypes under contrasting environments.

In conclusion, the findings suggest that useful terminal heat resilience is not just minimum yield reduction but, rather, high yield potential with yield retention, under heat stress. The identified genotypes have great potential for breeding and genetic study. Their performance, however, should be tested under different heat regimes, environments and seasons since the response to heat at the end of the growing season is strongly affected by contrasting heat environments and genotype × environment interaction. These indices based on yield can be used in combination with the physiological and molecular markers to increase the accuracy of selection of heat tolerant wheat.

Conclusion: The study showed that there is significant genetic variation among the 100 bread wheat genotypes for grain yield and yield based stress tolerance indices under timely and late sown conditions. The genotypes selected for high yield potential and improved performance under terminal heat stress were identified using the following selection criteria, identified by correlation and principal component analyses: STI, MP, GMP, HM and MRP. Among these, DBW 252, DBW 327, HPW 368, HI 8805, and PBW 822 proved to be good candidates for wheat improvement. These genotypes should be assessed in other environments to establish their performance and breeding value for terminal heat resilience.

Statements & Declarations

Funding: The authors declare that no funds, grants, or other support were received during the preparation of this manuscript
Competing Interests: The authors have no relevant financial or non-financial interests to disclose.
Large Language Models use: Large Language Models (LLMs) such as ChatGPT were used to assist with copy editing for clarity and style. Final content and responsibility for the work remain solely with the authors of manuscript.
Data availability: Not applicable
Ethics approval: Not applicable
Consent to participate: Not applicable
Consent to publish: All authors consent to publish the submitted version of manuscript

Acknowledgements: The author expresses sincere thanks to Dr. Divya Phougat, Dr. Yogender Kumar, Vinkal Saini, Ishwar Das, Prakhar Singla, Meenakshi and Hitesh Kashyap for their kind help in research programme. I am very thankful to HOD, Department of Genetic and Plant Breeding for providing necessary facilities to complete this research.

References

1. Bhandari, R., Paudel, H., Alharbi, S.A., Ansari, M.J., Poudel, M.R., Neupane, M.P., Solanki, P., & Kushwaha, U.K.S. (2024). Evaluating stress tolerance indices for their comparative validity to access terminal heat stress and heat drought tolerance of winter wheat (*Triticum aestivum* L.) genotypes. Journal of Agriculture and Food Research, 18, 101506.
2. Bidinger, F. R., Mahalakshmi, V., & Rao, G. D. P. (1987). Assessment of drought resistance in pearl millet [*Pennisetum americanu* .m (L.) Leeke]. I. Factors affecting yields under stress. Australian Journal of Agricultural Research, 38(1), 37-48.
3. Bouslama, M., & Schapaugh Jr, W. T. (1984). Stress tolerance in soybeans. I. Evaluation of three screening techniques for heat and drought tolerance 1. Crop Science, 24(5), 933-937.
4. Farshadfar, E. & Javadinia, J. Evaluation of chickpea (*Cicer arietinum* L.) genotypes for drought tolerance. Seed and Plant Improvement Journal, 27(4), 517–537 (2011).
5. Fernandez, G. C. (1992). Effective selection criteria for assessing plant stress tolerance. Adaptation of food crops to temperature and water stress. AVRDC Publication: Tainan, Taiwan: Shanhua: Chapter (25), 257–270 (1992).
6. Fischer, R. A., & Wood, J. T. (1979). Drought resistance in spring wheat cultivars. III.* Yield associations with morpho-physiological traits. Australian Journal of Agricultural Research, 30(6), 1001-1020.
7. Gavuzzi, P., Rizza, F., Palumbo, M., Campanile, R. G., Ricciardi, G. L., & Borghi, B. (1997). Evaluation of field and laboratory predictors of drought and heat tolerance in winter cereals. Canadian Journal of Plant Science, 77(4), 523-531.
8. Khanzada, A., Yan, K., Hu, W., Malko, M., Khan, K. A., Bao, Y., & Li, Y. (2025). Heat stress response mechanisms and resilience strategies in wheat. Journal of Agronomy and Crop Science, 211(1), e70023.
9. Kumar, P., Kumar, R., Kumar, A., Gangwar, L. K., Kumar, M., Kapoor, N., & Agrawal, A. (2024). Tolerance indices based evaluation of wheat (*Triticum aestivum*) genotypes under terminal heat stress conditions. Indian Journal of Agricultural Sciences, 94, 577–582.
10. Lamba, K., Kumar, M., Singh, V., Chaudhary, L., Sharma, R., Yashveer, S., & Dalal, M.S. (2023). Heat stress tolerance indices for identification of the heat tolerant wheat genotypes. Scientific Reports, 13, 10842.
11. Mousavi, S. S., Yazdi, S. B., Naghavi, M. R., Zali, A. A., Dashti, H., & Pourshahbazi, A. (2008). Introduction of new indices to identify relative drought tolerance and resistance in wheat genotypes. Desert, 12, 165-178.
12. Poudel, M.R., Neupane, M.P., Solanki, P., and colleagues. (2021). Evaluation of heat stress tolerance in spring wheat (*Triticum aestivum* L.) genotypes using stress tolerance indices in western region of Nepal. Journal of Agriculture and Food Research.
13. Ramirez-Vallejo, P., & Kelly, J. D. (1998). Traits related to drought resistance in common bean. Euphytica, 99(2), 127-136.
14. Rosielle, A. A., & Hamblin, J. (1981). Theoretical aspects of selection for yield in stress and non-stress environment 1. Crop Science, 21(6), 943-946.
15. Sharma, N., Kumar, M., Daetwyler, H. D., Trethowan, R. M., Hayden, M., & Kant, S. (2024). Phenotyping for heat stress tolerance in wheat population using physiological traits, multispectral imagery, and machine learning approaches. Plant Stress, 14, 100593.
16. Ullah, N., Nawaz, M.A., & Alsafran, M. (2024). Physiological mechanisms regulating source-sink interactions and grain yield formation in heat-stressed wheat. Plant Stress, 14, 100654.
17. Zheng, Y., Cai, Z., Wang, Z., Maruza, T.M., & Zhang, G. (2025). The genetics and breeding of heat stress tolerance in wheat: Advances and prospects. Plants, 14, 148.