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Stress Tolerance Indices and Performance of Elite Wheat Genotypes under Normal and Heat Stress Conditions in the Western Region of Nepal

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ABSTRACT

Heat stress has been one of the major abiotic stresses in South Asian regions. Heat stress reduces yield by influencing physiological processes and yield related traits. To evaluate heat stress tolerance of 20 elite wheat lines comprising 18 genotypes and two commercial checks viz., Bhrikuti and Gautam, the field experiment was conducted for three continuous wheat growing seasons of 2019-20, 2020-21 and 2021-22 in the western region of Nepal at Paklihawa Campus under normal and heat stress conditions using an alpha lattice design having two replications and five blocks. The genotypic evaluation was done with nine stress tolerance indices (STIs). The ANOVA of the AMMI model revealed that yield performance was significant across tested environments and genotypes. The combined ANOVA showed that days to booting (DTB), days to heading (DTH), plant height (Ph), spike length (SL), spike weight (SW), spikelets per spike (SPS), grains per spike (GPS) and grain yield (GY) were significantly reduced by 14, 15, 8.6, 4, 14, 4, 7 and 34%, respectively under heat stress condition as compared to normal condition. For three years, BL 4919 and Bhrikuti were the highest yielding wheat genotypes under normal and heat stress conditions with mean GY of 4860.8 and 3415.41 kg/ha, respectively. Principal component analysis (PCA) performed across STIs extracted; Modified stress tolerance indices (MSTI2) and stress tolerance indices (STI). From MSTI2, Bhrikuti (1.39) and NL 1350 (1.16) were identified as high yielding stable genotypes and from STI, Bhrikuti (0.87) and BL 4919 (0.86) were identified as heat-tolerant genotypes. Selection based on MSTI2 and STI would be helpful to identify high-yielding stable and stress-tolerant genotypes under heat stress conditions, respectively.

Key words: Wheat, stress tolerance, irrigated, drought, heat stress

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the most important cereal crop in the world (Bhandari *et al.*, 2021). It is the major staple crop of 35% of the global population and provides about 32.5% of the total calorie and 31.9% total protein in the diet (Poudel *et al.*, 2021). Wheat shares 19.13% of the total cereal cropping area of Nepal (MOALD, 2020). The productivity of wheat in Nepal is 2.99 t/ha which is lower compared to India and China (FAOSTAT, 2022). One of the major reasons behind poor productivity in Nepal is heat stress. About 25% of the total wheat growing area of Nepal falls under heat stress where the average productivity is around 1.79-2 t/ha (Regmi *et al.*, 2021). Wheat suffers from heat stress when the temperature exceeds 25°C. Since the optimum temperature for growth, anthesis and ripening is 16-22, 12-22 and 21-25°C, respectively. The rise in temperature and heat stress would have concerns about the overall production and productivity of wheat (Khan *et al.*, 2020).

Climate change and temperature rise have been major threats to cereal production in the world (Kamrani *et al.*, 2017; Djanaguiraman *et al.*, 2020). In Nepal, a mean annual rise of 0.0539 °C per year has been reported (Paudel *et al.*, 2020). Globally, wheat yield reduces by about 6-10% which reaches up to 46% if the high temperature coincides with the reproductive stage of wheat (Poudel *et al.*,

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2020). The rice-wheat cropping pattern of Nepal and residual moisture after rice harvest shifts the sowing of wheat up to December last which leads the reproductive stage of wheat to coincide with terminal heat stress in March-April. The productivity of wheat is reduced by 8-46% due to terminal heat stress. IPCC had forecasted the grain yield of wheat will further aggravate in the future and the yield is predicted to reduce on an average by 44-47% in south Asia by 2050 (Lesk *et al.*, 2016; Abhinandan *et al.*, 2018) due to climate change and lack of water for irrigation.

The productivity of wheat must be increased to eradicate the existing hunger and malnutrition in the world. In Nepal, about 16.67% of people are under malnutrition (MOF, 2022). The long-term sustainable plans for Nepal; the agriculture development strategy (ADS) and sustainable development goals (SDGs) aim at achieving food security, ending hunger and improving nutrition in the long run which can be fulfilled by the increment in the production and productivity of wheat (ADS, 2015). Increasing the yield of wheat by increasing the total cropping area is almost impossible. In 1961, about 1.36 billion hectares of land were cultivated for 3.5 billion people around the world. After half a century, the population became doubled (7 billion) but the area under cultivation increased only by 12-13% (FAOSTAT, 2022). Thus, identification of climate-resilient heat stress tolerant genotypes of wheat would play a significant role in achieving the goals of ADS and SDGs that makes heat-stress wheat breeding very crucial for the future food and nutritional security of the world.

MATERIALS AND METHODS

The field experiment was conducted at Bhairahawa, Western region of Nepal under three wheat growing seasons 2019-20, 2020-21 and 2021-22 under normal and heat stress environments comprising six wheat growing environments. Twenty elite wheat lines including 15 Nepal lines (NL), three Bhairahawa lines (BL) and two commercial checks viz., Bhrikuti and Gautam were used in the evaluation.

The experiment was carried out in alpha lattice design, replicated twice with five blocks for both normal and heat stress conditions. Each genotype was sown on a net plot size of 10 m^2 having the dimension of 4 x 2.5 m. The inter block and inter replication spaces were maintained by one meter. The normal environment was created by sowing the genotypes in the third week of November (25th November) and the heat stress condition was created by sowing the genotypes one month later (25th December) so that the flowering and reproductive stage of wheat coincide with the hot wave that had blown at the February-March in the western region of Nepal.

Phenological data days to booting (DTB) and days to heading (DTH); growth data plant height (Ph), spike length (SL), spike weight (SW) and yield attributing data, spikelets per spike (SPS) and number of grains per spike (NGPS) were collected. The yield of the wheat genotype under both normal and heat stressed environments was taken from two quadrants of 1 m^2 and averaged to get the mean yield.

The average yield and variation in the yield among the genotypes under stressed and non-stressed conditions were described through mean productivity (MP) and tolerance index (TOL), respectively (Table 1). The stress susceptibility index (SSI) measured the yield stability that seeks the change in both potential and actual yield in both the environments. SSI value of more than one above average susceptibility of the genotypes and vice versa was true. Geometric mean productivity (GMP) determined the relative performance of the genotypes since the severity of the stress varied from environment to environment. The stability of the genotypes was described through yield susceptibility index (YSI). The high-yielding and stress-tolerant genotypes were evaluated through stress tolerance indices (STI). MSTI1 was used to determine the yield potential of the genotypes under less stressed conditions, whereas MSTI2 identified genotypes having stable and high yields at stressed conditions.

Data entry and processing were done on Microsoft Excel- 2016. Descriptive statistics, combined analysis of variance (ANOVA) across genotypes, environments, year, correlation, and principal component analysis (PCA) were performed on IBM SPSS statistics v.26.

RESULTS AND DISCUSSION

The combined analysis of variance (ANOVA)

Table 1. Stress tolerance indices (STIs)

S. No.	Stress tolerance indices	Formula
1.	Tolerance index (TOL)	$(Ypi - Ysi)$
2.	Mean productivity (MP)	$\left(\frac{Ypi + Ysi}{2}\right)$
3.	Geometrical mean productivity (GMP)	$\left(\sqrt{Ypi * Ysi}\right)$
4.	Yield stability index (YSI)	$\left(\frac{Ysi}{Ypi}\right)$
5.	Relative efficiency index (REI)	$\left[\left(\frac{Ysi}{Ys}\right) * \left(\frac{Ypi}{Yp}\right)\right]$
6.	Stress tolerance index (STI)	$\left(\frac{Ypi * Ysi}{Yp^2}\right)$
7.	Modified stress tolerance index 1 (MSTI 1)	$\left[\left(\frac{Ypi^2}{Yp^2}\right) * STI\right]$
8.	Modified stress tolerance index 2 (MSTI 2)	$\left[\left(\frac{Ysi^2}{Ys^2}\right) * STI\right]$
9.	Stress susceptibility index (SSI)	$\left[\left(1 - \frac{Ysi}{Ypi}\right) \Big/ \left(1 - \frac{Ys}{Yp}\right)\right]$

revealed that there was a significant difference in yield and yield-attributing characteristics of wheat across normal and heat stress conditions (Table 2). DTB, DTH, Ph, SL, SW, SPS, NGPS, and GY were reduced by 14, 15, 8.6, 4, 14, 4, 7, and 34%, respectively, under heat stress conditions as compared to normal condition (Table 2).

The ANOVA of the AMMI model showed that there was a highly significant difference in yield across combined normal and combined heat stress conditions (Table 3). Environment and genotypes explained 85.68 and 9.44% variation in the yield suggesting the direct effect of the environment on the yield of wheat (Table 3).

BL 4919 was the high yielder (4860.83± 1231.89) followed by NL 1346 (4568.58±641.92 kg/ha) under combined normal conditions, whereas Bhrikuti was the highest yielding genotype (3415.41±209.56) followed by NL 1350 (3251.17±715.02 kg/ha) under combined heat stress condition (Table 4).

The combined ANOVA across the environments revealed that there was a highly significant difference in grain yield (GY) among genotypes under normal and heat stress conditions. Grain yield was reduced by 47.59±14, 20.77±6.61 and 30.06 ±13.96% in 2019, 2020 and 2021, respectively, under heat stressed conditions (Table 4). Moreover, wheat genotypes were found to have an average yield reduction of 33.84±8.19% over three years due to heat stress conditions.

The lower productivity of wheat under heat stress conditions was due to its effect on physiological, biological and biochemical processes. Heat stress induces reactive oxygen species (ROS) that cause changes in the membrane stability, lipid peroxidation, protein oxidation and damage to nucleic acids. Heat stress causes the deactivation of RUBISCO enzyme as a result decreases the photosynthetic capacity and helps in the reduction of assimilate translocation. The disruption of biosynthetic pathways results in premature leaf senescence and decreases in chlorophyll content which ultimately decreases the yield. The molecular basis of heat stress wheat has developed different tolerance mechanisms to avoid heat stress induced injury and damage. Heat shock proteins (HSPs) were produced in heat stressed

Table 2. Per cent reduction of yield attributing characters under heat stress conditions as compared to normal conditions

	Days to booting (DTB)	Days to heading (DTH)	Plant height (Ph)	Spike length (SL)	Spike weight (SW)	Spikelets/ spike (SPS)	No. of grains/spike (NGPS)	Grain yield (GY) (kg/ha)
Normal	79	85	93.6	10.3	22	17.5	43	4081
Heat stress (HS)	68	72	85.6	8.8	18	16.7	40	2693
% Reduction	14	15	8.6	4	14	4	7	34
F-Value	***	***	***	**	***	***	**	***

**, ***Denote level of significance at 1 and 0.1%, respectively.

Table 3. ANOVA of AMMI model

	SS	%	Porcenac	DF	MS	F	Prob. F
E	1.15E+08	85.68604	85.68604	1	1.15E+08	284.9588	0
G	12689335	9.44909	95.13513	19	667859.7	1.6539	0.0469
E × G	6533106	4.86487	100	19	343847.7	0.85151	0.64329
PC 1	6542088	100	100	19	344320.4	1.16575	0.29506
PC 2	0	0	100	17	0	0	1
Residuals	80761929	0	0	200	403809.6	NA	NA

E–Environment; G–Genotype; SS–Sum of square; DF–Degree of freedom; MS–Mean square; F–F-value; PROB F–P–value and PC–Principal component.

environment that maintains correct protein folding, refolding and synthesis and it also degrades the protein aggregate (Raza, 2020). The anti-oxidative defense system detoxified the accumulated ROS through various enzymatic and non-enzymatic antioxidants. Heat tolerance in wheat was governed by some traits such as stay green (SG), chlorophyll fluorescence and canopy temperature (Khan *et al.*, 2020).

High yielding and high yield potential genotypes could be identified using MP, GMP and STI (Ali and El-sadek, 2016; Bennani *et al.*, 2017; Poudel *et al.*, 2021). Kamrani *et al.* (2017) and Poudel *et al.* (2021) identified high yield potential and heat tolerant genotypes using MP, GMP and STI. BL 4919 was found to have maximum MP followed by Bhrikuti, BL 4407 and BL 4669. Bhrikuti had maximum GMP and STI followed by BL 4919. Higher MP, GMP and STI denoted higher yield and higher yield potential (Kamrani *et al.*, 2017; Poudel *et al.*, 2021).

A stable genotype can be selected using TOL, YSI and REI (Bennani *et al.*, 2016). Higher TOL indicates lower yield under stressed conditions and vice versa is true (Kamrani *et al.*, 2017; Puri *et al.*, 2020). A YSI value closer to 1 indicates the stability of the genotype. The value of REI above 1 indicates a highly efficient genotype across both the environment and vice versa. The lowest TOL was found for Bhrikuti followed by NL 1420 (Table 5). So, Bhrikuti and NL 1420 were identified as heat tolerant genotypes. The highest TOL was found for NL 1346 followed by NL 1412 which can be identified as heat susceptible genotypes. Similarly, Bhrikuti was found to have a maximum YSI (0.809) followed by NL 1350 (0.794). Hence, Bhrikuti and NL 1350 were identified as stable genotypes across three wheat growing seasons. Similarly, from the YSI value, NL 1412 (0.507) followed by NL 1346 (0.551) were the most heat stress susceptible genotypes under heat stress conditions.

Genotypes performing well in both the environments were selected by using SSI. SSI above 1 represents above average susceptibility, whereas below 1 represents below average susceptibility. Genotypes with the least SSI were heat tolerant genotypes, whereas genotypes with the highest SSI were heat susceptible genotypes. Bhrikuti had least SSI (0.56) followed by NL 1350 (0.61). These genotypes were heat tolerant. Bhrikuti, BL 4407, BL 4669, Gautam, NL 1350, NL 1369, NL 1376, NL 1413 and NL 1420 were the below-average susceptible genotypes, whereas NL 1346 and NL 1386 were found to have maximum SSI values and identified as the most heat stress susceptible genotypes.

BL 4919 was found to have maximum MSTI1. It also had the highest yield under a normal environment and still has a chance to improve yield under stressed conditions. Whereas MSTI2 identified genotypes having both stable and high yield under stressed conditions (Kamrani *et al.*, 2017; Puri *et al.*, 2020). Based on MSTI2, Bhrikuti was the highest yielding stable genotype under heat stress conditions followed by NL 1350.

MP, GMP, REI, STI and MSTI1 were highly significantly positively correlated with Yp and Ys which showed these were yield potential indices (Table 6). These indices would help to identify high yielding genotypes under both the conditions. Since, MP, GMP and MSTI1 were affected by the yield at both the conditions, it would be misleading to coin genotypes as high yielding under both conditions despite they are yield potential genotypes. So, MP, GMP and MSTI1 were suitable indices for the selection of genotypes under normal conditions. The correlation between GMP and STI with Ys was highly

Table 4. Mean grain yield (GY) of 20 elite wheat genotypes under normal and heat stress conditions of wheat growing years 2019-20, 2020-21 and 2021-22

Genotypes	Treatment T_1	2019-20 Normal	2019-20 HS	% Reduction	2020-21 Normal	2020-21 HS	% Reduction	2021-22 Normal	2021-22 HS	% Reduction	Combined normal GY±STD	Combined heat stress GY±STD	Mean % reduction
Bhrikuti	T_2	4398.5	3279	25.5	4437	3310.5	25.4	3828.25	3656.7	4.5	4221.25 ± 340.89	3415.4±209.56	18.4
BL 4407	T_3	4888	2799	42.7	4282	2962.5	30.8	3957.05	3113.1	21.3	4375.683± 472.49	2958.2±157.09	31.6
BL 4669	T_4	3877	2948	24.0	4159.5	3657	12.1	4612.75	2702.5	41.4	4216.417± 371.16	3102.5±495.65	25.8
BL 4919	T_5	4413	2616	40.7	3915.5	2803.5	28.4	6254	3420	45.3	4860.833±1231.89	2946.5±420.64	38.1
Gautam	T_6	3962	2477	37.5	3892	3053	21.6	3704.75	3158.5	14.7	3852.917±133	2896.167±366.82	24.6
NL 1179	T_7	5252.5	2726	48.1	3845	2759	28.2	3848.75	2798.5	27.3	4315.417±811.54	2761.167±36.3	34.5
NL 1346	T_8	4820	2038.5	57.7	3839	3058.5	20.3	5046.75	2448.5	51.5	4568.58±641.93	2515.167±513.26	43.2
NL 1350	T_9	4312.5	2792	35.3	3793.5	2886.5	23.9	4181.4	4075	2.5	4095.8±269.88	3251.167±715.02	20.6
NL 1368	T_{10}	4466.5	2782.5	37.7	3626.5	2499	31.1	4417.5	2661.5	39.8	4170.167±471.47	2647.667±142.26	36.2
NL 1369	T_{11}	3983	2295	42.4	3613	2609	27.8	4393.75	3659.5	16.7	3996.583±390.55	2854.5±714.61	29.0
NL 1376	T_{12}	4504.5	2022.5	55.1	3605.5	3071	14.8	4097.5	3134.5	23.5	4069.167±450.17	2742.667±624.49	31.1
NL 1381	T_{13}	3957.5	1830.5	53.7	3552	2806	21.0	4427.35	2445.5	44.8	3978.95±438.07	2360.667±493.25	39.8
NL 1384	T_{14}	3970.5	1547	61.0	3519.5	2930.5	16.7	3611.5	2776.5	23.1	3700.5±238.31	2418±758.23	33.6
NL 1386	T_{15}	4452.5	1356.5	69.5	3470.5	2718	21.7	4202.5	2694	35.9	4041.833±510.33	2256.16±779.23	42.4
NL 1387	T_{16}	4158	1936.5	53.4	3417.5	2732.5	20.0	4155.45	2531	39.1	3910.317±426.79	2400±413.85	37.5
NL 1404	T_{17}	4476	2209.5	50.6	3374.5	2803	16.9	4866	2840.5	41.6	4238.833±773.52	2617.66±7353.98	36.4
NL 1412	T_{18}	4144	754.5	81.8	3364	2809.5	16.5	4634.9	2594	44.0	4047.633±640.91	2052.667±1129.4	47.4
NL 1413	T_{19}	4241	2324	45.2	3353	2752	17.9	4069.45	2820	30.7	3887.817±471.04	2632±268.89	31.3
NL 1417	T_{20}	3597.5	1684.5	53.2	3331	2869	13.9	3805.15	2510.5	34.0	3577.883±237.68	2354.66±7607.43	33.7
NL 1420		4568	2893.5	36.7	2803	2628	6.2	3164.4	2554	19.3	3511.8±932.37	2691.833±178.52	20.7
Mean		4322.13	2265.6	47.6	3659.68	2885.9	20.8	4263.96	2929.72	30.1	4081.92±512.70	2693.74±468.92	32.8
STD		390.2	627.22	14.0	375.7	259.5	6.6	647.43	460.86	14.0	317.84	343.39	7.9
CV		9.03	27.68	29.4	10.27	8.99	31.8	15.18	15.73	46.5	7.79	12.75	24.0
F-value		NS	***	NS	*	NS	NS	NS	NS	NS	NS	NS	NS

HS–Heat stress, GY–Grain yield and STD–Standard deviation.

Table 5. Stress tolerance indices of wheat genotypes under normal (Yp) and heat stress (Ys) conditions.

Genotypes	Treatment	Normal (Yp)	Heat stress (Ys)	TOL	MP	GMP	YSI	REI	STI	MSTI1	MSTI2	SSI	% YL
Bhrikuti	T_1	4221.25	3415.4	805.85	3818.33	3797.01	0.809	1.31	0.87	0.93	1.39	0.56	19.09
BL-4407	T_2	4375.68	2958.2	1417.48	3666.94	3597.8	0.676	1.18	0.78	0.89	0.94	0.95	32.39
BL-4669	T_3	4216.42	3102.5	1113.92	3659.46	3616.83	0.736	1.19	0.79	0.84	1.04	0.78	26.42
BL-4919	T_4	4860.83	2946.5	1914.33	3903.67	3784.5	0.606	1.3	0.86	1.22	1.03	1.16	39.38
Gautam	T_5	3852.92	2896.17	956.75	3374.54	3340.46	0.752	1.01	0.67	0.6	0.77	0.73	24.83
NL-1179	T_6	4315.42	2761.17	1554.25	3538.29	3451.9	0.64	1.08	0.72	0.8	0.75	1.06	36.02
NL-1346	T_7	4568.58	2515.17	2053.42	3541.88	3389.8	0.551	1.05	0.69	0.86	0.6	1.32	44.95
NL-1350	T_8	4095.8	3251.17	844.63	3673.48	3649.13	0.794	1.21	0.8	0.8	1.16	0.61	20.62
NL-1368	T_9	4170.17	2647.67	1522.5	3408.92	3322.83	0.635	1	0.66	0.69	0.64	1.07	36.51
NL-1369	T_{10}	3996.58	2854.5	1142.08	3425.54	3377.61	0.714	1.04	0.68	0.66	0.77	0.84	28.58
NL-1376	T_{11}	4069.17	2742.67	1326.5	3405.92	3340.71	0.674	1.01	0.67	0.67	0.69	0.96	32.6
NL-1381	T_{12}	3978.95	2360.67	1618.28	3169.81	3064.8	0.593	0.85	0.56	0.54	0.43	1.2	40.67
NL-1384	T_{13}	3700.5	2418	1282.5	3059.25	2991.29	0.653	0.81	0.54	0.44	0.43	1.02	34.66
NL-1386	T_{14}	4041.83	2256.17	1785.67	3149	3019.78	0.558	0.83	0.55	0.54	0.38	1.3	44.18
NL-1387	T_{15}	3910.32	2400	1510.32	3155.16	3063.46	0.614	0.85	0.56	0.52	0.45	1.14	38.62
NL-1404	T_{16}	4238.83	2617.67	1621.17	3428.25	3331.04	0.618	1.01	0.67	0.72	0.63	1.12	38.25
NL-1412	T_{17}	4047.63	2052.67	1994.97	3050.15	2882.44	0.507	0.76	0.5	0.49	0.29	1.45	49.29
NL-1413	T_{18}	3887.82	2632	1255.82	3259.91	3198.86	0.677	0.93	0.61	0.56	0.59	0.95	32.3
NL-1417	T_{19}	3577.88	2354.67	1223.22	2966.28	2902.54	0.658	0.77	0.51	0.39	0.39	1.01	34.19
NL-1420	T_{20}	3511.8	2691.83	819.97	3101.82	3074.6	0.767	0.86	0.57	0.42	0.57	0.69	23.35
Mean		4081.92	2693.74	1388.18	3387.83	3309.87	0.66	1	0.66	0.68	0.7	1	33.84

Yp–Yield under normal conditions, Ys–Yield under heat stress conditions, TOL–Tolerance index, MP–Mean productivity, GMP–Geometrical mean productivity, YSI–Yield stability index, REI–Relative efficiency index, STI–Stress tolerance index, MSTI1–Modified stress tolerance index 1, MSTI2–Modified stress tolerance index 2, SSI–Stress susceptibility index and MSY–Mean stable yield.

Table 6. Correlation among Yp, Ys and 10 stress tolerance indices

	Yp	Ys	TOL	MP	GMP	YSI	REI	STI	MSTI1	MSTI2	SSI	% Yield loss
Yp	1											
Ys	0.339	1										
TOL	0.529*	-0.619**	1									
MP	0.802**	0.834**	-0.082	1								
GMP	0.709**	0.903**	-0.223	0.990**	1							
YSI	-0.27	0.812**	-0.958**	0.357	0.485*	1						
REI	0.710**	0.902**	-0.221	0.989**	0.999**	0.484*	1					
STI	0.710**	0.902**	-0.221	0.989**	0.999**	0.484*	1.000**	1				
MSTI1	0.916**	0.668**	0.162	0.962**	0.918**	0.121	0.921**	0.921**	1			
MSTI2	0.486*	0.974**	-0.473*	0.904**	0.948**	0.691**	0.953**	0.953**	0.776**	1		
SSI	0.27	-0.812**	0.958**	-0.357*	-0.485*	-1.000**	-0.484*	-0.484*	-0.121	-0.691	1	
% Yield loss	0.27	-0.812**	0.958**	-0.357	-0.485*	-1.000**	-0.484*	-0.484	-0.121	-0.691	1.000**	1

significant than MP. So, a genotype with higher GMP indicates higher yield at stressed conditions and denotes stress tolerance.

TOL and SSI were strongly negatively correlated with Ys, hence these indices can be used as heat stress tolerance indices. A highly significant positive correlation was seen between YSI and Ys indicating selection based on YSI would help to identify heat stress tolerant genotype. There was no significant correlation between Yp and Ys, which showed that the performance of the genotypes was independent of environment. MSTI2 would help to identify genotypes with higher and stable yields under both the conditions as it was strongly positively correlated with Ys than YSI (Bennani *et al.*, 2016).

PC1 and PC2 described 73.27 and 26.38% of the total variation in the indices, respectively (Fig. 1). Two components were extracted from the principal component analysis (PCA), Modified stress tolerance indices (MSTI2) and Stress tolerance indices (STI).

From MSTI2, Bhrikuti (1.39) followed by NL 1350 (1.16) were identified as the higher and stable yielding across both the conditions, whereas, from STI Bhrikuti (0.87) followed by BL 4919 (0.86) were identified as heat stress

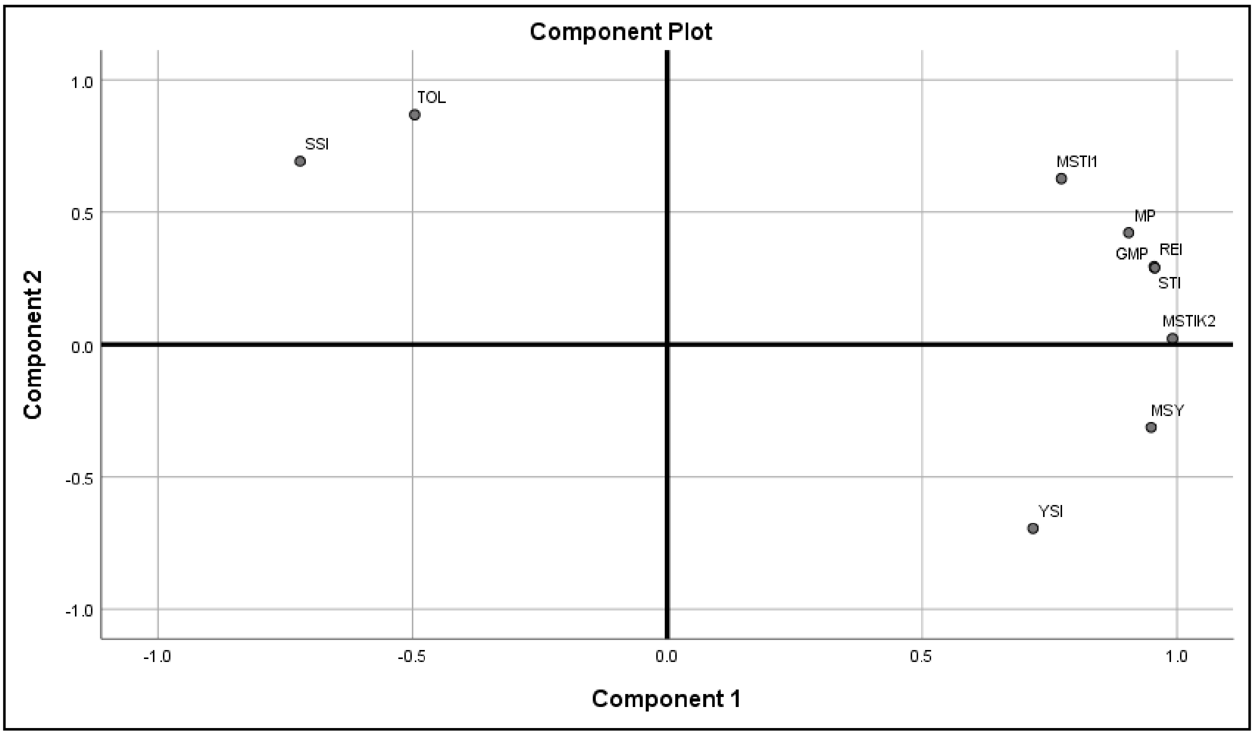

Fig. 1. Principal component analysis (PCA).

tolerant genotypes (Table 5). Bhrikuti and NL 1350 were identified as high-yielding stable genotypes across both the conditions for profitable cultivation. Furthermore, PC1 has described more of the variation in GY compared to PC2. Selection based on MSTI2 compared to STI would be more accurate. Hence, Bhrikuti was identified as the ideal genotype for cultivation under heat-stressed conditions (MSTI2 = 1.39), whereas BL 4919 (MSTI1 = 1.22) was identified as the highest yield potential genotype which has good performance under normal conditions.

CONCLUSION

Heat stress has been a serious problem in wheat cultivation in the world. The terminal heat stress at the time of the reproductive stage reduces the yield by reducing the grain-filling period and altering the physiology of the plant. To identify the heat-tolerant genotype of wheat under heat-stress environments, an evaluation of 20 elite wheat genotypes was done for three continuous wheat growing seasons with nine stress tolerance indices (STIs). DTB, DTH, Ph, SL, SW, SPS, NGPS and GY were reduced by 14, 15, 8.6, 4, 14, 4, 7 and 34%, respectively, under combined heat stressed conditions as compared to normal condition. BL 4919 was found to be a high yielder (4860.83±1231.89) followed by NL 1346 (4568.58±641.92 kg/ha) under normal conditions over three years, whereas Bhrikuti was found to be a high-yielding genotype (3415.41±209.56 kg/ha) followed by NL 1350 (3251.17 ±715.02) under heat stress condition. The principal component analysis (PCA) extracted two indices; Modified stress tolerance indices (MSTI2) and Stress tolerance indices (STI). Bhrikuti and NL 1350 were identified as high-yielding stable genotypes across both the conditions over three years for profitable cultivation. Hence, MSTI2 and STI can be used to identify high yielding stable genotypes and stress tolerant genotypes under heat stress conditions.

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