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Evaluation of heat stress tolerance in spring wheat (*Triticum aestivum* L.) genotypes using stress tolerance indices in western region of Nepal

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ABSTRACT

High temperature coinciding with the anthesis period in wheat is one of the major constraints in wheat production. Appropriate selection criteria help plant breeders to make maximum use of the genetic variation to improve stress tolerant in crops. Thus, the aim of the study was to explore heat stress tolerance indices in spring wheat genotypes to select the heat stress tolerant lines. In this study twenty wheat genotypes were evaluated during wheat growing season (2019–2020) under normal and late sown (heat stress) conditions. The experiment was conducted at Institute of Agriculture and Animal Science, Bhairahawa, Nepal using alpha lattice design with two replications. The results of the study reveal that the mean grain yield of all genotypes was decreased by 47.58% under stress condition as compared to normal sowing condition, suggesting significant effect of heat on grain yield. Tolerance index (TOL) and stress susceptibility index (SSI) had strong negative correlation (−0.804 to −0.945) with grain yield (Ys) of genotypes under stress condition. Similarly, the grain yield of genotypes under both conditions was found strongly and positively correlated (0.899 to 0.965) with mean productivity (MP), geometric mean productivity (GMP) and stress tolerance index (STI). Results suggest that these indices could be used to select high yielding genotypes under both conditions. Based on principal component and biplot analysis Bhrikuti, NL1420, BL4669, NL1350 and NL1368 were found to be superior genotypes with high yielding capacity under both conditions. Thus these genotypes are potential to cultivate in heat prone areas of Nepal and can be used as genetic resources in crop improvement program.

1. Introduction

Temperature is a major abiotic factor for regulating both growth and development of crop. But heat stress due to high ambient temperature is a serious threat to crop production worldwide [1]. By the end of 21st century, the global mean ambient temperature is predicted to increase by 6 °C [2]. Wheat is highly sensitive to heat stress. It was predicted that an increase of 1 °C temperature cause decline in global wheat production by 6% [3]. In wheat, the optimum temperature during anthesis and grain filling stage ranges from 12 °C to 22 °C. Thus, exposure to temperature above this can remarkably decrease the grain yield [4]. High temperature (>22 °C) between anthesis to grain maturity reduces grain yield due to decrease in grain filling duration [5]. Currently, terminal heat stress is affecting the majority of wheat growing area of South Asia [6]. Terai area of Nepal faces western hot winds with sudden increase in temperature starting from mid March which coincides with anthesis [7]. Dahal et al. [8] analyzed last 25 years weather data of the terai region of Nepal and reported that maximum temperature had increased by over 1 °C. Thus, this type of change in weather condition could be detrimental to wheat cultivation in South Asia including Terai region of Nepal. It is estimated that, in South Asia the grain yield losses ranges from 6% to 10% per ^{o}C rise in temperature during grain filling period of wheat [9–11].

Wheat is staple food in more than 40 countries and it provides basic calories for 85% of the world population [12]. By the end of 2050, the population is projected to increase up to 9.1 billion [13]. Therefore to meet the food requirement of growing population, improvement in crop production and productivity is the demand of 21st century. It is necessary to produce wheat variety that can cope with rising temperature. Screening of wheat genotypes to identify potential germplasms with better heat tolerance is a precondition for breeding for heat tolerance [14]. Many researchers [15,16] suggested selection of heat stress

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Table 1
List of wheat lines used for the experiment.

S.N.	Genotypes[a]	Origin
1	Bhirkuti	CIMMYT, Mexico
2	Gautam	Nepal
3	BL 4669	Nepal
4	BL 4919	Nepal
5	BL 4407	Nepal
6	NL 1179	CIMMYT, Mexico
7	NL 1346	CIMMYT, Mexico
8	NL 1350	CIMMYT, Mexico
9	NL 1368	CIMMYT, Mexico
10	NL 1369	CIMMYT, Mexico
11	NL 1376	CIMMYT, Mexico
12	NL 1381	CIMMYT, Mexico
13	NL 1384	CIMMYT, Mexico
14	NL 1386	CIMMYT, Mexico
15	NL 1387	CIMMYT, Mexico
16	NL 1404	CIMMYT, Mexico
17	NL 1412	CIMMYT, Mexico
18	NL 1413	CIMMYT, Mexico
19	NL 1417	CIMMYT, Mexico
20	NL 1420	CIMMYT, Mexico

[a] The pedigree information of NL and BL lines is confidential and maintained by NWRP, Bhairahawa.

tolerant genotypes by testing the promising advanced lines of wheat under normal and heat stress conditions. Selection of different genotypes under abiotic stress conditions helps plant breeder to exploit genetic variation to improve stress tolerant cultivar. Thus, a major challenge for plant breeder is to find the suitable selection criteria to identify heat tolerant genotype.

Different researchers have proposed various stress tolerance indices for the selection of stress tolerant cultivar but only a few indices are used for screening heat tolerant genotypes in wheat. Some of these indices are tolerance index (TOL), stress susceptibility index (SSI), yield stability index (YSI), mean productivity (MP), geometric mean productivity (GMP) and stress tolerance index (STI). Fernandez [17] had suggested selection based on TOL to identify high yield potential genotypes under stress condition. A positive correlation between MP and grain yield under stress condition was reported by Nouri et al. [18]. Thus, selection based on MP will improve average grain yield under both stress and non-stress conditions. Bansal and Sinha [19] suggested the use of SSI and grain yield as stability parameter for screening drought resistant genotypes of wheat. Ramirez-Vallejo and Kelly [20] reported that, combination of GMP and SSI was found effective for selecting drought resistant genotypes of common bean. Although many researchers had evaluated stress tolerance indices to identify the drought tolerant cultivars, few researches were carried out to find out heat stress tolerant wheat genotypes based on tolerance indices. Thus, the present study was conducted to identify appropriate stress tolerance indices to identify heat tolerant spring wheat genotypes for terai region of Nepal.

2. Materials and methods

The field experiment was carried out at Institute of Agriculture and Animal Science, Bhairahawa, Rupandehi District, Nepal (27°30′N, 83°27′E and 79 m above sea level). This site is selected because it experiences hot weather followed by heat waves during the flowering through to maturity of wheat crop. Additionally, the one and only one National Wheat Research Program (NWRP) is present in the area adds value to the site selection.

Twenty wheat genotypes obtained from National Wheat Research Program (NWRP), Bhairahawa. There were three Bhairahawa lines (BL), fifteen Nepal lines (NL) and two commercial lines; Bhirkuti (CMT/COC75/3/PLO/FURY/ANA75) and Gautam (SIDDHARTH/NING8319/NL297). These two commercial varieties were used as standard check. The complete set of genotypes with their entry names and origin are presented in Table 1.

The genotypes were evaluated using alpha lattice design with two replications on two sowing dates: 29th November (Normal condition) and 25th December (Heat stress condition), with two replicates. Wheat crop under late sown (25th December) will experience heat stress because of the high temperature in the month of March that coincides with the reproductive stage of wheat. The genotypes were planted in 10 m^2 (4 m × 2.5 m) plots at seed rate of 100 kg per hectare and each plot consists of 10 rows at 25 cm apart.

The experimental design consists of five blocks within a replication and each block consists of 4 plots. The recommended dose of 100:50:25 kg NPK per hectare was applied for each condition [21]. Irrigation was given at crown initiation stage and heading stage and remaining water requirement was fulfilled by natural rainfall in both conditions. The data for grain yield were recorded by harvesting crop from three sample areas (each of 1 m^2) from each plot. The grain obtained from these sample areas was weighed separately and average was taken to calculate mean grain yield from 1 m^2. The grain yield was measured in kilogram per hectare (kg ha^{-1}). Mean monthly maximum and minimum temperature and in-crop rainfall during wheat growing season at experimental site is presented in Fig. 1. The elevated temperature during March (>25 °C) coincides with the flowering and grain filling stages of late sown wheat

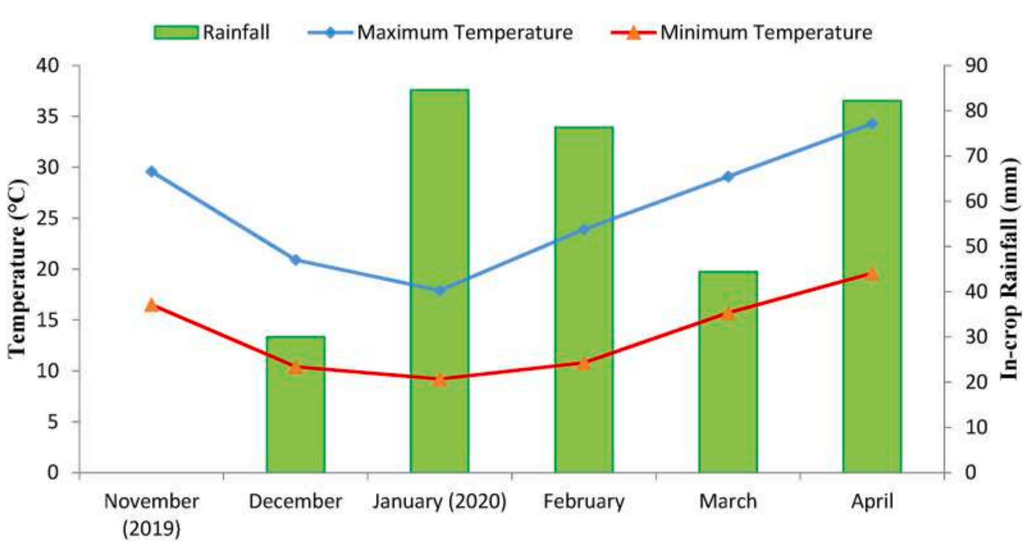

Fig. 1. Mean monthly maximum, minimum temperature and in-crop rainfall during wheat growing period (2019–2020).

Table 2
Analysis of variance for grain yield under normal and heat stress conditions of 20 wheat genotypes.

Source of variation	df	Mean Square	
		Normal condition	Heat stress condition
Replication	1	289850.63	411278.40
Genotype	19	227060.87NS	604118.43**
Block (within replication, ignoring treatment)	8	129528.21	58989.60
Residual	11	137835.11	109888.89

* Significant at 0.05 level of probability, ** Significant 0.01 level of probability, NS: non-significant. df = Degree of freedom.

genotypes.

The stress tolerance indices were calculated by the following relationships:

1. Tolerance Index (TOL)TOL = Yp – Ys [20]
2. Stress Susceptibility Index (SSI)SSI = $\frac{1-\left(\frac{Ys}{Yp}\right)}{\left(1-\frac{\overline{Ys}}{\overline{Yp}}\right)}$ [22]
3. Yield Stability Index (YSI)YSI = $\frac{Ys}{Yp}$ [23]
4. Mean Productivity (MP)MP = $\frac{Yp+Ys}{2}$ [24]
5. Geometric Mean Productivity (GMP)GMP = $\sqrt{Yp \times Ys}$ [16]
6. Stress Tolerance Index (STI)STI = $\frac{Yp\times Ys}{\overline{Yp}^2}$ [16]

Where, Yp and Ys are the grain yield of genotypes under normal and heat stress conditions respectively. Whereas, $\overline{Yp}$ and $\overline{Ys}$ are mean yield of all genotypes under normal and heat stress conditions respectively. The grain yield was measured in term of kilogram per hectare.

The experimental data were processed using Microsoft Excel 2010 and analysis of variance was conducted using ADEL-R (Analysis and design of experiments with R for Windows) developed by CIMMYT, Mexico. Stat Graphics software was used to perform correlation, principal component and biplot analysis.

3. Results and discussion

3.1. Yield performance

Analysis of variance revealed significant difference among wheat genotypes for grain yield under heat stress condition while it was non-significant in normal condition (Table 2). The results indicated that the wheat genotypes did not differ on yield performance at 95% level of significance, indicating that the genotypes responded similarly in normal condition. While, under stress condition the genotypes responded differently, as a result yield performance were significantly different at 95% level of significance. These results indicated a high variation among genotypes that allow us to choose superior genotypes under heat stress condition. The maximum grain yield was observed in NL1179 and Bhrikuti under normal and heat stress condition respectively. Whereas, minimum grain yield was recorded in NL1417 and NL1412 under normal and heat stress conditions respectively. The mean grain yield is reduced by 47.58% under heat stress condition. Similar result was reported by Puri et al. [7], where the most heat tolerant variety NL 1140 produced mean yield of 3730.5 kg/ha and 3000.3 kg/ha under normal and late sown conditions respectively. In wheat, period from onset of spike ignition to flowering is very sensitive to temperature acceleration and it seems to be the main reason for reduction in sink size under high temperature conditions, resulting in poor grain yield [21]. Moreover, heat stress cause reduction in duration of grain filling phase, tiller number and spikelets per spike [13].

3.2. Stress tolerance indices

Stress tolerance indices were determined on the basis of grain yield of genotypes under normal and heat stress condition (Table 3). Many researchers [7,25,26] had used stress tolerance indices of grain yield to identify stress tolerance genotypes. The greater value of TOL belongs to NL1412 (3389.5) and NL1386 (3096). These genotypes had low grain yield under stress condition. Thus, these genotypes were considered as heat susceptible genotypes. The minimum value of TOL was associated with BL4669 (929) and Bhrikuti (1119.50). Nouri et al. [18] and Rossielle & Hamblin [27] suggested that lower value of TOL is favourable for selection of high yielding genotypes under stress condition. The high value of SSI belongs to NL1412 and NL1386 and the low value of SSI was

Table 3
Grain yield (kg ha^{-1}) of wheat genotypes under normal (Yp) and heat stress (Ys) conditions and stress tolerance indices.

S·N	Genotype	Yp	Ys	TOL	YSI	SSI	MP	GMP	STI
1	Bhrikuti	4398.50	3279.00	1119.50	0.75	0.54	3838.75	3797.72	0.77
2	BL 4407	4888.00	2799.00	2089.00	0.57	0.90	3843.50	3698.85	0.73
3	BL 4669	3877.00	2948.00	929.00	0.76	0.50	3412.50	3380.74	0.61
4	BL 4919	4413.00	2616.00	1797.00	0.59	0.86	3514.50	3397.71	0.62
5	Gautam	3962.00	2477.00	1485.00	0.63	0.79	3219.50	3132.71	0.53
6	NL 1179	5252.50	2726.00	2526.50	0.52	1.01	3989.25	3783.96	0.77
7	NL 1346	4820.00	2038.50	2781.50	0.42	1.21	3429.25	3134.58	0.53
8	NL 1350	4312.50	2792.00	1520.50	0.65	0.74	3552.25	3469.94	0.65
9	NL 1368	4466.50	2782.50	1684.00	0.62	0.79	3624.50	3525.34	0.67
10	NL 1369	3983.00	2295.00	1688.00	0.58	0.89	3139.00	3023.41	0.49
11	NL 1376	4504.50	2022.50	2482.00	0.45	1.16	3263.50	3018.34	0.49
12	NL 1381	3957.50	1830.50	2127.00	0.46	1.13	2894.00	2691.51	0.39
13.	NL 1384	3970.50	1547.00	2423.50	0.39	1.28	2758.75	2478.38	0.33
14	NL 1386	4452.50	1356.50	3096.00	0.31	1.46	2904.50	2457.60	0.32
15	NL 1387	4158.00	1936.50	2221.50	0.47	1.12	3047.25	2837.60	0.43
16	NL 1404	4476.00	2209.50	2266.50	0.49	1.06	3342.75	3144.79	0.53
17	NL 1412	4144.00	754.50	3389.50	0.18	1.72	2449.25	1768.23	0.17
18	NL 1413	4241.00	2324.00	1917.00	0.55	0.95	3282.50	3139.44	0.53
19	NL 1417	3597.50	1684.50	1913.00	0.47	1.12	2641.00	2461.70	0.32
20	NL 1420	4568.00	2893.50	1674.50	0.63	0.77	3730.75	3635.59	0.71
Mean		4322.13	2265.60	2056.53	0.52	1.00	3293.86	3098.91	0.53
Range		1655.00	2524.50	2460.50	0.58	1.22	1540.00	2029.49	0.61

Yp = Grain yield of genotypes under normal condition, Ys = Grain yield of genotypes under heat stress condition, TOL = Tolerance index, YSI = Yield stability index, SSI = Stress susceptibility index, MP = Mean productivity, GMP = Geometric mean productivity, STI = Stress tolerance index.

Table 4
Correlation coefficient between grain yield (Yp and Ys) of wheat genotypes and stress tolerance indices.

	YP	YS	TOL	YSI	SSI	MP	GMP	STI
YP	1							
YS	0.331	1						
TOL	0.295	-.804**	1					
YSI	0.008	.945**	-.952**	1				
SSI	−0.008	-.945**	.952**	−1.000**	1			
MP	.711**	.899**	-.463*	.708**	-.708**	1		
GMP	.552*	.965**	-.629**	.831**	-.831**	.975**	1	
STI	.584**	.958**	-.602**	.810**	-.810**	.985**	.994**	1

* Significant at 0.05 level of probability, ** Significant 0.01 level of probability, Yp = Grain yield of genotypes under normal condition, Ys = Grain yield of genotypes under heat stress condition, TOL = Tolerance index, YSI = Yield stability index, SSI = Stress susceptibility index, MP = Mean productivity, GMP = Geometric mean productivity, STI = Stress tolerance index.

Table 5
Result of principal component analysis based on grain yield of genotypes and stress tolerance indices.

Component	Percent of variance	Cumulative percentage	YP	YS	TOL	YSI	SSI	MP	GMP	STI
PC1	77.53	77.53	0.14	0.40	−0.31	0.37	−0.37	0.36	0.31	0.38
PC2	22.30	99.83	0.69	−0.02	0.46	−0.26	0.26	0.30	0.16	0.19

PC1 = First principal component, PC2 = Second principal component, Yp = Grain yield of genotypes under normal condition, Ys = Grain yield of genotypes under heat stress condition, TOL = Tolerance index, YSI = Yield stability index, SSI = Stress susceptibility index, MP = Mean productivity, GMP = Geometric mean productivity, STI = Stress tolerance index.

related to Bhrikuti and BL4669. Bhrikuti and BL4669 had high grain yield under both conditions. According to Kamrani et al. [15], selection based on SSI helps to determine high yielding genotypes under both conditions. Also, SSI value greater than one represents ‘above average susceptibility’ and SSI value less than one represents ‘below average susceptibility’ [28]. The highest YSI indices was observed for BL4669 (0.76), followed by Bhrikuti (0.75).

The high value of MP, GMP and STI was obtained in Bhrikuti, NL1179 and BL4407. These genotypes are more productive under stress condition in comparison to other genotypes under study. Similar result was presented by Kamrani et al. [15], who suggested selection based on MP, GMP and STI would identify higher yielding and heat tolerant genotypes.

3.3. Correlation among Yp, Ys and stress tolerance indices

To determine the most suitable heat stress tolerant criterion, the correlation coefficient between Yp, Ys and heat tolerance indices were calculated (Table 4). The correlation coefficient between Yp and Ys was low and insignificant, indicating that the two environment (normal and heat stress) condition affect the genotype independently. Khan & Kabir [16] and Nouri et al. [18] had also reported low and insignificant association between grain yield of spring wheat genotypes under timely and late sowing conditions. So, selection of heat tolerant genotype based on the performance of genotype under normal condition is not beneficial. TOL and SSI was found negatively and significantly correlated with Ys, while YSI had positive significant correlation with Ys. Therefore, selection based on higher value of YSI and lower value of TOL and SSI helps to identify heat stress tolerant genotypes.

There was significant positive correlation of grain yield (Yp and Ys) of genotypes with MP, GMP and STI. Kamrani et al. [15] and Puri et al. [29] had reported similar results while evaluating durum wheat and spring wheat genotypes for heat stress tolerance, respectively. Therefore, selection of genotype considering MP, GMP and STI would

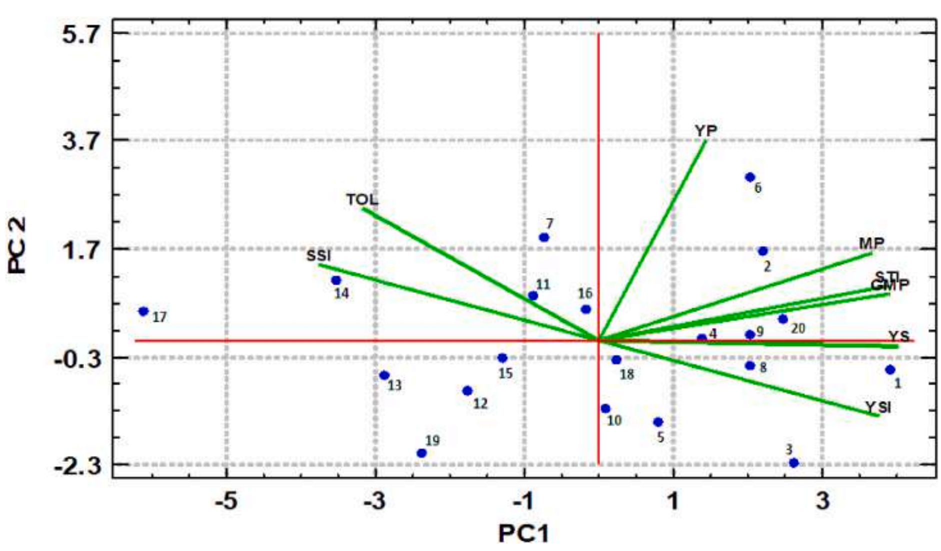

Fig. 2. Biplot drawn based on first two components obtained from PCA result. PC1 = First principal component, PC2 = Second principal component, Yp = Grain yield of genotypes under normal condition, Ys = Grain yield of genotypes under heat stress condition, TOL = Tolerance index, YSI = Yield stability index, SSI = Stress susceptibility index, MP = Mean productivity, GMP = Geometric mean productivity, STI = Stress tolerance index.

determine genotype with high yield potential under both conditions.

3.4. Principal component and biplot analysis

Several authors [18,30] had suggested selection of stress tolerant genotypes on the basis of combination of indices as a good criterion, although correlation coefficient is helpful to find out the degree of overall association between two attributes. Therefore, principal component analysis (PCA) was performed and biplot was constructed as a better approach than correlation coefficient to identify best performing genotypes in both normal and heat stress condition. PCA helps to figure out the relationship between all attribute at once.

Considering the eigen value greater than one, the first (PC1) and second (PC2) principal components explained 77.53% and 22.30% of the total variation, cumulative to 99.83% (Table 5). The result shows that the components with eigen value greater than 1 has contributed to the variation which is higher than the average. So, it is considered as the basis for the selection of the components. In this experiment, yield was considered as the major trait to conduct this analysis. PC1 had relatively high positive correlation with Ys, GMP, STI, YSI and MP. Thus, this component (PC1) can be considered as 'yield potential and heat tolerance component'. Similarly, PC2 had high positive correlation with Yp and TOL and can be considered as 'stress susceptibility component'. Researchers [7,15] used same method to name first two principal based on correlation analysis. Genotypes with higher value of PC1 and low value of PC2 are high yielding genotypes under both conditions. Based on this result, wheat genotypes 1, 20, 3, 8 and 9 (Bhrikuti, NL1420, BL4669, NL1350 and NL1368) are suitable genotypes under both conditions (Fig. 2). While genotypes with high value of PC2 and low value of PC1 are low yielding genotypes under stress condition. These heat susceptible genotypes include NL1346, NL1386, NL1376 and NL1412.

In biplot analysis, the correlation among the indices is given nearly by the cosine of the angle between their vectors [31]. Thus two indices are positively correlated when the angle between two vectors is less than 90° and negatively correlated if the angle is greater than 90°. There exists no correlation among two indices when the angle between their vectors is exactly 90°. The biplot revealed that Yp and Ys are positively correlated with MP, GMP, STI and YSI while Ys is negatively correlated with TOL and SSI as shown by obtuse angle between their vectors (Fig. 2).

4. Conclusion

Under heat stress condition, there was significant reduction in grain yield indicating that heat stress is one of the major constraints in wheat production. MP, GMP, STI had strong positive correlation with Yp and Ys. Therefore, these indices are found suitable for selection of high yielding genotypes under both conditions. Based on the study, genotypes Bhrikuti, NL1420, BL4669, NL1350 and NL1368 had high yield potential under both conditions. Thus, these genotypes can be used for further breeding programs for heat tolerance and/or potential to cultivated in the heat prone areas of Nepal.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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