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Evaluation of Wheat Genotypes Based on Heat Stress Tolerance

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ABSTRACT

The production and productivity of wheat are mainly limited by terminal heat stress in the South Asian regions of the world. The limited production of wheat has posed a significant threat to the food and nutritional security of the world. A field experiment was conducted to evaluate the heat stress tolerance of 20 elite wheat lines comprising 15 Nepal lines, two Bhairahawa lines, and three commercial checks viz., Bhrikuti, Gautam and RR 21. The field experiment was carried out using alpha lattice design at the Institute of Agriculture and Animal Science (IAAS), Paklihawa campus, Bhairahawa under irrigated and heat stress conditions. Heat stress environment was created by sowing the genotypes one month later as compared to irrigated and the evaluation was done using seven stress tolerance indices. The mean grain yield of wheat was reduced by 45.29% under heat stress conditions as compared to irrigated conditions. The correlation revealed the grain yield under irrigated condition (Yp) had a highly significant positive association with TOL (0.657), MP (0.916), GMP (0.917) and STI (0.836) and the grain yield under heat stress condition (Ys) had a highly significant positive correlation with YSI (0.694), MP (0.855), GMP (0.853) and STI (0.927; $P<0.01$). The grain yield under both the conditions (Yp and Ys) had a significant positive association with MP, GMP, and STI, so these indices can be used for the evaluation of high-yielding heat-stress tolerant genotypes. The principal component analysis revealed NL1402, NL1488 and NL1447 as the heat-tolerant genotypes that can be recommended in the tropical region of Nepal to increase the overall production and productivity of wheat.

Key words: Wheat, heat stress, tolerance, yield

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the most important cereal crop which has been ensuring the food and nutritional security of the world. It provides 20% of the calories and protein required by the total population in the world (Timsina *et al.*, 2021).Wheat is the most widely grown cereal and hence is traded as one of the major cereals in the international market (Ayaz, 2020). Wheat is harvested from 220 million hectares of land with 781 million metric tonnes annually. Due to the dietary and nutritional profile of wheat, its consumption has also been increasing gradually in Nepal (Bhandari *et al.*, 2021). Wheat is cultivated on 703,992 hectares of land and annually 2.1 million metric tonnes of wheat is harvested (MOALD, 2020). The majority (60%) of wheat in Nepal is cultivated in the Terai region of Nepal during the winter season (Poudel *et al.*, 2019). Even though wheat performs well in a temperature range of 18-22°C during vegetative and reproductive stages the production has still been majorly limited to the Terai region of Nepal (Kumari *et al.*, 2020).
Extreme carbon dioxide emissions and hazardous human activities had increased the global surface temperature by approximately 0.9°C since the 19th century (Abdelrahman *et al.*, 2020). The increase in global mean surface temperature causes heat stress in plants that trigger significant changes in the vegetative and reproductive stages (Li *et al.*, 2021). Heat stress inhibits root growth, seed germination, pollination, photosynthesis and grain formation. It interferes with the physiological process as well as the proper development of grains by affecting the activities of essential enzymes, glucose metabolism and protein synthesis in grains (Karki *et al.*, 2021).
Heat stress is the major abiotic factor reducing

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wheat productivity worldwide (Rangan *et al.*, 2020). Heat stress is a major problem in developing nations as it has an impact on about 57% of the wheat-growing region in the world (Sihag *et al.*, 2023). With the rise in 1°C temperature, the global production of wheat decreases by 6%. Within the next two decades, the Earth's average global temperature is expected to rise by 1.5°C and major concerns have been predicted. The temperature in the Terai region of Nepal increases by 0.04°C per year (Phuyal, 2015). By 2050, it is estimated that the 9.5 billion population on the earth will require an additional 198 billion wheat grains for consumption (Akter and Rafiqul Islam, 2017). To address the current situation of increasing temperature and food demand by the growing population it is necessary to understand the response of plants under heat stress conditions for the development of stress tolerant varieties (Yadav *et al.*, 2022). Combining stress-tolerant genotypes with good agronomic management techniques is the most effective and affordable way to increase plants' resistance to heat stress (Lal *et al.*, 2021).

With the rise in population, the rate of food insecurity has been prominent. About 4.6 million people in Nepal are in food poverty, with 20, 22 and 10% of households experiencing mild, moderate and severe food insecurity (Chemjong and Yadav, 2020). 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 (Poudel *et al.*, 2019). Heat stress, being the most limiting abiotic factor threatening food and nutritional security, has been a crucial challenge for the identification of heat-tolerant genotypes to meet the goals of ADS and SDGs.

MATERIALS AND METHODS

The field experiment was conducted at the Institute of Agriculture Science (IAAS), Paklihawa Campus, Rupandehi, Nepal. The site lies in the Terai agroecological zone of Nepal at the geographical location of 27°29'02" N and 83°27'17" E and an altitude of 104 meters above sea level. The agro-meteorological data during the experimental year were obtained from the Department of Hydrology and Meteorology (DHM), Bhairahawa, Nepal (Fig. 1). Twenty elite wheat lines comprising 15 Nepal lines, two Bhairahawa lines and three commercial checks viz., Bhrikuti, Gautam and RR 21 used in this experiment were provided by National Wheat Research Program (NWRP), Bhairahawa.

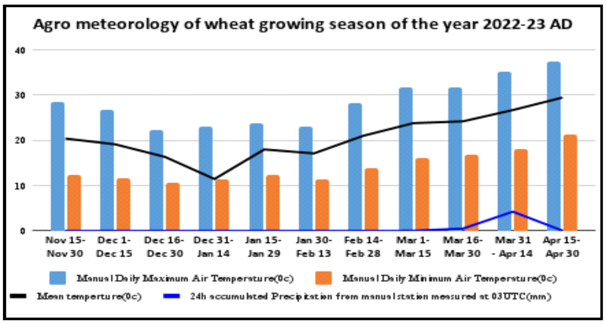

Fig. 1. Agrometrological parameters during the wheat growing season.

A set of 20 wheat genotypes was used as the experimental material under two wheat growing environments i.e. irrigated and heat stress in alpha lattice design with two replications. The plot size was 4 m^2 with a dimension of 2 x 2 m and a row spacing of 25 cm. The inter replication spacing was maintained at 1 m, while inter-plot spacing was maintained at 50 cm. The soil characterized in the field was clayey. The sowing of the wheat was done on 30 November 2022 to avoid high temperature at the anthesis and grain filling stage, whereas the late sowing was performed on 30 December to coincide with high temperature stress at later stages of growth. Except the time of sowing all the other conditions of the two environments were kept the same. Recommended doses of fertilizers were applied in the field i.e. 100:60:40 kg/ha NPK where the full dose of phosphorus and potassium was applied as basal. Nitrogen was applied at three split doses where 50% was applied at the basal dose and the remaining 50% in two split doses. Irrigation was provided to the field at six critical stages during pre-sowing, crown root initiation (CRI), tillering, booting, flowering and soft dough stage. Weeding was done manually during the jointing and booting stage of wheat. Grain yield (GY) of wheat was measured by harvesting 2 m^2 of the central portion leaving the border of each plot at the physiological maturity stage of wheat and was converted to tonnes per hectare.

Data entry and processing were performed using MS Excel 2016. The correlation between the grain yield and stress tolerance indices was calculated by using IBM SPSS Version 25. Principal component analysis (PCA) and biplot were constructed using PAST 4.03 software.

Among various stress tolerance indices developed, tolerance index (TOL), stress susceptibility index (SSI), yield stability index (YSI), mean productivity (MP), geometric mean productivity (GMP) and stress tolerance index (STI) were the widely used stress tolerance indices (Jahan *et al.*, 2017; Khobra *et al.*, 2019; Lestari *et al.*, 2019, Poudel *et al.*, 2021).

Seven stress tolerance indices (Table 1) were used for the evaluation of heat stree tolerance and susceptibility among 20 genotypes. Tolerance index (TOL) is the difference in yield between stress and non-stressed condition. Higher the TOL, the more will be the yield reduction in stressed conditions (Poudel *et al.*, 2021). Mean productivity (MP) is the average yield of genotypes under both the environments (Jahan *et al.*, 2017). Geometric mean productivity (GMP) determines the relative performance of stress tolerant genotypes in stress conditions (Devi *et al.*, 2021). Stress susceptibility index (SSI) is the ratio of genotypic performance under stress and non-stress condition (Khan and Kabir, 2015). Genotypes having SSI < 0.5 are tolerant, whereas the genotypes having SSI>1 are moderately tolerant. Stress tolerance indices (STI) are calculated to identify genotypes that produce high yields under both the environments (Lestari *et al.*, 2019). Selection based on stress tolerance indices helps in the identification of genotypes having higher stress tolerance and yield potential.

RESULTS AND DISCUSSION

The grain yield of wheat under normal (Yp) and heat stress (Ys) conditions was used to calculate stress tolerance indices (Table 2). NL1488 and NL1512 were found to have high yield under irrigated and heat stress conditions, whereas Bhrikuti and BL 5106 yielded lowest under irrigated and heat stress conditions, respectively. A mean yield

Table 1. Stress tolerance indices with the formula used in the study

S. No.	Stress tolerance indices	Formula
1.	Tolerance index (TOL)	Yp-Ys
2.	Stress susceptibility index (SSI)	$\frac{1-(\frac{Ys}{Yp})}{1-(\frac{\overline{Ys}}{\overline{Ys}})}$
3.	Yield stability index (YSI)	$\frac{Ys}{Yp}$
4.	Mean productivity (MP)	$\frac{Yp+Ys}{2}$
5.	Geometric mean productivity (GMP)	$\sqrt{Yp+Ys}$
6.	Stress tolerance index (STI)	$\frac{Yp*Ys}{\overline{Y}p^2}$
7.	Percentage yield reduction in heat stress (YR)	$\frac{Yp-Ys}{Yp}\times 100$

Where, Yp-Grain yield of genotypes under irrigated condition, Ys-Grain yield of genotype under heat stress condition, Yp-Mean grain yield of all genotypes under irrigated condition and Ys-Mean grain yield of all genotypes under heat stress condition.

Table 2. Stress tolerance indices of 20 wheat genotypes based on grain yield (t/ha)

Treatment	Genotypes	Yp	Ys	TOL	SSI	YSI	MP	GMP	STI	YR
T_1	BL 5106	3.895	1.720	2.175	1.229	0.442	2.808	2.370	0.370	55.841
T_2	BL 5099	3.975	1.825	2.150	1.191	0.459	2.900	2.408	0.401	54.088
T_3	BL 4984	4.570	2.025	2.545	1.226	0.443	3.298	2.568	0.512	55.689
T_4	Bhrikuti	3.605	2.090	1.515	0.925	0.580	2.848	2.386	0.417	42.025
T_5	NL 1437	3.890	2.380	1.510	0.855	0.612	3.135	2.504	0.512	38.817
T_6	NL 1402	4.460	2.805	1.655	0.817	0.629	3.633	2.695	0.692	37.108
T_7	Gautam	4.200	2.300	1.900	0.996	0.548	3.250	2.550	0.534	45.238
T_8	BL 5116	4.285	2.155	2.130	1.094	0.503	3.220	2.538	0.511	49.708
T_9	NL 1492	4.760	2.035	2.725	1.260	0.428	3.398	2.607	0.536	57.248
T_{10}	NL 1488	5.075	2.920	2.155	0.935	0.575	3.998	2.828	0.819	42.463
T_{11}	NL 1447	4.430	2.325	2.105	1.046	0.525	3.378	2.599	0.570	47.517
T_{12}	NL 1445	4.545	2.555	1.990	0.964	0.562	3.550	2.665	0.642	43.784
T_{13}	NL 1506	4.785	2.715	2.070	0.952	0.567	3.750	2.739	0.718	43.260
T_{14}	NL 1504	3.525	2.435	1.090	0.681	0.691	2.980	2.441	0.475	30.922
T_{15}	NL 1503	4.675	2.600	2.075	0.977	0.556	3.638	2.697	0.672	44.385
T_{16}	NL 1501	4.430	2.525	1.905	0.947	0.570	3.478	2.637	0.619	43.002
T_{17}	RR 21	3.610	1.975	1.635	0.997	0.547	2.793	2.363	0.394	45.291
T_{18}	NL 1512	4.470	2.845	1.625	0.800	0.636	3.658	2.705	0.703	36.353
T_{19}	NL 1509	4.235	2.165	2.070	1.076	0.511	3.200	2.530	0.507	48.878
T_{20}	NL 1508	3.63	2.02	1.61	0.976	0.556	2.825	2.377	0.405	44.353
	Grand Mean	4.2525	2.32075	1.93175	0.997	0.547	3.287	2.560	0.550	45.299

reduction of 45.29% was observed under heat stress as compared to normal conditions. The maximum TOL and SSI led to more yield reduction of wheat genotypes under heat stress conditions and vice versa (Khan and Kabir, 2015). The highest TOL and SSI were found for NL 1492. It means that the yield reduction in NL 1492 under heat stress conditions was maximum. The highest and lowest STI was observed in the genotypes NL 1488 and BL 5106, respectively. As BL 1506 had the lowest Ys and STI this genotype was not favourable for selection. The maximum value of YSI means a more stable genotype under stress conditions (Khobra *et al.*, 2019). NL1504 was found to have maximum YSI and TOL so it was the most stable genotype under heat stress conditions. The value of SSI above average (>1) was more susceptible under stress conditions. Thus, NL1492 was the most susceptible to stress conditions. Genotypes having high values of MP and GMP were high yielding genotypes under both the conditions (Devi *et al.*, 2021). Thus, NL1402 and NL1488 were high yielding genotypes under both the conditions. Puri and Gautam (2015) and Lamba *et al.* (2023) used stress tolerance indices to identify the suitable genotype under stressed environment.

The GY of wheat under irrigated conditions (Yp) was positive and highly significant with the GY under heat stress conditions Ys (Table 3). It means that the genotypes having high performance in irrigated have the possibility of high performance under heat stress and vice versa. Yp had a positive and highly significant association with TOL (0.657), MP (0.916), GMP (0.917) and STI (0.836). Ys had positive and highly significant association with YSI (0.694), MP (0.855), GMP (0.853) and STI (0.927), whereas negative and highly significant association with SSI (-0.694). Yp

Table 3. The correlation coefficients between grain yield and stress tolerance indices

	Yp	Ys	TOL	SSI	YSI	MP	GMP	STI
Yp	1	.575**	.657**	0.185	-0.185	.916**	.917**	.836**
Ys	.575**	1	-0.239	-.694**	.694**	.855**	.853**	.927**
TOL	.657**	-0.239	1	.858**	-.858**	0.298	0.303	0.138
SSI	0.185	-.694**	.858**	1	-1.000**	-0.224	-0.220	-0.374
YSI	-0.185	.694**	-.858**	-1.000**	1	0.224	0.220	0.374
MP	.916**	.855**	0.298	-0.224	0.224	1	1.000**	.985**
GMP	.917**	.853**	0.303	-0.220	0.220	1.000**	1	.982**
STI	.836**	.927**	0.138	-0.374	0.374	.985**	.982**	1

**Significant at P=0.01.

Table 4. Principal component analysis for stress tolerance indices

PC	Eigenvalue	% variance	Cumulative % variance	Yp	Ys	TOL	SSI	YSI	MP	GMP	STI
1	4.44	67.91	67.91	0.66	0.37	0.28	0.016	-0.0006	0.51	0.20	0.17
2	2.09	32.03	99.95	0.17	-0.53	0.71	0.33	-0.15	-0.18	-0.07	-0.10

Table 5. First principal component (PC1) and second principal component (PC2) of 20 wheat genotypes

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
PC 1	-0.71	-0.56	0.28	-0.92	-0.44	0.47	-0.08	-0.03	0.52	1.30	0.23	0.47	0.84	-0.88	0.66	0.31	-0.96	0.50	-0.09	-0.92
PC 2	0.64	0.54	0.74	-0.21	-0.42	-0.58	-0.01	0.29	0.89	-0.21	0.15	-0.11	-0.15	-0.84	-0.07	-0.16	-0.02	-0.63	0.23	-0.08

and Ys both had a positive correlation with MP, GMP and STI. Kamrani *et al.* (2017), Hooshmandi (2019) and Khobra *et al.* (2019) also used these indices as a major parameter to identify stress tolerant genotypes.

Principal component analysis helps in the determination of the association between all attributes (Ozukum *et al.*, 2019; Nayana *et al.*, 2022). The principal components having an Eigen value greater than one were considered as the superior components representing greater variation among all attributes (Zopluoglu and Davenport, 2017).

From the principal component analysis of the various stress tolerance indices (Table 4), the first two principal components (PC1 and PC2) had a greater influence contributing 67.91 and 32.03%, respectively, to the total variation with a cumulative share of 99.949%. The first component (PC1) had a positive association with Yp, Ys, TOL, MP, GMP and STI. So, this component was named as high yielding and stable component under both the conditions (Kamrani *et al.*, 2017; Poudel *et al.*, 2021). The second principal component had a positive association with Yp, TOL and SSI, whereas it had a negative association with Ys, YSI, MP, GMP and STI. So, this component was named as heat susceptible component.

The genotypes which had higher PC1 and lower PC2 were high yielding and stable under both conditions whereas the genotypes having lower PC1 and higher PC2 were stress susceptible (Ullah *et al.*, 2022). Hence, NL1402, NL1488, NL1447, NL1445, NL1506, NL1503, NL1501, and NL1512 were stable genotypes that can perform best under both conditions (Table 5).

The relationship between the stress tolerance indices and genotypes concerning the principal component was further explained by biplots (Lamba *et al.*, 2023). In biplot analysis, the cosine of the angle between the vectors of indices was used to explain the correlation between them (Watanabe, 2022). Among the two indices, when the angle between them was more than 90, equal to 90, parallel, or exactly 90 degrees, the two indices were positively, negatively, and not related, respectively (Mutwali *et al.*, 2016). Biplot showed Yp had a positive correlation with TOL, SSI, MP, GMP and STI (Fig. 2). Yp and Ys had a positive correlation with MP, GMP and STI.

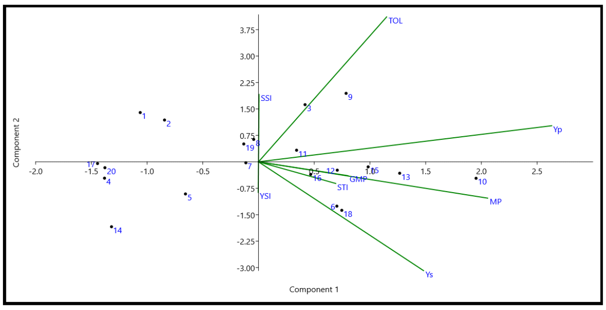

Fig. 2. Biplot showing stree tolerance indices among 20 wheat genotypes.

CONCLUSION

Heat stress is the major limiting factor affecting wheat production. A mean yield reduction of 45.29% was observed in heat stress conditions as compared to normal conditions. Correlation analysis showed Yp and Ys had a strong positive correlation with MP, GMP and STI so, these indices can be used for the identification of heat tolerant genotypes. From the PCA and biplot analysis, NL 1402, NL 1488, NL 1447, NL 1445, NL 1506, NL 1503, NL 1501, and NL 1512 were the best genotypes recommended for cultivation in heat prone areas in the Terai region of Nepal.

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