Journal of
Innovative Agriculture

Research Article
DOI: https://doi.org/10.37446/jinagri/rsa/10.4.2023.10-20

Yield performance and stress tolerance indices of wheat genotypes under irrigated and rainfed condition

Mukti Ram Poudel[1*], Madhav Prasad Neupane[2], Binod Panthi[1], Radhakrishna Bhandari[1], Shivalal Nyaupane[1], Anjali Dhakal[1], Harikala Paudel[1]

[1]Tribhuvan University, Institute of Agriculture and Animal Science (IAAS),Pakihawa Campus, Bhairahawa, Rupandehi, Nepal.
[2]Agriculture and Forestry University, Nepal.

Received: 20 July 2023
Accepted: 18 November 2023
Published: 31 December 2023

***Correspondence**
Mukti Ram Poudel
muktipoudel8@gmail.com

Volume: 10
Issue: 4
Pages: 10- 20

The majority of the wheat-growing area of Nepal depends upon seasonal rainfall for irrigation. Water scarcity during the critical wheat growing phases has been a major cause of poor production of wheat. To cope with the poor performance of wheat under rainfed conditions, it is crucial to identify the genotype adaptive to moisture-restricted conditions. The experiments were carried out using twenty wheat genotypes in alpha lattice design with two replications under irrigated and rainfed conditions at the Institute of Agriculture and Animal Science (IAAS), Bhairahawa, Rupandehi. The genotypic evaluation was done using the Tolerance Index (TOL), Stress Susceptibility Index (SSI), Yield Stability Index (YSI), Mean Productivity (MP), Geometric Mean Productivity (GMP), and Stress Tolerance Index (STI). Results showed grain yield of wheat was reduced by 64% under rainfed as compared to irrigated conditions. Correlation showed MP, GMP, and STI had a significant positive correlation with yield at irrigated (Yp) and yield at rainfed (Ys). Hence MP, GMP, and STI could be used to identify the high-yielding and stress-tolerant genotypes. The Principal Component Analysis (PCA) and biplot suggested, Nepal Line(NL) 1506 and NL 1508 as high-yielding and stress tolerant wheat genotypes. Hence these genotypes can further be evaluated in plant breeding programs to release as a climate resilient wheat genotypes for the overall yield improvement and food and nutritional security of Nepal.

Key words: *wheat, rainfed, tolerance, adaptive, stress, indices*

INTRODUCTION

Wheat (*Triticum aestivum.* L) is the number one crop in the world and the third most important cereal in Nepal contributing 80% of total calories and protein to the global population (Poudel et al., 2021). Wheat produces 2.99 tons/ha covering the 771,067-hectare land area of Nepal (MOALD, 2020). Since, wheat contains carbohydrates, protein, fat, and minerals, it is a major source of food and nutritional security of the world (Grote et al., 2021; Wieser et al., 2020). Wheat is cultivated in different environments in the world. About 45% of total wheat-growing area in the world lies in Asia which contributes about 44 % of the total global wheat production. South Asia contributes 49% of the total wheat growing area of Asia contributing 45% Asiatic wheat production.

South Asia is the hotspot for wheat production where the production is limited by several abiotic factors, especially water stress condition (Seleiman & Kheir, 2018; Shalaby, 2018). About 15.4% and 52% of the total wheat cultivating area in the world and Asia is weather dependent, producing only 2-3 tons per hectare (Arora, 2019; Hafeez et al., 2021; Singh et al., 2020). About 51% total agricultural area of Nepal is weather dependent (Tiwari et al., 2019). The production and productivity of wheat declined by up to 60% under water stress conditions (Bennani et al., 2016; Fahad et al., 2017).

The farming system in Nepal relies on seasonal rainfall for irrigation (Sharma et al., 2017). Due to the poor infrastructure development and uneven rainfall pattern of Nepal, the majority of wheat is cultivated in semi-arid conditions. Till 2022, NARC had released only 42 wheat varieties with a mean genetic yield potential of 4.47 tons per hectare reduces by 33 % under farmers' field conditions.

Annually 0.65 million metric tons of wheat is lost due to insufficient irrigation in Nepal. The annual population rise at 2.13%, poor rate of increment of wheat at 0.12 tons per hectare, climate-induced global warming, and industrialization, the pressure on water resources is increasing (Zahra et al., 2021). As a consequence of climate change the average precipitation is reducing at the rate of 16.65 mm per year (Paudel et al., 2021) and winters are receiving less rainfall (WBG, 2022). The poor irrigation facility has been a major reason for the higher yield gap between the potential and actual yield of wheat. Limited rainfall, unpredictability in distribution, low and high runoff events, low and high-temperature extremes, and desiccating winds during growth stages cause severe restrictions on crop development resulting in low production of wheat (Devkota & Phuyal, 2015).

High-yielding genotypes with stable performance remain an important goal in breeding programs. As a result, high-yielding varieties may be an option for making the nation self-sufficient in food through increasing production. About 21% of the Nepalese population has no direct access to sufficient nutritious food. About 16.67% of the population is under poverty, 6.1% of the population is under malnutrition, and 17% of the population is under severe micronutrient deficiency. To mitigate those issues it is necessary to enhance the production and the productivity of wheat.

The lack of water has been the major challenges for optimum production of wheat in Nepal therefore, it is necessary to identify climate-resilient genotypes that can well thrive in moisture-restricted conditions. The objectives of this study were carried out to identify the appropriate stress tolerance indices for the selection of high-yielding wheat genotypes under moisture-restricted conditions which might help to improve the production and productivity of wheat in rainfed areas of Nepal.

MATERIALS AND METHODS

Study area and period

The field experiment was conducted at the Institute of Agriculture and Animal Science (IAAS), Paklihawa campus, Bhairahawa. The research site was located at 27◦ 41'0" North, 83◦ 25'0" East.

Plant materials used in the experiment

Twenty elite wheat genotypes including four Bhairahawa Lines, thirteen Nepal Lines, and three commercial checks *viz.,* Bhrikuti, Gautam, and RR 21 for the experiment were provided by National Wheat Research Program (NWRP), Bhairahawa (Figure 1).

Geography of the study area

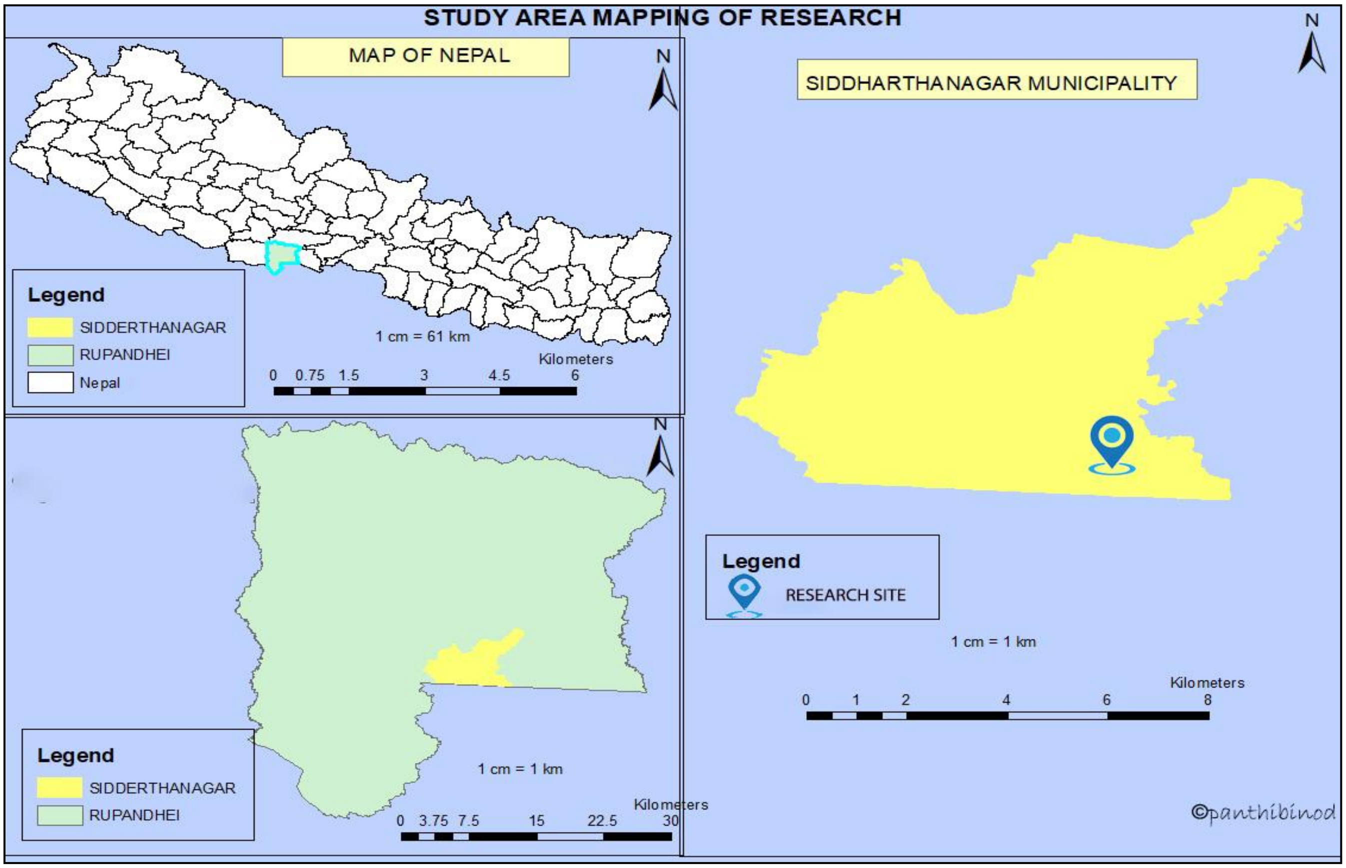

Figure 1. Study Area Mapping of Research Site Using GIS tool

Agro meteorology of the experimental site

The climatic data of the experimental site during the wheat growing season was obtained from the Department of Hydrology and Meteorology (DHM), Bhairahawa (Figure 2).

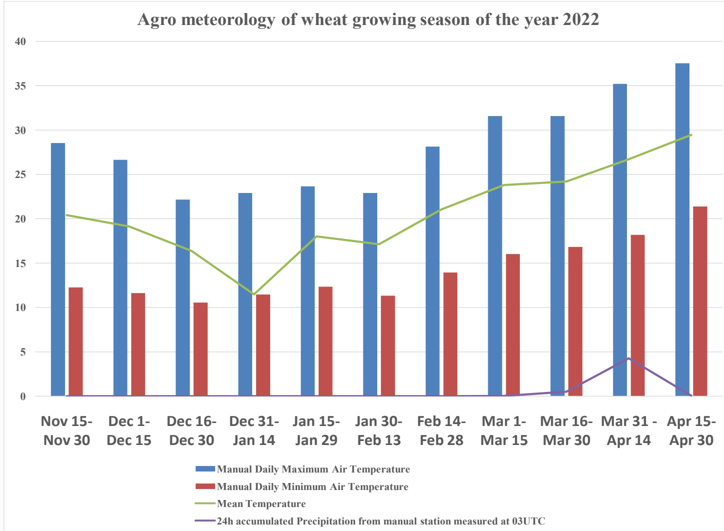

Figure 2. Agro meteorological data

Experimental design

The experiment was carried out in an alpha lattice design with two replications. The field was divided into five blocks and four plots with a plot size of 2m x 2m. The gap between replication and blocks was maintained at one meter.

Experimental treatments

Factor A = Wheat growing conditions; Irrigated and rainfed conditions
Factor B = Twenty wheat genotypes

Sowing of wheat genotypes

Wheat genotypes were sown at a spacing of 25 cm x 25 cm continuous on 30 November 2022 for both irrigated and rainfed conditions.

Water management in the field

Water management under Irrigated conditions

Under irrigated conditions, the crop was provided with six doses of irrigation at pre-sowing, crown root initiation (CRI), tillering, booting, flowering, and soft dough stage.

Water management under Rainfed conditions

Under rainfed conditions, irrigation was supplied at the time of sowing, and further irrigation required for the crop depends upon the rainfall.

Application of fertilizer and field management

Fertilizers were applied at the recommended dose of 120:50:50 NPK kg per hectare for both conditions.
All the fertilizers were provided at basal doses for rainfed and split doses for irrigated where 50% N and a full dose of P and K were provided at basal doses and the remaining 50% was split at the CRI stage (25%) and booting stage (25%). Harvesting and threshing of wheat were done manually.

Data collections

The grain yield data was taken from a 1-meter square of individual plots separately from both irrigated and rainfed conditions.

Data analysis and interpretation

The correlation among the grain yield and stress tolerance indices under two conditions was done using IBM SPSS v.26 and ranking was done using Ms Excel 2016. Principal Component and Biplot Analysis were done using PAST 4.03. The ranking biplot was constructed using GEAR-4.0 software provided by CIMMYT, Mexico.

The evaluation of the wheat genotype was done using six stress tolerance indices; Tolerance Index (TOL), Stress Susceptibility Index (SSI), Yield Stability Index (YSI), Mean Productivity (MP), Geometric Mean Productivity (GMP), and Stress Tolerance Index (STI) (Bennani et al., 2017; Poudel et al., 2021).

Stress susceptibility index (SSI) = $\frac{1-(\frac{Ys}{Yp})}{1-(\frac{\bar{Y}s}{\bar{Y}p})}$

Tolerance index (TOL)= $Yp - Ys$

Yield stability index (YSI)= Ys/Yp

Mean productivity (MP)= $\frac{Yp+Ys}{2}$

Geometric mean productivity (GMP)= $\sqrt{Yp + Ys}$

Stress tolerance index (STI)= $(Yp \times Ys)/\ \bar{Y}p^2$

Yp = yield under normal condition Ys= yield under rainfed condition $\bar{Y}s$ = mean yield under rainfed condition $\bar{Y}p$ = mean yield under normal condition TOL= tolerance index SSI = stress susceptibility index YSI= yield stability index MP= mean productivity STI= stress tolerance index GMP= geometric mean productivity.

RESULTS AND DISCUSSION

NL 1488 and NL 1506 were found to be the highest-yielding genotypes under irrigated and rainfed conditions with grain yield of (5.08 tons per hectare) and (2.11 tons per hectare), respectively. A 64% yield gap was observed in wheat grown under rainfed conditions as compared to irrigated conditions (Table 1).

The higher the TOL, the susceptibility to stress is high and the lower the TOL, the susceptibility to stress is low. NL 1508 had a low (1.535) TOL and NL 1488 had a high (3.705) TOL value, respectively. Thus, NL 1508 is less likely to be suffered in moisture-restricted conditions and was selected as a stress-tolerant genotype. NL 1508 had a low (0.649) SSI and RR 21 had a high (1.144) SSI. SSI more than 1 indicates less stress tolerance whereas SSI less than 1 indicates high stress tolerance. NL 1508 was a high stress tolerant and RR 21 was most susceptible under rainfed conditions. RR 21 had a low (0.254) YSI and NL 1504 has a high (0.5191) YSI. The genotype which has a high YSI value is more stable under different crop-growing conditions (Khobra et al., 2019). NL 1504 was identified as a stable genotype under both irrigated and rainfed conditions. MP, STI, and GMP were low in RR 21 and high in NL 1506. Thus, NL 1506 was identified as a high-yielding and stress-tolerant genotype under rainfed conditions.

Table 1. Comparison of grain yield and stress tolerance indices

Genotypes	Yp	Ys	TOL	SSI	YSI	MP	STI	GMP	YR
BL 5106	3.9	1.06	2.84	1.12	0.27	2.48	0.23	2.22	72.9
BL 5099	3.98	1.28	2.70	1.04	0.32	2.63	0.28	2.29	67.9
BL 4984	4.57	1.5	3.07	1.03	0.33	3.04	0.38	2.46	67.2
Bhrikuti	3.61	1.61	2.00	0.85	0.45	2.61	0.32	2.28	55.3
NL 1437	3.89	1.37	2.53	1.00	0.35	2.63	0.29	2.29	64.9
NL 1402	4.46	1.66	2.80	0.96	0.37	3.06	0.41	2.47	62.8
Gautam	4.2	1.26	2.94	1.07	0.30	2.73	0.29	2.34	70.0
BL 5116	4.29	1.43	2.86	1.02	0.33	2.86	0.34	2.39	66.6
NL 1492	4.76	1.56	3.20	1.03	0.33	3.16	0.41	2.51	67.2
NL 1488	5.08	1.37	3.71	1.12	0.27	3.22	0.38	2.54	73.0
NL 1447	4.43	1.34	3.09	1.07	0.30	2.89	0.33	2.40	69.8

NL 1445	4.55	1.67	2.88	0.97	0.37	3.11	0.42	2.49	63.4
NL 1506	4.79	2.11	2.68	0.86	0.44	3.45	0.56	2.62	56.0
NL 1504	3.53	1.83	1.70	0.74	0.52	2.68	0.36	2.31	48.1
NL 1503	4.68	1.44	3.24	1.06	0.31	3.06	0.37	2.47	69.2
NL 1501	4.43	1.28	3.16	1.09	0.29	2.85	0.31	2.39	71.2
RR 21	3.61	0.92	2.69	1.14	0.25	2.27	0.18	2.13	74.5
NL 1512	4.47	1.48	2.99	1.03	0.33	2.98	0.37	2.44	66.9
NL 1509	4.24	1.43	2.81	1.02	0.34	2.83	0.33	2.38	66.2
NL 1508	3.63	2.1	1.54	0.65	0.58	2.86	0.42	2.39	42.3
Mean	4.25	1.48	2.77	0.99	0.35	2.87	0.35	2.39	64.8
Range	3.53-5.08	0.92-2.11	1.54-3.71	0.65-1.14	0.25-0.58	2.27-3.45	0.18-0.56	2.13-2.62	42.29-74.52

Yp= yield under normal condition (t ha^{-1}); Ys= yield under rainfed condition (t ha^{-1}); Tolerance Index (TOL); Stress Susceptibility Index (SSI); Yield Stability Index (YSI); Mean Productivity (MP); Geometric Mean Productivity (GMP); and Stress Tolerance Index (STI); YR=Yield reduction

The correlation between Yp, Ys, and stress tolerance indices were evaluated (Table 2). Correlation showed that there was a non-significant positive correlation between grain yield (0.080) under irrigated (Yp) and yield under rainfed (Ys) conditions. This result indicates the genotypes having high yield under normal conditions, yields high under rainfed conditions but the selection for the high-yielding genotypes under rainfed conditions based on the yield under normal conditions might be misleading.

Table 2. Correlation analysis among Yp, Ys, and stress tolerance indices (STI)

	Yp	Ys	TOL	SSI	YSI	MP	STI	GMP
Yp	1	0.08	0.822**	0.414	-0.414	0.849**	0.557*	0.846**
Ys	0.08	1	0-.502*	-.867**	0.867**	0.596**	0.867**	0.598**
TOL	0.822**	0-.502*	1	0.855**	-0.855**	0.396	-0.012	0.393
SSI	0.414	0-.867**	0.855**	1	-1.000**	-0.126	-.504*	-0.131
YSI	-0.414	0.867**	-0.855**	-1.000**	1	0.126	0.504*	0.131
MP	0.849**	0.596**	0.396	-0.126	0.126	1	0.909**	0.999**
STI	0.557*	0.867**	-0.012	-0.504*	.504*	0.909**	1	0.907**
GMP	0.846**	0.598**	0.393	-0.131	0.131	0.999**	0.907**	1

*, ** denotes level of significance at 5% and 1%, respectively

There was a significant positive correlation of Yp and Ys with MP (0.849, 0.596), STI (0.557, 0.867), and GMP (0.846, 0.598), respectively (Table 2). The result implies that MP, STI, and GMP are appropriate indicators, and selection based on these indices would help to identify the high-yielding stress-tolerant wheat genotype under normal and rainfed conditions. A similar result was reported by (Khatibi et al., 2022; Pour-Aboughadareh et al., 2020).

Ys had a significant negative correlation with SSI (-0.867) and TOL (-0.502). This means wheat genotypes tolerant to stress has higher yields under rainfed conditions. YSI had a significant ($p \leq 0.01$) positive correlation with Ys (0.867) and a negative correlation with Yp (0.414) that suggests stable genotypes have a high YSI index. MP, GMP, and STI had significant ($p \leq 0.01$) positive correlations among each other thus, any of these indices can be used for the selection of genotypes that are adaptive under rainfed condition (Adhikari et al., 2019).

Table 3. Ranking of wheat genotypes based on stress tolerance indices (STIs)

Genotype	Yp	Ys	TOL	SSI	YSI	MP	STI	GMP	R	SD
1	6	2	10	18	3	2	2	2	5.6	5.8
2	7	4	7	13	8	4	3	4	6.3	3.3
3	16	13	15	11	10	14	14	14	13.4	2
4	2	15	3	3	18	3	7	3	6.8	6.3
5	5	7	4	7	14	5	5	5	6.5	3.2
6	13	16	8	5	16	16	16	16	13.3	4.4
7	8	3	13	16	5	7	4	7	7.9	4.5
8	10	9	11	9	12	10	10	10	10.1	1
9	18	14	18	12	9	18	17	18	15.5	3.5

10	20	8	20	19	2	19	15	19	15.3	6.7
11	11	6	16	15	6	12	8	12	10.8	3.8
12	15	17	12	6	15	17	18	17	14.6	4
13	19	20	5	4	17	20	20	20	15.6	6.9
14	1	18	2	2	19	6	11	6	8.1	7.2
15	17	11	19	14	7	15	13	15	13.9	3.7
16	11	4	17	17	4	9	6	9	9.6	5.2
17	3	1	6	20	1	1	1	1	4.3	6.6
18	14	12	14	10	11	13	12	13	12.4	1.4
19	9	9	9	8	13	8	9	8	9.1	1.6
20	4	19	1	1	20	11	19	11	10.8	8.1

R= mean rank; SD= standard deviation; Yp= yield under normal condition (t ha^{-1}); Ys= yield under rainfed condition (t ha^{-1}); Tolerance Index (TOL); Stress Susceptibility Index (SSI); Yield Stability Index (YSI); Mean Productivity (MP); Geometric Mean Productivity (GMP); and Stress Tolerance Index (STI); YR=Yield reduction

STIs provide a single basis for the identification of stress-tolerant genotypes (Table 3). For the determination of the most desirable genotypes which are tolerant to moisture stress, the ranking method was done where mean rank and standard deviation of rank were calculated based on all the stress tolerance indices. Higher the mean rank and standard deviation higher the stress tolerance of the genotype.

Results suggest that NL 1508 had a high mean rank (15.625) followed by NL 1492 (15.5) means NL 1508 and NL 1492 were highly stress-tolerant genotypes that can be cultivated under rainfed conditions and provide better yields. Whereas, RR 21 had a low mean rank (4.25) showed RR 21 as a susceptible genotype.

Ranking biplot ranks the ideal genotypes for cultivation (Regmi et al., 2021). The ranking was accomplished by drawing the two coordinate's axes-a line connecting the arrowhead and the origin, and the first axes and a line perpendicular to it at the origin. The arrowhead in the innermost concentric circles was used to choose the best genotype across all the environments. The genotype closest to the center of the concentric rings is most suited for cultivation. NL 1506 was identified as a most ideal genotype for cultivation across all tested conditions (Figure 3).

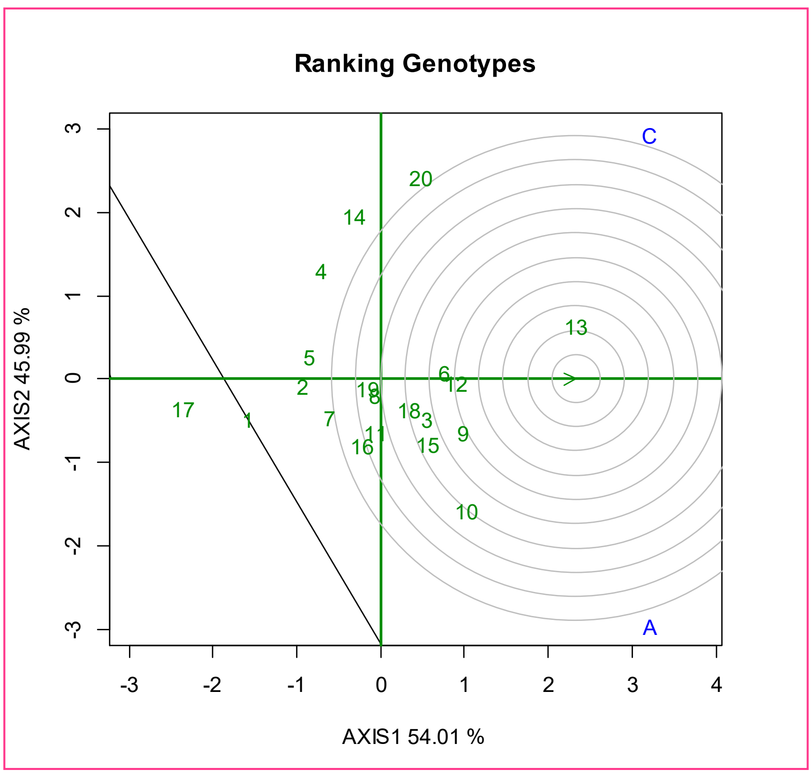

Figure 3. Ranking biplot of twenty wheat genotypes under irrigated and rainfed conditions

The principal component analysis (PCA) reduced six stress tolerance indices (STI) into two components. The first two principal components described PC1 53.61% and PC2 46.06% with a cumulated 99.67% of the total variation on the indices (Table 4). The PCA showed PC1 had a higher positive correlation with Ys, YSI, MP, STI, and GMP whereas PC2 has a higher positive correlation with Yp, TOL, SSI, MP, STI, and GMP.

The result from PCA suggested that MP, GMP, STI, TOL, and SSI were suitable criteria for the identification of high yielding genotype under normal conditions, whereas GMP, MP, STI, and YSI were suitable criteria for the selection of high yielding genotype under rainfed condition. To get a stable genotype, selection can be done with MP, GMP, and STI (Hooshmandi, 2019).

High-yielding genotypes under normal and rainfed conditions can be identified using the PC score of the genotype on the biplot. PCA shows Ys and Yp had a high positive correlation with PC1 and PC2, respectively. Hence, the genotype with a high PC1 score had a high yield under rainfed conditions, and the genotype with a high PC2 had a high yield under irrigated conditions. NL 1447 and NL 1488 were high-yielding genotypes under irrigated conditions while NL 1506 and NL 1508 were high-yielding genotypes under rainfed conditions.

Table 4. Principal component analysis

Principal component	% variance explained	Cumulative % Variance	Yp	Ys	TOL	SSI	YSI	MP	STI	GMP
PC1	53.61	53.61	0.188	0.4583	-0.09883	-0.3247	0.3247	0.3948	0.4707	0.3956
PC2	46.06	99.67	0.479	-0.1631	0.50927	0.3840	-0.3840	0.2998	0.1023	0.2979

The relationship between drought tolerance indices and genotypes were drawn on the biplot to get the suitable criteria for the identification of the genotype which is tolerant to moisture-restricted condition. The cosine of the angle between vectors of two indices gives the strength of correlation between them.

The acute angle estimates the positive correlation, the right angle estimates the independency and the obtuse angle estimates the negative correlation or very weak correlation between the two indices. Biplot showed a positive correlation of Ys with Yp, YSI, STI, GMP, and MP and a negative correlation with TOL and SSI (Figure 4) whereas Yp showed a positive correlation with Ys, MP, GMP, STI, and TOL. Ys and Yp were positively correlated with MP, GMP, and STI. Hence, these indices can be used for the selection of high-yielding and stress tolerant genotypes of wheat.

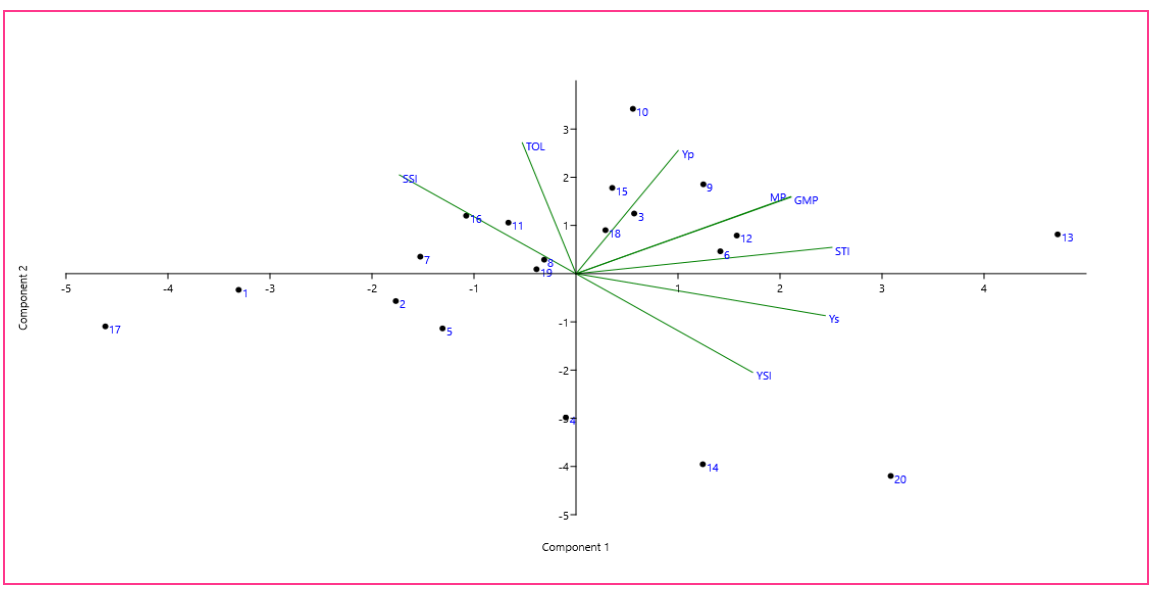

Figure 4. Biplot analysis

Yp = yield under normal condition, Ys= yield under rainfed condition, $\bar{Y}s$ = mean yield under rainfed condition, $\bar{Y}p$ = mean yield under normal condition, TOL= tolerance index, SSI = stress susceptibility index, YSI= yield stability index, MP= mean productivity, STI= stress tolerance index, GMP= geometric mean productivity.

CONCLUSION

Abiotic stresses are the major constraints of wheat production in the world. Result showed, the grain yield of wheat was reducing by 64% under rainfed conditions as compared to irrigated conditions. Yp and Ys were found to have a significant positive correlation with MP, GMP, and STI therefore MP, GMP, and STI can be used for selecting high-yielding stress-tolerant genotypes under rainfed conditions. From the ranking of STIs and biplot, NL 1506 and NL 1508 were the high-yielding and stress tolerant genotypes. It is concluded that these genotypes can further be evaluated in plant breeding programs to release as a climate resilient wheat genotypes for the overall yield improvement and food and nutritional security of Nepal.

ACKNOWLEDGMENTS

The authors acknowledge the National Wheat Research Program (NWRP), Bhairahawa for providing plant materials and the Institute of Agriculture and Animal Science (IAAS) for providing the field for the experiment.

AUTHOR CONTRIBUTIONS

Mukti ram Poudel conceptualized the research. Harikala Paudel, Radhakrishna Bhandari, Shivalal Nyaupane, Binod Panthi, and Anjali Dhakal conducted the experiment, collected the data, and performed analysis. Harikala Paudel wrote the manuscript. The manuscript was proofread by all the authors and submitted to journal.

COMPETING INTERESTS

The authors declare that there is no conflict of interest & the manuscript has not been submitted for publication in other journals.

ETHICS APPROVAL

Not applicable

REFERENCES

Adhikari, M., Adhikari, N. R., Sharma, S., Gairhe, J., Bhandari, R. R., & Paudel, S. (2019). Evaluation of drought tolerant rice cultivars using drought tolerant indices under water stress and irrigated condition. *American Journal of Climate Change*, *8*(2), 228–236.

Arora, N. K. (2019). Impact of climate change on agriculture production and its sustainable solutions. *Environmental Sustainability*, *2*(2), 95–96. https://doi.org/10.1007/s42398-019-00078-w.

Bennani, S., Nsarellah, N., Birouk, A., Ouabbou, H., & Tadesse, W. (2016). Effective selection criteria for screening drought tolerant and high yielding bread wheat genotypes. *Universal Journal of Agricultural Research*, *4*(4), 134-142. https://doi.org/10.13189/ujar.2016.040404.

Bennani, S., Nsarellah, N., Jlibene, M., Tadesse, W., Birouk, A., & Ouabbou, H. (2017). Efficiency of drought tolerance indices under different stress severities for bread wheat selection. *Australian Journal of Crop Science*, *11*(4), 395–405. https://doi.org/10.21475/ajcs.17.11.04.pne272.

Devkota, N., & Phuyal, R. K. (2015). Climatic impact on wheat production in Terai of Nepal. *Journal of Development and Administrative Studies*, *23*(1-2), 1-22. https://doi.org/10.3126/jodas.v23i1-2.15445.

Fahad, S., Bajwa, A. A., Nazir, U., Anjum, S. A., Farooq, A., Zohaib, A., ... & Huang, J. (2017). Crop production under drought and heat stress: plant responses and management options. *Frontiers in plant science*, *8*, 1147. https://doi.org/10.3389/fpls.2017.01147.

Grote, U., Fasse, A., Nguyen, T. T., & Erenstein, O. (2021). Food security and the dynamics of wheat and maize value chains in Africa and Asia. *Frontiers in Sustainable Food Systems*, *4*, 617009. https://doi.org/10.3389/fsufs.2020.617009.

Hafeez, M. B., Raza, A., Zahra, N., Shaukat, K., Akram, M. Z., Iqbal, S., & Basra, S. M. A. (2021). Gene regulation in halophytes in conferring salt tolerance. In *Handbook of bioremediation* (pp. 341-370). Academic Press. https://doi.org/10.1016/B978-0-12-819382-2.00022-3.

Hooshmandi, B. (2019). Evaluación de la tolerancia al estrés por sequía en genotipos de trigo. *Idesia (Arica)*, *37*(2), 37-43.

Khatibi, A., Omrani, S., Omrani, A., Shojaei, S. H., Mousavi, S. M. N., Illés, Á., Bojtor, C., & Nagy, J. (2022). Response of maize hybrids in drought-stress using drought tolerance indices. *Water*, *14*(7), 1012. https://doi.org/10.3390/w14071012.

Khobra, R., Sareen, S., Meena, B. K., Kumar, A., Tiwari, V., & Singh, G. P. (2019). Exploring the traits for lodging tolerance in wheat genotypes: a review. *Physiology and Molecular Biology of Plants*, *25*(3), 589–600. https://doi.org/10.1007/s12298-018-0629-x.

Ministry of Agriculture and Livestock Development (MOALD). (2020). *Statistical information in Nepalese agriculture* (p. 290). Government of Nepal.

Paudel, B., Wang, Z., Zhang, Y., Rai, M. K., & Paul, P. K. (2021). Climate change and its impacts on farmer's livelihood in different physiographic regions of the trans-boundary koshi river basin, central himalayas. *International Journal of Environmental Research and Public Health*, *18*(13), 7142. https://doi.org/10.3390/ijerph18137142.

Poudel, P. B., Poudel, M. R., & Puri, R. R. (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*, *5*, 100179. https://doi.org/10.1016/j.jafr.2021.100179.

Pour-Aboughadareh, A., Mohammadi, R., Etminan, A., Shooshtari, L., Maleki-Tabrizi, N., & Poczai, P. (2020). Effects of drought stress on some agronomic and morpho-physiological traits in durum wheat genotypes. *Sustainability*, *12*(14), 5610. https://doi.org/10.3390/su12145610.

Regmi, D., Poudel, M. R., K.C., Bishwas., & Poudel, P. B. (2021). Yield Stability of Different Elite Wheat Lines under Drought and Irrigated Environments using AMMI and GGE Biplots. *International Journal of Applied Sciences and Biotechnology*, *9*(2), 98–106. https://doi.org/10.3126/ijasbt.v9i2.38018.

Seleiman, M. F., & Kheir, A. M. S. (2018). Saline soil properties, quality and productivity of wheat grown with bagasse ash and thiourea in different climatic zones. *Chemosphere*, *193*, 538–546. https://doi.org/10.1016/j.chemosphere.2017.11.053.

Shalaby, O. A. E.-S. (2018). Alleviation of salinity stress in red cabbage plants by urea and sulfur applications. *Journal of Plant Nutrition*, *41*(12), 1597–1603.

Sharma, S., Acharya, N. R., Adhikari, S., & Mishra, K. K. (2017). Varietal improvement of wheat under rainfed conditions in mid-western terai of Nepal. *Global Journal of Biology, Agriculture and Health Sciences*, *6*(4), 15–19.

Singh, H., Kumar, P., Kumar, A., Kyriacou, M. C., Colla, G., & Rouphael, Y. (2020). Grafting tomato as a tool to improve salt tolerance. *Agronomy*, *10*(2), 263. https://doi.org/10.3390/agronomy10020263.

Tiwari, D. N., Tripathi, S. R., Tripathi, M. P., Khatri, N., & Bastola, B. R. (2019). Genetic variability and correlation coefficients of major traits in early maturing rice under rainfed lowland environments of Nepal. *Advances in Agriculture*, *2019*(1), 5975901. https://doi.org/10.1155/2019/5975901.

Wieser, H., Koehler, P., & Scherf, K. A. (2020). The two faces of wheat. *Frontiers in nutrition*, *7*, 517313. https://doi.org/10.3389/fnut.2020.517313.

World Bank Group (WBG). (2022). *International Journal for Modern Trends in Science and Technology, 8*(9).

Zahra, N., Wahid, A., Hafeez, M. B., Ullah, A., Siddique, K. H. M., & Farooq, M. (2021). Grain development in wheat under combined heat and drought stress: Plant responses and management. *Environmental and Experimental Botany*, *188*, 104517. https://doi.org/10.1016/J.ENVEXPBOT.2021.104517.