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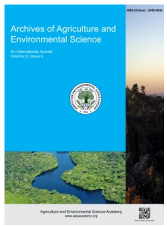

ORIGINAL RESEARCH ARTICLE

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AMMI GGE biplot analysis of wheat genotypes under heat stress and heat drought environment

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ABSTRACT

Wheat is the third most important cereal crop of Nepal. Climatic changes have been a major threat on overall production and productivity of wheat in Nepal. With the aim of evaluating twenty elite wheat genotypes under heat stress and heat drought environments, a field experiment was conducted using alpha lattice design at Bhairahawa, Rupandehi, Nepal. The analysis of variance (ANOVA) revealed significant differences in the yield across wheat growing environments ($p<0.001$). Environment explained 75.11% of the total variation in grain yield. NL 1404 was the most stable followed by NL 1368, and NL 1413. NL 1376, NL 1369. NL 1386 was the best adapted genotypes under heat stress environments whereas NL 1384, Gautam, and BL 4949 were best adapted to heat drought environments. NL 1346 was the best genotype. WWW model explained NL 1346 won under heat drought environment and NL 1384 under heat stress environment. Mean vs. stability model showed NL 1346 was the above yielder and stable genotype. In ranking, NL1179 was concluded to be the ideal genotype. From the study, NL 1368 was found to be the winning genotype under heat drought and heat stress environments. These genotypes should further be evaluated to release as a variety.

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INTRODUCTION

Wheat (*Triticum aestivum* L.) is the third most important cereal crop in Nepal in terms of production and area under cultivation (Bhandari *et al.*, 2021). It contains around 70- 73% carbohydrate, 7- 22% protein, 2-2.5% fat, and 1.7-1.8% minerals (Wieser *et al.*, 2020). Wheat is grown on mid and high hills, terai agroecological zones of Nepal (Devkota *et al.*, 2018). In the years 1988-2015, wheat production was 1.25 million metric ton with the productivity of 1.84 ton per hectare from 6.68 thousand hectares of land. The production of wheat increased by 82.18 % with 96.03% increment in wheat cultivated area in 2021 (MoALD, 2021). It covers about 20.91% of total cereal production area and 19.23% of cereal production with 6.98% contribution to AGDP in Nepal (Kharel *et al.*, 2021). Nepal is the fourth most vulnerable country to climate change hence, the climate change-induced poor production of wheat has become a major concern in the food and nutritional security of Nepal (Khadka *et al.*, 2020). Among several abiotic stress, temperature a major factor in altering the growth and development of wheat i.e. with an increase of 1 °C temperature, the production of wheat decreases by 6% (Poudel *et al.*, 2021). Heat and drought stress pose serious risk to wheat (Elhadi *et al.*, 2021). The yield loss varies according to the severity of heat stress. The reported yield loss is 23% (Poudel *et al.*, 2020), 49% (Djanaguiraman *et al.*, 2020), 16.1% (Dubey *et al.*, 2020) depending upon the severity of stress. According to IPCC, the average global temperature increased by 1.10 °C in the most recent decade (2011–2020).

With the decrease in annual precipitation, the highest reduction rate is 3.17mm in all geographical region. By the end of the century, it is expected to rise by 1.30 °C–5.70 °C with the number of wet days decreasing with drought period in Nepal (Dawadi *et al.*, 2022).

The population of Nepal will grow to 15.22% by the year 2031 consequently by 2050, the demand for wheat will be expected to increase up 60% higher than the present year finally then the food and nutrition will be secure in future (Poudel *et al.*, 2020). In 21st century, food security has become an emerging problem to the entire mankind (Poudel *et al.*, 2020). As a result of inadequate intake and a lack of dietary variety, Nepal has been struggling with food insecurity and undernutrition for a long time. According to the Nepal Living Standard Survey 2010/11, 38% of people failed to eat the suggested number of calories per day for a healthy life, and 25% of households were deemed to be food insecure (Regmi *et al.*, 2019). Genotype environment interactions has become the barrier to attain high yielding cultivars. To mitigate, Global Hunger Index score of Nepal (19.1), the additive main effects and multiplicative interaction (AMMI) model and the genotype main effects and genotype × environment interaction effects (GGE) model are used for the stability analysis of wheat. AMMI and GGE has higher significance in the agricultural researches as affect two-way data matrices where AMMI is used to find out the stability of genotype in several locations using principal component axis scores and AMMI stability values and GGE model is helpful in analysis of genotype and the environment interaction in order to find out multi-environment trial. The objective of the study is to evaluate the performance of stability and yield of promising wheat genotypes rating in several environments and finally release the genotype as a resistant variety.

MATERIALS AND METHODS

The field experiment was done at the Institute of Agriculture and Animal Science (IAAS), Paklihawa, which is located at 27° 30' N, 83° 27' E and 79 m above sea level, under two different environments, including heat stress and heat drought. The maximum and minimum temperatures with precipitation during the wheat growing season is shown in Figure 1. During the experiment we evaluated twenty genotypes. Among which fifteen were of Nepal Line, three Bhairahawa Line and two commercial checks (Table 1).

Experimental design and layout

The research was carried out in alpha lattice where twenty treatments in five blocks each consisting of four treatments. The field experiment was conducted in 2 × 2 m plot and had a 50 cm interval between plots within a block and a 1 m distance between any two blocks with eight rows. Two replications of the study were conducted, totaling forty plots.

Sowing, crop growth and management

The sowing was done on December 24th in both environments. NPK was applied at 120:50:50 kg ha^{-1}. Full dosages of phosphate and potash were employed during the preparation of the soil under both drought and heat stress conditions, but only half doses of nitrogen. One dose of nitrogen was applied 30 days after seeding, while the other was given 70 days later. In the stages of CRI, heading, milking, and soft dough, the heat-stress environment received irrigation, but only pre-sowing irrigation was put out in the heat drought environment.

Data collection

Grain yield was obtained by weighing a two-meter square quadrant and converting the weight to tons per hectare. The grain yield was obtained by manual threshing the wheat that had been harvested from a 2 × 2 m area using a sickle, with the exception of the border lines. Grain was measured and converted to kilograms per hectare (kg ha^{-1}).

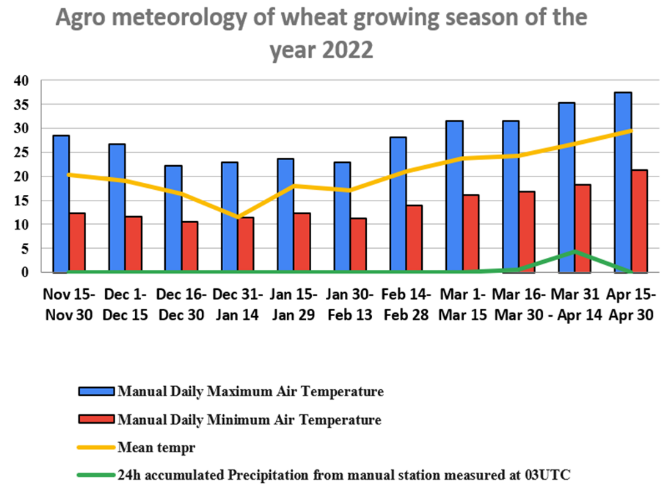

Figure 1. *Maximum and minimum temperature with precipitation data.*

Table 1. Genotypes used in experiment.

S. No.	Genotypes	Origin
1	Bhrikuti	CIMMYT, Mexico
2	BL 4407	Nepal
3	BL 4669	Nepal
4	BL 4949	Nepal
5	Gautam	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

Statistical analysis

The Additive Main Effect and Multiplicative Interaction (AMMI) and The Genotype main effect plus Genotype by Environment interaction (GGE) biplot was used to analyze the G×E interaction. In order to find the mean yield between two environments, AMMI biplot was used. The formulae to calculate AMMI:

$$Yij = \mu + \alpha i + \beta j + \sum_{n=0}^{N} \lambda n \ \ \gamma in \ \ \delta jn + \theta ij + \varepsilon i$$

where: Y_{ij}= the mean yield of elite line i in environment j, μ = the grand mean of the yield, α_i= the deviation of the elite lines mean from the grand mean, β_j = the deviation of the environment mean from the grand mean, λ_n = the singular value for the PCA; n, N = the number of PCA axis retained in the model, γ_{in} = the PCA score of an elite line for PCA axis n, δ_{jn} = the environmental PCA score for PCA axis n, θ_{ij} =the AMMI residual and ε_{ij}= the residuals.

GGE biplot tool used principal component of twenty elite genotypes and their study of the genotype plus genotype-environment interaction.

Data entry and processing were done using Microsoft Excel 2016. GEA-R was used to carry out the AMMI GGE analysis.

RESULTS AND DISCUSSION

The AMMI model ANOVA of twenty elite genotype in two different environments is presented in Table 2. The principal components (PC1 and PC2) showing two dimensional GGE biplot states that PC1 value less than 0 indicates low yielding genotype whereas the value more than 0 indicates the high yielding genotype.

AMMI biplot

Final score GY AMMI lattice

NL1179 was the most stable with the score -0.767 followed by the NL 1387 and BL 4919 with the score -0.555 and -0.553, respectively (Table 2). And NL 1350 was the most unstable with score 1 followed by NL 1368 and BL 4407 with the score 0.73 and 0.60, respectively.

ANOVA test

The ANOVA revealed there were significant difference among the environments (p< 0.001) that explains 75.11% of total variation in grain yield (Table 3).

Table 2. Final score GY AMMI lattice.

S. No.	NAME	YIELD	PC1	PC2
1	Bhrikuti	1447.5	-0.38	2.95E-08
2	NL 1369	1155.8	-0.55	5.54E-10
3	NL 1376	1273.3	-0.76	-2.80E-09
4	NL 1381	1364.1	-0.39	-1.20E-09
5	NL 1384	1654.1	1	1.51E-10
6	NL 1386	1215.0	-0.51	1.17E-10
7	NL 1387	1060.8	-0.35	-1.80E-09
8	NL 1404	1433.3	0.16	3.07E-10
9	NL 1412	1665.0	0.55	2.36E-09
10	NL 1413	1415.8	-0.28	3.24E-10
11	NL 1417	1593.3	0.38	1.41E-09
12	BL 4407	1590.0	0.53	-3.40E-10
13	NL 1420	1698.3	0.14	4.61E-10
14	BL 4669	1435.0	-0.46	-3.40E-09
15	BL 4949	1613.3	0.60	1.80E-09
16	Gautam	1571.6	0.73	3.16E-09
17	NL 1179	1707.5	0.26	1.24E-09
18	NL 1346	1700.0	0.07	2.65E-10
19	NL 1350	1381.6	-0.55	-2.30E-09
20	NL 1368	1366.6	-0.18	-7.80E-10

Table 3. ANOVA results of data.

Variable	SS	% Variation explained	% Variation accumulated	DF	MS [a]	F	P-Value
ENV	16480201	75.11	75.11	1	16480201	154.76	0
GEN	2796892	12.74	87.85	19	147204.80	1.38	0.19
ENV*GEN	2664218	12.14	100	19	140222	1.31	0.22
PC1	2664218	100	100	19	140222	1.53	0.16
PC2	0	0	100	17	0	0	1
Residuals	4259306	0	0	40	106482.60	NA	NA

SS is sum of squares, DF is degree of freedom, [a] MS is mean squares = sum of square/ degree of freedom.

AMMI PCA1 score vs. grain yield from a lattice

In Figure 2 the abscissa having grain yield and ordinate showed first multiplicative axis (PC1). Two environments with twenty elite genotype stability and adaptability were shown. Figure 2 shown that NL 1404 was the most stable followed by NL 1368, NL 1413. NL 1376, NL 1369, NL 1386, NL1387 were adapted best at heat stress environment whereas NL 1384, Gautam, BL 4949 and NL 1412 were best adapted at heat drought environment. Bhrikuti, BL 4669, NL 1350, NL 1381, NL 1413 and NL 1368 were clustered together. It explained genotypes had similar performance on specific environment. NL 1346 was the best genotype which combines high yield and stable performance across range of production environment.

GGE biplot

Which won where

GGE biplot's polygon view is used for visualizing the mode of interaction between genotypes and environments to establish the presence or absence of crossover interaction (Hashim *et al.*, 2021). The straight line connects the genotypes far from origin forming a polygon and those lines starting from the origin which divide the environments into sectors having genotype with best yield in that environment. In WWW model, the genotypes were divided by seven sectors. The sectors in Figure 3, heat drought environment contains NL 1179, BL 4407, NL 1346 which states that these genotypes showed better performance in heat drought environment. The genotype having longest distance from the origin was NL 1346 and was the vertex line of the heat drought sector but showing poor performance for heat stress environment. NL 1412, NL 1417, BL 4949, BL 4407, Gautam, NL 1384 were suitable for the heat stress environment. Similarly, NL 1384 was the best for heat stress environment as it has the longest distance from the origin. From WWW model, NL 1368 was considered as winning line in both heat drought as well as heat stress environment (Figure 3).

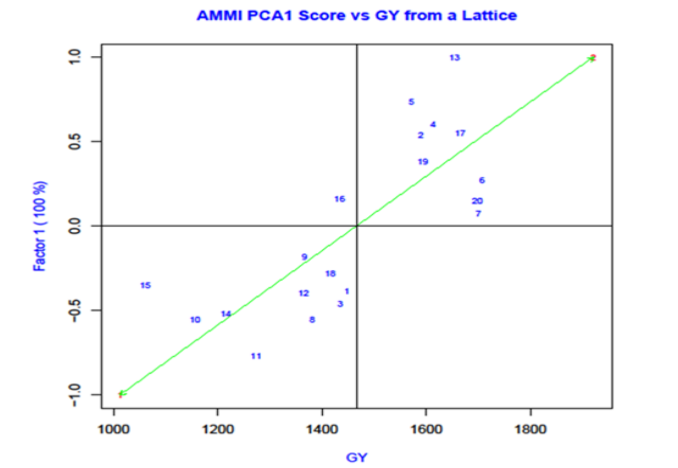

Figure 2. *AMMI PCA1 Score vs Grain yield from a Lattice of twenty genotype between heat drought and heat stress environment.*

Discriminativeness vs. representativeness

Discriminativeness vs. representativeness is used to show the discriminative power of tested genotype and representation of the genotype in the particular environment (Hashim *et al.*, 2021). The capacity of an environment to differentiate genotypes is discriminative power whereas the capacity of a tested environment to appear for other tested environments is representativeness. The discriminating power of test environment is dependent on the length of the vector associated with the standard deviation within each environment. The correlation coefficient between genotype means across the environment and genotype is determined by the cosine angle between the average environment axis. The representativeness of individual location is determined by the proximate angle with AEC, the smaller the angle between location vector and the AEC, the more representative of the tested environment. The representativeness of test environment is given by proximate angle with AEC, smaller the angle between the AEC and the environment vector, the more representative of the tested location and vice versa. The longer vector of heat stress environment implies greater standard deviation as compared to heat drought environment indicating greater discriminating ability of heat stress environment. Having smaller angle between AEC vector represented by arrow head and environment vector 2, this implies the representativeness of heat stress environment was better than the heat drought environment. The heat drought environment vector has relatively more length with smaller cosine angle showing that it has a higher discriminating ability and more representativeness (Figure 3).

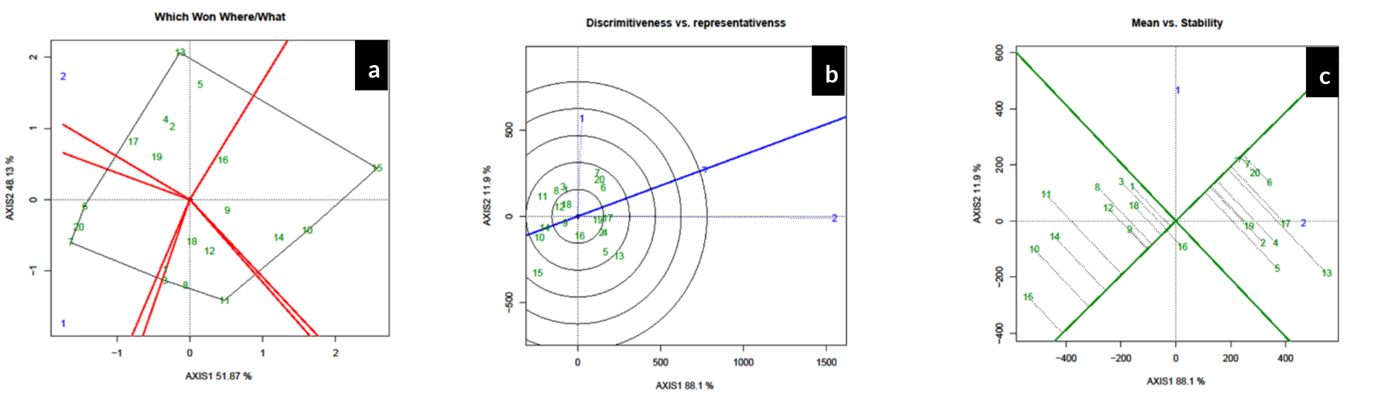

Figure 3. *Biplot showing which won where (3a), discriminativeness vs representativeness (3b), and mean vs stability (3c) of elite wheat genotypes across heat stress and heat drought condition.*

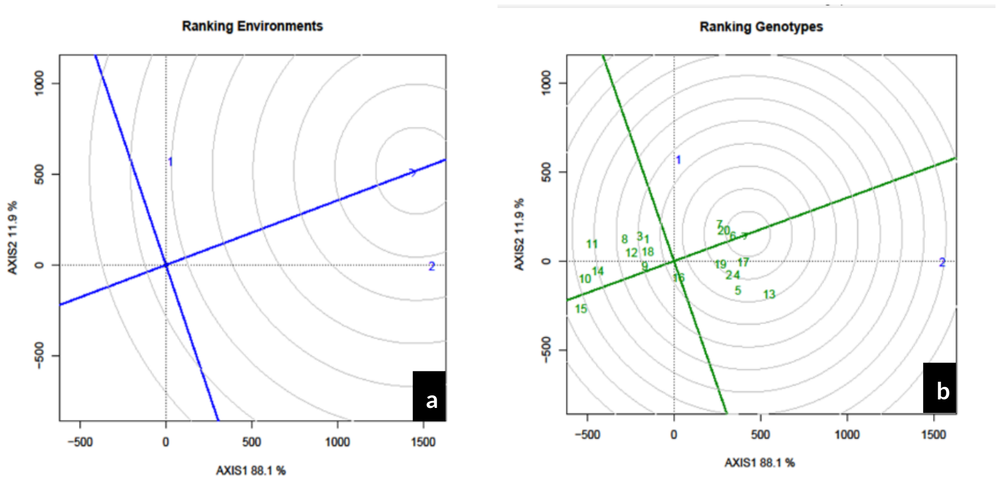

Figure 4. *Biplot showing ideal environment (4a), and ideal genotype (4b) across heat stress and heat drought condition from twenty elite wheat genotype evaluated.*

Means versus stability

Mean vs stability GGE biplot evaluates high yielders as well as stable genotype through Average Environment Coordinate (AEC**)** (Neisse *et al.*, 2018). The WWW model only shows the best genotype for the specific environment but the mean vs stability shows average yield giving genotypes. The arrow headed line is known as AEC where the horizontal line is abscissa and the vertical line is ordinate. This model implies that the line right to abscissa from origin shows high yield and the left abscissa left to abscissa implies low yield. Moreover, the length shows stability and variability i.e., the larger the length from the abscissa, more variability and low stability occurs and vice versa. NL 1346, NL 1420, NL 1179 were the above average yielders with more stability (Figure 3). Similarly, NL 1417, BL 4407, BL 4949, Gautam, NL 1384, NL 1412 WERE high yielder genotypes with low stability NL 1368, NL 1404, NL 1413, NL 1387 were the below average yielders with high stability gaining genotypes. Further, Bhrikuti, BL 4669, NL 1350, NL 1381, NL 1376, NL 1386, NL 1369 were the below average yielders with low stability. From above model, NL 1346 was the most stable and high yielder genotype lying right side of the abscissa and near to the AEC line.

Ranking environment

The GGE biplot for ranking ideal environment was estimated by the higher value of discriminativeness vs. representativeness. The environment being ideal should be suitable for the superior genotype. Figure 4 implies that heat stress environment was ideal environment than the heat drought environment. NL1179 have higher yield hence can be considered as an ideal genotype good performer in the heat stress environment. In ranking environment, NL1179 higher yield showed better performance in heat stress environment than the heat drought environment.

Ranking ideal genotype

Among twenty elite genotypes, the ideal genotype can be determined by the ranking genotype biplot tool. The genotype closer to the arrow head in the innermost circle is considered as the most ideal genotype (Khan *et al.*, 2021). NL 1179 was the best among others followed by NL 1420, NL 1412, NL 1346, NL 1417, BL 4949, BL 4407, and Gautam (Figure 4).

Conclusion

Abiotic stresses are the major yield limiting factors for wheat cultivation in Nepal among them heat drought is the major yielding limiting factor for poor wheat production. From the study, NL 1404 was found to be the stable genotype across both environments from AMMI model. The best genotype was NL 1384 and NL 1346 under heat stress and heat drought environment from which won where model. The heat stress environment had slightly higher discriminating power and higher representativeness than heat drought environment. The research revealed NL 1346 as the most stable and above yielder genotype via means versus stability model. The ranking showed NL 1179 as the ideal genotype. Hence, these selected genotypes should be promoted in wheat improvement program of Nepal for further evaluation to release as a variety.

Declarations of competing interest

The authors declare that they don't have any personal interest or competing financial interest on publishing this manuscript in the journal.

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