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Research Article

AMMI and GGE biplot analysis of yield performance of wheat genotypes under irrigated, heat stress and heat drought environments

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Abstract

Wheat is the third most important cereal crop in Nepal. The impact of global warming is threatening global wheat production and food security. The terminal heat stress reduces the grain quality of wheat. However, the drought is affecting more than 15% of global wheat productivity. To find out the stable and high- yielding wheat genotype the experiment was carried out in Rupandehi, Nepal with twenty genotypes under three different environmental conditions namely heat drought, heat stress and irrigated in an alpha lattice design with two replications in each environment. The AMMI (Additive mean effect multiplicative interaction) biplot analysis shows differences in 20 different genotypes in terms of yield and stability. The analysis of variance model showed the share of GE (genotype and environment) interaction in the variation in grain yield of twenty wheat genotypes. The grain yield of genotype varied significantly with environmental impact ($p < 0.05$). The AMMI stability value (ASV) examined NL1387 as the most stable line. The tested environments were discriminative for genotype and showed negative correlation between them. The GGE biplot analysis was conducted to find out the best performing line under different environments and the stable line in diverse environments. The NL1420 was found stable genotype in all three tested environment. The NL1376 line is most ideal ranking first in the ranking biplot. The mean versus stability model indicated NL1369 and NL1376 as elite genotypes and NL 1404, BL4919 and NL1387 can be recommended as new cultivars.

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1. Introduction

Wheat *(Triticum aestivum)* which belongs to the family Poaceae is a major staple food crop for half of the world's population (Rizwan et al., 2016) with a total cultivated area of 220 million ha and production of 650 million ton per year worldwide (Food and Agriculture Organization, 2014; Subedi et al., 2020). The acreage of wheat in south Asia is more than 36 million ha and or about 16% of total area (Food and Agriculture Organization, 2007). Wheat holds the third position in Nepal, after rice and maize with total cultivated area of 716978 ha and a productivity of 2.59 tons per hectare (Ministry of Agriculture and Livestock Development, 2022). Wheat have wide coverage in all agro-climates of Nepal where growing season varies due to topographic and climatic variation (Nayava et al., 1970). Wheat yield is higher in irrigated fields than under heat stress and drought conditions, as 16% of world's land is irrigated (Kaini et al., 2022).

The impact of climate change on global wheat production and other agricultural commodities is noticeable and climate change increases drought problem in arid and semi-arid lands (Masson et al., n.d.). In 60% of wheat growing areas worldwide, global warming causes various abiotic stresses (Redden, 2013) and drought problem that affect 15% of global wheat productivity (Elahi et al., 2022).

Drought impairs plant growth and morphology, resulting in a declining number of spike per meter square, number of grains per spike and grain yield (Poudel et al., 2019). Terminal drought condition is critical for the anthesis and grain filling period resulting in grain yield reductions up to 92% (Jasrotia et al., 2018). The heat stress environment shows the impact of high temperatures during the anthesis period of plants and their negative effect on yield (Rezaei et al., 2015). Heat stress and degraded soil conditions are causing a decline in wheat productivity (Joshi et al., 2007a). There is a high gap between actual yield and possible yield at different area (Subedi et al., 2019) and factors responsible for this are the direct impact of climate change, a rain-based farming system, a prolonged rice-wheat cropping pattern around 11 million ha (Joshi et al., 2007b) and less availability of input (Devkota & Phuyal, 2016). In rural Nepal, 49.6% of the population is at risk of malnutrition.

The research identifies a climate resilient wheat genotype would help to address the issue of global hunger and secure ecosystems (Li et al., 2021). Nepal is vulnerable to climate change and drought stress (Adhikari, 2018). Only a few drought-tolerant varieties like Gautam, Dhaulagiri are released in Nepal (Gairhe et al., 2017). National wheat research program, Rupandehi has recommended 40 improved wheat varieties for various agro-ecological zones of Nepal where 17 are for the Hilly region and 26 are for the Terai region (Timsina et al., 2018). The analysis of the stability of different lines is essential in Nepal where agro climatic condition vary greatly from the Terai to the Himalayas and there is a lack of genotypes with adequate performance in those environments (N et al., 2015). In developing countries like Nepal environment modifying tools are inappropriate due to a rain- based farming system and lower per capita income (Adhikari, 2018). The identification of stable genotype in different agro-climatic zones of the country is main aim of our research.

2. Materials and methods

2.1 Site selection

The study was carried out on an agronomy farm at the Institute of Agriculture and Animal Science (IAAS), Paklihawa, Nepal situated at 27°28' N and 83°25' E and 100m above sea level. 20 genotypes in 3 different environments normal irrigated condition, heat stress conditions and cumulative heat and drought conditions were maintained. The experimental layout in each environment was an alpha lattice with two replications. In irrigated and heat drought environment each plot consisted of 8 rows with a 2-meter length and a 2-meter width. For heat stress environment in each plot 8 rows were maintained with 2-meter length and 1.5-meter width. Line sowing was done leaving a 0.125 meter border and five blocks in each environment with an inter block distance of 1 meter and an inter plot distance of 0.5 meter. A one-meter distance is kept between first and second replications.

Table 1. List of Genotypes used in experiment

S. N	Genotypes	Treatment	Source
1	Bhrikuti	T1	CIMMYT, Mexico
2	BL 4407	T2	Nepal
3	BL 4669	T3	Nepal
4	BL 4919	T4	Nepal
5	Gautam	T5	Nepal
6	NL 1179	T6	CIMMYT, Mexico
7	NL 1346	T7	CIMMYT, Mexico
8	NL1350	T8	CIMMYT, Mexico
9	NL 1368	T9	CIMMYT, Mexico
10	NL 1369	T10	CIMMYT, Mexico
11	NL1376	T11	CIMMYT, Mexico
12	NL 1381	T12	CIMMYT, Mexico
13	NL1384	T13	CIMMYT, Mexico
14	NL 1386	T14	CIMMYT, Mexico
15	NL 1387	T15	CIMMYT, Mexico
16	NL 1404	T16	CIMMYT, Mexico
17	NL 1412	T17	CIMMYT, Mexico
18	NL 1413	T18	CIMMYT, Mexico
19	NL 1417	T19	CIMMYT, Mexico
20	NL 1420	T20	CIMMYT, Mexico

2.2 Data collection and statistical analysis

The data collection started in the booting days. Days to booting (DTB), days to heating (DTH), days to anthesis (DTA), plant height (PH), spike length (SL), number of spike per meter square (NSPMS), number of spikelet per spike (NSPS), number of grain per spike (NGPS), ten spike weight (TSW), thousand kernel weight (TKW), grain weight (GY), straw yield (SY) and harvest index (HI) was recorded. The data were entered into an excel sheet and by using GEA-R 4.1 developed by CIMMYT AMMI and GGE biplot analysis was carried out. The STD, CV and F value were calculated using Microsoft excel. The detail of the model are given below:

2.3 AMMI stability model

The AMMI (Additive mean effect multiplicative interaction) model was used for the examination of stability and yield performance of wheat genotypes which analyzes Genotype (G), Environment (E) and Genotype - Environment Interaction (Ajay et al., 2022). AMMI and GGE biplots were to find the most stable, adaptive genotype in irrigated, heat stress and heat drought condition (Dangol, 2015). Zobel et al, 1988 proposed the AMMI model for the first time for the analysis and prediction of stable and adaptable wheat genotypes in an environment. The GGE (genotype plus genotype by environment) analysis, based on principal component analysis (PCA) for the multi environmental trails (Hagos & Abay, 2013). The main models in GGE analysis are the additive main effect of genotype, environment and their multiplicative interaction (Alizadeh et al., 2017). The study relies on finding a superior wheat genotype with stable yield in a different environment and examining how G*E Interaction affects the agronomic trait of different wheat genotype by using AMMI and GGE analysis (Esan et al., 2023).

2.4 ASV value

The path between origin and coordinate point in a two-dimensional comparison of IPCA1 score against IPCA2 score in a scatter plot diagram is considered the AMMI Stability variation value first proposed by (Purchase et al., 2000) which is adjusted for accounting for the respective contribution of each score to the overall G*E sum of squares by the proportionate difference between IPCA1 and IPCA2. According to (Purchase, 2000) ASV is calculated as:

$$\text{ASV}= \sqrt{[\frac{SSIPCA1}{SSIPCA2}\ (PCA1)]^2 + (IPCA2)^2}$$

Where, SSIPCA1 and SSIPCA2 is Sum of squares due to PC1 and PC2 respectively.

3. Result and discussion

3.1 AMMI stability analysis

The AMMI model helps to examine the yield performance and the stability of genotypes using PCA and ANOVA (Gauch, 1988; Pour-Aboughadareh et al., 2022). Alake et al., 2015; Khan et al., 2021 Explained the effectiveness of AMMI and GGE biplot models to find out the high-yielding and stable genotype in different environment. In the AMMI biplot, grain yield is depicted as the dominant effect, with genotypes with PC1s that are closer to the origin being more stable and those with larger PC1s being particularly adapted (Biswas et al., 2021).

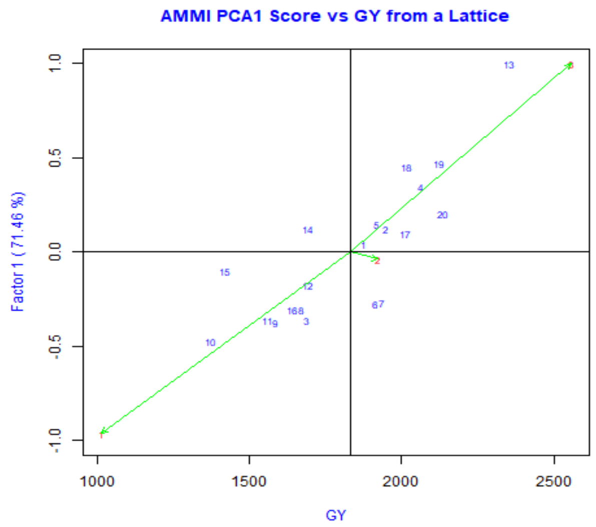

Figure 1. AMMI Biplot of PC1 versus GY of 20 genotypes in three different environments treatment

Figure 1 shows the stability of genotypes in tested environments. In the above biplot, Bhrikuti was seen stable in all three environmental conditions. NL1369, NL1381, NL1404 are adaptive in heat drought environment. The genotypes NL1179 and NL1346 are adapted to heat stress conditions. Gautam, NL1384, BL 4919 and NL 1417 give higher grain yields in irrigated conditions. Those genotype located near to origin, Gautam, BL4407, NL1412, NL1179, NL1346 are primarily stable lines. NL1384, NL1417, NL1413 and NL1369 are unstable lines. NL1376, NL 1368, NL 1404, NL1350, BL 4669 are clustered genotypes showing similar kind of performance.

Table 2. Final AMMI Score and ASV value of 20 wheat genotypes with standard deviation and coefficient of variation of three environmental condition

S.N	Treatment	Name	Yield (kg/ha)	PC1	PC2	PC3	ASV	Ranked ASV
1	1	Bhrikuti	1873.33	0.04339	-0.3222	-1.50E-05	0.33999	19
2	10	NL1369	1368.89	-0.4717	-0.1045	-6.90E-06	1.18569	3
3	11	NL1376	1558.89	-0.3636	-0.3377	-1.30E-05	0.971	5
4	12	NL1381	1692.78	-0.1750	-0.1826	-1.10E-05	0.47464	16
5	13	NL1384	2354.44	1	0.0865	6.06E-05	2.50531	1
6	14	NL1386	1690	0.12016	-0.4721	-1.90E-05	0.55985	14
7	15	NL1387	1417.22	-0.1018	-0.1971	-1.10E-05	0.32228	20
8	16	NL1404	1640.56	-0.3051	0.3278	2.45E-06	0.83126	9
9	17	NL1412	2010	0.09806	0.3511	7.06E-07	0.42849	18
10	18	NL1413	2013.89	0.45238	-0.5170	-2.20E-05	1.2451	2
11	19	NL1417	2123.89	0.46828	-0.0250	-1.00E-05	1.17274	4
12	2	BL4407	1948.33	0.12428	0.3232	-7.10E-05	0.44866	17
13	20	NL1420	2135.56	0.20268	-0.0231	-8.80E-06	0.50801	15
14	3	BL4669	1688.33	-0.3588	-0.1094	6.37E-05	0.90506	7
15	4	BL4919	2063.89	0.34521	0.2234	-3.80E-06	0.89274	8
16	5	Gautam	1917.78	0.14615	0.4571	2.97E-06	0.58554	13
17	6	NL1179	1915	-0.2777	0.3906	3.80E-06	0.79747	10
18	7	NL1346	1933.33	-0.2699	0.2351	3.24E-08	0.71541	12
19	8	NL1350	1669.44	-0.3051	-0.2146	6.08E-05	0.79341	11
20	9	NL1368	1582.78	-0.372	0.1101	-2.40E-06	0.93786	6

	Heat Drought	Heat Stress	Irrigated
Grand Mean of grain yield (Kg/ha)	1013.25	1920.997	2555.50
STD	130.88	355.79	488.61
CV (%)	12.92	18.52	19.12

In Table 2, the genotype with a higher ASV value is less stable and those genotypes with having least ASV value is more stable. In our study NL1387 followed by Bhrikuti, NL1412, BL4407, NL1386 and Gautam are seen as stable. The line NL1384 has the largest ASV value of 2.50 being the most unstable genotype followed by NL1369, NL1413, NL 1417, NL1368, NL1376 and B4669. NL1420, NL1346, NL1381 are average lines in terms of stability.

The grain yield of genotypes varied greatly across the tested environments. The PC score shows the stability of the genotype across three environments. Less PC1 refers to greater stability of the genotype in a particular environment and vice versa. From Table 2 , we can see that genotype 13 has a greater value of PC1 and grain yield of 2354.444kg/ha which is higher than any another genotype. Similarly, genotype 10 has a grain yield of 1368.889kg/ha which is less than the rest of the genotype and has the smallest PC1 value of -0.47171.

Table 3. AMMI analysis of variance over three environments

	SS	Percent explained	Percent Accumulated	Df	MS	F	Prob
Env	48068472	76.7844	76.7844	2	24034236	83.50921	0**
Gen	7529879	12.0282	88.8126	19	396309.4	1.37701	0.17348
ENV*GEN	7003521	11.1874	100	38	184303.2	0.64038	0.92785

Continued Table 3.

	SS	Percent explained	Percent Accumulated	Df	MS	F	Prob
PC1	5004696	71.45971	71.45971	20	250234.8	2.3693	0.01361*
PC2	1998825	28.54029	100	18	111045.8	1.05142	0.43608
PC3	0	0	100	16	0	0	1
Residual	17268206	0	0	60	287803.4	NA	NA

The Anova of the AMMI model in all 3 environments, and G*E interaction is shown in Table 3. The variation in GY are due 76.78% and 12.02% due to environment and genotypes respectively. The environment accounted for the majority of the difference in grain yield so, identification of adaptable wheat genotype compactible in different growing environments is necessary. The variation in GY of wheat due to interaction is 11.18%. The GY showed significant relationship with the environment and genotype. Similarly, GY is insignificant with the G*E interaction at the 0.05 probability level. The Sum of squares due to environment is larger which indicates that if environments are diverse the variation in mean GY differs (Rad et al., 2013).

3.2 GGE biplot analysis

The GGE biplot analyzes any crossover in GE interaction to aid in finding the best performing genotypes providing considerable flexibility and determining the most representative environment for a genotype (Kendal & Şener, 2015; Sabaghnia et al., 2013; Sayar & Han, 2015).

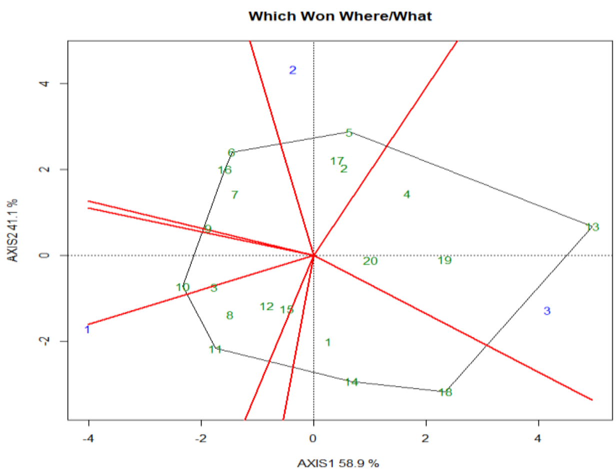

Figure 2. Polygon view of GGE biplot for which won what model of 20 wheat genotypes in three environments

In Figure 2, the biplot is divided into eight sectors where heat drought, heat stress and irrigated environments fall. The polygon view of biplot in Which-won-where model is the best way to visualize the interaction between genotype and environment and analyze the result. The vertex for each sector in which won where/what model represents greater yield for the particular environment (Erdemi, 2018). The genotypes NL1384, NL1404, NL 1386, NL 1376, NL 1369, NL1404, NL 1179 and Gautam lie at the vertex of polygon representing higher grain yield. The genotype NL1384 has the longest distance from origin of biplot. In heat drought condition, NL 1376, NL1350, NL 1381 and NL1387 falls. This means these genotype give better grain yield in heat drought condition where NL1376 is the wining genotype in Heat drought environment. Gautam, NL1412 and BL4407 give higher yields in heat stress environment where Gautam showed a winning performance. Genotype NL1384, NL 1420, NL 1417, BL 4919 are located under the vertex of

Irrigated environment giving greater grain yield under irrigated condition. In all three, genotype NL1384 gives a higher grain yield followed by NL1420 and NL1417. NL1420 and NL1417 are located close to the origin which is stable genotype in all three-test environment.

Ranking Genotypes Analysis

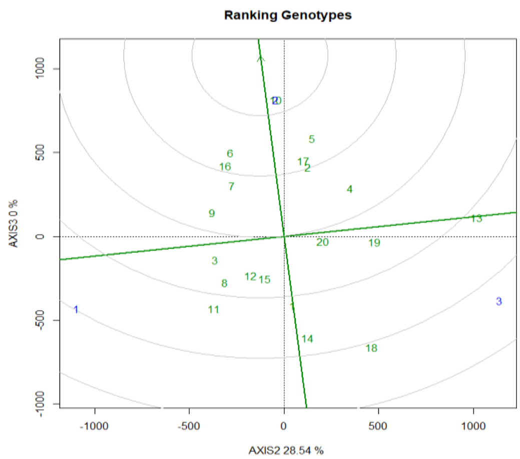

Figure 3(a): Ranking environment among heat stress, heat drought and irrigated conditions

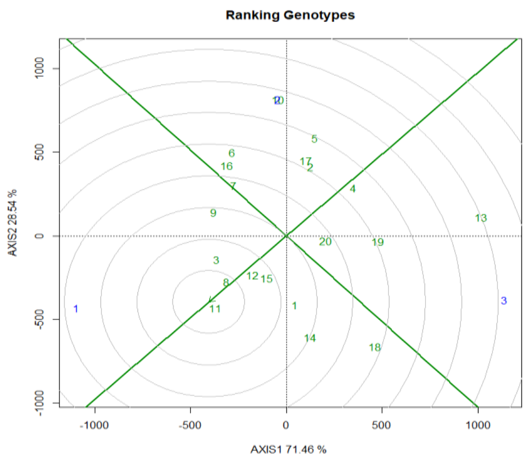

Figure 3(b): Ranking genotype biplot for GGE model

The ideal environment lies close to the ideal point which is represented by small arrow (Ruswandi et al., 2021). Ideal genotypes have high mean performance and stability for all three environments (Masson et al., n.d.). The position of the small arrow like projection represents the position of the ideal genotype and ideal environment in the Figure 3(a) and Figure 3(b) (Ruswandi et al., 2021). The genotype lying closer to the ideal genotype is desirable. NL1376 line is the ideal line which ranks first in ranking genotype analysis and NL1420 is the most stable line which is located near the origin. The check variety Gautam and lines BL4407, NL1412 lying above x axis perform averagely in terms of grain yield. The genotypes NL1386 and NL1413 lie below the x axis which is undesirable in terms of stability.

3.3 Mean Vs. stability model

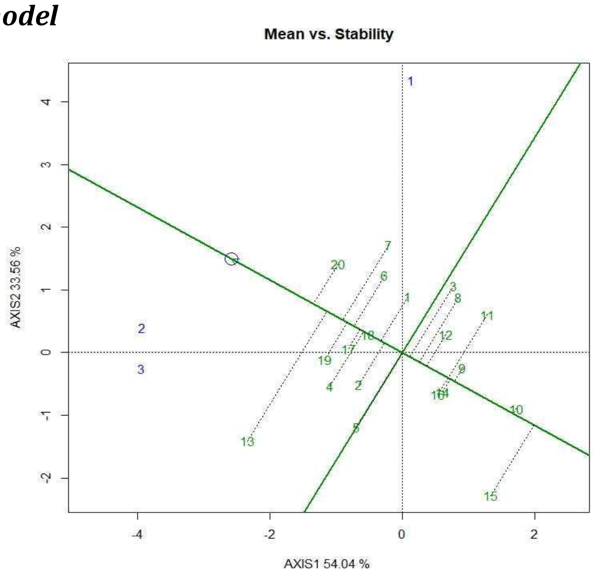

Figure 4. Mean vs. stability model of 20 wheat genotypes in 3 environmental conditions

The mean versus stability model shows the average GY and stability of all genotypes where the x axis represent grain yield and the y axis represents grain yield stability (Yan & Tsui, 2007). In the mean versus stability model, average environment coordination (AEC) view is used to analyze genotypes and their stability. The average environment coordinate represented as an arrowhead in the above figure is the mean of PC1 and PC2 (Biswas et al., 2021). The length of the abscissa gives GY so the genotype with a longer abscissa has a higher grain yield than the genotype with shorter abscissa.

Genotypes NL1384, NL1346, BL 4669, NL1350, NL1376 and NL1387 with longer abscissa lengths showed greater grain yield. NL1368 and NL1369 have shorter lengths of abscissa and less GY than other lines. According to (Karuniawan et al., 2021), genotypes lying right to the y axis have a higher than average GY and genotypes lying left to the y axis have a lower yield than the average overall yield. Heat stress environment is considered stable in the arrowhead sector. Genotypes NL1381, NL1368, NL1404, and NL1376 yield above average and NL 1420, BL 4919, BL 4407, Bhrikuti yield more grain average. The genotype far from X axis is less stable. Genotypes BL4669, NL1350, NL1376 give a higher yield but they are unstable compared to NL1384, NL1387 which is a stable genotype with a greater GY. Genotypes NL1369, NL1368, NL1376, NL 1381 and NL 1368 are desirable lines. NL 1404, BL4919, NL1387 and NL1384 can be recommended as a variety.

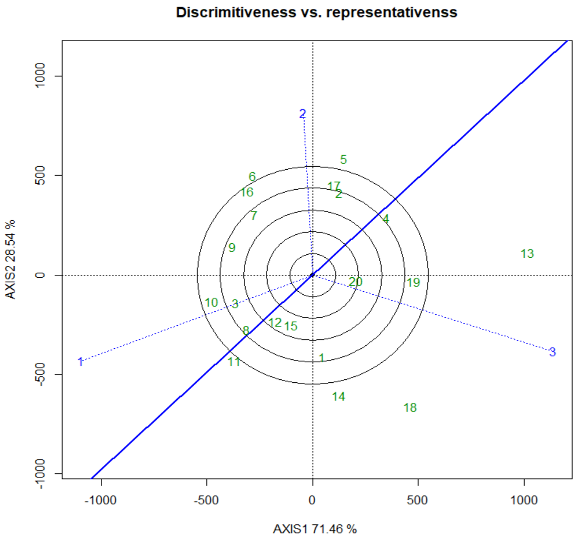

Figure 5. Discrimitiveness vs. representativeness model

In the Figure 6, the X axis represents PC1 (71.46%) and the Y axis represents PC2 (28.54%) whose sum represents goodness of fit (Liu et al., 2021). The small blue dotted line shows vector length and three different tests environments have different vector lengths. The cosine of the angle between vectors of two test environment represents correlation between them (Srivastava et al., 2022). The angles between the vectors of heat drought and heat stress, heat stress and irrigated, heat drought and irrigated all were greater than 90° indicating a negative correlation between the environments. All three environmental conditions were plotted far from the origin of the biplot, which indicated that they were able to discriminate between the genotypes.

4. Conclusion

The main objective of our trial is to identify the genotype that is best adopted in different environmental condition. This study examined the genotype and environment interaction effect, stability of wheat genotypes in different environments. The result of the analysis revealed that drought conditions negatively impair GY and performance of wheat so adaptation of stable wheat genotypes in those environments is necessary. The grain yield was affected by environmental conditions and genotype-environment interaction that is 11.18%. The AMMI stability value (ASV) was the appropriate model showing NL1387 and Bhrikuti as the most stable genotypes and NL1384 as a most unstable. The AMMI biplot showed Bhrikuti as a stable line in all three environments. The GGE biplot showed NL1384 as the highest yielding line followed by NL1420 in multi environment trails. The ranking genotype analysis showed NL1376 as an ideal line and NL1420 as the most stable line. The mean versus stability analysis examined lines NL 1404, BL4919, NL1387, and NL1384 able to be recommended as a variety as they are adapted to all three environments and provide satisfactory performance. The second environment can be considered an ideal environment where the impact of drought and irrigation is cumulative. The environments chose were negatively correlated with each other and discriminative over the genotypes.

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Author's declaration and contribution

There is no any conflict of interest between the authors during the whole experimental work. The research was guided by MRP and RB. The author BT and all the coauthors SG, PR, RP, SS, KB, AA, GGC, KN, PG, MKP, SS, EC, played role in conducting whole research and data analysis. The main author BT, designed the paper which was revised by RB, and other coauthors.

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