Stability analysis of different Wheat (Triticum aestivum L.) varieties using AMMI and GGE biplot under Heat drought and Irrigated environment

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Abstract

Wheat a widely grown cereal crop, which accounts for about 30 percent of the world grain output and affects the half of the land cultivated with wheat. Drought has a robust impact which affect 40 percent of wheat production and crop response, and other factor like plant growth, productivity, pigments contents, leaf senescence, fertility of spike, water relations and also photosynthetic activities. Low yield can be attributed to the planting time and varietal selection. To meet the need for food grains, high yielding genotypes resistant to diverse biotic and abiotic stress must be established and well performed genotypes are selected using multiplicative trails. So, the main objective of the study is to find the most stable, high yielding and adaptive genotype through genotype-environment interaction. The data were interpreted using AMMI (Additive Main Effect and Multiplicative Interaction) and GGE biplots. The experiment was conducted on twenty wheat genotypes in alpha lattice design on irrigated and heat drought environment. AMMI model showed that the grain yield is significantly affected by environment and 83.03%, 8.24%, 8.73% is attributed to environment, genotype and environment*genotype interaction. According to AMMI model, NL 1384 is the high yielding genotype in irrigated environment and NL 1179 under heat drought. NL 1346 is the winning elite line of drought environment and NL 1384 is the winning elite line for this environment as per GGE biplot analysis. Mean versus stability showed that NL 1384 is the highest mean yielding genotype and ranking genotype revealed NL 1420 is the ideal genotype.

1 INTRODUCTION

Wheat (*Triticum aestivum L.)*, which belong to Poaceae family is one of the most widely grown cereal crop which accounts for about 30 percent of global grain output and 50 percent of global grain trade (Akter & Rafiqul Islam, 2017). Wheat is first grown ten thousand years ago, during the shift from a hunting and gathering period to an agriculture society. Due to its adaptability, nutritional content and high yielding potential, wheat is considered as a significant crop for human consumption and is among the top three cereals in the world. 35 developed cultivars, 540 landraces and 10 wild relatives of wheat exist in Nepal (Poudel & Regmi, 2021). Wheat requires less irrigation than other cereal crops like rice, hence area under wheat cultivation is increasing. Wheat is cultivated in the driest, least rainy months of the year (Shirazi et al., 2014). As wheat is a mesophytic plant, temperature range for wheat ranges from 10 to 15°C during sowing and 21 to 26°C during ripening stage, though some type of wheat grows at 35°C (Poudel et al., 2020). As upto 2021, wheat is cultivated in 220759739 ha round the world with global production of 770877072.89 tons (FAOSTAT). Total wheat production is 2127276 tones with the production area of 711067 ha in Nepal (FAOSTAT).

It is predicted that drought affects about half of the wheat cultivated land in developing nation (Regmi et al., 2021). With an increase in temperature of every 1°C above the average temperature of 23°C, the output is negatively affected by 10 percent. This affects over 40 percent of the wheat growing areas globally (Ru et al., 2023). The degree of drought stress has an impact on wheat production and crop response varies depending on the stage of wheat development. The number and weight of wheat grain decrease due to drought right prior to anthesis and grain filling, respectively (Eyshi Rezaei et al., 2015).

Likewise, drought have a profound impact on other various factor like plant growth, productivity, pigments contents, leaf senescence, fertility of spike, water relations and also photosynthetic activities (Tyagi & Pandey, 2022). Wheat crops are affected by heat drought in all the stages of growth and reproduction but especially during anthesis and booting. Their genotypes experience small and non-significant increase and losses in thousand grain weight under heat drought environment (Zahra et al., 2021). The IPCC's most recent assessment report estimates that between 2046 and 2065, the average global surface temperature will be 0.4 to 2.6°C higher than it was between 1986 and 2005, which will decrease grain yield as it shortens the growth period of wheat (Li et al., 2019). From the time of seed germination to the time of maturity of the wheat plant, irrigation is crucial for their development. Applying irrigation at a critical moment is a beneficial management strategy for increasing production (AbdallaI Ali et al., 2016). In irrigated wheat, the temperature increase of every 1°C, above 30°C shortens grain filling by 0.38–0.58 percent (Liu et al., 2016) which reduces yield. It has also been observed that a temperature increase to 0 to 5°C causes a 60 percent decrease in rainfed wheat grain yield (Ahmed et al., 2016).

Wheat productivity of Nepal has been greatly limited by the huge disparity between the research and extension which can be minimized by the improved seed and improved package of practices (Timsina et al., 2019). Sowing time and varietal selection are the key factor that are responsible for low yield of the wheat (Thapa et al., 2020). After the inception of the semi-dwarf varieties in Nepal from Mexico, the area and production of the wheat has been markedly increased which has also contributed to food supply (Subedi et al., 2019). To meet the need for food grain, it will be essential to create high yielding genotypes that are also resistant and tolerant to variety of biotic and abiotic stress. In order to select the genotypes that perform consistently well in multiples scenario, multiplication trails are essentials (Singh et al., 2019).

Among the multivariate methods, AMMI (Additive Main Effect and Multiplicative Interaction) and GGE biplots is widely used for identification and introduction of the high stable and high performing genotypes (Ale et al., 2017). AMMI model uses ANOVA(analysis of variance) (Singh et al., 2019) and principal component analysis (PCA) to measure genetic stability across the site. The AMMI method is successful because it offers an interpretation of the data that is agronomically significant (MOHAMMADI et al., 2015). The GGE biplot is an effective framework that provides a graphical representation of the highest performing cultivars across conditions. These graphical features makes it easier to find high-yielding, stable genotypes especially in multi environment experiments (Singh et al., 2019). It is claimed that this approach offers useful detail on the genotypes and study surrounding s(Omrani et al., 2022). The major objective of the study was to study the adaptability and stability of the wheat genotype using AMMI and GGE models and to determine the significance of G*E interaction on yield and pinpoint the best acting genotypes in the irrigated and drought environment. Thus, this study aims at the study of the adaptability and stability of the wheat genotype using AMMI and GGE models and to determine the significance of G*E interaction on yield and pinpoint the best acting genotypes in the irrigated and drought environment.

2 METHODOLOGY

2.1 Experimental site

The Agronomy farm of IAAS Paklihawa, located at NL 27°28'58" and EL 83°26'47" and 100 meters above the sea level was served as the site for the study with hot summers and cold winters with annual precipitation of 1725.3 mm.

The graph of variation is shown in Fig. 1:

2.2 Planting materials

The research was conducted with 20 genotypes consisting of 3 Bhairahawa Lines (BL), 15 Nepal Lines (NL) and 2 commercial varieties Gautam and Bhrikuti.

Table 1
List of elite wheat line with their origin

S. N	Genotypes*	Source
1	Bhrikuti	CIMMYT, Mexico
2	BL 4407	Nepal
3	BL 4669	Nepal
4	BL 4919	Nepal
5	Gautam	Nepal
6	NL 1179	CIMMYT, Mexico
7	NL 1346	CIMMYT, Mexico
8	NL1350	CIMMYT, Mexico
9	NL 1368	CIMMYT, Mexico
10	NL 1369	CIMMYT, Mexico
11	NL 1376	CIMMYT, Mexico
12	NL 1381	CIMMYT, Mexico
13	NL1384	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

2.3 Experimental layout

With the total of 80 plots which include 5 blocks, our research was carried out using Alpha Lattice design with 40 plots each in irrigated and heat drought environment. 20 genotypes were used which was replicated twice in each environment. The individual plots were 2meter breadth and 2meter length with an area of $4m^2$. Distance between the plots were 0.5 meter, between the blocks 1meter distance was maintained and 1meter between two replications.

2.4 Land preparation and sowing

Land was prepared with the help of spade the day before sowing on 27th November. With the row spacing of 25cm and leaving 12.5 cm on either side seed was sown in the plot. Sowing was done for irrigated environment took place on November 29th, 2022 and for a drought 25th December, 2022.

2.5 Fertilizer dose and time

For irrigated and heat drought environment urea 87.336 gm, DAP 43.48gm and potash 33.32gm were applied per plot on 25th December 2022. Urea was top dressed another time on 24th January 2023, at the rate of 21.834gm per plot.

2.6 Data collection

The data were collected for Days to booting (DTB), Days to heading (DTH), Days to anthesis (DTA), Plant height (PH), Spike length (SL), Number of spikes per meter square (NSPMS), Number of spikelets per spike (NSPS), Number of grains per spike (NGPS), Ten spike weight (TSW), Thousand kernel weight (TSW), Grain weight (GW), Straw yield (SY) and Harvest Index (HI).

2.7 Harvesting and threshing

On April 17th harvesting was finished in both irrigated and drought-stricken environment. Sickles were used for harvesting and sticks were pounded to thresh grain manually.

2.8 Statistical analysis

The collected data were entered in excel and entire processing and analysis was done using AMMI and GGE model from GEA-R statistical software.

By maintaining genotype constant and environment in random effect, the amplitude of the genotypes and Genotype*Environment (G*E) interaction was evaluated using ANOVA in AMMI model(Gautam et al., 2021). The AMMI model equation is written as(Rad et al., 2013):

$$Yge = \mu + \alpha g + \beta e + \sum n\lambda n\gamma gn\delta en + \rho ge$$

Yge is the yield for genotype(g) in the environment(e) for the additive parameters. μ is the grand mean, αg denotes genotype deviation, βedenotes environment deviation. $\lambda n$is the singular value for component n. γgn is eigenvector value for g. $\delta en$is the eigenvector value for e and the residual term is ρge. In AMMI literature, GGE model is represented as

$$Yge - \beta e - \mu = \vartheta ge = \sum n\lambda n\gamma gn\delta en + \rho ge$$

ϑge is the environment centered-yields and $Yge - \beta e$ is the nominal yields.

3 RESULTS AND DISCUSSION

3.1 AMMI (Additive Main Effect and Multiplicative Interaction) model analysis

Table 2
Analysis of variance of Grain Yield using AMMI models

	SS	Percent explained	Percent accumulated	DF	MS	F	PROBF
ENV	47570701	83.03	83.03	1	47570701	134.5187	0
GEN	4721944	8.24	91.27	19	248523.4	0.70277	0.79395
ENV*GEN	5001274	8.73	100	19	263224.9	0.74434	0.75231
PC1	5001274	100	100	19	263224.9	3.03839	0.00691
PC2	0	0	100	17	0	0	1
Residuals	14145450	0	0	40	353636.3	NA	NA

ENV = Environment; GEN = Genotypes; SS = Sum of squares; DF = degree of freedom; MS = Mean Sum of squares; PC1 = Principal component 1; PC2 = Principal component 2; ENV*GEN = Environment*Genotypes.

The AMMI model ANOVA showed, 83.03%, 8.24%, 8.73% is marked to environment, genotype and environment*genotype interaction (Table 2.). This means the grain yield is significantly ($p < 0.05$) affected by environment. Likewise, PC1 explained 100% of the sum of squares which means there is 100% interaction between the environment and genotype with DF 19 of PC1 and DF 17 of PC2.

AMMI model has been used as a statistical tool for fixed effect multiplicative models analysis to find the GE interaction by implying genotypes clusters based on the similarity of their response (Bocianowski et al., 2019). X-axis of AMMI model denotes environment and genotype main effect and effect of interaction is represented by Y-axis (Tekdal & Kendal, 2018). If genotypes are closer to the X-axis, then they are more stable than the farthest from the same axis. The genotypes located on the right of the Y-axis are the above average yielding genotypes and that located left to the Y-axis are below average yielding genotypes(Hamurcu, 2023).

Figure 1 shows AMMI biplot of 20 genotypes in two environments (heat drought and irrigated) for grain yield. Genotypes that are cluster together shows the similar characteristics and adaptation. NL 1386 and BL 4407 shows the same response in the environment. The genotypes NL 1368, NL 1381 and NL 1404 are adaptive genotype across drought environment and NL 1179 being the highest yielding genotype in heat drought environment. Similarly, NL 1412, NL 1413and NL 1417 are the adaptive line in irrigated environment with genotype NL 1384 being the highest yielding genotype and is unstable in irrigated environment. Similarly, the lowest yielding genotype under irrigated environment is NL 1386 and BL 4407 and heat drought environment is NL 1369.

Table 3
Interaction Principal Components of AMMI (PC1and PC2) with Yield of 20 elite wheat lines.

S.N.	NAME	Yield	PC1	PC2
1	1 (Bhrikuti)	1930	-0.03466	$-2.2*10^{-08}$
2	10(NL 1369)	1350	0.473417	$2.95*10^{-10}$
3	11(NL 1376)	1615	0.371802	$-1.1*10^{-09}$
4	12(NL 1381)	1702.5	0.179459	$1.36*10^{-10}$
5	13(NL 1384)	2295	-1	$-1.3*10^{-09}$
6	14(NL 1386)	1795	-0.10724	$7.41*10^{-11}$
7	15(NL 1387)	1432.5	0.106877	$-7.9*10^{-11}$
8	16(NL 1404)	1487.5	0.295591	$9.31*10^{-10}$
9	17(NL 1412)	1855	-0.10724	$7.41*10^{-11}$
10	18(NL 1413)	2137.5	-0.43749	$1.83*10^{-10}$
11	19(NL 1417)	2092.5	-0.46652	$-2*10^{-10}$
12	2(BL 4407)	1802.5	-0.13264	$4.87*10^{-10}$
13	20(NL 1420)	2100	-0.2016	$3.2*10^{-10}$
14	3(BL 4669)	1672.5	0.360915	$-1.2*10^{-09}$
15	4(BL 4919)	1952.5	-0.35039	$1.34*10^{-09}$
16	5(Gautam)	1730	-0.15805	$1.49*10^{-10}$
17	6(NL 1179)	1742.5	0.266558	$-9.6*10^{-10}$
18	7(NL 1346)	1810	0.262929	$-1*10^{-09}$
19	8(NL 1350)	1687.5	0.310107	$-3.8*10^{-10}$
20	9(NL 1368)	1497.5	0.368173	$-1.1*10^{-09}$

3.2 GGE biplot analysis – “which-won-where model”

The farthest genotypes from the origin are joined to form the Which-won-where graph, containing all other genotypes within the polygon with one genotype in the polygon’s vertex. Next perpendicular lines are drawn from the biplot origin on each side of the polygon, dividing the biplot into several sector (Sciences et al., 2017). In which-won-where model of GGE biplot analysis, a polygon was made by joining the elite lines of wheat in two tested environments. This model shows 6 sectors where two tested environment lies in two sectors.

The vertex genotype in each sector represent the highest yielding genotypes in the location that was within that specific sector, according to the polygonal view of the biplot which revealed which genotype performed best in which environment(Oyekunle et al., 2017).

Genotypes NL 1346, NL 1179, NL 1350, BL 4669 lies in the drought environment sector (1) and are responsive in this environment with NL 1346 having the farthest vertex from the origin and is the winning elite line of drought environment. Likewise, Fig. 2 indictes genotypes NL 1384, NL 1413, NL 1417, BL 4919, NL 1386, BL 4407 are responsive to irrigated environment (2) with genotype NL 1384 being the winning elite line for this environment as it lies the farthest from the origin. Genotypes NL 1420, Bhrikuti, NL 1376, NL 1381, NL 1368, NL 1404, NL 1369, NL 1387, Gautam lies beyond the sector of tested environment, so these lines are not adapted in either environment. Genotype NL 1412 which lies in the center is stable in both the environments.

3.3 Mean VS stability of the genotypes

The GGE model gives plant breeders a lot of discretion for yield and stability selection simultaneously. It is effective for method for achieving high mean yield genotypes with acceptable stability(Kendal et al., 2019). The identification of genotypes with high average performance and stability across a variety context is made possible through mean and stability analysis by GGE biplot, graphically through Average Environment Coordinates (AEC) with the arrowhead. The other line running through AEC and origin is called AEC abscissa.

Above Fig. 3 shows that genotypes Bhrikuti, BL 4407, NL 1386, NL 1420, NL 1412 are both above average yielders and stable whereas genotypes NL 1384, NL 1346, NL 1413, NL 1417, NL 1381 are above average yielders but are less stable. Genotypes BL 4407, NL 1387, Gautam are below average yielders and are stable but NL 1179, NL 1350, BL 4669, NL 1376, NL 1368, NL 1404, NL 1369 are both less stable and below average yielders.

3.4 Evaluating the idealness of the environment (Discriminativeness VS Representativeness)

The biplot was useful tool for evaluating the environment, something that the AMMI model was unable to do because of its lack of discriminative power and representativeness (SOLONECHNYI et al., 2018). Discriminativeness is the capacity of an environment or location to define genotypes, whereas representativeness is the capacity of the tested environment to reflect the other tested environment(Hasan et al., 2022). The cosine of the angles between the environment vectors indicates the correlations between test environments, with acute angles denoting the strong positive correlation, obtuse angle denoting a significant negative correlations or a cross over GEI of genotypes, and right angle denoting no association (SOLONECHNYI et al., 2018).

The vector length of the environment represents the discriminating ability. In the Fig. 4 the vector of irrigated environment is longer than that of the drought environment, implying that the irrigated environment has a greater standard deviation and thus higher discriminative ability than the drought-stricken environment. The cosine angle between the environment vector represents its representative ability; Larger the angle, less representative the environment is. The cosine of the vector between the environment was perpendicular meaning that there is no correlation between the environment or they are not associated.

3.5 Ranking genotypes

A biplot tool called Ranking genotypes, is used to test the best ideal variety from among the tested kinds. The most suitable variation is that which is located near the arrowhead in the innermost circle(Khan et al., 2021). Other tested variations can be graded in relation to the innermost variety based on how closely they resemble the innermost ideal variety(Bishwas et al., 2021).

If genotype is found closer to the ideal genotype, it is considered to be more desirable. As per Fig. 5, NL 1420 is the ideal genotype with which other genotypes are tested. Genotypes NL 1413, Bhrikuti, NL1417, BL 4919 are the desirable ones.

The general ranking from the biplot is given below:

NL 1420 > NL 1413 > Bhrikuti > NL 1417 > BL 4919 > NL 1412 > NL 1386 > BL 4407 > NL 1346 > Gautam > NL 1179 > NL 1381 > NL 1350 > BL 4669 > NL 1384 > NL 1376 > NL 1368 > NL 1404 > NL 1387 > NL 1369

Below is the comparison of 20 elite wheat line positions on mean yield and biplot ranking for both drought and irrigated environments:

Table 4
Comparison of the rank of 20 elite wheat lines based on mean yield and biplot ranking

Genotype rank	Mean Yield Ranking	Biplot Ranking
1.	NL 1384	NL 1420
2.	NL 1413	NL 1413
3.	NL 1420	Bhrikuti
4.	NL 1417	NL 1417
5.	BL 4919	BL 4919
6.	Bhrikuti	NL 1412
7.	NL 1412	NL 1386
8.	NL 1346	BL 4407
9.	BL 4407	NL 1346
10.	BL 4669	Gautam
11.	NL 1179	NL 1179
12.	Gautam	NL 1381
13.	NL 1381	NL 1350
14.	NL 1350	BL 4669
15.	BL 4669	NL 1384
16.	NL 1376	NL 1376
17.	NL 1368	NL 1368
18.	NL 1404	NL 1404
19.	NL 1387	NL 1387
20.	NL 1369	NL 1369

4 CONCLUSION

Wheat the global cereal crop, which accounts for about 30 percent of the grain production is majorly affected by drought and irrigated environment, which results in decrease in productivity and yield which ultimately affects the food security and safety. Hence, there is the necessity to find the high yielding and most stable genotypes which contribute to the food security. So, this study was performed to find the best stable genotypes in irrigated and heat drought environment using AMMI and GGE biplot which reveals the differential action of genotypes which are exposed to two environments (drought and irrigated). Wheat growing environment was found to be the major source of yield variation ($P < 0.05$). NL 1420 is the ideal genotype with which the other genotypes were compared. According to GGE biplot NL 1346 is the stable elite line of drought environment and genotype NL 1384 is the most stable elite line for irrigated environment. Likewise, genotype NL 1412 which lies in the center of the GGE model is stable in both the environment. Irrigated environment has higher discriminative ability than the drought-stricken environment and there is no correlation between the environment and hence, they are not associated. High yielding genotype under irrigated environment is NL 1384 and under heat drought is NL 1179 and the lowest yielding genotype under irrigated environment is NL 1386 and BL 4407 and heat drought environment is NL 1369 according to AMMI model. NL 1368, NL 1381 and NL 1404 were adaptive genotype in heat drought environment and NL 1412, NL 1413and NL 1417 were adaptive in irrigated environment according to AMMI model.

Declarations

CONFLICT OF INTEREST STATEMENTS

The author declares no conflict of interest.

CONTRIBUTION OF AUTHOR

Manuscript is written by Sweksha Ghimire and all other authors have equally contributed during the experiment. The manuscript is read and approved by all the authors.

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Figures

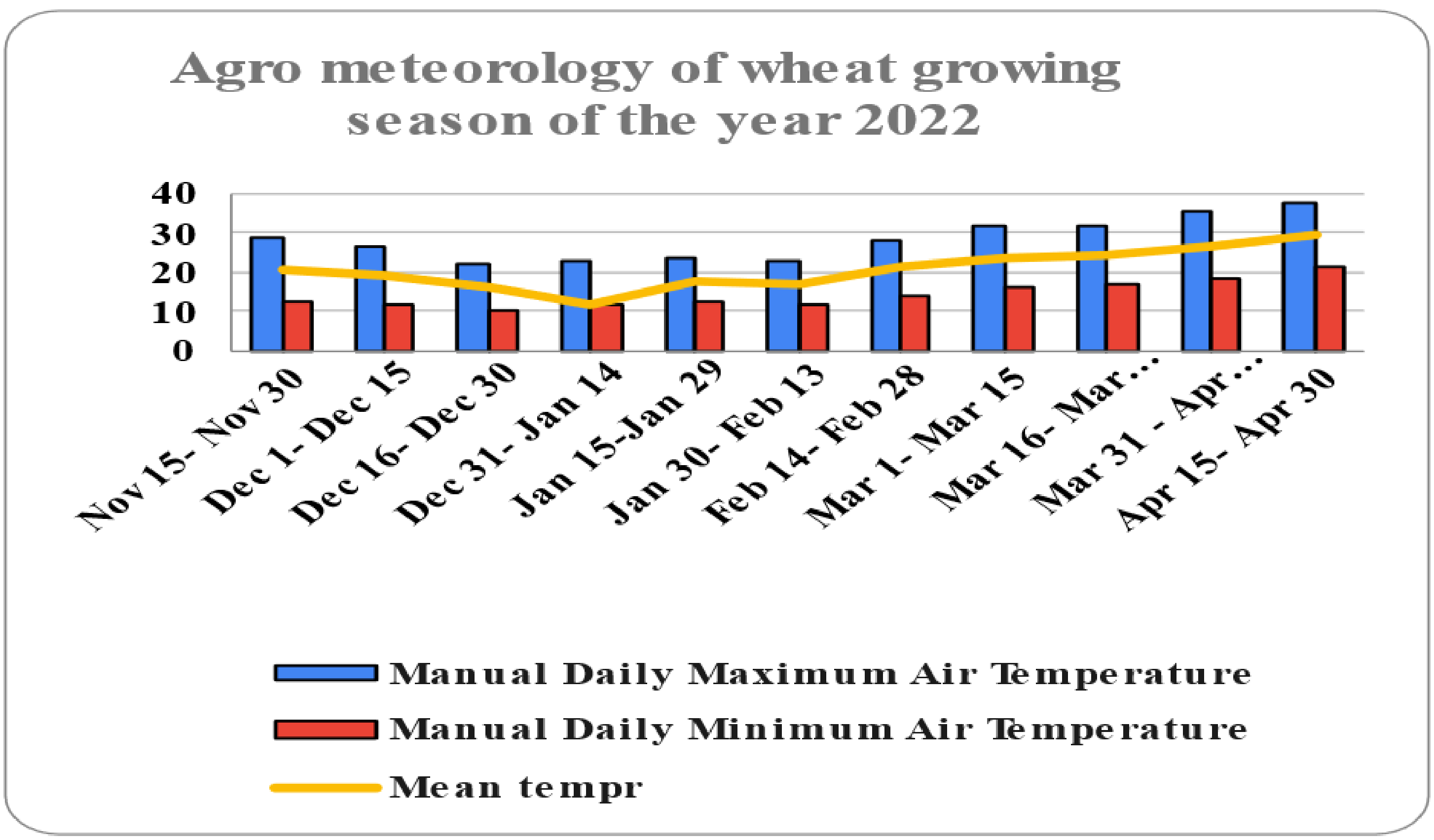

Figure 1

Temperature and precipitation data of experimental site throughout the wheat growing season. *Source: Department of Hydrology and meteorology, Rupandehi.*

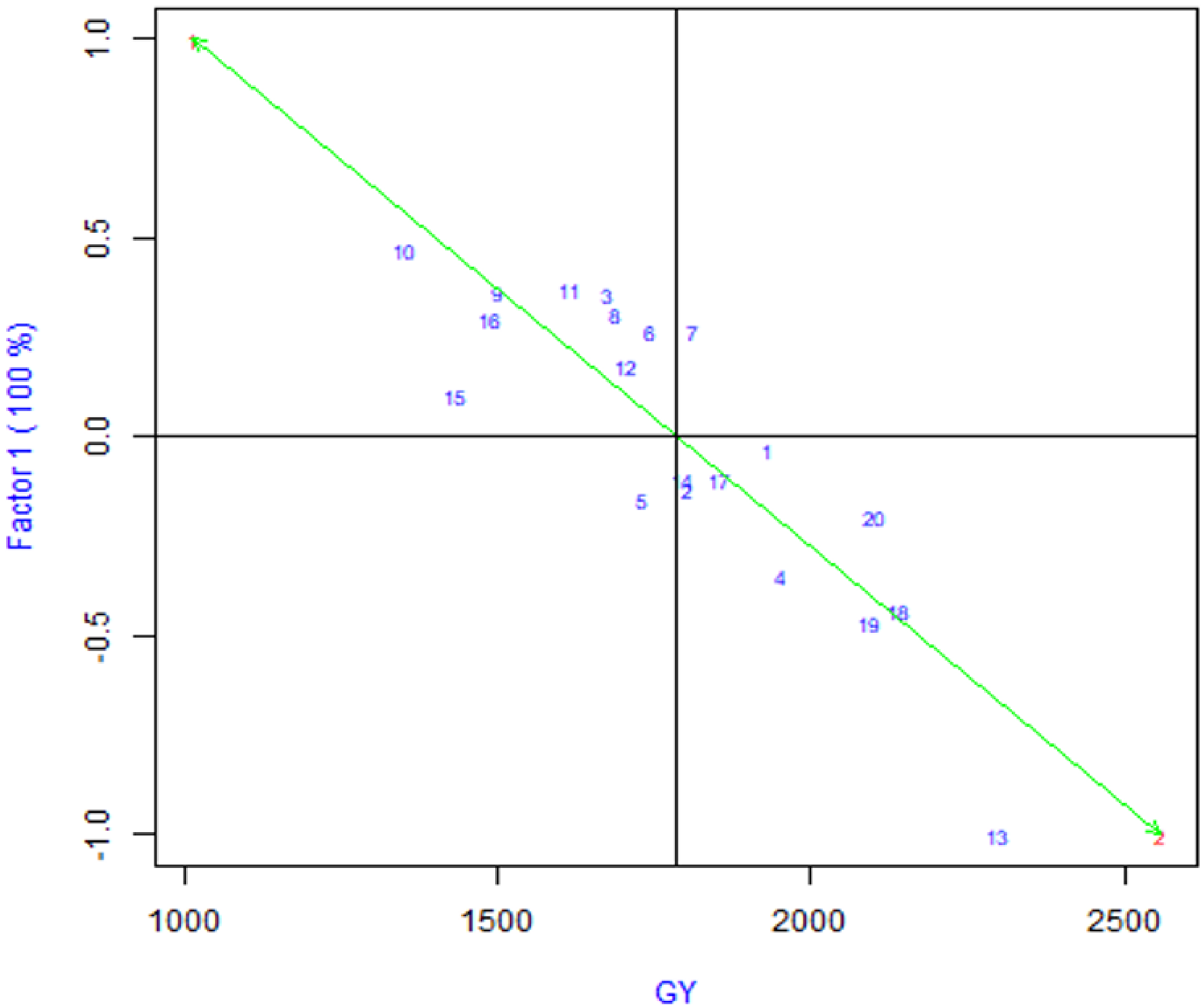

Figure 2

AMMI biplot PC1 VS yield of 20 elite wheat lines of drought and irrigated environments.

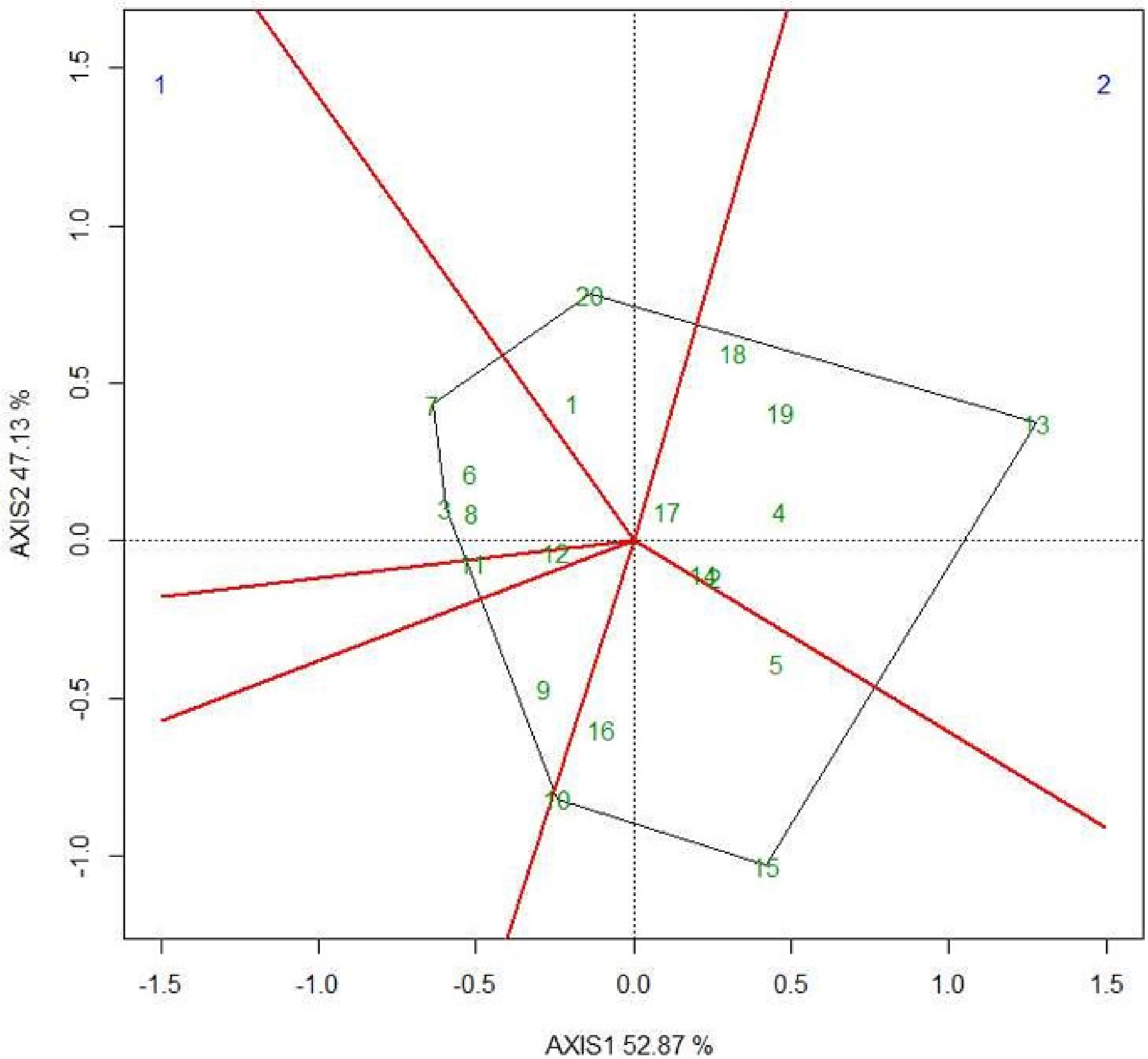

Figure 3

Polygon view of GGE biplot (which-won-where model) of 20 elite wheat lines in drought and irrigated environments. The biplots were based on scaling= 1, centering=2, S.V.P= Symmetrical.

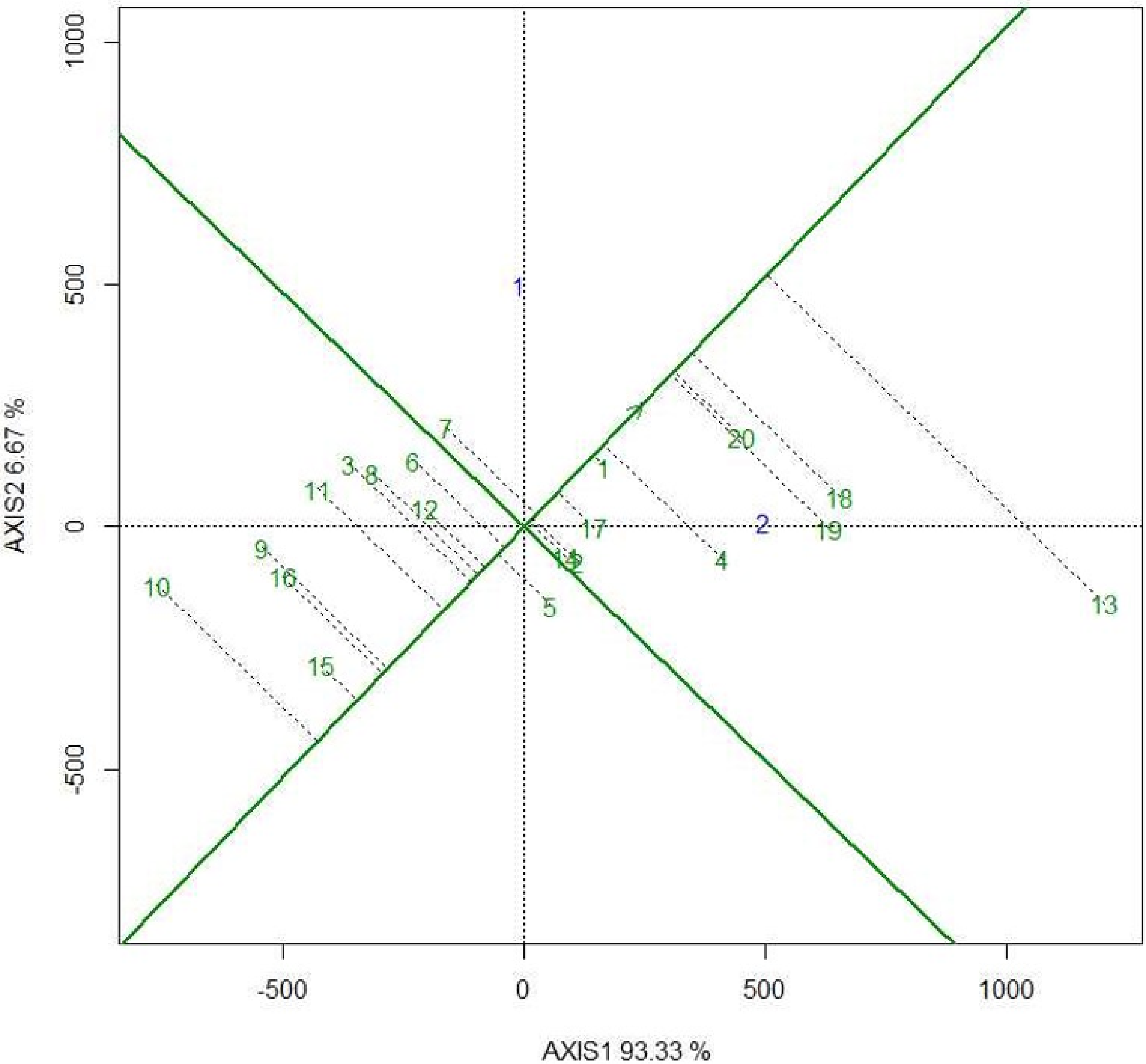

Figure 4

Mean VS Stability of GGE biplot showing the mean performance and stability of 20 elite wheat line in drought and irrigated environments. The biplots were based on scaling= 0, centering=2, S.V. P= Row metric preserving.

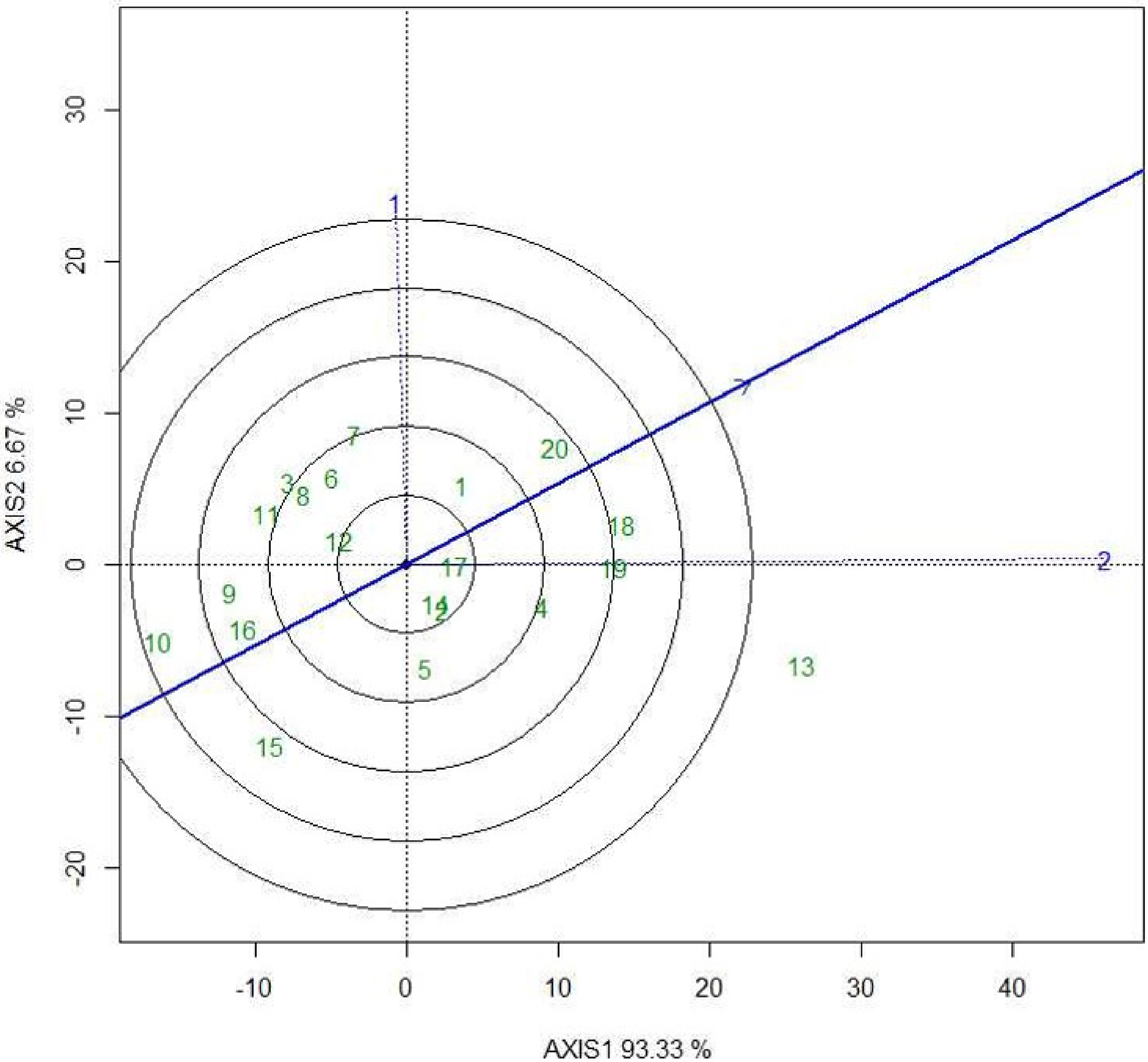

Figure 5

Discriminativeness VS representativeness view of GGE biplot showing 20 elite wheat line in drought and irrigated environments. The biplots were based on scaling= 0, centering=2, S.V. P= Symmetrical.

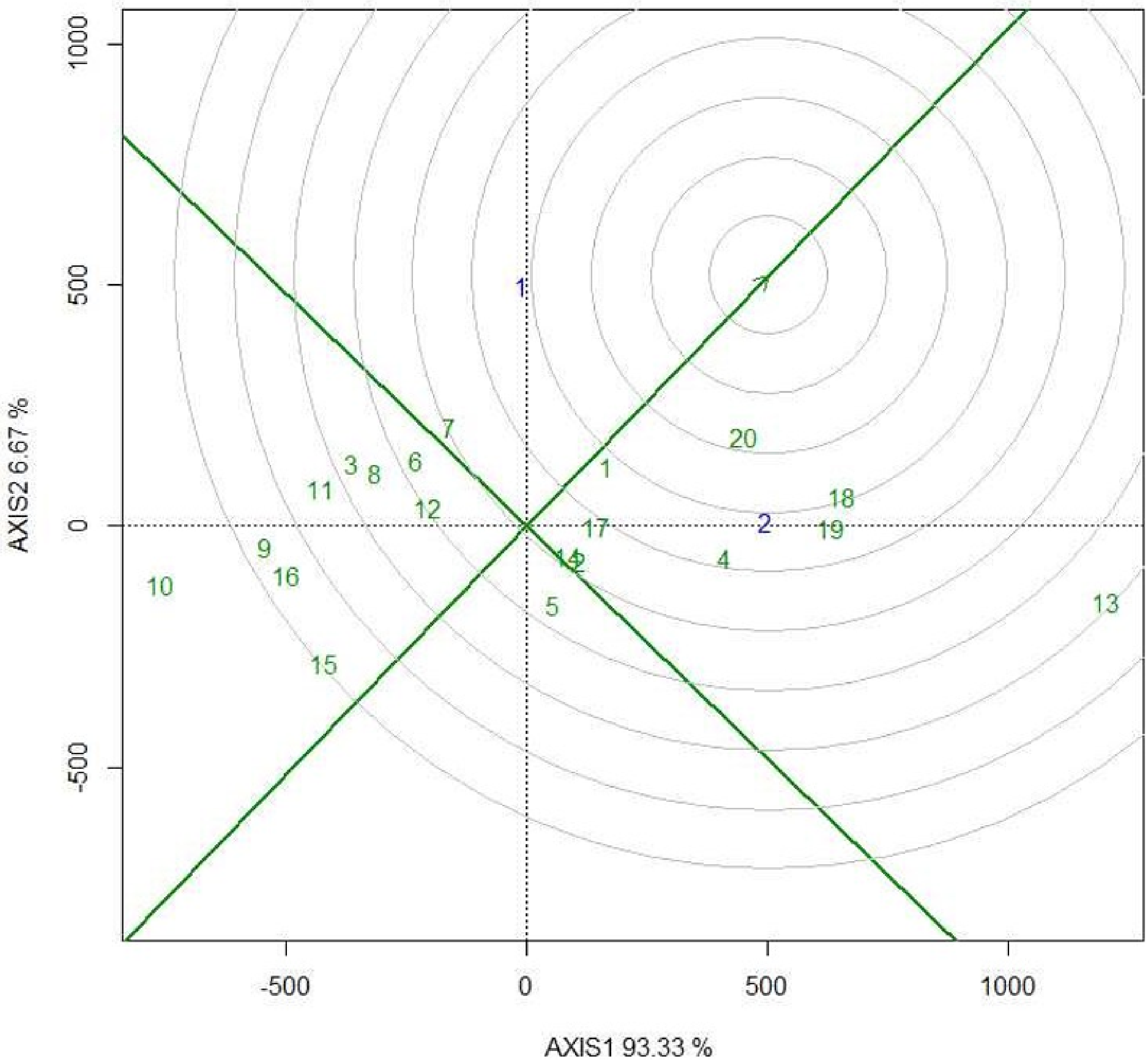

Figure 6

GGE biplot showing the ranking of 20 elite wheat line with reference to the ideal line in drought and irrigated environments. The biplots were based on scaling= 0, centering= 2, S.P.V= Row metric preserving.