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**Research Article**

# Yield Stability of Different Elite Wheat Lines under Drought and Irrigated Environments using AMMI and GGE Biplots

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## Abstract

Wheat is the principal winter crop in Nepal. Drought affects 44% of the lands of the total wheat area in the country with a yield loss of 15–20%. This research focuses to minimize this loss through the identification of high-yielding lines stable across the drought stress and irrigated environments. The experiment was conducted in Alpha Lattice Design with 20 genotypes replicated twice with five blocks per replication from November 2019 to April 2020. The findings showed that genotypes, environments, and genotype-environment interaction have a highly significant effect on grain yield and explained 28.95%, 52.57%, and 18.47% of variation on yield, respectively. The which-won-where model revealed elite line NL 1420 is the most responsive line in the drought environment, followed by BL 4407, while elite line NL 1179 is the most stable line in irrigated environment. The mean vs stability model with principal component 1 and 2 explaining 65.76% and 34.24% respectively, showed that elite line NL 1420, BL 4407, BL 4919, Bhrikuti are both high yielding and stable lines while line NL 1179, Gautam, and NL 1384 are less stable in both test environments. Similarly, the ranking genotypes model indicated lines close to the ideal line are NL 1420, BL 4407, BL 4919, Bhrikuti as the most representative line for genotype evaluation. Thus, elite wheat line NL 1420 and NL 1179 are recommended as specifically adapted to drought and irrigated environments, respectively, and elite line NL 1420, BL 4407, BL 4919, Bhrikuti are recommended for further evaluation for stability.

**Keywords:** Biplot; Elite lines; Gene-environment interaction; Principal component

## Introduction

Wheat (*Triticum aestivum* L.) belongs to the family Poaceae, which is an important food crop for human and animal feed worldwide (Sallam *et al*., 2019). It shows great genetic diversity with 25000 types (Feldman *et al*., 1995). These varieties are adapted to a wide range of temperate environments with sufficient water and mineral available.

In Nepal, it is the principal winter crop and the third most important crop after rice and maize with a cultivated area of 7, 03,992 hectares, production of 20,05,665 tonnes, and average productivity of 2.85 ton/ha (MoALD, 2020). It is estimated that almost half the area sown with wheat in developing countries and up to 70% of the area in the developed countries suffer from periodic drought

(Trethowan and Pfeiffer, 2000). By 2100, the predicted temperature rise is 1.5–5.8 $°C$ and this global warming leads to an increase in drought intensity and severity (Ansari *et al*., 2014; Field, 2012) which progress to desertification and cause a distressing condition of arable land (Solomon, 2007). In past (2013) drought approximately affected 65 million ha of wheat and its frequency will increase in the future, which will decrease the crop productivity (FAO, 2019). The major cause of water deficiency along with nutrient deficiencies and others had resulted in a low global wheat yield (Shewry, 2009). Moisture stress is a threat to wheat production in South Asian countries and is a major abiotic factor in wheat production declination in Nepal (Bhatta *et al*., 2008).

Drought cuts off around 50% of wheat production annually in the globe. In Nepal, 44% of lands of the total wheat area are affected due to low rain with a yield loss of 15–20%. Under water stress plant's capacity to assimilate is adversely affected along with gas exchange capacity, which reduces plant height, growth, and development (Shan *et al*., 2012). Yield loss occurs when wheat faces drought in any of the vegetative, reproductive stages or both. Early season stress causes a 22% reduction in yield and mid-season stress causes a 58% reduction in yield, and up to 72% yield reduction is observed when drought occurs during anthesis (Nezhadahmad *et al*., 2013). In field conditions, a one-degree rise can reduce up to 190 kg/ha (Bennett *et al*., 2012). Drought affects all the morphological, physiological, biochemical, and molecular aspects of the plant. Morphological effects include root depth, stomatal movements, and cuticle thickness (Bowne *et al*., 2012); change in hormonal composition and transpiration pattern comprises physiological effect (Nezhadahmadi *et al*., 2013); and several biochemical effects, such as accumulation of abscisic acid and pollen sterility leads to grain deformations and yield loss (Ji *et al*., 2010).

Most of the Nepalese farming system is solely based on rain. Wheat cultivation also depends on the limited rain of the winter. The problem of water scarcity predominantly reduces the wheat production in Terai, Inner-Terai, and Hilly areas of Nepal which lead to a slow increase in wheat productivity over the years. Varietal improvement to drought tolerance along with increased production can be accomplished by selection under drought conditions for maintaining the productivity. Therefore, there is a need to analyze and evaluate the new and diverse combination of genes to develop the advanced drought resistance/tolerance lines suitable for Nepalese farmers (Sharma *et al*., 1995).

The plant breeders should target to produce high drought-tolerant cultivars with improved yield attributing character to get yield. Production of a new variety is a must essential and initial step which is initiated through selection of potential germplasm that has genotypic differences for drought tolerance (Baenziger, 2016). Many breeding procedures follow this with kin attention to interaction among the genotypes, environment. Further, this can be characterized using statistical tools (Jat *et al*., 2017). The variety with the highest average yield in all the test environments alone cannot be used for recommendation to the farmers; analysis of the stability of variety in the environment that is G × E interaction and physiological basis is also to be studied (Vergas *et al*., 2001). Thus, stability analysis can be an effective tool to select genotypes for drought tolerance.

This research focuses on the stability of different genotypes in drought stress and normal field environment as yield is variable in a different environment (Mahak *et al*., 2002). The need is to find a stable genotype which yield constant across these environments. This is performed by understanding the interaction of genotype to the environment in both normal and stress conditions, thereby, the genotype with low fluctuation under a diverse environment is suitable (Hamada *et al*., 2007).

## Materials and Methods

***Experiment site***

The field experiment was conducted in the research field of the Institute of Agriculture and Animal Science, Siddharthanagar, Rupandehi. The field is at 27° 30′ N latitude and 83° 27′ E longitude at the altitude of 79 masl. It has a subtropical climate with hot summer with a maximum temperature range of 32℃ to 41 ℃ and cold winter with a minimum temperature range of 7 ℃ to 12℃ with a total annual rainfall of about 1700 mm.

The record of maximum and minimum temperatures, and the total rainfall during each fortnight was obtained from National Wheat Research Program, Bhairahawa which is presented in Fig. 1.

***Plant Material***

The research is conducted with 20 wheat genotypes collected from National Wheat Research Program, Bhairahawa which includes 15 Nepal Lines (NL), 3 Bhairahawa lines (BL), and two commercial varieties Gautam and Bhirkuti as check varieties. The complete set of genotypes with their entry name is given in Table 1.

***Design and layout of the experiment***

The experiment was conducted in Alpha Lattice Design with 20 genotypes in 5 blocks with a block consisting of 4 genotypes. Each genotype was randomized along with the blocks and replicated twice in irrigated as well as drought stress environments. The experiment was performed in 20 individual plots in a replication. The individual plots were 2.5 m in breadth and 4 m with an area of 10 $m^2$. Each plot was separated by 1m distance. The seed were sown in 10 continuous rows in each plot with a row-to-row distance of 25 cm.

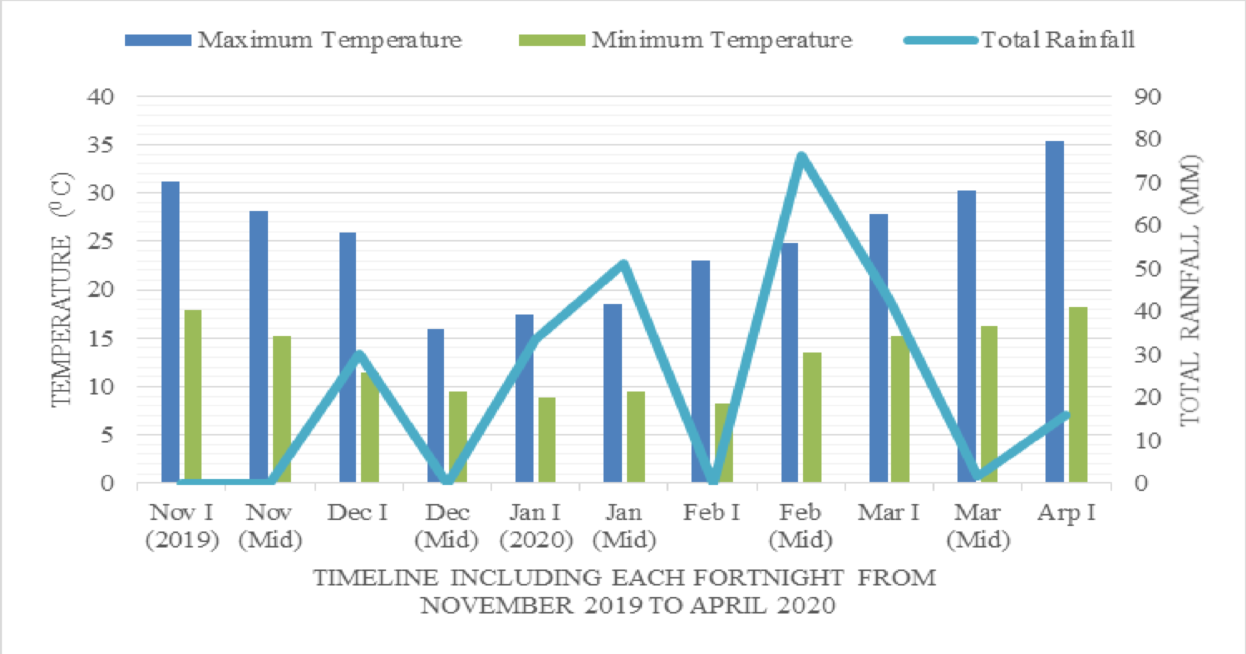



**Fig. 1**: Maximum and minimum temperature; and the total rainfall during November 2019 to April 2020 in the experiment field (Source: National Wheat Research Program, Bhairahawa).

**Table 1:** The names, origin of elite wheat lines as treatment

| **S.N.** | **Name of elite lines** | **Origin** | **Treatment** |
|---|---|---|---|
| 1. | Gautam | Nepal | $T_1$ |
| 2. | BL 4669 | Nepal | $T_2$ |
| 3. | NL1412 | CIMMYT, Mexico | $T_3$ |
| 4. | BL 4407 | Nepal | $T_4$ |
| 5. | NL 1368 | CIMMYT, Mexico | $T_5$ |
| 6. | NL 1417 | CIMMYT, Mexico | $T_6$ |
| 7. | Bhrikuti | CIMMYT, Mexico | $T_7$ |
| 8. | BL 4919 | Nepal | $T_8$ |
| 9. | NL 1376 | CIMMYT, Mexico | $T_9$ |
| 1O. | NL 1387 | CIMMYT, Mexico | $T_{10}$ |
| 11. | NL 1179 | CIMMYT, Mexico | $T_{11}$ |
| 12. | NL 1369 | CIMMYT, Mexico | $T_{12}$ |
| 13. | NL 1350 | CIMMYT, Mexico | $T_{13}$ |
| 14. | NL 1420 | CIMMYT, Mexico | $T_{14}$ |
| 15. | NL 1384 | CIMMYT, Mexico | $T_{15}$ |
| 16. | NL 1346 | CIMMYT, Mexico | $T_{16}$ |
| 17. | NL 1404 | CIMMYT, Mexico | $T_{17}$ |
| 18. | NL 1413 | CIMMYT, Mexico | $T_{18}$ |
| 19. | NL 1386 | CIMMYT, Mexico | $T_{19}$ |
| 20. | NL 1381 | CIMMYT, Mexico | $T_{20}$ |

T- Treatment

***Crop Management***

The first plowing was done 1-week prior sowing date, followed by harrowing. At sowing again, harrowing was performed, followed by leveling of each plot. Afterward, rows for planting were plowed manually. After field preparation and incorporation of a basal dose of fertilizer, seeds were manually sown and covered by fine tilled soil manually.

Farmyard manure was also incorporated during the initial plowing. The recommended doses of 100: 50: 25 NPK were applied in three split doses in form of urea, DAP, and Potash, respectively. The basal Dose- ½ dose of nitrogen, full dose of phosphorus, and potash was applied in each row during field preparation. First split dose- ¼ dose of nitrogen was applied 30 DAS and second split dose - ¼ dose of nitrogen was applied 70 DAS.

Normal irrigation of normal cropping was performed in fields under irrigated environment and irrigation towards the terminal growing season was escaped to get drought stress environment (Poudel *et al*., 2020a).

***Statistical Analysis***

MS Office 2013 was used for data entry and processing. The AMMI model with GGE bi-plots was used for analyzing the stability of genotypes in the irrigated and drought environment by using R software GEAR (version 4.0, CIMMYT, Mexico).

Additive Main Effect and Multiplicative Interaction (AMMI) model was used for the mean of the yield of the 20 elite wheat lines from both the environments using GEAR software. The AMMI model equation is:

$$Y_{ij} = \mu + \alpha_i + \beta_j + \sum_{n=0}^{N} \lambda_n \gamma_{in} \delta_{jn} + \theta_{ij} + \varepsilon_{ij} \text{ …….. (1)}$$

Where, $Y_{ij}$ = the mean yield of elite line i in environment j, $\mu$ = the grand mean of the yield, $\alpha_i$= the deviation of the elite lines means from the grand mean, $\beta_j$ = the deviation of the environment means from the grand mean, $\lambda_n$ = the singular value for the PCA n, N = the number of PCA axis retained in the model, $\gamma_{in}$ = the PCA score of an elite line for PCA axis n, $\delta_{jn}$ = the environmental PCA score for PCA axis n, $\theta_{ij}$ = the AMMI residual and $\varepsilon_{ij}$= the residuals. The degrees of freedom (DF) for the PCA axis were calculated based on the following method (Zobel *et al*. 1988).

DF=G+E–1–2n……………………………………..… (2)

Where, G = the number of elite lines, E = the number of environments, and n = the $n^{th}$ axis of PCA.

The Genotype main effect plus Genotype by environment interaction (GGE) biplot used principal component comprising a set of elite lines scores multiplied by environment scores which gives a two-dimensional biplot (Ding *et al*. 2008) and simultaneous study of the genotype plus genotype-environment interaction was performed.

## Results and Discussion

***AMMI Model***

Table 2 shows the combined analysis of variance for the grain yield of 20 elite wheat lines under drought and irrigated environments. Analysis revealed that genotype, environment, genotype-environment interaction was highly significant (p<0.001) for the grain yield, these explained 28.95%, 52.57%, and 18.47% of the effect on yield, respectively. Also, the first principal component itself was able to explain 100% of the effect on yield, and according to Gollob's F test, it was significant with p < 0.001.

Similar results of AMMI analysis with greater than 50% of the variation in yield is attributed to environment effect is reported by Nejad *et al*. (2019) and Munjal *et al*. (2020). These results are supported by the findings of Alexei *et al*. (2007) and Poudel *et al*. (2000b).

***AMMI Model***

Fig. 2 represents the biplot with principal component 1 in the ordinate and the grain yield of the 20 elite wheat lines in the abscissa with environment vectors (green). The AMMI biplot reveals the stable genotypes are close to the origin, while low stable lies far from the origin. Also, Fig. 2 shows elite lines NL 1387, NL 1412, BL 4919, NL 1368, NL 1346 are relatively stable lines in both the test environment while lines NL 1179, NL 1420, NL 1384, NL 1404, NL 1381, Gautam have low stability than the other tested lines. Moreover, elite line NL 1179 lies close to the irrigated environment indicates this line is specifically adapted to the irrigated environment, and lines NL 1417, NL 1412, BL 4669are more adapted to the drought environment.

The genotypes in a cluster in AMMI biplot behave similarly in the environment. The figure shows NL 1413, NL 1350, NL 1376, and NL 1386 in a cluster that behaves the same in irrigated as well as in drought environment (Fig. 2).

Munjal *et al*. (2020) also exploited the AMMI biplot to distinguish the stable and unstable genotypes across the environment. Similar concepts are used in the report of Alexei *et al*. (2007) and Poudel *et al*. (2020b).

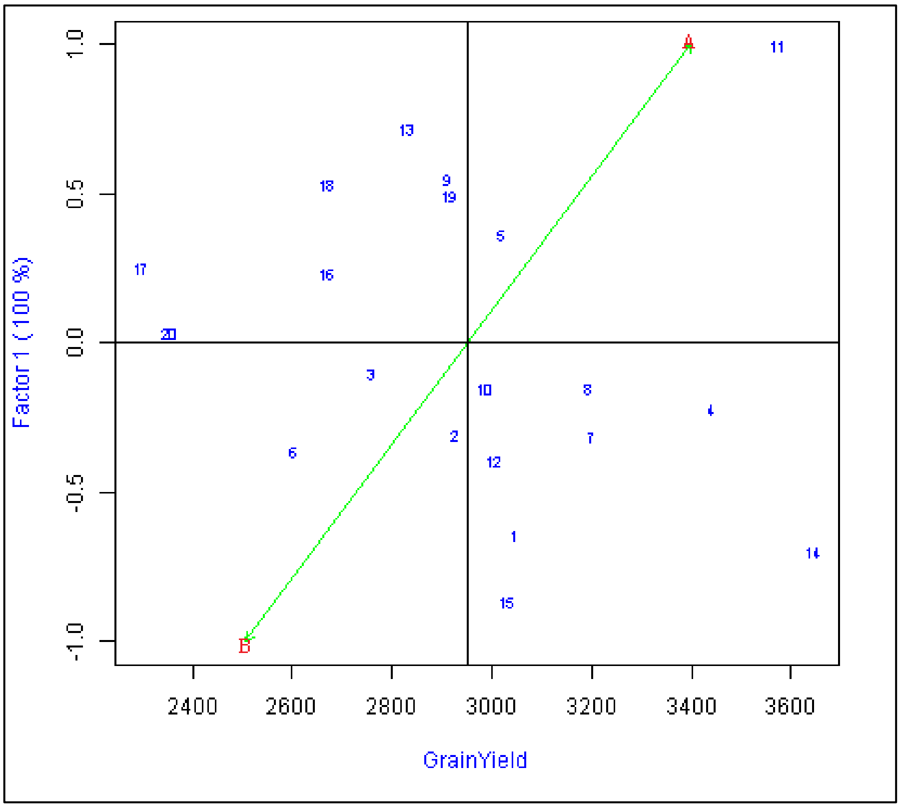
***GGE Biplots (Which-Won-Where Model)***

The polygon view of the GGE biplot revealed 6 sectors for the 20 elite lines and 2 sectors for the two test environments as shown in Fig. 3. Clearly, elite line NL 1179 is the vertex line of the sector with the irrigated environment (A) is the winning line; also elite lines NL 1368, NL 1376, NL 1386, NL 1350 lie in this sector which indicates these are responsive lines in irrigated environment. Similarly, elite line NL 1420 lies farthest from the origin, and at the vertex of the sector with drought environment (B) is the winning line. Also, elite lines BL 4407, BL 4919, BL 4919, NL 1387 are responsive in drought environment.

**Table 2:** The analysis of variance of grain yield using AMMI models

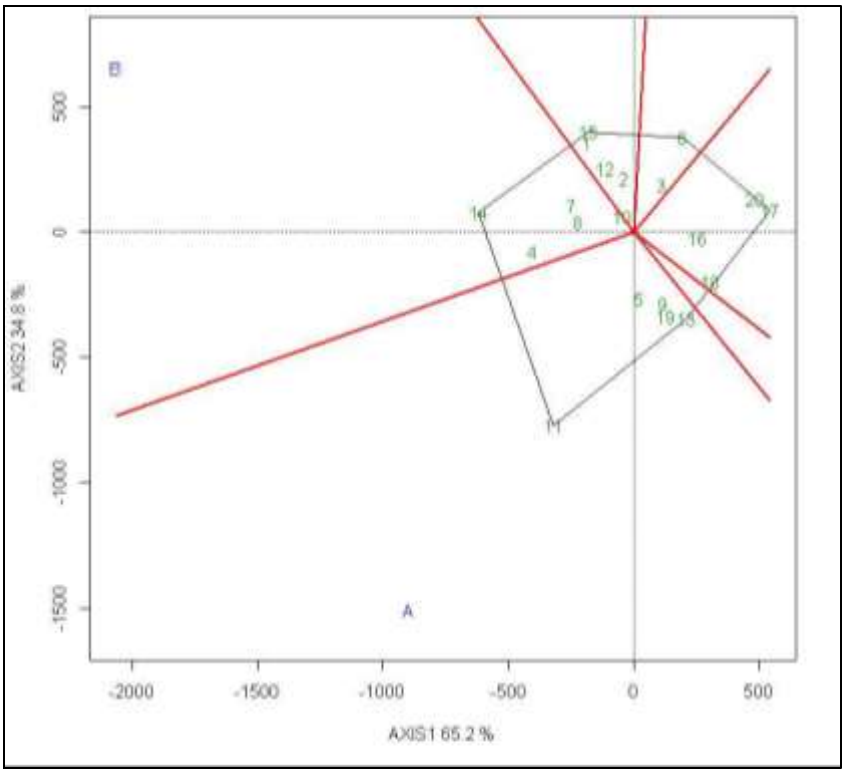
| | DF | SS | MS | F | % explained |
|---|---|---|---|---|---|
| ENV | 1 | 16961136.2 | 16961136.2 | 258.33*** | 52.57 |
| GEN | 19 | 9340535.5 | 491607.1 | 7.49*** | 28.95 |
| ENV*GEN | 19 | 5959341.3 | 313649.5 | 4.78*** | 18.47 |
| PC1 | 19 | 5931549.8 | 312186.8 | 5.70*** | 100.00 |
| Residuals | 40 | 2626306.0 | 65657.7 | NA | 0.00 |

DF- Degree of Freedom. SS – Sum of square, MS- Mean Sum of Square, ENV – Environment, GEN-Genotypes, ENV*GEN-Genotype-Environment Interaction, PC- Principal Component and '***'- Significant at p-value < 0.001.




1-20 – Treatments (1-20), A- Irrigated environment and B- Drought environment

**Fig. 2**: AMMI biplot PCA 1 versus grain yield of 20 elite wheat lines in terminal heat stress and irrigated environment.




1-20 – Treatments (1-20), A- Irrigated environment and B- Drought environment

**Fig. 3**: Polygon view of GGE biplot (which-won-where model) showing 20 elite wheat lines in irrigated and drought environment.

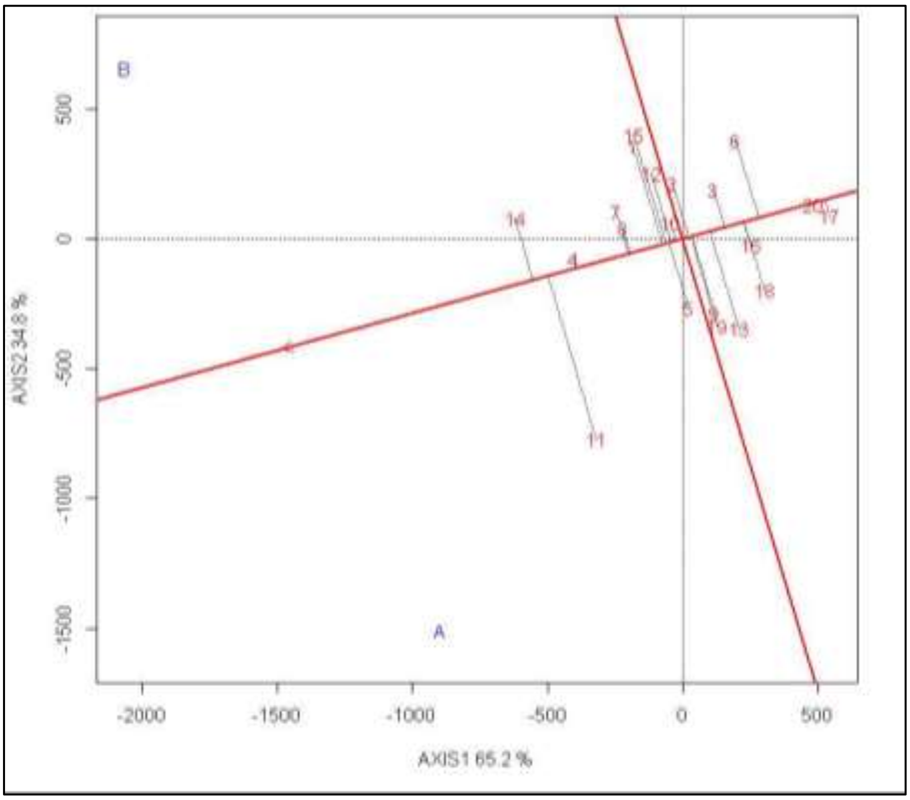
The model showed the elite lines Gautam, NL 1384, BL 4669, NL 1412, NL 1417, NL 1346, NL 1381, BL 4919, NL 1413 lies in the sector without the test environment indicating these lines have poor adaptation in both environments (Fig.3).

Yan *et al*. (2000) introduced that vertex genotype in a sector is the highest yielding. The concept is also demonstrated by Mungal *et al*. (2020) and Poudel *et al*. (2020b) to indicate the winning genotypes in the drought-stressed environment.

***Mean vs Stability***

The mean performance and stability of the elite lines are shown graphically with the help of Average Environment Coordinate (AEC) with the help of arrowhead in Fig. 4 (mean vs stability model). The model reveals that elite lines NL 1420, BL 4407, BL 4919, BL 4919, NL 1387 have higher than average yield and are comparatively stable while elite lines NL 1179, NL 1369, NL 1384, Gautam having higher than average yield but with low stability. Moreover, elite lines NL 1412, NL 1417, NL 1381, NL 1404 have lower than average yield and are comparatively stable while elite lines BL 4669, NL 1376, NL 1386, NL 1350, NL 1413, NL 1417 have both lower-than-average yield and low stability (Fig.4).

The mean vs stability view of the GGE biplot is also used by Apraku *et al*. (2016) to find the tolerant and above-average yielders genotypes. Using this view of GGE biplot is seen in reports of Poudel *et al*. (2020b).




1-20 – Treatments (1-20), A- Irrigated environment and B- Drought environment

**Fig. 4**: Mean vs. Stability view of GGE biplot showing the mean performance and stability of 20 elite wheat lines in irrigated and drought environments.

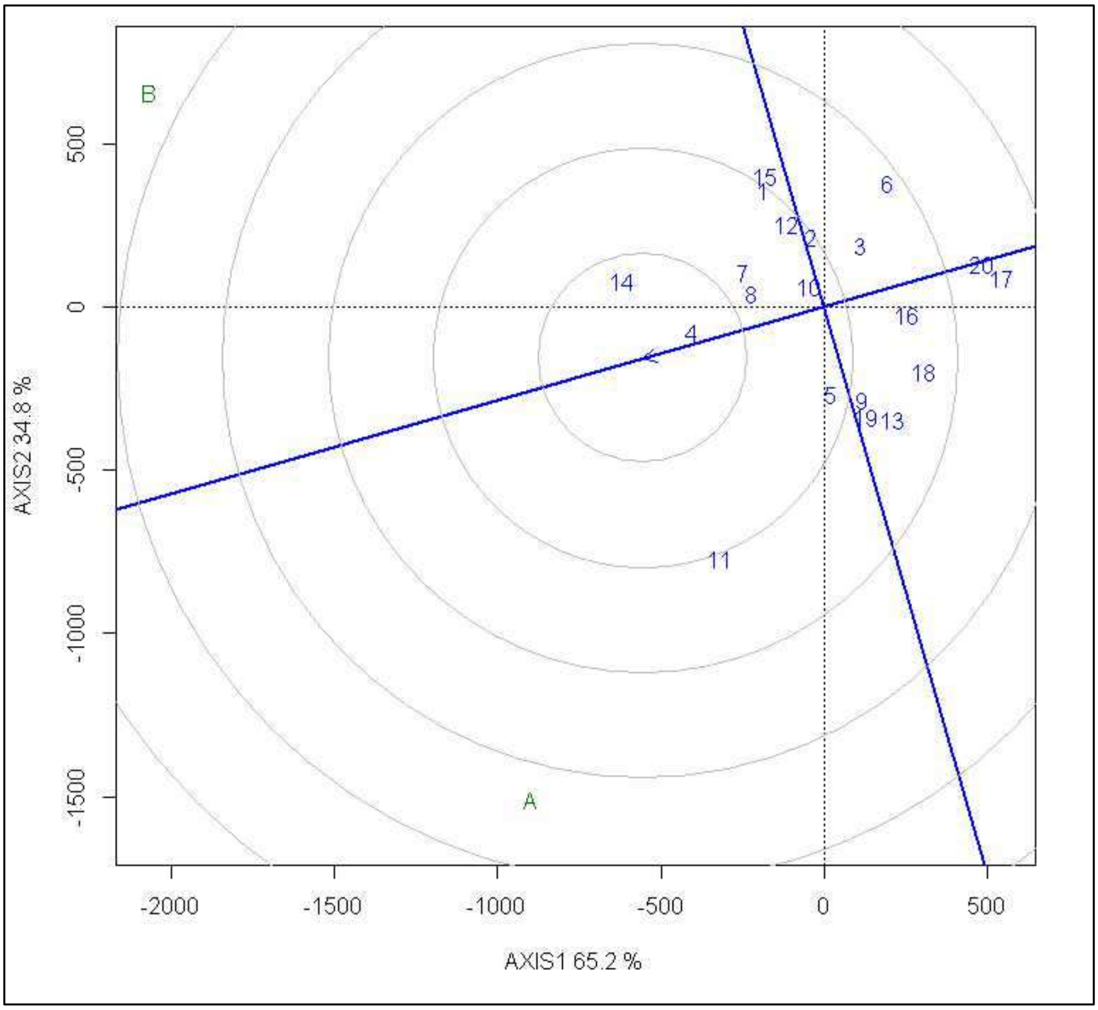
***Ranking Genotypes***

Ranking of genotypes is performed based on closeness to the ideal line represented by arrowhead and distance marked by concentric circles in Fig. 5. Although practically ideal lines are not possible, lines NL 1420 and BL 4407 close to the ideal can be used as reference lines for evaluation. The general ranking from the biplot for the desirability of the elite lines in the irrigated and drought environment is as:

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

The idea of the average environment coordinate (AEC) and concentric circle to find the desirability of the genotypes with respect to the ideal genotype was visualized by Yan and Kang (2003). The use of ideal genotypes is supported by Mungal *et al*. (2020) and Poudel *et al*. (2020b).

The comparison of biplot ranking and mean yield ranking of the genotypes in the combined environment (drought and irrigated environment) is given in Table 3.




1-20 – Treatments (1-20), A- Irrigated environment and B- Drought environment

**Fig. 5:** GGE biplot showing the ranking of 20 elite wheat lines with reference to the ideal line in irrigated and drought environments.

**Table 3:** Comparison of the rank of 20 elite wheat lines based on mean yield and biplot ranking

| **Ranks** | **Mean Yield Ranking** | **Biplot Ranking** |
|---|---|---|
| 1 | NL 1420 | BL 4407 |
| 2 | NL 1179 | NL 1420 |
| 3 | BL 4407 | BL 4919 |
| 4 | Bhrikuti | Bhrikuti |
| 5 | BL 4919 | NL 1387 |
| 6 | NL 1384 | NL 1179 |
| 7 | NL 1368 | NL 1369 |
| 8 | Gautam | NL 1368 |
| 9 | NL 1387 | NL 1384 |
| 10 | NL 1369 | Gautam |
| 11 | BL 4669 | BL 4669 |
| 12 | NL 1386 | NL 1376 |
| 13 | NL 1376 | NL 1386 |
| 14 | NL 1350 | NL1412 |
| 15 | NL1412 | NL 1350 |
| 16 | NL 1413 | NL 1346 |
| 17 | NL 1346 | NL 1413 |
| 18 | NL 1417 | NL 1417 |
| 19 | NL 1381 | NL 1381 |
| 20 | NL 1404 | NL 1404 |

## Conclusion

The present study concluded that grain yield is significantly affected by genotypes, environments, and genotype-environment interaction which explained 28.95%, 52.57%, and 18.47% out of total. The which-won-where model revealed that elite line NL 1420 is the most responsive line in the drought environment followed by BL 4407, BL 4919, Bhrikuti, and elite line NL 1179 is the most stable line in the irrigated environment. The mean vs stability model indicated that line NL 1420, BL 4407, BL 4919, Bhrikuti are both high-yielding and stable lines while line NL 1179 have low stability. Similarly, the ranking genotypes model ranks line BL 4407, NL 1420, BL 4919, Bhrikuti as the most representative line close to the ideal line. Both AMMI and GGE biplots conclude line NL 1387 as most stable line. Thus, for further evaluation of high-yielding stable lines across both irrigated and drought environments, elite line NL 1420 along BL 4407, BL 4919, Bhrikuti is recommended while line NL 1420 and NL 1179 are recommended as specifically adapted to drought and irrigated environment.

## Authors' contribution

Dipendra Regmi: Conception and design, data acquisition, analysis and interpretation of data, critical revision of the manuscript as for important intellectual content, final approval of the manuscript**.**

Mukti Ram Poudel: Conception and design, analysis and interpretation of data, critical revision of the manuscript as for important intellectual content, final approval of the manuscript**.**

Bishwas K.C.: Analysis and interpretation of data, drafting of the manuscript, critical revision of the manuscript as for important intellectual content, final approval of the manuscript**.**

Padam Bahadur Poudel: Conception and design, data acquisition, critical revision of the manuscript as for important intellectual content, final approval of the manuscript**.**

## Conflict of Interest

The authors declare no conflict of interest with this study.

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