Journal of
Innovative Agriculture

Research Article
DOI: https://doi.org/10.37446/jinagri/rsa/9.4.2022.22-31

AMMI and GGE biplot analysis of yield of different wheat varieties under irrigated and moisture-restricted environments

Bishnu Bhusal[1]*, Kushal Bhattarai[1], Mukti Ram Poudel[1], Nav Raj Adhikari[1], Deepak Pandey[2]

[1]Department of Plant Breeding and Genetics, Institute of Agriculture and Animal Science, Tribhuvan University, Kathmandu, Nepal.
[2]National Wheat Research Program (NWRP), Nepal Agriculture Research Council (NARC), Bhairahawa, Rupandehi, Nepal.

Received: 11 June 2022
Accepted: 26 October2022
Published: 31 December 2022

***Correspondence**
Bishnu Bhusal
mrbishnubhusal@gmail.com

Volume: 9
Issue: 4
Pages: 22-31

Wheat is an important winter cereal of Nepal but drought limits its production as 34.44% of wheat producing area is under non-irrigated environment. The identification of high yielding potential varieties with stable performance under drought environment may be the way forward to cope with limited productivity. So, in this study, the effect of genotype by environment interaction on yield of fourteen wheat varieties and two promising lines under two environmental conditions, irrigated and moisture-restricted environments were inspected. The research was carried out in a randomized complete block design with three replication in each environment. The result showed significant difference between grain yield in irrigated and moisture restricted environments. In irrigated environment, highest yield was obtained in BL 4341 and lowest yield was obtained in Gautam while in moisture restricted environment, highest yield was obtained in NL 1327 and lowest yield was obtained in Nepal 297. In moisture-restricted environment, grain yield was reduced by 43.28% in comparison with irrigated environment. The AMMI analysis revealed that genotype, environment, genotype-environment interaction was highly significant for grain yield, and these explained 15.78%, 71.55%, 12.66% of the effect on yield, respectively. The which-won-where polygon view of GGE biplot revealed that BL 4341 and NL 1327 as vertex varieties and

winning in irrigated and non-irrigated environment respectively. Furthermore, the mean-versus-stability pattern identified Bhrikuti as high yielding and stable variety while NL 1368 and Banganga were stable but produced below average yield. Similarly, from the ranking genotype pattern, we identified varieties Bhrikuti, BL 4341 and NL 971 to be close to the ideal variety respectively.

Key words: *adaptability, AMMI, environment, genotype, stability, stress, wheat*

INTRODUCTION

Wheat (*Triticum aestivum* L.), a member of poaceae family, is the world's foremost staple cereal grown in 219.01 million hectares with 760.92 million tons of production in 2020 (FAO, 2022). It is widely grown in diverse environments from tropical to temperate regions up to 4570 masl in Tibet (Tadesse et al., 2015). In Nepal, 2.13 million tons of wheat is produced in 0.711 million hectares of land in 2020/21 (MoALD, 2022). The trend analysis of wheat production in Nepal shows steady increase in productivity over a decade i.e. 2.12 t/ha in 2010 to 3.08 t/ha in 2020 but it is still below world average productivity, 3.54 t/ha (FAO, 2022). Nepal has wide variation in climatic condition due to its unique diverse topographical distribution; it experiences tropical climate in the southern part to artic climatic condition in north (Shrestha and Aryal, 2011). The climatic condition is dominated by Asian monsoon system which results in 70-85% of total precipitation in just four months from June to September (Shrestha and Aryal, 2011). This suggests that during wheat growing season, between November to April, country experiences little to no rainfall (Nayava et al., 2009). Only 35% of cultivated land receives year round irrigation, implying most wheat field experience moderate to high drought stress condition (MoALD, 2022). Drought is projected to be the major challenge in global food production because of global warming (Anwaar et al., 2020). Aadhar and Mishra (2019) predicted 3-5 degree Celsius increase in temperature of south Asia including Nepal by the end of 21st century. The increase in temperature will increase dryness which directly affects water resource and agriculture (Aadhar and Mishra, 2019). The development of high yielding varieties resistant to various biotic and abiotic stress is a way forward to cope with increasing desertification and producing more food (Anwaar et al., 2020). Agricultural scientist should aim at developing varieties that can cope with the various stresses. Furthermore, the available genotypes should also be evaluated for their performance across different environmental stress condition. AMMI and GGE biplot models are effective tools that have been used by the researcher to assess the performance and stability of genotype in specific environments. Therefore, the aim of this study is to identify varieties which have stable performance over different environments and to identify varieties which are specifically adapted to irrigated and moisture restricted environments via the use of AMMI and GGE biplots.

MATERIALS AND METHODS

The field work was conducted in the research field of Deurali Institute of Agro-tourism and Educational Research Center, West Nawalparasi, Nepal for the years 2020 and 2021. The fourteen released wheat varieties and two promising lines were used in experiment. The plant materials were provided by National Wheat Research Program (NWRP), Nepal (Table 1). The field trial consisted two different environments - moisture restricted and normal irrigated. In each environment, the trial was arranged in randomized complete block design with three replications. The plot size was 2m*1.5m, with row-to-row distance of 25cm and seeds were sown continuously in each row. The prescribed fertilizer, 100:50:25 kg NPK/ha in normal irrigated trial and 50:50:20 kg NPK/ha in moisture restricted environment, was used.

Table 1. Plant materials used in research

E.N.	Plant Materials	E.N.	Plant Materials
1	NL 971	9	Nepal 297
2	Vijaya	10	NL 1368
3	Gautam	11	BL 4341
4	NL 1307 (Borloug 2020)	12	Aditya
5	Dhaulagiri	13	Banganga
6	Swargadwari	14	Tilotama
7	NL 1367	15	NL 1327 (Zinc Gauh 1)
8	Bhrikuti	16	RR 21

Note: E.N. = Entry Number in the experiment, NL= Nepal Line and BL= Bhairahawa Line

In irrigated trial, complete dose of phosphorus and potassium and half of recommended nitrogen was used as basal dose during land preparation and other half was applied in two basal doses once at crown root initiation and other at booting stage. In moisture restricted environment, all fertilizers were applied as basal dose during land preparation. Hand weeding was done when needed. Ten sample plants from each plot, except from border rows, were selected and data were recorded from those sample plants. The parameters recorded during study followed the guidelines of the field guide to wheat phenotyping developed by CIMMYT (Pask et al., 2012). The parameters recorded are number of days to heading (DTH), number of days to maturity (DTM), SPAD, plant height (Ph), number of spikes/m^2(NSPM), number of spikelet per spike (NSPS), spike weight (SW), spike length (SL), number of grains per spike (NGS), thousand grain weight (TGW) and grain yield (YLD). The input and processing of data was done using Microsoft Office Excel 2013. The AMMI and GGE biplots were calculated using GEA-R - Genotype * Environment Analysis with R for Windows version 4.1 - software developed by CIMMYT.

RESULTS AND DISCUSSION

AMMI (Additive main effects and multiplicative interaction) model analysis

According to the AMMI model's analysis of variance, environment, genotype, and genotype by environment interaction all significantly ($p<0.01$) influenced yield, accounting for 71.54%, 15.79%, and 12.67% of the total variation, respectively. Moreover, it showed two principle component with PC1 explaining the 100% of the GE interaction (Table 2).

Table 2. The analysis of variance of grain yield using AMMI model

	DF	SS	MS	F	% explained
ENV	1	75329495	75329495	777.6***	71.54
GEN	15	16620512	432108034	11.44***	15.78
ENV*GEN	15	13338843	889256.2	9.18***	12.68
PC1	15	13338843	889256.2	9.36***	
Residuals	64	6199939	96874.05		

'***'= Significant at p-value <0.001, ENV = Environment, GEN = Genotype (Varieties), PC = Principal Component of AMMI, DF = Degree of Freedom, SS = Sum of Square, MS = Mean Sum of Square

AMMI model is used to accurately estimate yield and summarize the relationship between varieties and environment (Bocianowski et al., 2019). AMMI model revealed higher contribution of variation is due to environments which suggest diverse environment condition were taken under study. This results are in consistent with Bocianowski et al.,

(2019) and Mohammadi et al., (2018). In AMMI, the biplot abscissa indicates the main effect of yield and the ordinate represents the principal component. The genotypes that fall within the same vertical line have same yield and genotypes that fall within the same horizontal line have same interaction pattern (K.C. et al., 2021). Furthermore, varieties lying close to origin (zero) of PC1 are adoptable to different environment while varieties far from origin of PC1 are good for specific environment. In this study, figure 1 shows AMMI biplot of different varieties under two environments for grain yield. The different varieties were found similar based on their mean and interaction with the environment. In comparison to other varieties, varieties RR21, NL 1367, and Vijaya have a PC1 score or vector close to origin, indicating a lower interaction impact and therefore improved performance in both irrigated and moisture-restricted environments. The varieties Nepal 297, NL 1327, BL 4341, NL 971 are relatively inconsistent in yield as these varieties are distant from the origin and thus adopted to specific environments. Specifically, variety BL 4341 is adopted to irrigated environment and NL 1327 is adopted to moisture restricted environment.

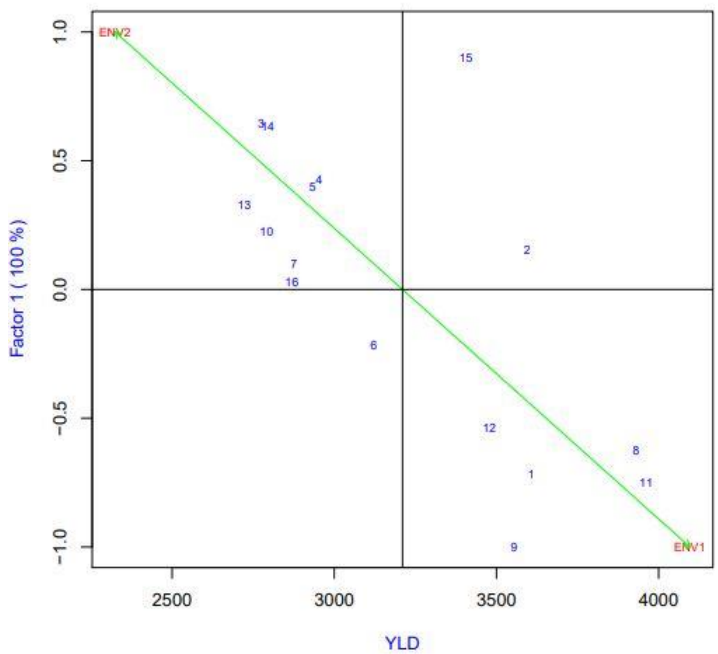

Figure 1. AMMI biplot PC1 versus grain yield of 16 wheat varieties in irrigated and moisture restricted environments

Furthermore, PC1 and PC2 scores help to identify the stability of varieties in different environments, the variety which has the least PC score is highly stable and vice versa (K.C. et al., 2021). In terms of PC1 score, Nepal 297, which has a score of -1, represents the most stable variety preceded by BL 4341 and NL971 with score of -0.747 and -0.716 respectively and PC2 score shows NL 1367 is most stable variety with score of $-8.8*10^{-9}$ followed by BL 4341 and swargadwari with score of $-6.5*10^{-9}$ and $-6.4*10^{-9}$ respectively.

GGE biplot analysis- 'which-won-where/what' pattern

'Which-won-where/what' biplot is an asymmetrical polygon made up of joining varieties that lies farthest from the origin and these varieties are known as vertex varieties (Yan and Kang, 2003). The longest vector is found in the vertex varieties, and it serves as a metric for how responsive they are to a given environment (Singh et al., 2019). Therefore, varieties lying farthest from origin are highly responsive to specific environment and variety lying close to origin have similar performance over variety of environments (Yan and Kang, 2003). The polygon view of which-won-where/what biplot pattern for yield is presented in figure 2. In the biplot, PC1 and PC2 explained 100% of the variation. The biplot is divided into seven sectors, with different varieties winning in different sectors. This signifies the occurrence of interaction effect between different varieties and environment for all the evaluated traits.

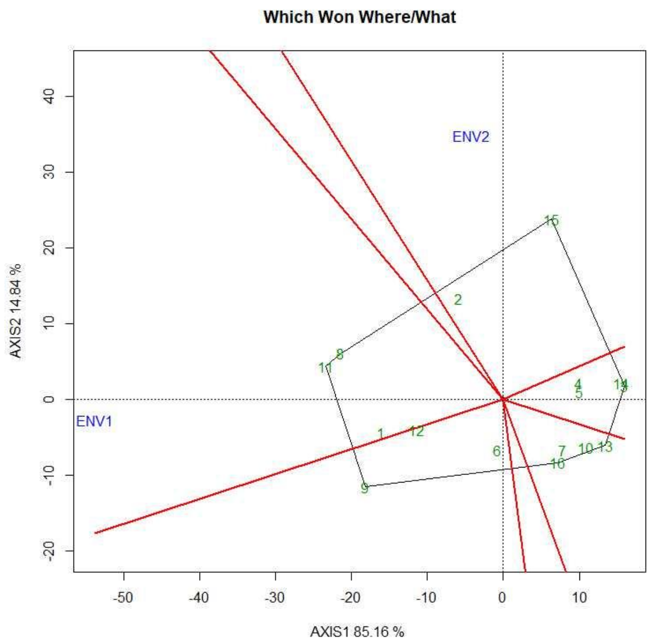

Figure 2. 'Which-won-where/what' pattern of GGE biplot polygon view showing the genotype main effect plus GE interaction effect of wheat varieties for yield. The biplots were based on centering=0, scaling = 0 and SVP = symmetrical.

The reference to varieties labels is presented in Table 1; ENV1 is normal irrigated environment and ENV2 is moisture restricted environment. The varieties BL4341 and Bhrikuti were responsive in irrigated environment and among them, the vector of BL 4341 was longest from the origin and also the vertex line of this segment which signifies that BL 4341 was specifically adopted in irrigated environment. Similarly, varieties NL 1327 and Vijaya were more responsive in moisture restricted environment and variety NL 1327 was the vertex of this segment which implies that NL 1327 was specifically adopted in moisture restricted environment. Therefore, the which-won-where/what pattern of the trial revealed that variety BL 4341 as winning variety in irrigated environment and variety NL 1327 as winning variety in moisture restricted environment. Similar to this research, Hagos and Abay (2013) and Singh et al. (2019) also used which-won-where/what model of GGE biplot to identify responsive varieties of wheat under normal and moisture restricted environments. Furthermore, Niak et al. (2022) and Rad et al. (2013) used GGE biplot for the evaluation of genotypes in different environmental conditions.

Mean vs. Stability

Mean vs. stability graph analyses the varieties based on mean performance and stability under different environments. It illustrates graph using Average Environment Coordinates (AEC) (Yan and Kang, 2003) . AEC, denoted by an arrowhead in figure 3, is the average of the environments' first and second principal component scores. Abscissa is the line in the graph going through the arrowhead and origin, while ordinate is the line perpendicular to abscissa at origin (K.C. et al., 2021). In abscissa, the arrow is pointed towards greater mean performance for yield. Those varieties which lies left from the origin produce above-average yield and those which lies right from the origin produces below-average yield (K.C. et al., 2021). The ordinate axis differentiate varieties based on stability. Greater the perpendicular ordinate length of varieties from abscissa, higher will be the variability and lower will be the stability among different environments (Poudel et al., 2020).

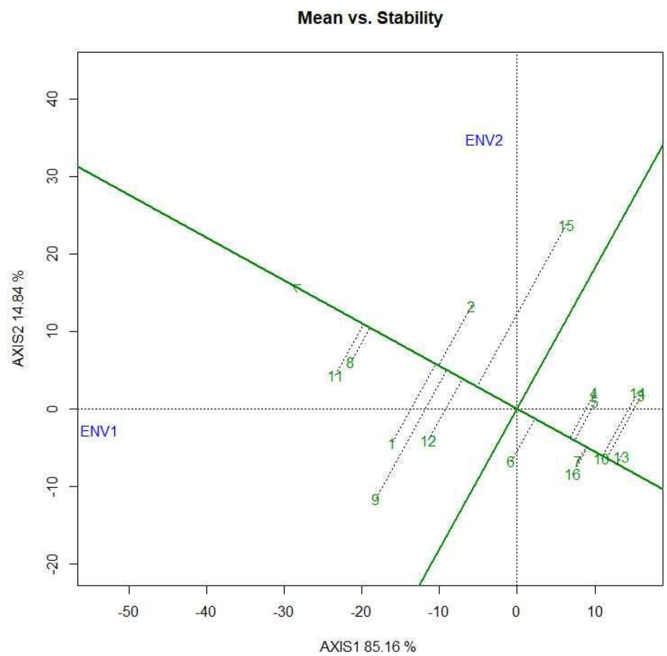

Figure 3. 'Mean vs. stability' pattern of GGE biplot polygon view showing the genotype main effect plus GE interaction effect of wheat varieties for yield. The biplots were based on centering=0, scaling = 0 and SVP = symmetrical. The key to genotype labels is presented in Table 1; ENV1 is normal irrigated environment and ENV2 is moisture restricted environment.

The varieties Bhrikuti and BL 4341 produced higher yield with greater stability whereas varieties NL 1327 and Nepal 297 also produced higher yield but with lower stability. Furthermore, NL 1368, Banganga and NL 1367 were stable but produced below-average yield and Gautam, Tilotama and NL 1307 were both less stable and produced below average yield.

Ranking Genotypes

Ranking genotypes is a biplot tool used to identify best ideal variety among tested varieties. The variety which lies close to the arrowhead in the innermost circle is the most ideal variety (Khan et al., 2021). In reference to the innermost variety, other tested varieties can be ranked based on their closeness to the innermost ideal variety (Bishwas et al., 2021). Bhrikuti was closest to the arrowhead which implies that it was the best leading variety relative to other varieties. It was followed by BL 4341, Vijaya, NL 971 which can be further used in breeding programs for selection of moisture restricted environment (Khan et al., 2021). The overall ranking of tested varieties based on the ideal genotype is Bhrikuti>BL 4341>Vijaya>NL 971>Aditya>Nepal 297>Swargadwari>NL 1327>NL 1307>Dhaulagiri>NL 1367>RR21>NL 1368>Banganga>Tilotama>Gautam.

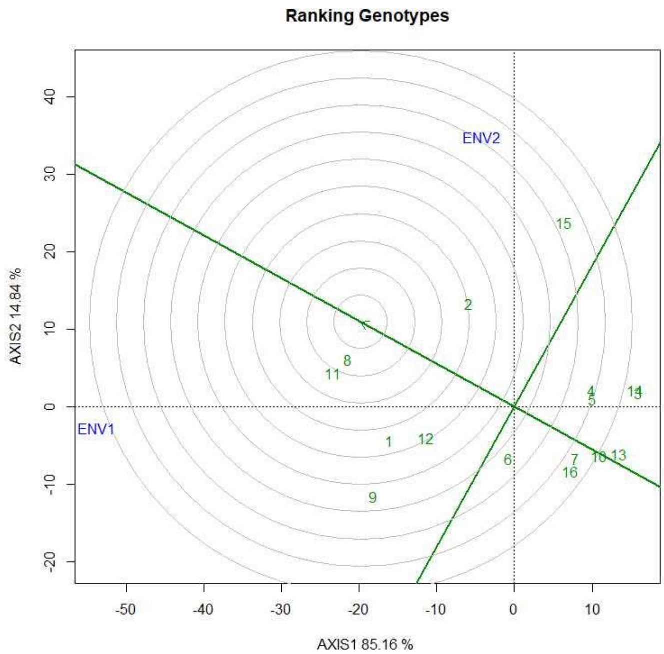

Figure 3. 'Ranking genotypes' pattern of GGE biplot polygon view showing the genotype main effect plus GE interaction effect of wheat varieties for yield. The biplots were based on centering=0, scaling = 0 and SVP = symmetrical. The key to genotype labels is presented in Table 1; ENV1 is normal irrigated environment and ENV2 is moisture restricted environment.

Discrimitiveness vs. representativeness

Discrimitiveness vs. representativeness pattern of GGE biplot was analyzed to identify best test environment to select superior varieties. Discrimitiveness helps to differentiate varieties in test environment while representativeness refers to an environment's ability to represent all the other tested environments (Hashim et al., 2021). The key to genotype labels is presented in Table 1; ENV1 is normal irrigated environment and ENV2 is moisture restricted environment. The longer vector of irrigated environment in figure 4 compared with moisture restricted environment implies that standard deviation was higher in irrigated environment compared with moisture restricted environment resulting in greater discriminating ability. The relationship between two environments is represented by angle between those two environments (K.C. et al., 2021). Since the angle between irrigated and moisture restricted environment was just below 90 degrees, these two environments have small positive correlation.

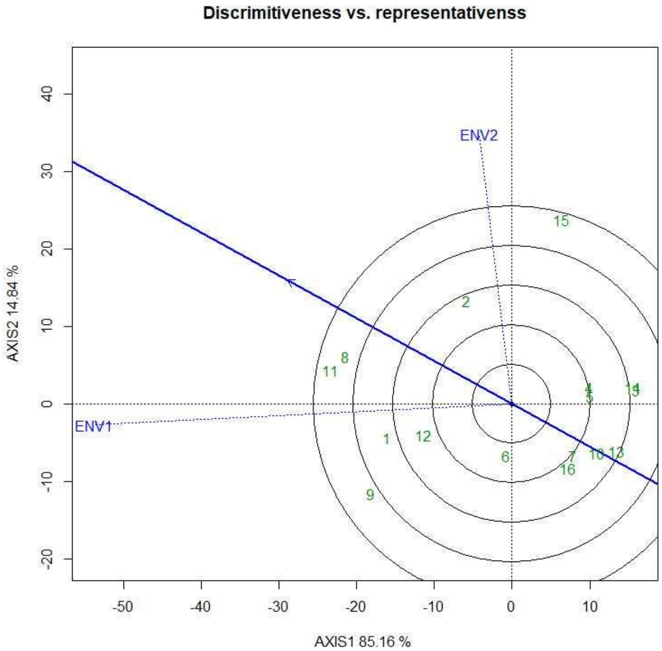

Figure 4. 'Discrimitiveness vs. representativeness' pattern of GGE biplot polygon view showing the genotype main effect plus GE interaction effect of wheat varieties for yield. The biplots were based on centering=0, scaling = 0 and SVP = symmetrical.

CONCLUSION

This study was conducted to examine wheat varieties on the basis of mean performance in multi-environmental trials (MET)-irrigated and moisture restricted environments. Based on results, the varieties are categories in three groups. Group one consists of highly stable varieties which are appropriate for both environments; the most stable variety on both environment was Bhrikuti followed by Vijaya and RR21. Group two consists of high yielding varieties but with lower stability, so they are suitable for specific environments. The most suitable varieties for irrigated and moisture restricted environment were BL 4341 and NL 1327 respectively. The third group consists of varieties that are highly stable but produce low yield. Varieties RR21, Banganga, NL 1367 fall in this category and these varieties can be used in breeding schemes to improve specific characters of high yielding varieties.

ACKNOWLEDGEMENT

The authors would like to acknowledge Deurali Institute of Agro-Tourism and Educational Research Center for physical and human resource support. We would also like to thank National Wheat Research Program, Bhairahawa, Nepal for providing planting material for research. We are also thankful to intern students and 10th batch students of Paklihawa Campus for their help in conducting research activities.

AUTHOR CONTRIBUTIONS

Conceptualization and designing of the research work (Bhusal, B.; Bhattarai, K.; Poudel, M.R.). Execution of field experiments and data collection (Bhusal, B.; Bhattarai, K.; Poudel, M.R.). Analysis of data and interpretation (Bhusal, B.; Bhattarai, K.; Poudel, M.R.). Preparation of manuscript (Bhusal, B.; Bhattarai, K.; Poudel, M.R.).

COMPETING INTERESTS

The authors have declared that no conflict of interest exists. The manuscript has not been submitted for publication in other journal.

ETHICS APPROVAL

Not applicable

REFERENCES

Aadhar, S. & Mishra, V. (2019). A substantial rise in the area and population affected by dryness in South Asia under 1.5 °C, 2.0 °C and 2.5 °C warmer worlds. *Environmental Research Letters, 14*(11), 114021.

Anwaar, H. A., Perveen, R., Mansha, M. Z., Abid, M., Sarwar, Z. M., Aatif, H. M., & Khan, K. A. (2020). Assessment of grain yield indices in response to drought stress in wheat (*Triticum aestivum* L.). *Saudi Journal of Biological Sciences*, *27*(7), 1818–1823.

K. C. Bishwas, Poudel, M. R., & Regmi, D. (2021). AMMI and GGE biplot analysis of yield of different elite wheat line under terminal heat stress and irrigated environments. *Heliyon*, *7*(6), e07206.

Bocianowski, J., Warzecha, T., Nowosad, K., & Bathelt, R. (2019). Genotype by environment interaction using AMMI model and estimation of additive and epistasis gene effects for 1000-kernel weight in spring barley (*Hordeum vulgare* L.). *Journal of Applied Genetices*, *60*(2), 127–135.

De Vita, P., Mastrangelo, A. M., Matteu, L., Mazzucotelli, E., Virzì, N., Palumbo, M., & Cattivelli, L. (2010). Genetic improvement effects on yield stability in durum wheat genotypes grown in Italy. *Field Crops Research*, *119*(1), 68–77.

Food and Agriculture Organization of the United Nations. (2022). Online Statistical Database. Retrieved from https://www.fao.org/faostat/en/#data/QCL

Hagos, H. G., & Abay, F. (2013). AMMI and GGE biplot analysis of bread wheat genotypes in the northern part of Ethiopia. *Journal of Plant Breeding and Genetics*, *1*(1), 12–18.

Hashim, N., Rafii, M. Y., Oladosu, Y., Ismail, M. R., Ramli, A., Arolu, F., & Chukwu, S. (2021). Integrating multivariate and univariate statistical models to investigate genotype–environment interaction of advanced fragrant rice genotypes under rainfed condition. *Sustainability*, *13*(8), 4555.

Hooshmandi, B. (2019). Evaluation of tolerance to drought stress in wheat genotypes. *Idesia*, *37*(2), 37–43.

Khan, M. M. H., Rafii, M. Y., Ramlee, S. I., Jusoh, M., & Al Mamun, M. (2021). AMMI and GGE biplot analysis for yield performance and stability assessment of selected Bambara groundnut (*Vigna subterranea* L. Verdc.) genotypes under the multi-environmental trails (METs). *Scientific Reports, 11*(1), 1–17.

Kumar, A., Verulkar, S. B., Mandal, N. P., Variar, M., Shukla, V. D., Dwivedi, J. L., & Raman, A. (2012). High-yielding, drought-tolerant, stable rice genotypes for the shallow rainfed lowland drought-prone ecosystem. *Field Crops Research*, *133*, 37–47.

MOALD. 2022. *Agriculture Diary*. Retrieved from http://aitc.gov.np/english/downloadsdetail /2/2019/19794382/

Mohammadi, R., Armion, M., Zadhasan, E., Ahmadi, M. M., & Amri, A. (2018). The use of AMMI model for interpreting genotype × environment interaction in durum wheat. *Experimental Agriculture*, *54*(5): 670–683.

Nayava, J. L., Singh, R., & Bhatta, M. R. (2009). Impact of Climate, Climate Change and Modern Technology on Wheat Production in Nepal: A Case Study at Bhairahawa. *Journal of Hydrology and Meterology, 6*(1) 1–14.

Niak, A., Wani, S. H., Rafiqee, S., Sofi, M., Sofi, N. R., Shikari, A. B., & Rahimi, M. (2022). Deciphering Genotype times Environment Interaction by AMMI and GGE Biplot Analysis Among Elite Wheat (*Triticum aestivum* L.) Genotypes of Himalayan Region. *Ekin Journal of Crop Breeding and Genetics, 8*(1), 41–52.

Oladosu, Y., Rafii, M. Y., Abdullah, N., Magaji, U., Miah, G., Hussin, G., & Ramli, A. (2017). Genotype × Environment interaction and stability analyses of yield and yield components of established and mutant rice genotypes tested in multiple locations in Malaysia*. *Acta Agriculture Scandinavica Section B: Soil and Plant Science*, *67*(7), 590–606.

Pietragalla, J., Mullan, D.M., & Reynolds, M.P. (2012). *Physiological Breeding II: A Field Guide to Wheat Phenotyping*. CIMMYT.

Poudel, M. R., Ghimire, S., Dhakal, K., Thapa, D. B., & Poudel, H. K. (2020). Yield Stability Analysis of Wheat Genotypes at Irrigated, Heat Stress and Drought Condition. *Journal of Biology and Today's World*, *9*(4), 1–10.

Rad, M. R. N., Kadir, M. A., Rafii, M. Y., Jaafar, H. Z. E., Naghavi, M. R., & Ahmadi, F. (2013). Genotype × environment interaction by AMMI and GGE biplot analysis in three consecutive generations of wheat (Triticum aestivum) under normal and drought stress conditions. *Australian Journal of Crop Science, 7*(7), 956–961.

Shrestha, A. B., & Aryal, R. (2011). Climate change in Nepal and its impact on Himalayan glaciers. *Regional Environmental Change*, *11*(1), 65–77.

Singh, C., Gupta, A., Gupta, V., Kumar, P., Sendhil, R., Tyagi, B. S., & Singh, G. P. (2019). Genotype x environment interaction analysis of multi-environment wheat trials in India using AMMI and GGE biplot models. *Crop Breeding Applied. Biotechnology*, *19*(3), 309–318.

Tadesse, W., Amri, A., Ogbonnaya, F. C., Sanchez-Garcia, M., Sohail, Q., & Baum, M. (2016). Wheat. In *Genetic and Genomic Resources for Grain Cereals Improvement* (pp. 81-124). Academic Press.

Yan, W., Hunt, L. A., Sheng, Q., & Szlavnics, Z. (2000). Cultivar evaluation and mega-environment investigation based on the GGE biplot. *Crop Science*, *40*(3), 597–605.

Yan, W., & Kang, M. S. (2003). GGE Biplot Analysis. In *CRC Press*.