Effect of Genotype by Environment Interaction (GEI), Correlation, and GGE Biplot analysis for high concentration of grain Iron and Zinc biofortified lentils and their agronomic traits in multi-environment domains of Nepal

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Abstract— *Lentil (Lens culinaris Medik. culinaris) is a cool season food legume contains the high quality of proteins and minerals. Selecting genotypes for high mean yield and yield stability has been a challenge for lentil breeders. The complexities of genotype × environment interaction (GEI) make selection difficult to identify the best performing and most stable genotypes. Therefore, this study was carried out to apply a GGE biplot and AMMI analysis model to evaluate the magnitude of the effect of GE interaction on grain yield of 25 lentil accessions at three environments during the year of 2016 and 2017 seasons in alpha-lattice design (5x5) with three locations and to evaluate relationships between test environments for identification of favorable genotypes for lentil production areas. Combined pooled mean analysis of variance for grain yield tested at three environments over the two subsequent years 2016 and 2017 showed that highly significant differences in genotypes, environment and G x E interaction effect indicating the possibility of selection for stable accessions. The stability of the assessed genotypes using some stability statistics derived from three types of statistical concepts (variance and regression analyses), AMMI (additive main effect and multiplicative interaction) analysis and GGE biplot (genotype main effects and genotype-by-environment interaction effects) models were applied to obtain good understanding of the interrelationship and overlapping among the used stability statistics. Research results showed that lentil accession WBL-77 (1451 kg ha-1) , RL-79(1446 kg ha-1) and PL-4(1429 kg ha-1) were the best performer and well adopted across the environments and over the years. AMMI analysis of variance for lentil grain yield (tha^{-1}) of lentil accessions tested at three environments over the years showed that 80.71% of the total sum of squares was attributed to environmental effects, only 8.38 % to genotypic effects and 10.90% to genotype × environment interaction effects. The partitioning of GGE sum of squares through the GGE biplot analysis showed that PC1and PC2 accounted 74.75%, and 25.24% of GGE sum of squares respectively over the years. Accessions ILL8006, RL-6, Shital, ILL3490 and simal were more close to the center point and indicated that stable across the environments. In another words, the genotypes which have low stability value (ASV) is said to be stable and the breeder chose the stable genotypes along with grain yield above the mean grand yield. In this experiment accessions RL-6(G-2) ranked 1st stability (ASV-0.53) followed by Simal (ASV-2.05), ILL-3490 (ASV-2.42) and Shital (ASV-2.72) and suitable for all environment.*

Keywords— ***Stability parameters, lentil, GGE biplot, AMMI-additive main effects and multiplicative interaction; ASV– AMMI stability value.***

I. INTRODUCTION

Lentil (*Lens culinaris* Medik. culinaris) is a cool season food legume and "the house of essential nutrients", contains the high quality and quantity of proteins (up to 35%) and minerals calcium, phosphoros, potassium, folic acids, iron, zinc, selenium and vitamins. Lentil is the fourth most important crop grown after rice, maize, wheat & millet in terms of area (MoAD, 2016). In Nepal, it is mostly eaten as dal (Concentrated soup) with rice besides various food preparations. Rice or wheat bread and dal are the best combination in daily dish of low income people of Nepal who cannot afford the animal products. Virtually the major proportion of rural people relies on lentil and other pulses for their nutritional security. It has diverse role in farming system which adds 42-75 kg biological nitrogen fixation. Lentil seed is rich in protein for human consumption, and lentil straw is a valued animal feed. It is also known as the exportable commodity, in 2016/17 lentil was exported in the value of USA $ 10 million from Nepal. It is grown as sole crop as well as mixed crop and intercropped with sugarcane, mustard, linseed, wheat, mango-orchard etc. In general, lentil is commonly grown as relay cropping system prior to rice harvest and in Nepal, still 0.24 million hectares of lands are rice fallows and has a great scope to vertical and horizontal expansion. In most lentils producing areas yield seems to be not more than one-half of potential yields while improved genotypes contribute to increase lentil production (Erskine, 2009). Lentil is adapted to low rainfall and is predominantly grown in the winter in regions (Sarker et al., 2003). Selecting genotypes for high mean yield and yield stability has been a challenge for lentil breeders. Yield is a quantitative trait while GxE interaction showed the yield stability and micronutrients heritability. It is also the interplay in the effect of genetic and non-genetic on development of any genotypes. Consequently Gx E interaction helps breeder to select the desirable varieties in the process of evaluation & increase efficiency of selection (Sabaghnia et al., 2008). It is reported the main environmental effects (E) and Genotype by Environment Interaction (GEI) as the most important sources of variation for the measured yield of crops. The yield is a combined result of the effects of the genotype (G), E and GE interaction. Environment is responsible more than 80% effects of the total yield variation, while Genotype and G x E interaction has small effect. Environmental factors include soil moisture, sowing time, fertility, temperature and day length which is strong influenced during the various stages of plant growth (Bull et al., 1992). Therefore GEI is an extremely important in the development and evaluation of plant varieties. Flores et al. (1998) compared 22 univariate and multivariate methods to analyze genotype by environment (GE) interactions. There are two possible strategies for interpreting GE interaction with univariate parametric methods including analysis of variance and simple linear regression analysis of cultivar yield. The requirement for stable genotypes that perform well over a wide range of environments becomes increasingly important as farmers need reliable production quantity (Gauch et al.,2008). Therefore, identifying most stable genotypes is an important objective in many plant breeding programs for all crops, including lentil. The performance of a genotype is determined by three factors: genotypic main effect (G), environmental main effect (E) and their interaction (Yan et al.,2007). Understanding genotype by environment (GE) interactions is necessary to accurately determine stability in lentil genotypes and help breeding programs by increasing efficiency of selection (Sabaghnia et al.,2008). The complexities of genotype × environment interaction (GEI) make selection difficult to identify the best performing and most stable genotypes (Yau, 1995). Thus, first we need to identify the stable genotypes for their yield and yield component traits. Stability of genotypes over wide range of environments is desirable and depends upon GEI (Ali and Sawar, 2008). AMMI analysis has been shown to improve both the post-dictive and predictive success of yield trials by altering the noise (random variation) from the data pattern, thereby improving predictive accuracy (Gauch and Zobel, 1988). Understanding the structure and nature of GEI is of utmost significance in crop improvement programs because the significant GEI can seriously impair efforts in selecting the superior genotypes (Danyaliet al., 2012). The objectives of this investigation were: to apply a GGE biplot and AMMI analysis model to evaluate the magnitude of the effect of GEI on grain yield of 25 high grain Fe and Zn lentil accessions tested across the three locations over the years and to evaluate relationships between test environments for identification of favorable genotypes for lentil production areas in terai agro-domains.

II. MATERIALS AND METHODS

2.1 Description of the Study Sites

G x E interaction trials were conducted at Grain Legumes Research Program (GLRP), Khajura, Banke at 81^0 37” East longitudes and 28^0 06” North latitude and an altitude of 181 meters above mean sea level, NMRP/NCRP, Rampur, Chitwan at 27^o 40′ N latitude, 84^o19′ E longitude at an altitude of 228m above mean sea level and RARS, Parwanipur at the latitude 27^0 4’40.9’’N and longitude $84^0$56’9.85”E as well altitude 75m above sea level for two consecutive cropping seasons (October 2016 to March 2017) in Nepal.

2.2 Plant Materials

For this study, 25 high grain concentrations of iron (Fe) and zinc (Zn) lentil accessions including local landraces was planted for phenotypic evaluation. Sources of these accessions were originated from SAARC countries (14 accessions: Nepal-7, India-6, Bangladesh-1) and ICARDA (11 accessions). Released lentil varieties Shital and Simal was used as a check.

2.3 Experimental Layout and Design

Present experiment was carried out in Alpha-lattice design (5 x 5) with three replications. A unit plot comprise 2-meter length row with a plot size of (3 m^2). The accessions were planted in the third week of October to 2^{nd} week of November. Seeds of each accession were distributed thoroughly to seed packets, representing number of rows of each plot size and then randomized plot numbers were assigned to each plot seed packets and arranged according to planned field- layout. Recommended agronomic practices were strictly followed for raising a good crop at all the testing sites. The crop was supplied as recommended dose of fertilizers @20:40:20 NPK during the final land preparation.

2.4 Data Collection

Quantitative traits were recorded on 10 randomly selected plants followed by IBPGR Descriptors (Anonymous, 1985). Data was recorded on plant basis for plant height (Plht cm), number of pods/plant (P/P), number of seeds/pod (S/P), number of seeds/plant (S/P), and seed weight/plant (SWPP) whereas Morphological parameters of quantitative data was recorded days to 50% flowering (DF), days to maturity (DM), above ground biomass (BY), 100-seed weight in gram (HSWT), seed yield/plant (SYPP), and *stemphylium* blight severity scored on a 1–9 scale (1–9 rating scale where 1 = highly resistant and 9 = highly susceptible) before flowering and after flowering was recorded on plot basis according to the Chen, 2007 that can be exploited for developing future breeding material in lentil breeding improvement program. Data for crop phenology, growth, yield and yield components were collected based on either from 10 randomly taken sample plants or from plants in net plot. Mean values of these samples were utilized to estimate the performance of each genotype for the traits under consideration.

2.5 Statistical Data Analysis

Plot means values was calculated for all traits and used for the analysis of variance (ANOVA). The estimation of genetic parameters was analyzed using R-stat version and GEA-R. Phenotypic and genotypic variances for the Alpha Lattice design (5 x 5) was computed for all traits based on the methods of Federer, 1961.

2.5.1 The GGE biplot

GEI is commonly observed by crop producers and breeders as the differential ranking of cultivar yields among locations or years (Samonte et al. 2005). Plant breeders conduct multi-location trial primarily to identify the superior accession for a target region and secondarily to determine whether the target region can be subdivided into different mega-environments (Yan et al. 2000).

Analysis of variance for genotype x environment interaction

Analysis of variance (ANOVA) was computed using Additive Main Effects and Multiplicative Interaction (AMMI) (Zobel et al., 1988; Guach, 1988) and regression models (Eberhart and Russell, 1966) for grain yield that exhibited significant mean squares for genotype and genotype by environment interaction. The GEI analysis of variance using Eberhart and Russell (1966) model was computed by GEA-R (Genotype by Environment Analysis with R) statistical software, while META-R (Multi-Environment Trial Analysis with R) and R-Stat version 3.5.3 statistical software was used to calculate ANOVA for AMMI (Zobel et al., 1988; Guach, 1988). The analysis of variance of each location (Annex i) and combined analysis of variance over locations (Annex ii) were done as per Gomez and Gomez (1984).

Specifically, for the data matrix Y= (yij); with response variables Yij, the ANOVA model is

$$Y_{ij} = \mu + \alpha_i + \beta_j + \phi_{ij} + \varepsilon_{ij}$$

where Yij is the yield of the genotype i in the environment j, μ is the overall mean, αi is the genotype (row) main effect, βj is the environment (column) main effect, ϕij is the specific genotype i (row) by the environment j (column) interaction, and εij is the error term of the model, where εij~iid N(0,δ2)

ANNEX 1
OUTLINE OF ANALYSIS OF VARIANCE FOR A SINGLE LOCATION

Source of variation	Degree of freedom	Sum of square	mean square	F value Expected mean Square
Block(R)	(r-1)	$(r-1)^2$	MSr	-
Genotypes	(g-1)	$(g-1)^2$	MSg	$\sigma^2_e + r\,\sigma^2 g$
Error	(r-1) (g-1)	$(r-1)^2 (g-1)^2$	MSe	σ^2_e

Where: r= no. of blocks; g = number of genotypes; e = error; MSr= replication mean square; MSg= genotype mean square; MSe= error mean square

The combined analysis was done using mixed linear model as outlined in Annex ii to examine the additive and interaction effects of genotypes and environments.

ANNEX 2
THE OUTLINE OF THE COMBINED ANALYSIS OF VARIANCE OVER LOCATIONS

Source of variation	Degree of freedom	mean square	F value Expected mean Square	F-ratio
Environment (E)	e-1	MSE	$\sigma^2e + r\sigma^2g{*}e + gr\ \sigma^2e-$	MSl/MSr
Blocks in Loc[R]	1(r -1)	MSr	$\sigma^2e + g\sigma^2R(L)$	MSr/MSe
Genotype (G)	g-1	MSg	$\sigma^2_e + r\ \sigma^2g{*}e + r\Sigma\alpha i^2/g-1$	MSg/MSe
G * E	(g-1)(e-1)	MS ge	$\sigma^2_e + r\sigma^2ge$	MSge/MSe
Pooled error (e)	1(g-1)(r-1)	MSe	σ^2_e	
Total	1rg-1			

Where: E= number of locations; G = number of genotypes; r= number of blocks; MSE=environment mean square; MSr= block mean square; MSg= genotype mean square; MSGxE= GxE mean square; MSe=error mean square; σ²=Variance

2.5.2 AMMI model

The model AMMI uses the biplot constructed through the principal components generated by the interaction environment-genotype. If there is such interaction, the percentage of the two principal components would explain more than the 50% of the total variation; in such case, the biplot would be a good alternative to study the interaction environment-genotype, Crossa (1990).

The AMMI model is

$$Y_{ij} = \mu + \alpha_i + \beta_j + \sum_{k=1}^{t} \lambda_\kappa \xi_{ik} ή_{ik} + \varepsilon_{ij}$$

where t is the number of SVD axes retained in the model, λk is the singular value for the SVD axis k, ξ_{ik} is the singular value of the genotype i for the SVD axis k, $ή_{jk}$ is the singular value of the environment j for the SVD axis k, and ε_{ij} is the error term of the models, where $\varepsilon_{ij} \overset{iid}{\sim} N(0,\delta^2)$.

We used GGE biplot to indicate any possible specific adaptations of accessions to these environments instead of evaluating the slopes. The basic model for a GGE biplot is:

$$Y_{ij} - \mu - \beta_j = \sum_{k=1}^{K} \lambda_\kappa \xi_{ik} ή_{ik} + \varepsilon_{ij}$$

Where Yij = the mean yield of genotype i (= 1,2,...,g) in environment j (= 1,2,...e), μ = the grand mean, β_j = the main effect of environment j, $(\mu+\beta_j)$=mean yield of environment j, λk =the singular value (SV) of kth principal component (PC), ξ_{ik} = the eigen-vector of genotype i for PCk, η_{jk} = the eigen-vector of environment j for PCk, K is the number of PC axes retained in the model (K ≤ min (g,e) and K = 2 for a 2-dimensional biplot) and ε_{ij} =the residual associated with genotype iin environment j.

2.5.3 Stability Analysis

The stability parameters are useful in characterizing genotype by showing their relative performance in various environments. This parameters we can calculate as follows.

A linear regression model with interaction genotype by environment is like:

$$Y_{ij} = \mu + d_i + (1 + \beta_i)e_j + \delta_{ij} + \varepsilon_{ij}$$

Where, Yij is the average phenotypic value of the i-th genotype in the j-th environment, μ is the general mean, di is the effect of the i-th genotype (i=1,...,t), ej is the effect of the j-th environment (j=1,...,s), 1 + βi is the regression of Y_{ij} in e_j, δ_{ij} is the deviation of the regression for the i-th genotype in the j-th environment, εij is the error. GEA-R (Genotype x Environment Analysis whith R for Windows) Version 2.0 was used to construct GGE biplot graph.

2.5.4 Pearson correlation coefficient

Principal component analyses (PCA) based on the correlation matrix was performed to obtain an understanding of the relationship among stability parameters. To correlate the relationship in between lentil lines and quantitative traits like days to 50% flowering, plant height, 100 seed weight and grain yield were evaluated using Pearson correlation coefficient using BLUPs (Best Linear Unbiased Predictors) of single environment as well as across the environments.

III. RESULTS AND DISCUSSION

3.1 Weather patterns

Development of lentil plant is exceptionally touchy to climate conditions, particularly precipitation, high temperature and early frost. Precipitation in the wake of blossoming favors vegetative development. Unnecessary wet conditions at the time of planting delay it's planting, which results in the late advancement of lentil plant, leaving the crop defenseless against summer heat. High temperature stresses flowers, resulting in no podding or potentially excessive flowers and pod shedding. Late planting may likewise bring about insufficient root advancement and stemphyliun disease incidences and the vulnerability of crop to early frost in the fall.

Average monthly mean temperature during the growth period varied among the three environments. Khajura in 2017 had a hotter trimming season than Rampur and Parwanipur. . Anyway the mean temperature in the two years over the situations played out similar patterns (16-28.8 ^{0}C). During the two years of study, rainfall distribution varied among the environments. In 2016, Parwanipur got 260 mm of precipitation when contrasted with 202 mm in Rampur and 48.1 mm in Khajura. The major rainfall distribution difference was in the months of October received about 4 times higher rainfall as compared to Khajura). In 2017, Parwanipur, Khajura and Rampur received rainfalls of 204.2, 99.2 and 87.5 mm, respectively. Overall Parwanipur received much higher rainfall especially in both years as compared to other locations (Annex i). These weather conditions have an impact on the results obtained which are covered during discussion.

3.2 Pooled mean yield analysis of variance of twenty five high Fe and Zn grain biofortified lentil accessions tested at three environments

Pooled mean analysis of variance (ANOVA) for grain yield tested at three environments over the two subsequent years 2016 and 2017 showed that highly significant differences in genotypes, environment and G x E interaction effect (Table 1). From the study , it was concluded that accession WBL-77 (1451 kg ha^{-1}) , RL-79(1446 kgha^{-1}) and PL-4(1429 kgha^{-1}) were the best performer and well adopted across the environments while accessions ILL-7723 (970 kg ha^{-1}) and ILL-4605 (1076 kg ha^{-1}) were the poor performer and adopted in location specific. In Box and Whisker plot graph clearly also indicated that there was large variation of grain yield performances of lentil accessions tested in three environments over the years. Lentil accessions WBL-77 showed the highest yield in the graph followed by RL-79 and PL-4 than the check sagun (Fig. 1)

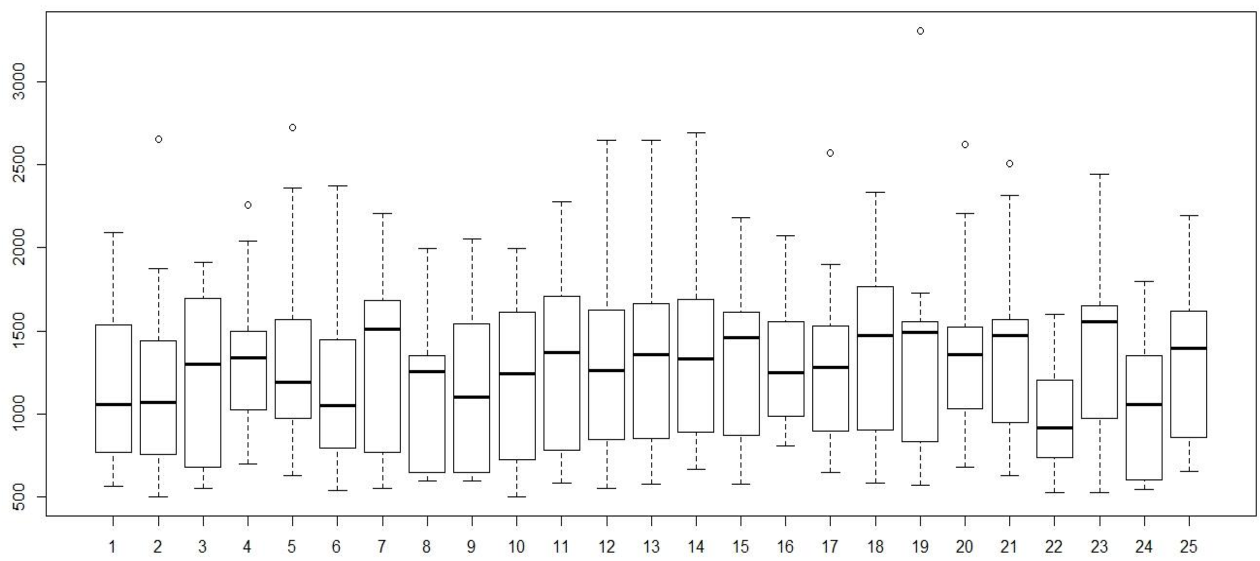


FIGURE 1: Combined mean yield analysis in Box and Whisker plot tested at three environments over the years 2016-2017

TABLE 1
COMBINED ANALYSIS OF MEAN PERFORMANCES OF LENTIL ACCESSIONS IN G X E BIO-TRIAL ACROSS THE LOCATIONS (KHAJURA, PARWANIPUR AND RAMPUR) AND OVER THE YEARS (2016-2017)

Gen	Names	DF	DM	Plht(cm)	PP	SP	HSWT	GY
1	ILL-8006	60	128	40	62	1.89	1.78	1188
2	RL-6	58	127	39	67	1.89	1.67	1206
3	RL-12	58	128	39	57	1.94	1.72	1270
4	ILL-7715	59	129	40	61	2.00	1.78	1301
5	ILL-7164	62	130	40	57	1.94	1.78	1316
6	ILL-3490	58	127	39	70	1.94	1.44	1136
7	Khajura-2	59	127	39	62	2.00	1.72	1326
8	Simal	58	129	41	62	1.94	1.78	1144
9	Shital	56	125	37	70	2.00	1.67	1134
10	Sagun	58	127	39	71	1.94	1.56	1209
11	HUL-57	58	129	42	55	2.00	1.78	1299
12	LG-12	58	128	40	59	2.00	1.72	1337
13	**PL-4**	58	129	40	67	2.00	2.22	1429
14	RL-11	58	129	39	65	2.00	1.61	1364
15	RL-4	59	130	40	64	2.00	1.83	1276
16	ILL-2712	60	129	38	59	2.00	1.61	1305
17	Black Masuro	67	134	40	66	2.00	1.61	1338
18	**RL-79**	56	124	40	62	2.00	2.11	1446
19	ILL-6467	60	131	45	63	2.00	1.67	1380
20	ILL-7979	56	130	37	68	1.94	1.78	1393
21	**ILL-6819**	59	130	40	59	2.00	1.72	1383
22	ILL-7723	60	136	39	52	1.94	1.94	970
23	**WBL-77**	57	129	42	56	2.00	1.89	1451
24	ILL-4605	58	127	38	65	1.94	2.89	1076
25	RL-49	54	122	39	64	1.83	2.61	1356
	Mean	59	129	40	62	1.97	1.84	1281
	P-Value							
	Genotypes	<0.001	<0.001	0.021**	0.35	0.29	<0.001	<0.001
	Environment	<0.001	<0.001	<0.001	<0.001	0.038*	<0.001	<0.001
	GxE	<0.001	0.95	0.066*	0.29	0.038*	0.037*	0.003**
	CV%	12.74	4.70	14.49	33.24	9.50	24.03	26.32
	LSD	5.09	4.08	2.84	13.79	0.11	0.277	225.61

3.3 Additive main effects and multiple interactions (AMMI) analysis

Results of AMMI analysis of variance for lentil grain yield (tha^{-1}) of twenty five lentil accessions tested at three environments over the years showed that 80.71% of the total sum of squares was attributed to environmental effects, only 8.38 % to genotypic effects and 10.90% to genotype × environment interaction effects (**Table 2**). The partitioning of GGE sum of squares through the GGE biplot analysis showed that PC1and PC2 accounted 74.75%, and 25.24% of GGE sum of squares respectively over the years. The two principal components explained a total of 99.99% variation. The average grain yield of each environment and accessions over the years 2016-2017 are given in **Table 3**. Environment grain yield ranged from 769 kg ha^{-1} (Parwanipur) to 1626 kg ha^{-1} (Khajura), while genotype grain yield ranged from 970 kg ha^{-1} (ILL-7723) to 1451 kg ha^{-1} (WBL-77). Also, results of AMMI analysis indicated that both AMMI PC1 and AMMI (PC2) were found non-significant. In the biplot, a total fifteen lentil accessions namely PL-4, RL-11, ILL-6819, ILL-7979, WBL-77, HUL-57, ILL-

7715, ILL-6467, ILL-7164, LG-12, ILL-2712, Black Masuro, Khajura-2, RL-79 and RL-49 and two environments (Khajura and Rampur) located on the right side of the black vertical line (Figure 2).

TABLE 2
AMMI ANALYSIS OF VARIANCE FOR GRAIN YIELD OF 25 LENTIL ACCESSIONS TESTED IN THREE ENVIRONMENTS OVER THE YEARS 2016- 2017

	SS	PORCENT	PORCENAC	DF	MS	F	PROBF
ENV	61407926	80.7139	80.7139	2	30703963	302.3473	0
GEN	6376975	8.38183	89.09573	24	265707.3	2.61647	0.00007
ENV*GEN	8296077	10.90427	100	48	172834.9	1.70194	0.00372
PC1	3100841	74.7544	74.7544	25	124033.7	1.21197	0.22479
PC2	1047197	25.2456	100	23	45530.3	0.44489	0.98857
PC3	0	0	100	21	0	0	1
Residuals	38081993	0	0	375	101552	NA	NA

TABLE 3
AMMI ANALYSIS OF VARIANCE FOR POOLED MEAN GRAIN YIELD OF 25 LENTIL ACCESSIONS TESTED AT THREE ENVIRONMENTS AND OVER THE YEARS 2016-2017

	TYPE	NAME	YLD	DIM1	DIM2	DIM3
1	GEN	1	1187.5	-0.17471	-0.0186	-4.2E-05
2	GEN	10	1209.222	-0.23513	0.223462	-5.9E-05
3	GEN	11	1299.167	0.231725	0.170429	-5.4E-05
4	GEN	12	1336.889	0.155857	0.314179	-6.4E-05
5	GEN	13	1429.222	0.674001	0.539839	2.94E-05
6	GEN	14	1364.222	0.542952	-0.15662	7.7E-05
7	GEN	15	1276.389	0.577529	0.000629	-4.2E-05
8	GEN	16	1305.389	-0.20384	-0.57267	-4.2E-06
9	GEN	17	1337.944	-0.42274	0.096082	5.68E-05
10	GEN	18	1446.222	-0.91191	0.581784	2.2E-05
11	GEN	19	1379.722	0.160574	0.37275	3.94E-05
12	GEN	2	1205.944	-0.02759	-0.01218	6.54E-05
13	GEN	20	1393.167	0.501999	-0.23486	-2.5E-05
14	GEN	21	1383.056	0.318877	-0.24163	-2.6E-05
15	GEN	22	969.7778	-0.55258	-0.7471	6.81E-06
16	GEN	23	1451	0.370912	0.274479	4.68E-05
17	GEN	24	1076	-0.54732	-0.23913	7.96E-05
18	GEN	25	1356.222	-1	0.165491	-5.7E-05
19	GEN	3	1269.778	-0.04115	0.278227	-6.2E-05
20	GEN	4	1301.167	0.203554	-0.38733	-1.6E-05
21	GEN	5	1316.278	0.216272	-0.34748	-1.9E-05
22	GEN	6	1135.889	0.107905	-0.14515	-3.3E-05
23	GEN	7	1326.333	-0.0568	0.313729	4.29E-05
24	GEN	8	1144.278	0.013274	-0.14325	-3.3E-05
25	GEN	9	1134.444	0.098347	-0.08508	7.08E-05
26	ENV	Khajura	1626.253	1	0.343942	-8.7E-05
27	ENV	Parwanipur	769.1267	-0.10927	-0.83216	-8.7E-05
28	ENV	Rampur	1448.847	-0.89073	0.488217	-8.7E-05

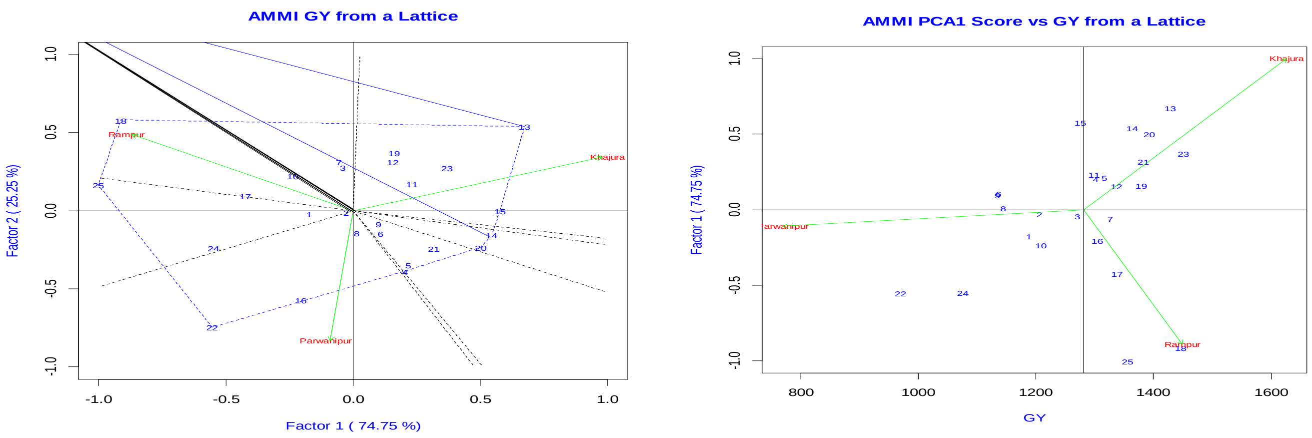


FIGURE 2: AMMI PCA 1 score vs GY from lattice tested at three environments over the years 2016-2017

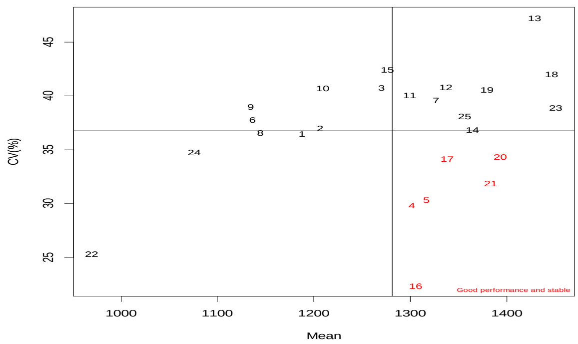


FIGURE 3: Stability and high yield accessions based on Plot CV over the years 2016-2017

Accordingly, the AMMI1 graph shows that accessions Khajura-2 and RL-12 stood out with the lowest PCA1 scores (Figure 12). This indicates that these were least involved with the interaction, and are therefore the most stable. However, only the yield of lentil accession Khajura-2 had high than the RL-12. On the other hand, the accessions WBL-77 and PL-4 were found the most unstable, however WBL-77 had with the highest average yield. Rampur environment stood out with a small contribution to the interaction and with a high contribution (Khajura) (Figure 3). Environments Rampur and Khajura averages were recorded above the overall averages (1281 kg ha^{-1}), indicating that these were favorable environment to obtain high means. The most ideal accessions should combine high yield and stable performance across a range of production environments. Among the high yielding accessions ILL-7979, ILL-6819, ILL-7715, ILL-2712, ILL-7164 and Black Masuro can be best evaluated based on stability and good performance of grain yield with combined low absolute PC1 score and high yield (Figure 3).

3.4 Stability coefficient analysis of different parameters in AMMI model

In the study over the years, lentil accessions Shital, ILL-7979, RL_6, RL-11 and Sagun (bi=0.9752-1.07) were found to be biologically stable which can be adapted to all the environments. Based on the value of Eberhart and Russel mean square deviation (S_2di) resulted from stability coefficient -35689.79 to -6012.4454) consequently lentil accessions RL-6, Simal, ILL-2712, ILL-6467, LG-12, RL-12, Shital, Khajura-2, ILL-3490, ILL-8006, HUL-57, Sagun, ILL-7715, ILL-7164 , WBL-77 , ILL-6819 and ILL-7723 were found to be stable and adapted to all environments. Based on the value of determination of the coefficient (R_2), lentil accessions RL-49, RL-79, ILL-7723 and ILL-4605 were found to be agronomic stable across the environments over the years. Based on the smaller values of variation coefficient (CV), lentil accessions ILL-2712, ILL-7723, ILL-7715 and ILL-7164 had small values in the ranges (22.38-30.38%) and therefore these accessions were found to be biologically stable across the environments over the years 2016-2017. Based on the small values (-1147.50) of Shukla's variance (ri^2), lentil accessions RL-6 was found to be agronomic stable across the environments over the years. Perkin and Jink's (1968) regression coefficient is similar to the FW method but the observations are adjusted for site effects before the regression is invoked. Based on the smallest values (127.56 -454.56) of Perkin's and Jinks(DJ$_i$) lentil accessions RL-6 and Simal were found to be stable across the environments over the years. Wricke's (1962) ecovalance (W2) stability parameter gives the relative contribution of each genotype in a test of total GE interaction. Based on the lowest values (193.05) of Wricke's Ecovalence (W), lentil accessions RL-6 was found to be stable and well adapted across the environments over the years. Based on the Superiority Measure (Pi) increased the stability if it has small values (39457.39-51215.09), lentil accessions WBL-77 and ILL-6467 were found to be stable and well adapted across the environments over the years 2016-2017 (Table 4).

TABLE 4
STABILITY COEFFICIENT ANALYSES FOR GRAIN YIELD (KGHA-1) TESTED AT THREE ENVIRONMENTS OVER THE YEARS 2016-2017

		*	*	Francis	Eberhart &Russell	*	*	Shukla	Perkins &Jinks	*	Wricke's Ecovalence	Superiority Measure
GEN	Names	Mean	Sd	CV(%)	bi	S2di	R2	ri2	Bi	DJi	Wi	Pi
1	ILL - 8006	1187.5	434.0855	36.5546	0.9517	-29769.9	0.984	2552.755	-0.0483	6047.424	7001.536	134890.3
10	Sagun	1209.222	492.9771	40.7681	1.0702	-18620.6	0.9646	9189.179	0.0702	17196.74	19212.55	118494.6
11	HUL - 57	1299.167	520.9608	40.0996	1.1433	-28140.6	0.9859	7488.601	0.1433	7676.723	16083.49	84366.71
12	LG-12	1336.889	545.787	40.8252	1.2049	-34398.2	0.9976	8860.657	0.2049	1419.131	18608.07	65997.43
13	PL- 4	1429.222	675.4352	47.2589	1.4408	26754.72	0.9314	75986.58	0.4408	62572.08	142119.8	55675.34
14	RL - 11	1364.222	503.5754	36.913	1.0334	34155.08	0.862	37024.52	0.0334	69972.44	70429.59	82821.34
15	RL - 4	1276.389	542.6601	42.5153	1.1265	33643.07	0.8821	40057.43	0.1265	69460.43	76010.14	111156.3
16	ILL - 2712	1305.389	292.2599	22.3887	0.644	-34791.2	0.994	27497.54	-0.356	1026.134	52899.95	107702.7
17	Black Masuro	1337.944	457.4478	34.1903	0.9599	5474.282	0.9013	21546.14	-0.0401	41291.64	41949.37	71931.38
18	RL - 79	1446.222	608.152	42.0511	1.1172	192892.7	0.6908	126103.7	0.1172	228710.1	234335.2	53828.46
19	ILL - 6467	1379.722	560.5175	40.6254	1.2378	-34689.4	0.9982	11941.37	0.2378	1127.936	24276.58	51215.1
2	RL - 6	1205.944	446.7794	37.0481	0.9874	-35689.8	0.9997	-1147.51	-0.0126	127.5666	193.0533	125653.4
20	ILL - 7979	1393.167	479.227	34.3984	0.9819	28782.44	0.8594	33928.88	-0.0181	64599.8	64733.61	75123.05
21	ILL - 6819	1383.056	441.4315	31.9171	0.9382	-6474.46	0.9247	15543.44	-0.0618	29342.9	30904.39	71332.53
22	ILL - 7723	969.7778	246.3688	25.4047	0.473	-6012.45	0.7545	76739.32	-0.527	29804.91	143504.8	309070
23	WBL - 77	1451	565.3628	38.9637	1.2303	-16198.9	0.9693	21209.24	0.2303	19618.41	41329.46	39457.4
24	ILL- 4605	1076	374.7414	34.8273	0.7504	14517.34	0.8208	39964.34	-0.2496	50334.7	75838.85	211985.2
25	RL - 49	1356.222	517.5693	38.1626	0.8716	188947.6	0.5805	124571.7	-0.1284	224765	231516.4	90959.99
3	RL - 12	1269.778	517.955	40.791	1.1423	-33472.3	0.9956	4528.918	0.1423	2345.101	10637.68	89883.49
4	ILL - 7715	1301.167	388.9898	29.8955	0.8338	-17813.1	0.9405	14677.49	-0.1662	18004.29	29311.05	102708.4
5	ILL - 7164	1316.278	399.9915	30.3881	0.8583	-17392.3	0.9424	13230.8	-0.1417	18425.04	26649.14	95460
6	ILL - 3490	1135.889	429.8212	37.8401	0.9446	-31628.8	0.9887	1706.143	-0.0554	4188.546	5443.768	167579.1
7	Khajura - 2	1326.333	525.6886	39.6347	1.1582	-32294.6	0.9936	6231.401	0.1582	3522.722	13770.24	67354.29
8	Simal	1144.278	418.7663	36.5966	0.925	-35362.8	0.9987	246.3736	-0.075	454.5692	2757.793	161807.1
9	Shital	1134.444	442.8602	39.0376	0.9752	-32906.1	0.9926	466.5451	-0.0248	2911.289	3162.909	166078.4

3.5 Mean yield performances and stability analysis of the lentil accessions

GGE biplot based on environment-focused scaling for pooled mean performances and stability of the accessions over the years 2016-2017 and across the three environments indicated that lentil accessions PL-4, WBL-77, RL-4, RL-11 and ILL-7979 had the highest mean yield (Fig. 4) while accessions RL-79, RL-49, ILL-7723 and ILL-4605 were highly unstable and below average yield, whereas Shital, RL-6, ILL-3490 and Simal highly stable, were followed by HUL-57, ILL-8006 and RL-4 with above average yield over the years 2016-2017 across the three environments.

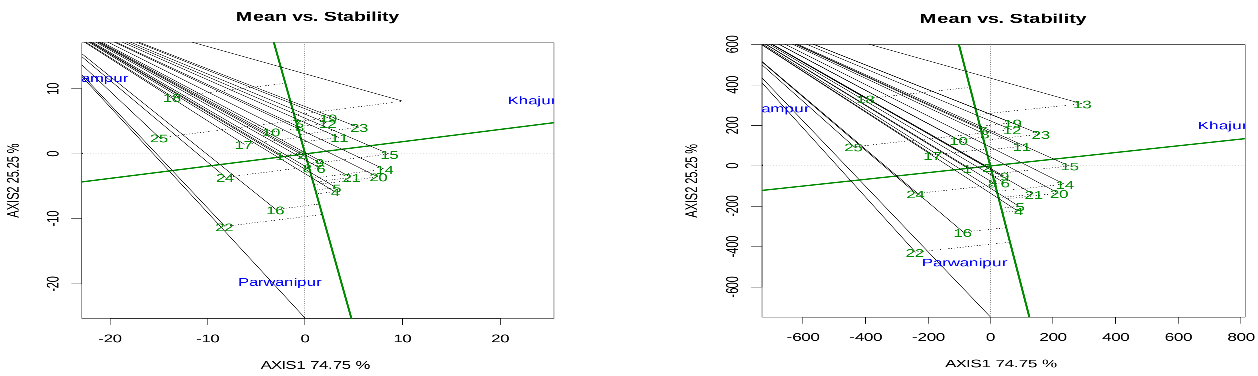


FIGURE 4, 5: GGE biplot based on environment-focused scaling for mean performance and stability of the genotypes over the years 2016-2017

3.6 Discriminating ability and representativeness of the test environment

GGE biplot discriminating ability and representativeness is an important measure of the testing environments. The concentric circles on the biplot as shown in Figure 5 help to visualize the length of the environment vectors, which is proportional to the standard deviation within the respective environments and is a measure of the discriminatory ability of the environments. Based on ranking accessions based on the discriminativeness against representativeness of test environments for biofortified lentil data over the years indicated that all environments looked diverse and they are discriminating based on the location specific across the three environments over the years (Fig 6). However, Parwanipur are looked close to the centers and might be discriminative (informative) whereas Khajura and Rampur least representative over the years (Fig vi). All three test environments (locations) that are discriminating and representative are good test environment for selecting wider adaptable accessions. Discriminating but non-representative test environments like Khajura and Rampur are useful for selecting specifically adaptable accessions if the target environments can be divided into mega-environments or they are useful for culling unstable accessions if the target environment is a single mega-environment.

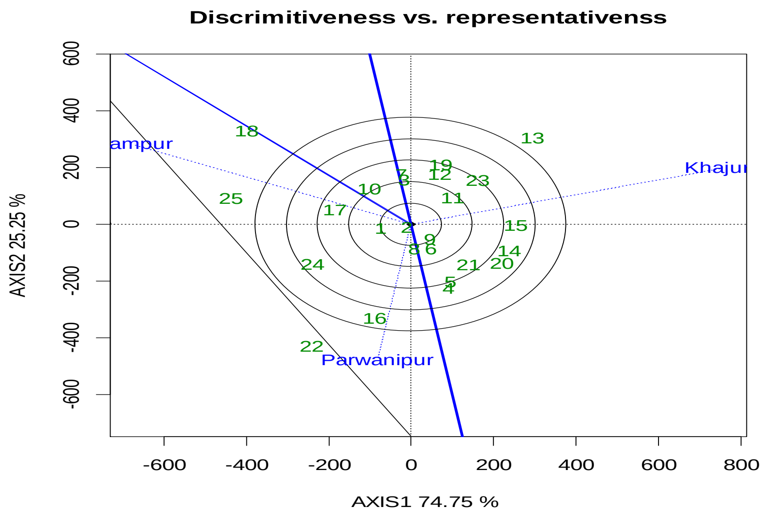


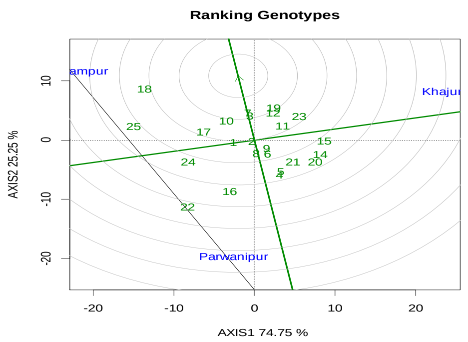
FIGURE 6: Ranking accessions based on the discriminativeness against representativeness of test environments for biofortified lentil data over the years 2016-2017

3.7 Ranking accessions relative to the ideal genotype

An ideal genotype should have the highest mean performance and be absolutely stable (that is, performs the best in all environments). Such an ideal genotype is defined by having the greatest vector length of the high yielding accessions and with zero GEI, as represented by an arrow pointing to it (Figure 7). A genotype is more desirable if it is located closer to the ideal genotype. Thus, using the ideal genotype as the centre, concentric circles were drawn to help visualize the distance between each genotype and the ideal genotype. Because the units of both PC1 and PC2 for the accessions are the original unit of yield in the genotype focused scaling (Figure 7), the units of the AEC abscissa (mean yield) and ordinate (stability) should also be in the original unit of yield.

3.8 Ranking of environments relative to the ideal environments

Based on this, Rampur located in the first concentric circle and has been the most ideal environment (Figure 8). Thus, Rampur environment was close to the ideal environment and this environment has been identified as desirable environments while Khajura environment was close to the second concentric circle and has been good for grain yield performances but Parwanipur environment was far distance than the centre therefore it might be useful to identify the location specific accessions. This difference between environments can be related to soil fertility, climate changes and other environmental variations from year to year.



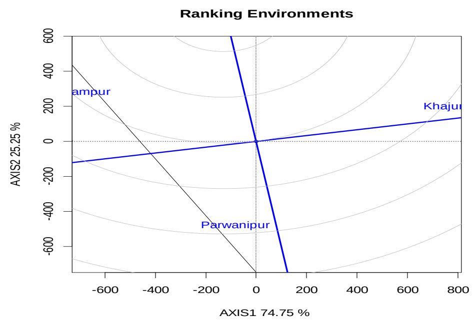


FIGURE 7, 8: GGE biplot based on genotype-focused scaling for comparison of the genotype with ideal genotype over the years 2016-2017 (Left) and Fig viii GGE biplot based on environment-focused Scaled by no scaling model centered by tester-centered G+GE for comparison of the environment with ideal environment over the years 2016-2017(Right)

3.9 Which genotype won where and mega environments with GGE bi-plot

One of the most attractive features of a GGE biplot is its ability to show the which-won-where pattern of a genotype by environment data set (Figure 9). Figure 9 indicated that accessions PL-4, RL-79, RL-49, ILL-7723 and ILL-7979 were the vertex accessions which showed the highest yield in specific environments. Here an example, the equality line among PL-4 and RL-79 indicates that PL-4 was better in Khajura while RL-79 was better in Rampur environment. This pattern suggests that the target environment may consist of two different mega-environments and that different accessions should be selected and deployed for each.

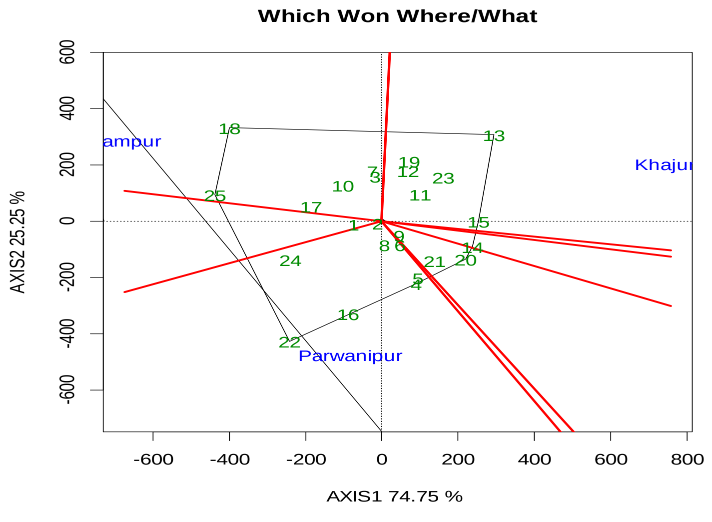


FIGURE 9: The which-won-where view of the GGE biplot to show which genotypes performed best in which environment in no scaling models centered by double centered GE over the years 2016-2017

3.10 AMMI 1 biplot analysis

Based on the stability analysis of AMMI Biplot Model Type 1 across the environments over the years in the graph showed that the genotypes which are in the right side of perpendicular i.e. accessions PL-4, RL-4, RL-11 and ILL-7979 are less affected by G x E inter action. Accessions ILL8006, RL-6, Shital, ILL3490 and simal were more close to the center point and indicated that stable across the environments (Figure 10).

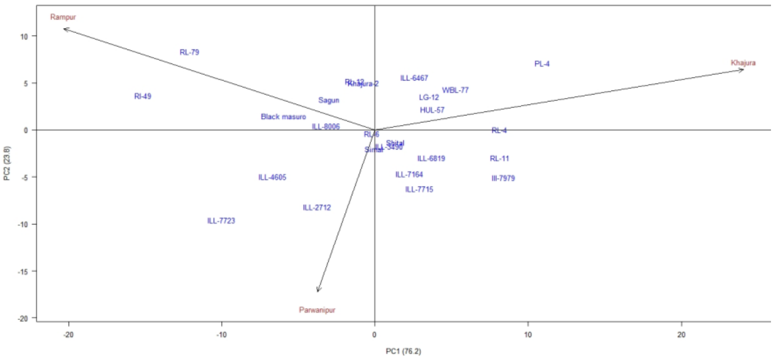


FIGURE 10: Stability analysis of AMMI Biplot Model Type 1 across the environments over the years (2016-2017)

TABLE 5
AMMI STABILITY VALUE AND YIELD STABILITY VALUE BASED ON THE # CROPS WITH IMPROVED STABILITY, 2016-2017

GEN	ASV	YSI	rASV	rYSI	means
2	0.53	19	1	18	1202
8	2.05	23	2	21	1146
6	2.42	25	3	22	1145
9	2.72	27	4	23	1136
7	5.08	16	5	11	1326
1	5.67	26	6	20	1196
3	5.71	24	7	17	1283
5	6.16	18	8	10	1329
10	6.18	28	9	19	1201
11	7.1	25	10	15	1295
21	7.24	15	11	4	1399
19	7.26	17	12	5	1379
12	7.31	25	13	12	1319
4	8.14	28	14	14	1299
23	10.41	16	15	1	1458
16	10.59	29	16	13	1311
17	10.79	26	17	9	1332
24	12.9	42	18	24	1047
15	14.59	35	19	16	1285
14	14.86	27	20	7	1363
20	15.87	27	21	6	1377
22	20.3	47	22	25	991
13	20.8	26	23	3	1420
18	23.2	26	24	2	1424
25	27.36	33	25	8	1359

The AMMI Stability Value (ASV) and AMMI stable index are calculated as suggested by Zobel et al, 1998 and Purchase et al.1997 and their ranks are presented in Table 5. The highest mean grain yield of genotypes averaged across the environments over the years 2016-2017 were produced by WBL-77(G-23) (1458 kg ha^{-1}) followed by RL-79(G-18) (1424 kg ha-1), PL-4(G-13) (1420 kgha-1) and ILL-6819(G-21) (1399 kgha^{-1}) while lowest by ILL-7723(G-22) (991 kg ha^{-1}). The genotypes which has low stability value (ASV) is said to be stable and the breeder chose the stable genotypes, having grain yield above the mean grand yield. In this experiment accessions RL-6(G-2) ranked 1st stability(ASV-0.53) followed by Simal(G-8) (ASV-2.05) , ILL-3490(G-6)(ASV-2.42) and Shital(G-9) (ASV-2.72) and suitable for all environment but out of test accessions; WBL-77(G-23), RL-79, PL-4 and ILL-6819(G-21), ILL-6467(G-19), ILL-7979(G-20), RL-11(G-14), RL-

49(G-25), Black Masuro(G-17),ILL-7164(G-5), Khajura-2(G-7), LG-12(G-12) and ILL-2712(G-16) produced the mean yield above grand mean (Table 2).

3.11 Pearson Correlation Coefficient Analysis

TABLE 6
PEARSON'S PRODUCT-MOMENT CORRELATION BETWEEN THE GRAIN YIELD AND YIELD CONTRIBUTING TRAITS OF LENTIL

Traits	DF	DM	PLHT	PP	SP	HSWT	GY
DF	1	0.576**	0.011	0.048	0.278**	0.057	0.306**
DM		1	0.103*	-0.036	0.216**	0.165**	0.497**
PLHT			1	0.324**	0.324**	0.383**	0.564**
PP				1	0.217**	0.278**	0.246**
SP					1	0.017	0.474**
HSWT						1	0.330**
GY							1

Note: ** and * indicates significant at 1% and 5% level of significance

Correlation between the grain yield and yield attributing traits was done as in Table 6. Yield is one of the most important trait during the selection criteria and influenced by different yield attributes i.e days to flowering, days to maturity, plant height, number of pods and seeds per plant, hundred seed weight. The correlation Table showed that there was a positive and highly significantly correlation with yield and days to 50% flowering (r=0.306, P≤.001). Similarly, based on the correlation, there was highly significant and positive correlation between the yields with the yield attributing traits like days to maturity, plant height, pods per plant, seeds per pod and hundred seed weight at 1% level of significance. Days to 50% flowering was positively and highly significantly associated with days to maturity (r=0.576, P≤.001) and number of seeds per pod (r=0.278, P≤.001). There was also positive but no significant correlation with 100 seed weight, pods per plant and plant .Similarly, there was positive and significant correlation between days to maturity and plant height (r=0.103, P≤.005), seeds per pod(r=0.216, P<0.001), hundred seed weight(r=0.165, P<0.001) and grain yield (r=0.497, P≤0.001) but negative correlation with pods per plant(r=-0.036) . Likewise, plant height had significantly positive correlation with number of pods per plant (r=0.324, P≤.001), seeds per pod(r=0.324, P≤.001), hundred seed weight(r=0.383, P≤.001) and grain yield (r=0.564, P≤.001) .There was a positive and significant correlation with number of pods per plant with seeds per pod(r=0.217, P≤0.001), and similarly positive association was observed with 100 seed weight(r=0.278, P≤0.001) and also with seed yield(r=0.246, P≤0.001). Similarly positive correlation was observed between the number of seeds per pod with the hudred of seed weight ((r=0.017) but the highly significant correlation with the grain yield of (r=0.474, P≤.001) and likely highly significantly and positive correlation with grain yield was also recorded between the 100 seed weight and the yield (r=0.330, P≤.001) .

IV. DISCUSSION

GGE biplot based on environment-focused scaling for pooled mean performances and stability of the accessions across the three environments over the years indicated that lentil accessions PL-4, WBL-77, RL-4, RL-11 and ILL-7979 had the highest mean yield whereas Shital, RL-6, ILL-3490 and Simal were found highly stable. Based on ranking accessions based on the discriminativeness against representativeness of test environments for biofortified lentil data over the years indicated that all environments looked diverse and they are discriminating based on the location specific across the three environments over the years. An ideal genotype is defined as one of the highest yielding across the test environments and is definitely stable in performance (Yan and Kang, 2003). In the genotype-focused the GGE biplot analyses, concentric circles are drawn to help visualize the distance between each genotype and the ideal genotype (Naroui Rad et al., 2013). Lentil accessions Khajura-2. RL-12, Sagun, LG-12 and ILL-6467 which fell into the centre of concentric circles, was the ideal genotype in terms of stability, compared with the rest of the accessions. In addition, RL-79, PL-4, WBL-77, HUL-57 and Black Masuro located on the next consecutive concentric circle, may be regarded as desirable accessions in terms of higher yielding ability. Based on this, Rampur located in the first concentric circle and has been the most ideal environment. The yield performances was found poor at Parwanipur because of high rainfall (204-260 mm) occurred during the cropping season and looked more prevalent of stemphylium diseases consequence reduced yield substantially than other locations. Many researchers find this use of a biplot intriguing, as it graphically addresses important concepts such as crossover GE, mega environment differentiation, specific adaptation etc. as discussed in Yan and Tinker (2006). Lentil accessions PL-4, RL-79, RL-49, ILL-7723 and ILL-7979 were the vertex accessions which showed the highest yield in specific environments. It has been proposed that GGE biplot analysis was a useful multi-location trial for the analysis of GE interactions (Butron et al., 2004;

Fan et al., 2007; Laffont et al., 2007; Yan and Kang, 2003; Samonte et al., 2005) and had been exploited in the variety evaluation of wheat (Yan and Hunt 2001; Yan et al., 2000), Maize (Fan et al., 2007) and soybean (Yan and Rajcan, 2002). Based on the stability analysis of AMMI Biplot Model Type 1 across the environments over the years in the graph showed that the genotypes which are in the right side of perpendicular i.e. accessions PL-4, RL-4, RL-11 and ILL-7979 are less affected by G x E interaction. Accessions ILL8006, RL-6, Shital, ILL3490 and simal were more close to the center point and indicated that stable across the environments. In another words, the genotypes which have low stability value (ASV) is said to be stable and the breeder chose the stable genotypes along with grain yield above the mean grand yield. In this experiment accessions RL-6(G-2) ranked 1st stability (ASV-0.53) followed by Simal (ASV-2.05), ILL-3490 (ASV-2.42) and Shital (ASV-2.72) and suitable for all environment. Based on the value of Eberhart and Russel mean square deviation (S_2di) resulted from stability coefficient (-35689.79 to -6012.4454) consequently lentil accessions RL-6, Simal, ILL-2712, ILL-6467, LG-12, RL-12, Shital, Khajura-2, ILL-3490, ILL-8006, HUL-57, Sagun, ILL-7715, ILL-7164 , WBL-77, ILL-6819 and ILL-7723 were found to be stable and adapted to all environments. Based on the lowest values (193.05) of Wricke's Ecovalence (W), lentil accessions RL-6 was found to be stable and well adapted across the environments over the years. Based on the small values (-1147.50) of Shukla's variance (ri^2), lentil accessions RL-6 was found to be agronomic stable across the environment. These stability coefficient parameters showed the diverse results of stable accessions however accession RL-6 was found the most stable accession because all the stability parameters provided the same results.

Plant breeders consistently face GE interactions when testing genotypes across the environments. Combined pooled mean analysis of variance (ANOVA) for grain yield tested at three environments over the two subsequent years showed that highly significant differences in genotypes, environment and G x E interaction effect. From the study, it was concluded that accession WBL-77 (1451 kg ha^{-1}), RL-79(1446 kgha^{-1}) and PL-4(1429 kgha^{-1}) were the best performer and well adopted across the environments. The different performance of genotypes across environments could also be indicative of wide variation in climatic conditions and soil types in the different growing environments. Consequently, comparisons can only be made in each environment separately (Breese, 1969). Crossa et al. (1991) had noted that the use of AMMI in G x E interaction analysis would lead to the selection of superior genotypes even in the field experiment. Here, AMMI analysis of variance for lentil grain yield (tha^{-1}) of lentil accessions tested at three environments over the years showed that 80.71% of the total sum of squares was attributed to environmental effects, only 8.38 % to genotypic effects and 10.90% to genotype × environment interaction effects. The partitioning of GGE sum of squares through the GGE biplot analysis showed that PC1and PC2 accounted 74.75%, and 25.24% of GGE sum of squares respectively over the years. In the biplot, a total of fifteen lentil accessions namely PL-4, RL-11, ILL-6819, ILL-7979, WBL-77, HUL-57, ILL-7715, ILL-6467, ILL-7164, LG-12, ILL-2712, Black Masuro, Khajura-2, RL-79 and RL-49 and two environments (Khajura and Rampur) located on the right side of the black vertical line showed the highest yield and more stable accessions. It seems that other statistical models such as regression procedures are more useful for understanding and describing G x E interactions. The GxE interaction is an important source of variation in any crop. Geographic differentiation of landraces of lentil emphasizes the specific adaptation of this crop (Erskine, 1997). According to Freeman (1972), one of the main reasons for growing genotypes over a wide range of environments is to estimate their stability and adaptability. Biological stability is not acceptable to most plant breeders, who prefer an agronomic concept of stability. In this concept of stability, it is not necessary for the genotypic response to environmental conditions to be equal for all genotypes.

V. CONCLUSION

Pooled mean analysis of variance for grain yield tested at three environments over the two subsequent years showed that highly significant differences in genotypes, environment and G x E interaction effect indicating the possibility of selection for stable accessions. Research results showed that lentil accession WBL-77 (1451 kg ha-1) , RL-79(1446 kg ha-1) and PL-4(1429 kg ha-1) were the best performer and well adopted across the environments and over the years. AMMI analysis of variance for lentil grain yield (tha^{-1}) of lentil accessions tested at three environments over the years showed that 80.71% of the total sum of squares was attributed to environmental effects, only 8.38 % to genotypic effects and 10.90% to genotype × environment interaction effects. Based on the value of Eberhart and Russel mean square deviation (S2di) resulted from stability coefficient (-35689.79 to -6012.4454) consequently lentil accessions RL-6, Simal, ILL-2712, ILL-6467, LG-12, RL-12, Shital, Khajura-2, ILL-3490, ILL-8006, HUL-57, Sagun, ILL-7715, ILL-7164 , WBL-77, ILL-6819 and ILL-7723 were found to be stable and adapted to all environments. Accessions ILL8006, RL-6, Shital, ILL3490 and simal were more close to the center point and indicated that stable across the environments. In another words, the genotypes which have low stability value (ASV) is said to be stable and the breeder chose the stable genotypes along with grain yield above the mean grand yield. In this experiment accessions RL-6(G-2) ranked 1st stability (ASV-0.53) followed by Simal (ASV-2.05), ILL-3490 (ASV-2.42) and Shital (ASV-2.72) and suitable for all environment.

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ANNEX 3

MEAN AGRO-METEOROLOGICAL DATA FOR THE FY 2016-2017 AND GEOGRAPHIC INFORMATION

Environment		Mean Yield (Kg/ha)	Latitude	Longitude	Altitude (m)	Temp (0c)		Rainfall (mm)
Location	Year					Min	Max	
Khajura	2016/17	1351	28^{0} 06" N	81^{0} 37" E	181	14.81	25.26	48.1
	2017/18	1865				19.58	29.24	99.2
Parwanipur	2016/17	796	27^{0} 4' 40.9'' N	84^{0}56' 9.85''	75	16.01	28.19	260
	2017/18	779				16.22	28.35	204.2
Rampur	2016/17	1387	27^{o} 40′N	84^{o}19′ E	228	14.82	28.18	202
	2017/18	1438				16.00	28.8	87.5