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GGE BIPLOT ANALYSIS FOR YIELD STABILITY OF LENTIL GENOTYPES

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Abstract

The experiment was conducted at three different locations of Bangladesh Agricultural Research Institute viz., at PRC, Ishurdi, Pabna, at PRSS, Joydebpur, Gazipur and RARS, Jashore, during the period November to March in 2014-15 and 2015-16. The experiment was laid out in Randomized Complete Block Design with three replications. Variance analysis showed significant interaction between genotype and environment on yield and its related traits. The highest yield was recorded in genotypes BARI Masur-7 followed by BARI Masur-6, BARI Masur-5, BARI Masur-4 and the lowest was in BLX-66004-12. The PCA (Principal component analysis) scores of a genotype in the GGE analysis indication of the stability or adaptation over environments. GGE biplot analysis related that the PC1 and PC2 for different traits, i.e. 80.8% and 11.7% for days to flowering, 72.4% and 18.7% for days to maturity, 66.3% and 15.4% for plant height, 73.8% and 17.3% for pods/plant, 70.1% and 22.8% for 100 seed weight and 38.37% and 31.04% for yield of the total variation, respectively. Considering regression co-efficient values and also biplot analysis most stable variety was BARI Masur-4 followed by BARI Masur-5 and BARI Masur-6 and lowest stable variety was BLX-05002-6. Among the six environments, Ishurdi 2014-15 and Gazipur 2014-15 were most discriminating (informative) and Jashore 2014-15 and Jashore 2015-16 were less discriminating. Among two years (2014-15 and 2015-16) at different location 2015-16 was found favorable for lentil production.

Keywords: PCA (Principal component analysis), GGE biplot, genotype × environment interaction, lentil.

Introduction

Lentil (*Lens culinaris* M.) is a diploid (2n=14), self-pollinating, winter grain legume with a slender semi erect winter leguminous crop . It is one of the oldest grain legumes having remains dated to 11,000 BC from Greece's Franchthi cave, is originated from Near East and Central Asia (Sandhu and Singh, 2007). Lentil is a vital elemental source of energy, protein, carbohydrates, fiber, minerals, vitamins and antioxidant compounds (Urbano *et al.*, 2007). It is having low level of fat and sodium, high in protein and is an excellent source of both soluble and insoluble fiber, complex carbohydrates, vitamins and minerals, especially B

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vitamins, potassium, phosphorus and cholesterol-lowering fiber (Yadav *et al.*, 2007). In 2011-2012 Bangladesh produce 1.76 lakh mt of lentil from 1.58 lakh ha of land with an average yield 1.11 t/ha (Anonymous, 2013). The most important goal of lentils improvement programs not only high yield, biotic and abiotic stresses tolerant cultivars, but also wide adaptability and stability (Hamdi *et al.*, 2002; Dehghani *et al.*, 2008). Genotype which can adjust its phenotypic state in response to environmental fluctuation in such a way that is gives maximum stable economic return, can be termed as well “buffered” or stable (Allard and Bradshaw, 1964). It is necessary to identify the stable genotypes suitable for wide range of environments. Stability analysis helps in the identification of location specific and widely adaptable genotype. The additive main effects and multiplicative interaction (AMMI) model has been suggested as efficient means in determining stable and high yielding genotypes (Zobel *et al*., 1988). Yan *et al*. (2000) adopted GGE biplot is a graphical tool which displays, interprets and explores two important sources of variation, namely genotype main effect and GE interaction of multi-environmental trails (MET) data.

Genotype-environment (G×E) interaction is essential particularly for the selection of location specific genotypes, genotype-environment interaction is of major consideration to the breeders (Eberhart and Russell, 1966). GGE biplot methodology allows visual examination of GE interaction pattern of multi-environmental data based on two concepts. First, yield is measured as the combined effect of G, E and GE. Only G and GE are relevant to and considered in genotype evaluation. The yield of each cultivar in a tested environment is a result of genotypic main effect (G), environmental main effect (E) and genotype × environment (GE) interaction (Yan and Kang, 2003). Second, GGE biplot technique separates two principal components, PC1 and PC2, which are also referred to as primary and secondary effects, respectively. The principal components are derived from subjecting environment-centered yield data (the yield variation due to GGE) to singular value decomposition. Then the pattern of genotypic response across environments can be graphically determined in a GGE biplot (Yan and Tinker, 2006). For cultivar evaluation, G and GE are important components for explaining a meaningful relationship between genotypes and environments from the GGE biplot. GGE biplot is exploited for graphical display of G×E pattern of yield trial data with several advantages. Selecting genotypes with high yield and yield stability in a wide range of environments become important as reliable production in quantity (Gauch *et al*., 2008). 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). So the present study is undertaken with the objectives of (a) To analysis yield stability and adaptability of newly lentil genotypes and (b) To evaluate discrimination and representativeness of test locations.

Materials and Methods

Planting materials: Twelve lentil genotypes BARI Masur-1, BARI Masur-2, BARI Masur-3, BARI Masur-4, BARI Masur-5, BARI Masur-6, BARI Masur-7, BLX-05008-05, BLX-05002-6, BLX-05008-21, BLX-66004-12 and ILL-5134 genotypes of lentil were evaluated in this study. Among them seven released variety and other four advanced lines of lentil were collected from Pulse Research Centre (PRC), Ishurdi, Pabna, whereas another advanced line ILL-5134 was collected from ICARDA, Aleppo, Syria.

Field Trails: The study was conducted at three diverse experimental sites of Bangladesh Agricultural Research Institute viz., Pulses Research Centre (PRC), Ishurdi, Pabna; Pulse Research Sub-station (PRSS), Joydebpur, Gazipur; and Regional Agricultural Research Station (RARS), Jashore. Trials were carried out in two consecutive season viz., during the period Rabi (November to March) 2014-15 and 2015-16. Three sites and two years combinations were considered as 6 environments- Environment-1: Gazipur' 14-15, Environment-2: Gazipur' 15-16, Environment-3: Ishurdi' 14-15, Environment-4: Ishurdi' 15-16, Environment-5: Jashore 14-15 and Environment-6: Jashore 15-16. The experiments were laid out in a Randomized Complete Block Design (RCBD) with 3 (three) replications. In each replication, a lentil genotypes was sown in a size of 4 m long with 2 rows. Row to row distance was 40 cm with 80 cm spacing between the adjacent plots. In each row, spacing between the adjacent plants was 6-8 cm. The entire quantity of N, P, K, S, Zn and B @ 20-20-20-10-2-1 kg/ha were applied during final land preparation. Intercultural operations were done as necessary during the growing period for proper growth and development of the plants.

Table 1. Characteristics of the three tested locations

Site	Soil type	AEZ	Soil pH
PRC, Ishurdi	Silty loam	High Ganges River Floodplain of Agro-ecological Zone (AEZ-11)(Anonymous, 2004)	6.91
PRSS, Gazipur	Clay loam	Madhupur tract of Agro-ecological Zone (AEZ- 28) (Brammer, 1971)	5.7
RARS, Jashore	Sandy loam	High Ganges River Floodplain of Agro-ecological Zone (AEZ- 11)	8.2

Trait measurement: Plant height, days to flowering, days to maturity, pod per plant, seeds per pod, weight of 100 seed and yield per plant were recorded. Variance and GGE biplot analysis were done accordingly. All graphic summaries were done using the 'GGE biplot' package in 'R' program.

Results and discussion

Yield and other traits was highly influenced and this might be due to the effects of environments. There was significant variation also found for days to flowering, days to maturity, plant height, pods/plant, 100 seed weight and yield (kg/ha) (Table 3). For days to flowering BLX-66004-12 and BLX-05002-6 was found earlier at Gazipur and Ishurdi during 2015-16 compare to other genotypes and years (Table 4). Considering year for all locations, in 2015-16 all the genotypes was flowered earlier, this might be due to environmental effect on genotypes. In case of days to maturity BLX-05008-05 was found earlier at Jashore (72 days) for both years. But at Ishurdi and Gazipur BLX-05008-05 was also found earlier in 2015-16 compare to 2014-15. Among the 12 genotypes BARI released variety was found late compare to advance line for days to maturity. Plant height also showed significant difference at three locations for both the years at Ishurdi 2014-15 and Gazipur 2014-15, all the genotypes have longest plant compare to 2015-16. Apart from this pods/plant and 100 seed weight varied significantly both the years at three- locations.

Table 3. Combined Analysis of Variance (ANOVA) of lentil genotypes for yield related traits at location during 2014-15 & 2015-16

Source of variance	DF	DM	PHT	PP	100 Swt. (g)	Yield (kg/ha)
Environment	318.24***	695.64***	1329.81***	17147.9***	6.32***	407987.5*
Rep. (Env.)	3.49	7.51	14.06	218.5	0.23*	71454.1***
Genotype	236.72***	462.23***	53.60***	1536.7***	1.12***	69183.3***
Env.× Genotype	72.13***	111.29***	31.39***	499.9***	0.51***	39916.6*
Residuals	18.24	18.36	8.11	152.2	0.10	200041.00

NB:* Significant at $P \leq 0.05$, ** Significant at $P \leq 0.01$ and *** Significant at $P \leq 0.001$

DF= Days to flowering, DM= Days to maturity, PHT= Plant height, PP=Pods per plants, Swt.= Seed weight

Highest number of pods/plant was found in BARI Masur-6 which was followed by BARI Masur-3 at Jashore in 2015-16. Similar trend was also observed at Ishurdi for genotypes BARI Masur-6 and BARIMasur-7. For 100 seed weight, highest seed weight was in BLX-05008-05 over three locations followed by BLX-05002-6, BARI Masur-7, ILL-5134 and BARI Masur-3. The highest mean yield (1390 kg/ha) was found in BARI Masur-7 followed by BARI Masur-6 (1390 kg/ha), BARI Masur-5 (1380 kg/ha) and BARI Masur-4 (1320 kg/ha). The genotypes BARI Masur-3 (1290 kg/ha), ILL-5134 (1250 kg/ha) and BCX-05008-05 (1250 kg/ha) are performed comparatively well. Each genotype was defined in respect of stability by three values 1) Mean yield across environment 2) The linear regression (b values) of genotype mean yield in each environment and 3) The mean square deviation from the regression of each genotype.

Table 4. Mean performance of 12 Lentil genotypes for yield contributing traits at three locations during 2014-15& 2015-16, Conducted at Gazipur, Ishurdi, and Jashore in Bangladesh

Sl. No	Genotypes	Days to flower						Mean & Rank	Days to maturity						Mean & Rank
		Gazipur		Ishurdi		Jashore			Gazipur		Ishurdi		Jashore		
		2014-15	2015-16	2014-15	2015-16	2014-15	2015-16		2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	
1	BLX-05008-21	62	43	46	41	44	42	51 d	95	91	94	91	89	78	98 f
2	ILL-5134	64	48	50	43	45	51	45 g	101	94	96	88	89	101	95 i
3	BLX-05002-6	50	40	46	42	43	51	46 f	104	94	97	92	89	99	97 g
4	BLX-66004-12	55	39	46	41	50	52	47 e	115	101	93	95	93	102	100 e
5	BLX-05008-05	58	43	45	46	35	41	45 g	93	91	93	93	83	72	96 h
6	BARIMasur-1	55	46	62	55	50	51	53 b	104	95	109	93	102	101	101 d
7	BARIMasur-2	56	43	61	54	51	52	53 b	105	93	112	93	101	100	101 d
8	BARIMasur-3	51	44	62	56	52	51	53 b	103	94	112	93	101	101	101 d
9	BARIMasur-4	51	42	62	54	52	52	52 c	105	93	112	95	102	102	102 c
10	BARIMasur-5	53	47	63	54	52	51	53 b	103	99	113	97	103	102	103 b
11	BARIMasur-6	52	49	62	54	52	52	54 a	104	100	111	95	103	101	102 c
12	BARIMasur-7	52	49	62	53	53	52	54 a	106	100	113	96	104	101	104 a
Average		54.91	44.41	55.58	49.41	48.25	59.83		103.16	95.41	95.16	85.66	88.08	91.5	
CV (%)		1.2	1.4	1.9	1.6	1.7	0.67	-	0.72	0.92	0.65	0.55	-	-	-
LSD (0.05)		1.88	1.34	1.41	1.22	1.36	1.08	-	1.99	1.67	1.96	1.41	NS	NS	-

Table 4. Cont'd

Sl. No	Genotypes	Plant height							Pods/Plant						
		Gazipur		Ishurdi		Jessore		Mean & Rank	Gazipur		Ishurdi		Jessore		Mean & Rank
		2014-15	2015-16	2014-15	2015-16	2014-15	2015-16		2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	
1	BLX-05008-21	27	23	32	37	34	33	32 d	14	14	11	26	38	43	24 k
2	ILL-5134	25	22	36	31	32	42	31 e	23	16	27	31	34	78	35 h
3	BLX-05002-6	31	29	34	30	36	45	34 b	12	14	18	37	59	75	36 g
4	BLX-66004-12	27	24	31	31	35	44	32 d	11	16	23	31	47	72	33 i
5	BLX-05008-05	24	23	30	32	25	30	27 f	26	13	15	27	31	36	25 j
6	BARIMasur-1	33	24	35	30	37	42	34 b	35	14	43	35	60	78	38 f
7	BARIMasur-2	27	25	36	31	38	40	33 c	22	12	47	24	53	68	45 c
8	BARIMasur-3	31	26	41	33	39	46	36 a	37	14	44	36	61	79	43 e
9	BARIMasur-4	28	24	38	31	37	40	33 c	31	16	38	34	53	84	47 b
10	BARIMasur-5	28	24	41	28	34	40	33 c	32	19	53	32	75	71	48 a
11	BARIMasur-6	28	25	36	33	37	39	33 c	30	20	59	37	60	83	43 e
12	BARIMasur-7	30	26	41	31	37	41	34 b	38	19	23	39	61	75	44 d
Average		28.25	24.58	35.91	31.5	35.08	40.16		25.91	15.58	33.41	32.41	52.66	70.16	
CV (%)		3.5	3.6	2.2	2.8	5.6	6.7	-	16.2	15.4	14.5	16.5	12.1	14.2	-
LSD (0.05)		7.82	8.33	6.6	4.2	ns	ns	-	18.3	20.05	31.2	33.6	3.06	2.05	-

Table 4. Cont'd

Sl. No	Genotypes	100 seed weight						Mean & Rank	Grain yield (Kg ha^{-1})						Mean & Rank
		Gazipur		Ishurdi		Jashore			Gazipur		Ishurdi		Jashore		
		2014-15	2015-16	2014-15	2015-16	2014-15	2015-16		2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	
1	BLX-05008-21	1.6	1.7	2.2	2.3	2.2	2.4	2.0 e	880	1020	930	770	1020	1730	1060 h
2	ILL-5134	2.1	2.0	1.8	2.8	1.9	1.8	2.1d	980	1800	1320	1170	1280	920	1250 e
3	BLX-05002-6	2.1	1.6	2.0	3.9	1.8	2.1	2.3 b	560	500	1620	1040	880	2170	1130 g
4	BLX-66004-12	2.2	2.2	1.6	2.2	1.7	1.9	1.9 f	400	520	1470	900	810	1170	880 i
5	BLX--05008-05	2.3	1.9	3.0	2.2	3.1	2.6	2.5 a	1080	1570	1020	1300	750	1800	1250 e
6	BARIMasur-1	1.5	1.5	1.8	2.3	1.4	1.5	1.7 h	850	1430	1250	1090	1360	1320	1220 f
7	BARIMasur-2	1.7	1.6	1.6	2.6	1.5	1.5	1.8 g	840	1100	1300	1030	1230	1300	1130 g
8	BARIMasur-3	2.0	1.9	2.1	2.9	1.9	2.0	2.1 d	1190	1300	1300	1210	1290	1450	1290 d
9	BARIMasur-4	1.6	1.7	2.0	3.2	1.7	1.9	2.0 e	880	1190	1380	1220	1470	1770	1320 c
10	BARIMasur-5	1.8	1.7	2.3	2.8	1.9	1.6	2.0 e	850	1230	1470	1350	1530	1830	1380 b
11	BARIMasur-6	2.0	1.6	1.8	2.7	1.9	1.9	1.9 f	730	1640	1530	1110	1300	2050	1390 a
12	BARIMasur-7	1.9	1.7	2.0	3.2	1.8	2.8	2.2 c	560	1510	1600	1410	1300	1980	1390 a
Average		1.9	1.75	3.59	2.75	3.1	2.0		817	1234	1240	1055	1092	1524	
CV (%)		2.44	4.21	3.22	3.56	7.33	8.91	-	18.52	15.32	9.56	7.43	12.44	14.65	-
LSD (0.05)		0.19	0.17	0.26	0.29	ns	ns	-	7.33	8.33	14.23	12.11	4.42	5.23	-

Regression co-efficient ranged from 0.8562 (for genotype BLX-05008-6) to 1.3833 (for genotype BARI Masur-2). Among the 12 genotypes, seven genotypes had regression co-efficient greater than 1.0 indicate sensitive to environment changes in respect of yield but five genotypes (BARI Masur-4, BARI Masur-6, BARI Masur-7, BLX-05008-05 and BLX-05002-6) had regression co-efficient less than 1.0 (Table 5). These genotypes were relatively better adapted to poor environment and were insensitive to environment changes in respect of yield. Such genotypes could be recommended only for cultivation for unfavorable conditions. However on of the genotypes BARI Masur-4 having regression co-efficient closer to unity (0.9862) with highest yield than the overall genotypes mean suggest that it could be recommended for cultivation under any type of environments for higher yield. Therefore, this genotype can be selected as stable over the environments. Regarding Mean square Deviation the genotypes BARI Masur-4, BARI Masur-6, BARI Masur-7 and BLX-05008-05 possess minimum values therefore, these four genotypes are more stable across the environments. If we consider year, most of the genotypes showed better yield in Ishurdi 2015-16 compare to 2014-15 and similar results was also obtained by Jashore. Apart from these Ishurdi locations showed better yield in 2015-16 compare to 2014-15. This may be due to favorable or in favorable environmental effects on genotypes.

Table 5. Regression Co-efficient and Mean Square Deviation of 12 lentil genotypes

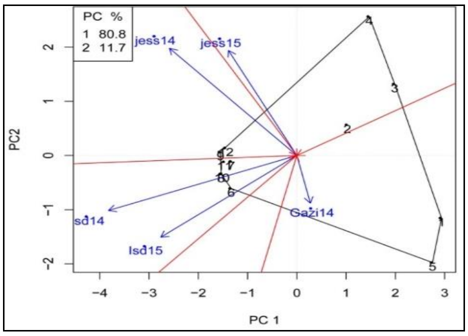
Sl. No	Genotypes	G×E Mean Yield	Regression Coefficient	Mean Square Deviation
1.	BLX-05008-21	1060	1.2033	1873
2.	ILL-5134	1250	1.0343	2890
3.	BLX-05002-6	1130	0.8562	967
4.	BLX-66004-12	880	1.1520	8932
5.	BLX--05008-05	1250	0.9632	825
6.	BARIMasur-1	1220	1.1855	6114
7.	BARIMasur-2	1130	1.3833	67893
8.	BARIMasur-3	1290	1.3452	68363
9.	BARIMasur-4	1320	0.9862	234
10.	BARIMasur-5	1380	1.0028	56734
11.	BARIMasur-6	1390	0.8812	113
12.	BARIMasur-7	1390	0.9784	214

GGE Biplot analysis

GGE biplot analysis was done to find out stable genotypes among locations. GGE biplot is exploited for graphical display of G×E pattern of yield trial data with several advantages. The yield of each genotype in a tested environment is a result of genotypic main effect (G), environmental main effect (E) and genotype

× environment (GE) interaction (Yan and Kang, 2003). The stability performance of the lentil genotypes is presented in the biplot based on grain yield and other yield contributing traits data (Figure 1-5). The horizontal axis (PC1) indicates the main effect of genotype while the vertical axis (PC2) shows the interaction of genotype and environment which is the basic criterion for judging genotypic stability. The lines passing from the origin (0.0) of the coordinate of a location and genotype are referred to as environmental vector and genotype vector, respectively. The average environmental axis (AEA) is the line that passes through the coordinates of all the locations and the biplot origin. The length of the environmental vector from the origin to its coordinate is used to measure the discriminating ability of the location. In this experiment, the principal component 1 (PC1) and PC2 obtained from all the six observed characters accounted for 80.8% and 11.7% for days to flowering, 72.4% and 18.7% for days to maturity, 66.3% and 15.4% for plant height, 73.8% and 17.3% for pods/plant, 70.1% and 22.8% for 100 seed weight and 38.37% and 31.04% for yield of the total variation, respectively. Seed yield showed as high as 38.37% variation that can be explained by PC1.

Days to flowering: According to Figure 1 genotypic main effect explain 80.8% of total variation and G × E interaction explain 11.7% of total variation for days to flowering. Six locations fall into two sector of polygon. Among twelve genotypes, five genotypes are corner of the polygone to days to flowering indicates that these are vertex genotypes. The polygon also showed that Ishurdi location for both the years was found earlier compare to best for other locations.



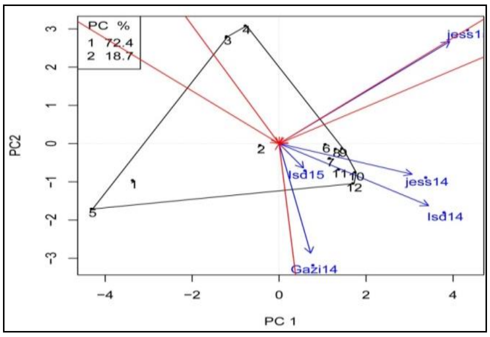


Fig. 1. **GGE Biplot for Days to flowering showing the interaction of PC2 against PC1 scores12 lentil genotypes in three locations (six environments) at 2014-15 and 2015-16**

Fig. 2. **GGE Biplot for Days to maturity showing the interaction of PC2 against PC1 scores12 lentil genotypes in three locations (six environments) at 2014-15and and 2015-16**

Days to maturity: Figure 2 showed that the genotypes BARI Masur-1(101 days), BARI Masur-2(101 days), BARI Masur-3(101 days), BARI Masur-4 (102 days), BARI Masur-5 (103 days), BARI Masur-6 (102 days) and BARI Masur-7 (104 days) are the better performance for days to maturity in Ishurdi and Jashore location comparatively other genotypes. Genotypes ILL-5134 (95 days) are the better performance for days to maturity as it is closer to the origin. So the genotype can be selected for the earlier genotype.

Pods per plant: Figure 3 explained the genotype and environment interaction. According to fig 4.3 showed that the genotypes BARI Masur1, BARI Masur-3, BARI Masur4, BARI Masur5, BARI Masur-6 and BARI Masur-7 are the better performance for pods per Plant in Ishurdi 2014-15,Ishurdi 2015-16, Gazipur 2014-15 and Jashore 2014-15 locations comparatively other genotypes. On the other hands the genotypes BARI Masur-4 and BARI Masur-7 was found as stable for pods per plant as it is closer to the origin. Genotypes BARI Masur-4 and BARI Masur-7 close to the origin of axes had wider adaptation i.e, most stable genotypes.

Seed weight: Figure 4 explained the genotype and environment interaction. According to fig 4 we showed that the genotypes BARI Masur-4 and BARI Masur-7 are the better performance for seed weight in Gazipur location comparatively other genotypes. On the other hands BARI Masur-3, BARI Masur-5 and BARI Masur-6 were found as stable for SWT as those genotypes positioned near to origin.

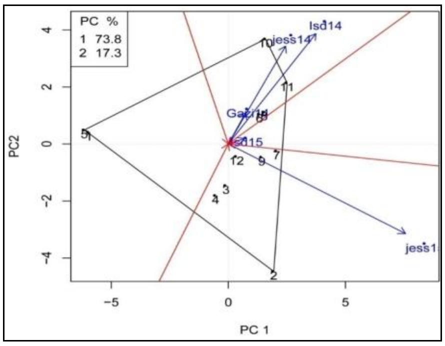


Fig. 3. GGE Biplot for pods per plants showing the interaction of PC2 against PC1 scores 12 lentil genotypes in three locations (six environments) at 2014-15 and 2015-16

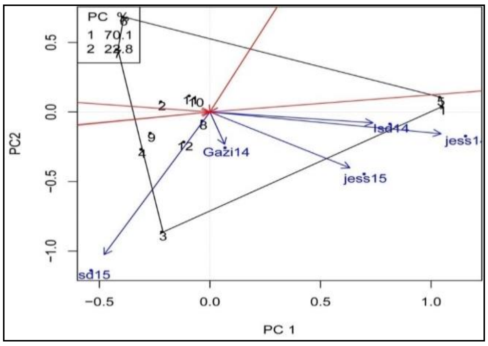


Fig. 4. GGE Biplot for seed weight showing the interaction of PC2 against PC1 scores 12 lentil genotypes in three locations (six environments) at 2014-15 and 2015-16

Yield (kg/ha): Figure 5 explained the genotype and environment interaction. The first two PCs explained 69.41% (PC1 = 38.37% andPC2 = 31.04%) of total variation for lentil multi-environmental trials. Twelve genotypes represent a polygon and the genotypes corner of the polygon most responsive genotypes. Most of the genotypes situated in mega environment which show the Ishurdi and Jashore locations. The genotypes BARI Masur-4, BARI Masur-5, BARI Masur-6 and BARI Masur-7 showed most interaction with environment followed by others. The genotypes BARI Masur-4, BARI Masur-5, BARI Masur-6 and BARI Masur-7 were the better performance show for yield in Ishurdi and jashore comparatively other genotypes. All entries distributed in to four sectors. Among the tested locations, Ishurdi and Jashore had larger environmental vectors indicating high discriminating ability.

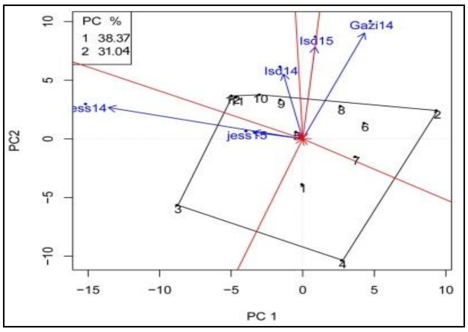


Fig. 5. GGE Biplot for Yield (kg/ha) showing the interaction of PC2 against PC1 scores 12 lentil genotypes in three locations (six environments) at 2014-15 and 2015-2016

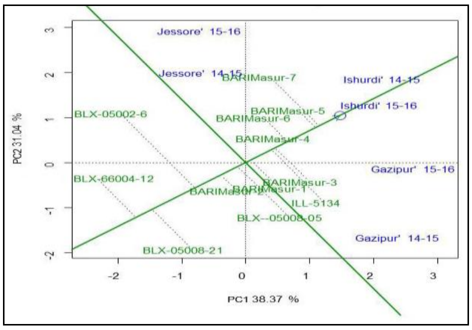


Fig. 6. GGE Biplot for yield mean and Stability performance

Biplot for yield mean and Stability performance

In Figure 6, a vector is drawn from the biplot origin to each marker of the stability statistics to facilitate visualization of the relationship among different stability statistics. The correlation coefficient between any two stability statistics is approximated by the cosine of the angle between the vectors. Therefore, the most stable variety was BARIMasur-4 and second one BARIMasur-5 and third one BARIMasur-6 and lowest stable variety was BLX-05002-6. Although, multi-environment trials are used for genotype evaluation, they can also be used in stability statistics evaluations. Ideal stability statistics should be highly differentiating of the genotypes and at the same time identifying high yielding genotypes. In Figure 6, the stability statistics are ranked based on both discriminating ability and representativeness. The center of the concentric circles is where an ideal stability statistics should be; its projection on the average tester coordinate PC1 was designed to be equal to the longest vector of all stability statistics; therefore, it is the most discriminating; its projection on the average tester coordinate PC2 was obviously zero, meaning that it is absolutely representative of the average stability statistics. Therefore, the closer stability statistics are to this mean yield, the better it is as stability statistics.

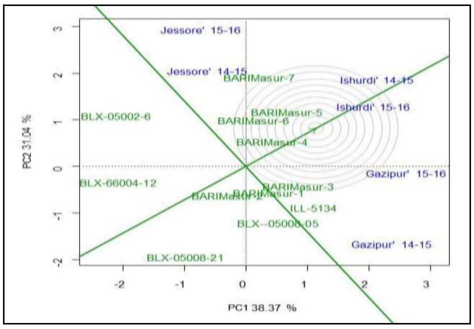


Fig. 7. **Ranking of Genotypes based on Yield and Stability performance**

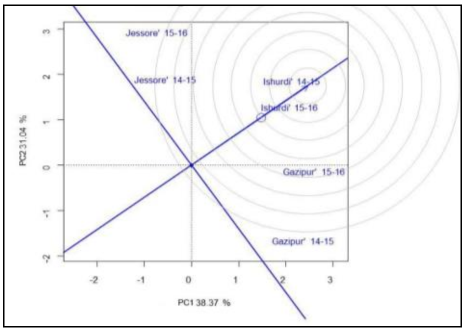


Fig. 8. **Ranking of environment based on yield and stability performance**

Ranking of Genotypes based on Yield and Stability performance

The estimation of yield and stability of genotypes (Figure 7) were done by using the average co-ordinates of the environment (AEC) methods (Yan, 2001; Yan and Hunt, 2002). The average environment is defined by the average values of PC1 and PC2 for the all environments and it is presented with a circle. The average ordinate environment (AOE) was defined by the line which is perpendicular to the average environment axis (AEA) line and pass through the origin. This line divided the genotypes in to those with higher yield than average and in to those with lower yield than average. By projecting the genotypes on AEA axis, the genotypes are ranked by yield, where the yield increases in the direction of arrow. In this study the highest yield had genotypes BARI Masur-5, BARI Masur-6, BARI Masur-4, BARI Masur-7 and the lowers was in BLX-66004-12. In this study, the greatest stability in the high yielding group had genotypes BARI Masur-4, BARI Masur-5 and BARI Masur-6, while the most stable of all was BARIMasur-4. These results are in agreements with those obtained by Naheif (2013) in wheat.

Ranking Environment

Stability performance of genotypes is an important consideration in breeding programs (Kang and Pham 1991, Kang 2002). According to Yan (2002), discriminating ability and representativeness are the important properties of a test location, an ideal location should be highly differentiating of the tested genotypes and at the same time representative of the target locations. According to Figure 8, location Ishurdi 2014-15 is more desirable test environment than the other test locations. Thus, genotype evaluation in Ishurdi 2014-15 maximizes the observed genotypic variation among genotypes for grain yield of lentil. The discriminating ability of a location can show the comparison of genotypes, but the presence of GE interaction complicates the identification of genotypes in the ideal test location (Yan *et al.* 2000). Usually non-additive or crossover GE interaction was observed in the most MET and it is essential to reveal the nature of GE interaction. GGE methodology is suitable tool to analyze these kinds of interactions and partitioning them into their PCs. The test location should has large PC1 scores in order to discriminate genotypes in terms of the genotypic main effect and absolute small PC2 scores in order to be more representative of the overall locations (Yan and Rajcan, 2002).

Conclusion

It was revealed that the most stable varieties were BARI Masur-4, BARI Masur-5 and BARI Masur-6 across the six environments. The varieties BARIMasur-3, BARIMasur-4, BARIMasur-5, BARIMasur-6 and BARIMasur-7 exhibited comparatively higher mean yield (>1.30 t/ha) and stable performance across the environments and the location Ishurdi 2014-15 was stable for most of the genotypes of lentil.

References

Admassue, S., M. Nigussie and H. Zelleke. 2008. Genotypex environment interaction and stability analysis for yield of maize. *Asian J. Plant Sci*. **7:** 163-169.

Allard, R.W and A.D. Bradshaw. 1964. Implications of genotype-environment interation in applied plant breeding. *Crop Sci.* **4:** 503-508.

Anonymous. 2013. Krishidiary, Agricultural Information Service (AIS), Khamarbari, Farmgate, Dhaka, Bangladesh-1215. P. 17.

Dehghani, H., S.H. Sabaghpour and N. Sabaghnia. 2008. Environment interaction for grain yield of some lentil genotypes and relationship among univariate stability statistics. *Spanish J. Agric. Res*. **6**(3): 385-394.

Eberhart, S.A and W.A. Russell. 1966. Stability parameters for comparing varieties. *Crop Sci.* **6:** 36-40.

Gauch, H.G. Jr. Piepho H.P. and P. Annicchiarico. 2008. Statistical analysis of yield trials by AMMI and GGE: further considerations. *Crop Sci.* **48:** 866-889.

Hamdi, A, Somaya, M. Morsy, E. and A. El-Garreib. 2002. Genetic and environmental variations in seed yield and its components, protein and cooking quality of lentil. *Egypt J. Agric. Res*. **80**(2): 737-752.

Kang, M.S. and H.N. Pham. 1991. Interrelationships among repeatabilityof several stability statistics estimated from international maize trails. *Crop Sci*. **28:** 925-928.

KangMS2002.Quantitativegenetics, genomics, and plant breeding. wallingford, UK, CABI.

Sabaghnia, N., H. Dehghani and S.H. Sabaghpour. 2008. Graphic analysis of genotype by environment interaction for lentil yield in Iran. *Agronomy J.* **100:** 760-764.

Sandhu, J.S. and S. Singh, 2007. History and origin. Pages 1-9 in Yadav, S.S., Mcneil, D.L. and Philip, C. S. eds. Lentil: An ancient crop for modern time. Dordrecht: Springer.

Urbano, G., J.M. Porres, J. Frias, C. Vidal-Valverde. 2007. Nutritional Value. Pages: 47-93. In: Lentil: An Ancient Crop for Modern Times. Yadav, S.S. Mc Neil, D., Stevenson, P.C. eds. Springer, the Netherlands.

Yadav, S.S., P.C. Stevenson, A. H. Rizvi, M. Manohar, S. Gailing, and G. Mateljan. 2007. Uses and Consumption. Pages: 33-46. In: Lentil: An Ancient Crop for Modern Times. Yadav S.S., Mc Neil, D and Stevenson, P.C. eds. Springer, the Netherlands.

Yan, W. 2001. GGE biplot- a windows application for graphical analysis of multi-environment trial data and other types of two way data. *Agron. J.* **93:** 1111-1118.

Yan, W. 2002. Singular-value partitioning in biplot analysis of multi-environment trial data. *Agron. J.* **94:** 990–996.

Yan, W. and L.A. Hunt. 2002. Biplot analysis of diallel data. *Crop Sci*. **42:** 21-30.

Yan, W. and M.S. Kang. 2003. GGE-biplot analysis: Agraphical tool for breeders, geneticists, and agronomists. CRC Press, Boca Raton, FL, USA.

Yan, W. and I. Rajcan. 2002. Biplot evaluation of test sites and trait relations of soybean in Ontario. *Crop Sci.* **42:** 11-20.

Yan, W., L.A. Hunt, Q. Sheng and Z. Szlavnics. 2000. Cultivar evaluation and mega-environment investigation based on GGE biplot. *Crop Sci.* **40:** 597-605.

Yan, W., M.S. Kang, B. Ma, S. Woods and P.L. Comelius. 2007. GGE Biplot vs. AMMI analysis of genotype-by environment data. *Crop Sci*. **47:** 643- 655.

Zobel, R.W., M.J. Wright and H.G. Gauch. 1988. Statistical analysis of yield trial. *Agron. J.* **85:** 168-170.