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Yield Stability and Agronomic Performance of Rain Fed Upland Rice Genotypes by Using GGE Bi-Plot and AMMI in North West Ethiopia

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Abstract: *The study was conducted at Fog era, Pawe, Assosa, Gondar and Mai-tsebri in Ethiopia during 2016-2017 with the objective of identifying high yielding, major disease resistance and stable rice varieties for rain fed upland ecosystem. A total of seventeen rain fed upland genotypes including one check were used for the study. The trial was laid out in randomized complete block design with three replication with a plot sized of 7.5 m2 with six rows in each location. Data were analyzed using combined analysis of variance, GGE bi-plot and AMMI. The combined analysis of variance for grain yield, days to maturity, days to heading, panicle length and filled grain per panicle showed significant difference (P≤0.01). G7 and G4 showed significant difference than the standard check on grain yield and better resistance to blast disease and gave grain yield advantage of 11 % and 10 %, respectively. The three way interaction of genotypes x environment x years were revealed significant variation (P≤0.01) for yield and other agronomic characters. The GGE bi-plot analysis showed that PCA 1 and PCA 2 described for 51.63 % and 27.31% of GGE sum of squares, respectively for grain yield, explaining a total of 78.95 % variation. In AMMI bi-plot, environments E2, E3 and E4 exerted strong interaction forces while the rest (E1 and E5) did less. Based on GGE bi-plot analysis result, Genotype (G4) and genotype (G7) were recommended for national variety releasing committee to release for future production by considering their high yielding and stability.*

Keywords: *Multi-environment trial, Stability, GGE bi-plot, AMMI*

1. Introduction

Rice is one of the target commodities that have received due emphasis in Ethiopian agriculture and is considered as the "Millennium crop" expected to contribute to ensuring food security in the country. Ethiopia has 5 million hectare of highly suitable growing areas in the country [1]. Rain-fed lowland, rain-fed upland and irrigated rice growing ecosystems are currently applying in Ethiopia among the five recognized rice growing ecosystems in the world. There is an increasing trend in area coverage and volume of production of rice in the country [2] (Figure 1). According to the report from CSA, the grain yield increases from 1.8 t/ha (2005) to 2.8 t/ha (2016) and the production increases from11, 244.3 tons (2007) to 126,806.4 tons (2016). However, the country increasingly importing (22,500 tons in 2008; 311, 827 tons in 2016) rice, which costed the country more than US $ 170 million. In Ethiopia, rice surve as for the preparation of different local dishes like *Injera, dabbo, kinche and local bear*. More over the crop is playing a significant role for means of employment for the local community [3]. Multi-environment variety trials had been conducting to select high yielding varieties with wider adaptation with major disease resistance and early maturing characters.

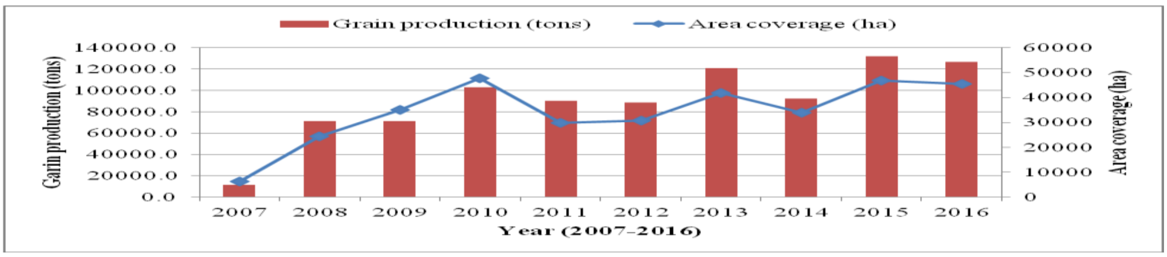

Figure1. *Rice grain production and area coverage trend in Ethiopia (CSA, 2007-2016)*

Due to the variation on soil fertility, pattern of rainfall, biotic and abiotic factors; the response on yield varies from genotype to genotype across different locations and over years [4]. Environmental factors are essential for the growth and the interaction effect result on phenotypic variation of an individual genotype. The performance of a given genotype is determined by growing environment, genetic makeup and their interaction effect. This revealed that genotypes are responsible for the genotype by environment interaction in multi-environment trials in breeding [5]. To determine the adaptability of genotypes and stability across different locations, GEI is often used among several methods [6]. The genotype main effects plus genotype by environment interaction effects (GGE bi-plot) [7] is the most frequently used tool for multi-environment trials data analysis. Therefore, the main objective of this study was to evaluate the stability and performance of introduced upland rice genotypes for their wider or specific recommendation in Northe-West Ethiopia.

2. Material and Methods

The experiment was conducted for 2 years (2016-2017) for five locations. Including one check, a total of 17 rain fed upland genotypes introduced from Africa rice centre and Brazil used (Table 1). The locations are where the trials conducted differ in soil type, annual rain fall, altitude, annual temperature (Table 2). The trial was laid out in randomized complete block design with three replications for all location. Each plot had a size of 7.5 m^2 (Six rows with 5 m long with 0.25 m row spacing). Seed rate of 60 kg/ha was used and direct seeding methods in a row was applied. Fertilizer (UREA and DAP) were applied based on each location recommendation. All DAP was applied at the time of sowing. For UREA, split application was applied; 1/3 at sowing, 1/3 at active tillering and the remaining 1/3 during panicle initiations. Other agronomic practices were applied according to each location recommendations. The data were subjected to the GLM procedure for analysis of variance using SAS software V.9.0. And Genotype x environment and stability analysis were done by using Gens tat 18th edition software.

Table1. *List of genotypes used in the study*

No	Genotype	Code for Genotype	Source
1	NM1-29-4-B-P-80-8	G1	Africa Rice Center
2	ART16-9-29-12-1-1-2-B-1-1	G2	Africa Rice Center
3	ART16-9-14-16-2-2-1-B-1-2	G3	Africa Rice Center
4	ART16-9-33-2-1-1-1-B-1-2	G4	Africa Rice Center
5	ART16-9-122-33-2-1-1-B-1-1	G5	Africa Rice Center
6	ART15-19-5-4-1-1-1-B-1-1	G6	Africa Rice Center
7	ART16-5-9-22-2-1-1-B-1-2	G7	Africa Rice Center
8	ART16-21-4-7-2-2-2-B-2-2	G8	Africa Rice Center
9	ART16-9-16-21-1-2-1-B-1-1	G9	Africa Rice Center
10	ART15-13-2-2-2-1-1-B-1-2	G10	Africa Rice Center
11	ART15-16-45-1-B-1-1-B-1-2	G11	Africa Rice Center
12	ART16-5-10-2-3-B-1-B-1-1	G12	Africa Rice Center
13	ART16-4-1-21-2-B-2-B-1-2	G13	Africa Rice Center
14	PARC.DAT.V-1.2013	G14	Brazil
15	PARC.DAT.V-2.2013	G15	Brazil
16	PARC.DAT.V-3.2013	G16	Brazil
17	NERICA-4(Check)	G17	Pawe Research Center

Table2. *Description of study environment*

Location	Altitude (m)	Latitude	Longitude	Annual rain fall (mm)	Temperature (Mean) ^{0}C	
					Max	Min
Fogera/Woreta	1810	11^{0}58'N	37^{0}41' E	1300	27.9	11.5
Pawe	1050	11^{0}9' N	36^{0}3' E	1457	32.8	17.2
Assosa/Kamashi	1250	10^{0}04'	34^{0}56'	1200	31.5	17.0
Shire/Mai-tsebri	1350	13^{0}05' N	38^{0}08' E	1296	36.0	15.0
Gondar/Metema	750	12^{0}54' N	36^{0}15' E	1100	29.0	22.0

3. Result and Discussion

The combined analysis of variance for grain yield, days to maturity, days to heading, panicle length and filled grain per panicle showed significant difference ($P \leq 0.01$); similarly plant height ($P \leq 05$) and fertile tiller per panicle (P≤10). The analysis of environment effect also revealed significant difference (P≤0.01) for yield and other agronomic characters and plant height also showed significant difference (P≤05). The analysis of variance for years revealed significant difference (P≤0.01) for all characters. The genotype x environment interaction effect was significant for days to heading and days to maturity; grain yield and filled grain per panicle (P≤0.01), (P≤0.05), (P≤0.10), respectively. However there were no significant different for panicle length, fertile tiller per panicle and plant height (table 3). The three way interaction of genotypes x environment x years were showed significant variation (P≤0.01) for yield and other agronomic characters. The study revealed that genotypes responded differently to grain yield and other agronomic characters in different environments over years. This pointed out the advantage of executing multi location trial to investigate the response of genotypes for their specific or wider adaptability.

The significant interaction difference of the three way interaction of genotype x environment x years revealed that the possibility of getting genotypes which can be adapted widely/or specifically. As indicated (table 3), the mean grain yield of the 17 upland genotypes ranged from 3426.1 kgha^{-1} (G10) to 4439.3 kg ha^{-1} (G7). Compared to the standard check (G17), the five genotypes (G4, G7, G5, G12, G8) were statistically high yielder than the check. However only the two genotypes G7 and G4 showed significant difference than the standard check on grain yield and better resistance to blast disease and gave grain yield advantage of 11 % and 10 %, respectively. These two genotypes (G7 and G4) genotypes proposed for national variety release. The high mean grain yield of the two genotypes (G7 and G4) at different locations were scored (table 4), and confirmed that these genotypes repeatedly showed their better performance in different environments.

Table3. *Combined mean grain yield and other yield related parameters of 17 upland rice genotypes in North West Ethiopia (5 locations over 2 years)*

Trt	Genotype	Code	DM	DH	PL	PH	FTP	FGP	Gykgha	LB	PB	BS
1	NM1-29-4-B-P-80-8	G1	110.60	75.58	20.12	85.4	5.08	117.93	3992.7	1.1	1.8	0
2	ART16-9-29-12-1-1-2-B-1-1	G2	111.40	76.38	20.06	92.27	5.5	105.58	3529.7	1	0	0
3	ART16-9-14-16-2-2-1-B-1-2	G3	110.00	74.37	20.93	86.78	5.1	107.93	3889.1	1	0	1
4	ART16-9-33-2-1-1-1-B-1-2	G4	114.00	81.20	20.19	92.12	5.3	118.75	4399.0	0	1.1	0
5	ART16-9-122-33-2-1-1-B-1-1	G5	111.00	79.18	19.82	90.52	5.3	105.58	4225.9	0	1.1	0
6	ART15-19-5-4-1-1-1-B-1-1	G6	112.20	79.23	20.49	89.83	4.95	101.75	3931.7	1.2	0	1
7	ART16-5-9-22-2-1-1-B-1-2	G7	113.60	80.13	19.52	91.58	5.3	119.03	4439.3	0	1.2	1.1
8	ART16-21-4-7-2-2-2-B-2-2	G8	111.20	76.58	19.95	86.52	5.43	111.58	4095.3	0	1.0	0
9	ART16-9-16-21-1-2-1-B-1-1	G9	112.90	79.80	20.62	91.33	5.68	113.88	3992.2	1.6	1.2	0
10	ART15-13-2-2-2-1-1-B-1-2	G10	109.30	76.60	20.83	86.64	5.42	102.5	3426.1	1.7	1.1	0
11	ART15-16-45-1-B-1-1-B-1-2	G11	110.70	77.00	19.92	86.84	4.98	110.93	3715.0	0	0	1.1
12	ART16-5-10-2-3-B-1-B-1-1	G12	111.40	78.48	21.32	92.06	5.18	117.28	4113.3	1.	1.1	1
13	ART16-4-1-21-2-B-2-B-1-2	G13	113.10	78.43	20.39	92.1	4.93	117.5	3964.4	0	1.1	1
14	PARC.DAT.V-1.2013	G14	114.80	83.70	21.14	87.8	5.6	108.5	3843.1	0	1.3	0
15	PARC.DAT.V-2.2013	G15	115.30	84.85	21.20	90.53	5.53	107.68	3718.0	0	1.7	0
16	PARC.DAT.V-3.2013	G16	115.20	84.20	20.87	89.62	5.42	109.58	3714.9	0	1.2	0

17	NERICA-4(Check)	G17	110.40	75.75	19.90	86.38	5.8	109.9	4007.6	0	1.2	0
	Mean		112.16	78.92	20.42	89.31	5.20	110.90	19.5			
	CV (%)		2.5	2.8	8.0	11.1	23.0	15.0	19.5			
	Genotype (G)		***	***	***	**	*	***	***			
	Environment (E)		***	***	***	**	***	***	***			
	Year (Y)		***	***	***	***	***	***	***			
	GxE		***	***	NS	NS	NS	*	**			
	GxExY		***	***	***	***	***	***	***			

Note: **, **, and *** refers to significant at 5%, 1% and 0.1% level, NS=non -significant, DH= days to 50% heading, DM= days to 85% maturity, PL= panicle length(cm), PH= plant height(cm), FTP= fertile tillers/plant, FGP= filled grains/panicle, Gykgha= grain yield (kg/ha),LB=leaf blast, PB=Panicle blast, BS=Brown spot*

Table4. *Mean grain yield of 17 upland rice genotypes across five environments in Northwest Ethiopia*

No	Genotype	Assosa 2016	Assosa 2017	Fogera 2016	Fogera 2017	Gondar 2016	Gondar 2017	Pawe 2016	Pawe 2017	Shire 2016	Shire 2017
1	NM1-29-4-B-P-80-8	6598.0	3895.9	**1770.9**	2732.5	**2980.0**	**6085.3**	4090.0	4723.8	3593.8	3456.8
2	ART16-9-29-12-1-1-2-B-1-1	5237.0	4415.4	1540.0	2519.1	2775.9	4853.9	3865.8	3404.5	3750.0	2934.6
3	ART16-9-14-16-2-2-1-B-1-2	6516.0	2577.1	1545.7	2233.1	2634.5	5375.9	**4437.8**	5742.3	**4425.0**	3403.5
4	ART16-9-33-2-1-1-1-B-1-2	**6762.0**	**5028.5**	1495.5	**3828.8**	2807.9	5575.2	**5119.9**	5693.2	3643.8	**4035.1**
5	ART16-9-122-33-2-1-1-B-1-1	**6754.0**	3988.0	1637.5	3581.8	3182.6	**5960.0**	4176.4	5363.8	3862.5	**3752.3**
6	ART15-19-5-4-1-1-1-B-1-1	6008.0	3824.2	1238.3	3228.4	2543.5	5341.7	3859.6	5468.6	**4409.3**	3395.7
7	ART16-5-9-22-2-1-1-B-1-2	6346.0	**4840.6**	1462.4	**4143.7**	**2946.5**	5533.4	**4154.7**	**7035.9**	3762.5	**4166.8**
8	ART16-21-4-7-2-2-2-B-2-2	6454.0	3904.5	**1648.7**	**3726.2**	2831.9	5879.5	3763.1	5377.3	**4050.0**	3318.1
9	ART16-9-16-21-1-2-1-B-1-1	4784.0	4525.5	1344.4	3430.2	2840.2	5482.3	4222.7	**6067.5**	3806.3	3419.1
10	ART15-13-2-2-2-1-1-B-1-2	5404.0	3840.6	1198.0	2949.0	2227.5	4651.2	2998.0	3953.9	3675.0	3363.6
11	ART15-16-45-1-B-1-1-B-1-2	5509.0	4127.0	1216.8	2399.0	2553.4	5292.3	4655.9	4420.8	3943.8	3032.2
12	ART16-5-10-2-3-B-1-B-1-1	5990.0	5410.8	1497.3	3496.1	2631.2	4649.6	4278.3	6123.9	3468.8	3587.4
13	ART16-4-1-21-2-B-2-B-1-2	6476.0	**4976.4**	1522.2	3463.8	2474.7	5056.4	3490.9	5525.9	3312.5	3345.0
14	PARC.DAT.V-1.2013	**6959.0**	3526.2	1157.3	2053.1	**2968.0**	5171.5	4094.2	5374.2	3881.3	3246.0
15	PARC.DAT.V-2.2013	6507.0	3524.6	**1802.3**	2326.5	2755.9	4688.7	3637.5	5439.7	3400.0	3097.4
16	PARC.DAT.V-3.2013	4444.0	3808.1	1082.5	2299.2	2922.0	5187.9	3980.0	**6719.9**	3593.8	3112.1
17	NERICA-4(Check)	5744.0	4099.6	1791.2	3593.2	2670.2	**6125.8**	3818.9	5320.8	3700.0	3211.5
	Mean	6028.9	4136.1	1467.7	3059.0	2749.8	5347.7	4037.9	5397.4	3781.1	3404.5
	CV (%)	23.5	20.0	27.9	15.3	13.6	12.4	17.8	18.8	13.8	10.0
	LSD (5 %)	2010.7	1176.6	583.6	667.2	532.06	945.63	1022.3	1442.4	742.5	505.7

Note1. *The underlined figures show the first three high yielding genotypes under each environment*

4. GGE Bi-Plot Analysis

The G x E interaction pattern of data can be identifying by using GGE bi-plot and clearly showed which genotypes perform best in which environments [8]. The GGE bi-plot analysis showed that PCA 1 and PCA 2 described for 51.63 % and 27.31% of GGE sum of squares, respectively for grain yield, explaining a total of 78.95 % variation (Figure 2). The vertex genotypes (G7, G4, G18, G1 and G13) have the longest vectors in their respective directions and provided the highest grain yield for each respective environment. The polygon view of the GGE bi-plot indicates the best genotypes in each environment and group of environment [9]. The genotype with the highest mean yield in E1 and E2 is G4 followed by G12, G5, G8 and G17. In E4, the highest yielding genotype is G7. The other vertex genotypes (G2, G1, G11, G18, G3, G9, G14, G6 and G15) are poorest in all environments because there is no environment in their sectors (Figure 2).

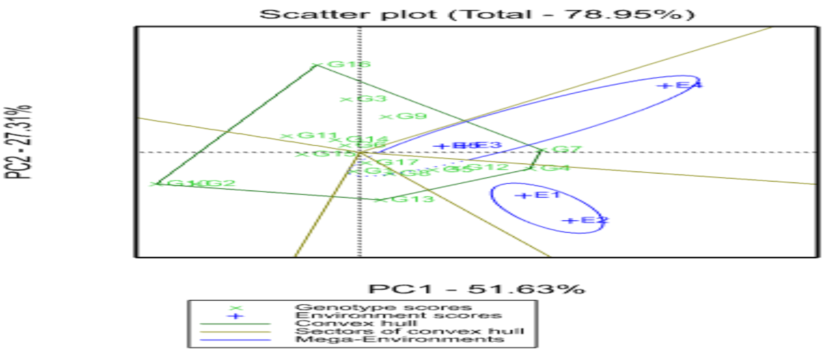

Figure2. *GGE bi-plot of 17 upland rice genotypes for grain yield based on which won where pattern.*

The 17 rain fed upland rice genotypes are ranking (figure 3) based on their mean yield and stability performance. The line passing through the bi-plot origin called the average tester axis (ATA), which is defined by the average PC1 and PC2 scores of all environments **[10]**. The line which passes through the origin and is perpendicular to the ATC represents the stability of genotypes. Genotypes close to the origin (G6, G14, G17 and G15) have average performance in all environments (Broadly adapted) and genotypes far from the origin have a large genotype plus interaction effect. The perpendicular to the ATA that passes through the origin separated genotypes (G16, G10, G2, G11, G3, G6, G14 and G15) with below-average means from those with above-average means (G1, G17, G8, G13, G9, G12, G4, G7 and G5). Of these, G4 and G7 was the highest yielding genotype (4439.3 kgha^{-1}) followed by G4 (4399.0 kgha^{-1}). Genotype (G4) was the most stable followed by Genotype (G7) and in terms of yield Genotype (G7) slightly high yielding (4439.3kgha^{-1}) than G4 (4399.0 kgha^{-1}) (Figs.2, 3 and table 3). Genotype (G16) was the most unstable however high yielding than Genotype (G2) and Genotype (G10). In addition, ggenotype (G12, G5 and G17) were the most stable genotypes next to Genotype (G4).

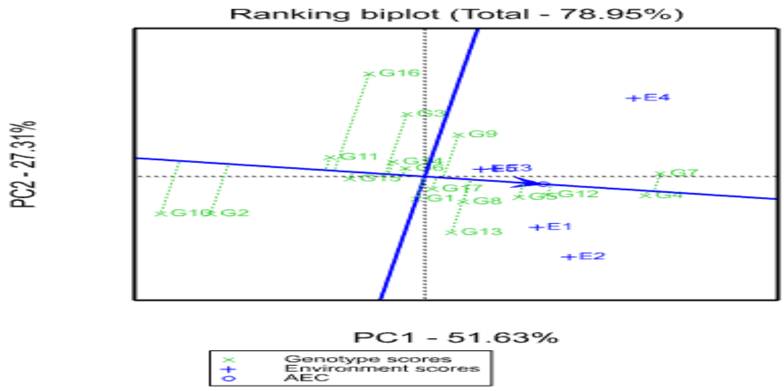

Figure3. *GGE biplot for ranking of tested genotypes mean based on their mean grain yield performance and stability*

5. Comparison of All Genotypes With Ideal Genotype

The ideal genotype, represented by the small circle with an arrow pointing to it, is defined as having the highest yield in all environments [11], revealed highest mean yield and absolutely stable. Such an ideal genotype is defined by having the greatest vector length of the high yielding genotypes and with zero GEI [12], as represented by an arrow pointing to it (Figure 4). Using the ideal genotype as the center, concentric circles were drawn to visualize the distance between genotype and the ideal genotype. G4 is the ideal genotype followed by G7 because they are close to the virtual ideal genotype. On the other hand, G2, G10 and G11 were the poorer genotypes because they are far from the ideal genotype (Figure 4).

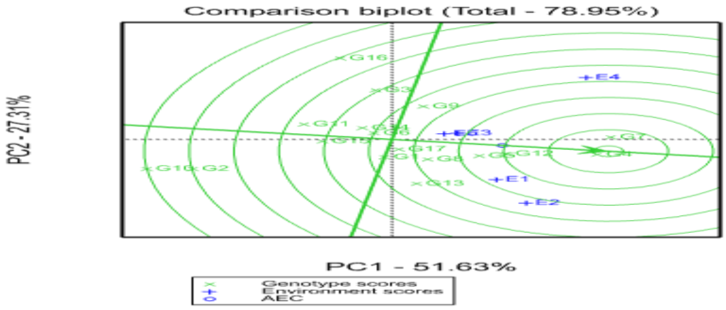

Figure4. *GGE bi-plot of ideal genotype and comparison of the genotypes with the ideal genotype*

In AMMI bi-plot, the environmental scores are joined to the origin by side lines. Spots with short lines do not exert strong interactive forces. Those with long lines exert strong interaction. Thus, environments E2, E3 and E4 exerted strong interaction forces while the rest (E1 and E5) did less. Genotypes near to the origin are not responsive to environmental interaction and those distant from the origins are responsive and have large interaction. Thus, genotypes G16, G12, G13, G10, G2 and G3 had more sensitive because they were far from the origin. Genotypes like G11, G6, G14 and G15 were the most closest to the origin and hence had almost no interaction forces. The rest were close to the origin and hence they were less sensitive to environmental interactive force (Figure 5)

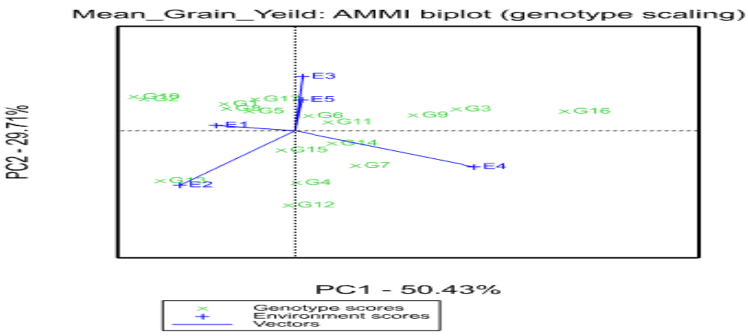

Figure5. *AMMI bi-plot for mean grain yield showing the interaction of PC1 against PC2 of genotypes (G) and Environment (E)*

6. Conclusion and Recommendation

The study revealed that significant difference among genotypes and testing environments for mean grain yield and other agronomic traits. This indicated that genotypes response differently in different environments. The study also indicated that yield and other related traits were influenced by Genotype x Environment interaction effect, genotype and environment. The GGE bi-plot analysis agreed to visualize the winner genotype in each sector to classify high yielding and stable genotypes. The stability of the genotypes was graphically represented by the projection from the entry symbol to the ATA (Average Tester Axis), the longer the greater is the GxE interaction and therefore the lower is the stability of the genotype across locations. Genotype (G4) was the most stable genotype followed by Genotype (G7). Genotype (G4) and genotype (G7) were recommended for national variety releasing committee to release for cultivation. In AMMI bi-plot, Genotypes near to the origin are not responsive to environmental interaction and those far from the origins are responsive and have large interaction.

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