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AMMI Analysis of G X E Interaction in Finger Millet Genotypes for Yield Stability and Adaptability

S. Das[1], A. Mishra[1], N. Senapati[1] and S. Swain[2]

[1]*Department of Plant Breeding and Genetics, College of Agriculture, Orissa University of Agriculture and Technology, Bhubaneswar-751 003, Orissa*
[2]*Department of Horticulture, College of Agriculture, Orissa University of Agriculture and Technology, Bhubaneswar-751 003, Orissa*

Email: swarnalata1967@rediffmail.com

ABSTRACT: Multilocation yield trials on fifteen early duration finger millet (*Eleusine coracana* Gaertn.) genotypes were conducted under early and late transplanting condition at Bhubaneswar and early direct sown condition at Berhmpur for three years during *kharif* season. G X E interaction analysis of grain yield in AMMI (Additive Main and Multiplicative Interaction) model showed differential interaction of the genotypes in three planting conditions. IPCA-1 explained 66.5% of G X E interaction. AMMI I biplot of G X E interaction showed that RAU 8, DM 7, SRS 2 and BM 107-2 had high mean and moderate negative interaction effects, while Bhairabi and Neelachal had high mean and small positive interaction effects. AMMI biplot showed differential interaction of the genotypes in different environmental conditions. On the basis of AMMI II predicted yield, the genotypes SRS 2 and RAU 8 would be better adapted to all planting conditions. Genotype Bhairabi would be suited for early cropping, but not late cropping. The genotype DM 7 would be best suited for transplanting condition and not for the direct seeded condition. BM 107-2 would be best suited for late transplanting, while Neelachal would be best suited for the direct seeded condition, indicating their specific adaptation.

Key words: Finger millet, AMMI analysis, G X E interaction, stability and adaptability

Introduction

Among the millets of the world, Ragi or finger millet (*Eleusine coracana* Gaertn.) ranks fourth after pearl millet, fox-tail millet and proso millet. It is usually grown on marginal lands under moisture stress and low fertility. It forms a component of risk prone dry land/rainfed agriculture. Finger millet or ragi is the most important of the small millets grown in India. It covers an area of 1.7 million hectares in India with a production of 2.44 million tones and productivity of 1481 kg/ha. In Odisha state the crop is generally grown under direct seeded condition in low rainfall zones and in the transplanted condition in high rainfall zones. Lack of high-yielding varieties adapted to diverse agro-ecological conditions are the major reason of low productivity. Though more than 200 finger millet varieties have been released in India and the number is increasing every year, many of them have become out of cultivation due to inconsistent performance in diverse environments and only few varieties with stable performance continue to be under cultivation even after15-20 years of release. In fact very few varieties show adaptability to a wide range of environments, while most others show better adaptability to specific agro-ecological or agro-management conditions. Evaluation of the interaction of genotypes with locations and other agro-management conditions would help in getting information on adaptability and stability of performance of genotypes. The linear regression model of Eberhart and Russell (1966) has been the most frequently used model for analysis of genotype-environment interaction, adaptability and stability of performance of genotypes. But the linear regression model does not provide for critical analysis of interaction of genotypes in specific environments. AMMI (Additive Main and Multiplicative Interaction) model is considered to be a better model for analysis of G X E interaction in multilocation varietal yield trials (Zobel *et al.* 1988, Gauch, 1992 and Purchase, 1997). It not only gives estimates of G X E interaction effect of each genotype, but further partitions it into interaction effects due to individual environments. The present study was undertaken to analyze G X E interaction of 15 early duration finger millet genotypes in AMMI model and to evaluate the adaptability and stability of yield performance.

Materials and Methods

Yield trials on 15 early duration (90-105 days) finger millet genotypes were conducted in three environmental conditions (early and late transplanting at Bhubaneswar and early direct seeded at Berhmpur) for 3 years (2004-2006) during *kharif* season. The genotypes included ten released varieties and five pre released varieties (OEB 65, BM 107-2, SRS 2, VL 322and DM 7). At Bhubaneswar, nursery sowing was done in the last week of June for early planting and in the last week of July for late planting and 25-30 days old seedlings were transplanted with 22.5 cm x 10 cm spacing and 2 seedlings per hill. At Berhampur, the trials were conducted under direct seeded condition and sowing was done in 1st week of July each year. Seeding was done in rows with 22.5 cm spacing between rows. All 9 trials were laid out in a randomized block design with 3 replications and plot size was 1.8 m x 3 m. Fertilizers were applied @ 50 kg N, 40 kg P_2O_5 and 25 kg K_2O per hectare and normal cultural practices and plant protection measures were followed in each trial. At Bhubaneswar the rainfall received during the crop growth period in 2004, 2005 and 2006 were 1051, 1189 and 1236 mm for early planted crop and 928, 1037 and 1055 mm for late planted crop (Figure 1 A, 1 B &1 C). At Berhmpur the direct seeded crop received 766,787 and 838 mm rainfall during 2004, 2005 and 2006. Grain yield data on 15 genotypes in the 9 environments was recorded and analyzed. The year component of the environment variables was eliminated by averaging over the years and the G X E interaction was analyzed in Additive Main and Multiplicative Interaction (AMMI) model (Zobel *et al.,* 1988 and Gauch,1992) with a view to identify finger millet genotypes better adapted to different planting conditions.

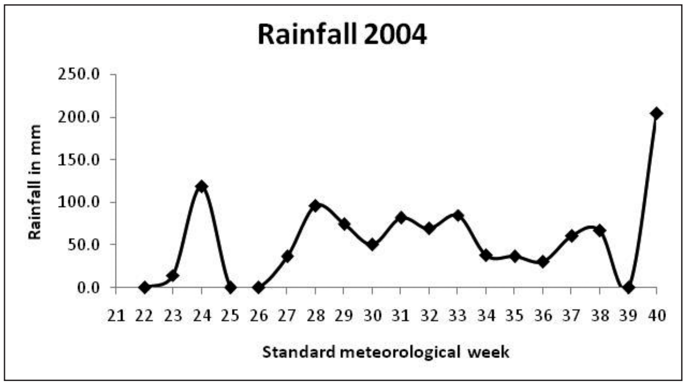

Fig.1(A) : Rainfall distribution (weekly) during crop growing season, 2004
(Standard meteorological week 22 starts from 28th May to 3rd June)

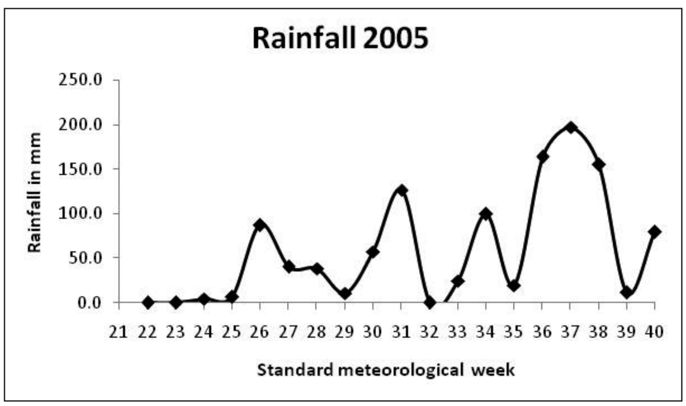

Fig.1(B) : Rainfall distribution (weekly) during crop growing season, 2005

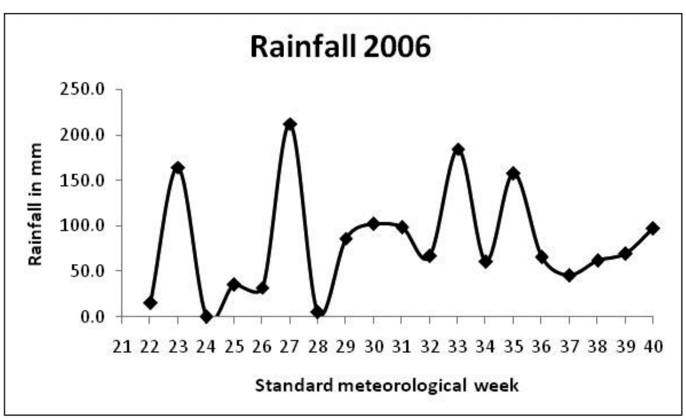

Fig.1 (C) : Rainfall distribution (weekly) during crop growing season, 2006

Results and Discussion

The genotypes showed significant differences (Table 1) in grain yield in the three environmental conditions in all the three years. During the 3 years, average trial yield under early planting conditions at Bhubaneswar varied from 23.68 to 26.34 q/ha with a grand mean of 25.04 q/ha, while under late planting, it varied from 21.72 to 24.22 q/ha with a grand mean of 22.67 q/ha (Table 2). Late transplanted crop did not show much reduction in yield due to fairly uniform distribution of rainfall during the cropping season. Yield level at Berhampur under direct seeded condition varied between 11.72 and 18.21 q/ha during the three years with a mean of 14.78 q/ha and the low yield level was due to low rainfall and the crop was grown under direct seeded condition. Average yield of the 15 genotypes at Bhubaneswar under early planting condition ranged from 13.05 to 31.68 q/ha and under late planting, average yield of the genotypes varied from 14.51 to 28.41 q/ha. Average yield of genotypes at Berhampur under direct seeded condition were generally low, ranging between 11.55 and 20.32 q/ha. Ranking of the genotypes on the basis of their yield performance in three environmental conditions showed G X E interaction as the G X E interaction component of combined analysis (Table 1) was significant.

The linear regression (LR) model of Eberhart and Russell (1966) is most frequently used for G X E interaction study and in this model a stable genotype should have a low deviation from the regression (S^2_d). So many genotypes having a very high yield potential accompanied with high S^2_d due to differential interaction with environments often get rejected. Thus, a genotype showing high positive interaction at certain environment and negative interaction at others is likely to show high S^2_d and would be classified as unstable. The LR model does not provide information for critical analysis of interaction of genotypes in specific environments and does not help in identifying promising genotypes to take advantage of their high positive interaction with the agro-ecological conditions of specific locations or specific agro-management conditions like early or late sowing, high or low fertility, rainfed or irrigated etc.

AMMI analysis of variance of yield data of the 15 genotypes under three environmental conditions showed that all three components, i.e. genotypes (G) and environments (E) and the

Table 1 : Pooled analysis of variance for grain yield (q/ha) in finger millet genotypes

Source	df	MS	F-Cal
Genotypes (G)	14	124.70**	35.82
Environments (E)	8	377.56**	108.44
G x E	112	11.33**	3.25
E + G x E	120		
Environment (linear)	1	3020.47**	400.56
G x E (linear)	14	34.09**	4.52
Pooled deviation	105	7.54**	2.17
Pooled error	252	3.48**	

** significant at 1% level; P = 0.01

Table 2 : Grain yield (q/ha) of early duration finger millet genotypes in the three environmental conditions during 2004 to 2006

Genotype		Duration (days)	Bhubaneswar (early planted)				Bhubaneswar (late planted)				Berhampur (direct sown)				Grand mean
			2004	2005	2006	Mean	2004	2005	2006	Mean	2004	2005	2006	Mean	
1	Bhairabi	102.3	32.60	26.63	28.98	29.40	29.30	22.27	22.27	24.62	21.74	17.54	19.44	19.57	24.53
2	Dibyasinha	91.2	16.79	18.34	21.89	19.01	12.67	17.19	13.66	14.51	15.83	13.47	14.82	14.70	16.07
3	Neelachal	100.6	29.38	32.63	25.68	29.23	22.39	24.06	21.89	22.78	18.79	19.65	22.53	20.32	24.11
4	OEB 65	99.3	30.13	31.22	25.51	28.95	24.03	22.12	22.06	22.74	11.87	10.38	18.21	13.49	21.73
5	VL 149	95.6	26.18	27.16	23.05	25.46	22.05	26.90	25.10	24.69	8.90	16.49	17.90	14.43	21.53
6	RAU 8	103.7	29.14	33.51	27.74	30.13	26.67	28.55	22.72	26.00	9.89	18.17	20.37	16.14	24.08
7	VR 708	94.5	22.22	21.16	21.40	21.59	16.79	21.97	19.92	19.56	7.42	12.49	13.58	11.16	17.45
8	BM 107-2	98.7	30.87	31.74	27.65	30.09	29.30	31.39	24.53	28.41	11.87	16.84	21.91	16.87	25.12
9	SRS-2	106.7	30.87	34.21	29.96	31.68	21.07	29.23	25.76	25.35	15.83	12.63	22.53	17.00	24.68
10	KM 231	97.0	22.23	16.93	20.08	19.75	18.43	23.91	21.57	21.30	9.39	12.56	17.2	13.08	18.04
11	HR 374	102.0	25.93	30.16	24.03	26.70	23.37	30.34	20.41	24.71	6.28	17.75	17.59	13.87	21.76
12	PES 400	98.3	23.21	22.22	18.44	21.29	17.29	21.23	20.74	19.75	10.88	9.12	18.52	12.84	17.96
13	VL 322	99.0	14.82	20.81	22.06	19.23	21.39	20.93	23.79	22.04	8.90	10.52	16.36	11.93	17.73
14	DM 7	106.2	28.15	34.75	27.22	30.07	27.98	30.79	23.70	27.49	10.88	12.63	20.99	14.83	24.13
15	AKP 2	89.0	14.20	13.58	11.36	13.05	13.01	12.36	22.81	16.06	7.42	16.14	11.11	11.55	13.55
	Average.		25.11	26.34	23.68		21.72	24.22	22.06		11.72	14.42	18.21		20.83
	CD (5 %)		5.01	5.70	3.83		5.53	5.97	5.05		2.58	3.17	5.45		

G X E interaction component were highly significant (Table 3). The main effects of genotypes and locations accounted for 35.68 and 53.01%, respectively and G X E interaction accounted for 11.31% of the total variation in G X E data for grain yield. The G X E interaction effects of the genotypes in the three environments (Table 4) showed that the genotypes OEB 65 and SRS 2 had high positive interaction and AKP 2, VL 322 and KM 231 had high negative interaction at Bhubaneswar under early planting. The genotype VL 322 showed high positive interaction and Dibyasinha and Neelachal showed high negative interaction under late planting condition at Bhubaneswar. Under direct sown condition at Berhampur, the genotypes Dibyasinha, AKP 2 and Neelachal showed high positive interaction and DM 7, BM 107-2 and OEB 65 showed high negative interaction.

The G X E interaction for grain yield was partitioned into IPCA 1 and IPCA 2 and both IPCA components were significant (Table 3). The most powerful interpretive tool in analysis of G X E interaction by AMMI model is the biplot analysis. It permits easy visualization of differences in interaction effects. In AMMI I biplot, the IPCA 1 scores of genotypes and environments are plotted against their respective means and in AMMI II biplot, the IPCA 1 and IPCA 2 scores of genotypes and environments

Table 3 : AMMI ANOVA of early duration finger millet genotypes for yield (q/ha)

Source	df	SS	% of G-E SS	MS	F-Cal	% of G X E interaction SS
Genotype (G)	14	581.936	35.68	41.57**	35.82	
Environment (E)	2	864.625	53.01	432.31**	372.5	
G X E	28	184.467	11.31	6.59**	5.68	
IPCA 1	15	122.765	7.53	8.18**	7.05	66.55
IPCA 2	13	61.742	3.78	4.75**	4.09	33.47
Residual	-	-0.040	-	-	-	-0.02
Error	252	292.471		1.16		

** significant at 1% level; P = 0.01

Table 4 : Interaction effects of early duration finger millet genotypes for yield (q/ha) in different environmental conditions

	Genotype	Location		
		Bhubaneswar (early planted)	Bhubaneswar (late planted)	Berhampur (direct sown)
1.	Bhairabi	0.66	-1.75	1.09
2.	Dibyasinha	-1.28	-3.40	4.68
3.	Neelachal	0.91	-3.17	2.26
4.	OEB 65	3.02	-0.82	-2.19
5.	VL 149	-0.28	1.33	-1.05
6.	RAU 8	1.84	0.06	-1.90
7.	VR 708	-0.06	0.29	-0.23
8.	BM 107-2	0.76	1.45	-2.21
9.	SRS-2	2.79	-1.16	-1.64
10.	KM 231	-2.51	1.43	1.08
11.	HR 374	0.73	1.11	-1.85
12.	PES 400	-0.88	-0.04	0.92
13.	VL 322	-2.71	2.47	0.24
14.	DM 7	1.73	1.53	-3.26
15.	AKP 2	-4.72	0.67	4.05

are plotted against each other. AMMI I biplot for grain yield of 15 genotypes at three environments (planting conditions) is presented in Figure 2. The main effects (G & E) accounted for 88.69 % and IPCA 1 accounted for 7.53 % of total variation (Table 4) and thus AMMI I biplot had a model fit of 96.22%. The scatter of the genotype points in the biplot showed four adaptive groups of genotypes (Figure 2). The group of genotypes Bhairabi and Neelachal had high mean and small positive interaction effects, while the group containing RAU 8, DM 7, SRS 2 and BM 107-2 had high mean and moderate negative interaction effects. The group comprising VL 149, HR 374 and OEB 65 had intermediate mean and moderate negative interactions, while VR 708, VL 322, PES 400 and KM 231 had low mean and small positive interactions. The genotypes AKP 2 and Dibyasinha scattered away from other genotypes and both the genotypes had low mean and very high positive interactions. Direct sown crop at Berhampur had a low mean effect accompanied with high positive interactions, while the late planting condition at Bhubaneswar had a high mean effect and small interactions and the early planting condition at this location showed the highest mean effect accompanied with high negative interaction.

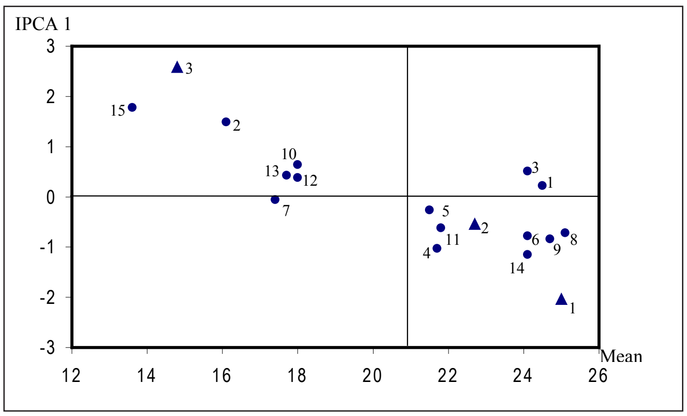

Fig. 2 : AMMI I biplot of main effects and GxE interaction of 15 finger millet genotypes (•) in three environments (▲)

AMMI II biplot for yield is depicted in Figure 3. The IPCA 1 and IPCA 2 accounted for 66.55% and 33.47% of the G X E interaction sum of squares (Table 3). In the AMMI II biplot, the genotypes Bhairabi, VL 149, RAU 8, BM 107-2, HR 374, KM 231 and PES 400 scattered close to the origin, indicating small interactions that is stability of performance over environments. The biplot showed that the remaining eight genotypes were more sensitive to environmental interactive forces. Judged by length of environment spokes in the AMMI II biplot, interactive forces of environments were greater under direct sown than transplanted cropping. Interaction of genotypes with specific environmental conditions was judged by the projection of genotype points onto environment spokes (Figure 3). On this basis, the genotypes OEB 65, DM 7, VR 708 and SRS 2 had high positive interaction, while Dibyasinha and AKP 2 had high negative interaction at Bhubaneswar under early planting. But under late planting at the location, the genotypes Dibyasinha, AKP 2 and Neelachal had high negative interaction and most of the remaining genotypes had small positive or negative interactions. Interaction of most genotypes under direct sown condition at Berhampur was in opposite directions from those under transplanted conditions. The genotypes Dibyasinha, AKP 2 and Neelachal showed high positive interaction, while DM 7, VR 708 and OEB 65 had high negative interaction under direct sown cropping.

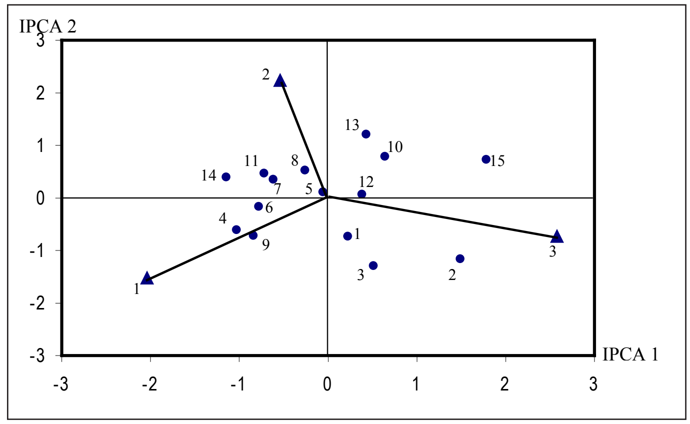

Fig. 3 : AMMI II biplot of GxE interaction of 15 finger millet genotypes (•) in three environments (▲)

AMMI analysis gives an estimate of total G X E interaction effect of each genotype and also further partitions it into interaction effects due to an individual environment (Zobel *et al.*,1988, Gauch, 1992 and Purchase, 1997). Low G X E interaction of a genotype indicates stability of performance of the genotype over the range of environments. A genotypes showing high G X E interaction in an environment obviously has the ability to exploit the agro-ecological or agro-management conditions of the specific environment and is therefore best suited to that environment. AMMI analysis permits estimation of interaction effect of a genotype in each environment and it helps to identify genotypes best suited for specific environmental conditions. Though analysis of G x E interaction of multilocation yield data in AMMI model have been reported by Mc Laren and Chaudhury (1998), Asenjo *et al.* (2003), Mahalingam *et al.* (2006); Naveed *et al.* (2007); Anandan *et al.* (2009); Fentie *et al.* (2013) and Islam *et al.* (2014) in rice; Tarakanovas and Ruzgas (2006) and Mohammadi *et al.* (2007) in wheat; Shinde *et al.* (2002) in pearl millet; Hariprassana *et al*. (2008) in groundnut; Balapure *et al.* (2016) in chick pea and few other crops but such reports in finger millet is lacking. All these workers found significant G X E interaction for grain yield and stressed the usefulness of AMMI analysis for selection of promising genotypes for specific locations or environmental conditions.

Conclusion

The present investigation indicates that genotypes SRS 2 and RAU 8 would be better adapted to all conditions. Bhairabi performed better under early transplanting at Bhubaneswar and early direct sown condition at Berhmpur indicating that the genotypes would be more suitable for early cropping. The genotype DM 7 showed better adaptation to both early and late transplanting conditions in Bhubaneswar, indicating that the genotype is suitable for transplanting condition and not for direct sown condition. The genotypes BM 107-2 ranking first under late transplanting at Bhubaneswar and Neelachal ranking first under direct seeded condition at Berhmpur indicated their specific adaptation.

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