World Applied Sciences Journal 6 (12): 1650-1654, 2009
ISSN 1818-4952

AMMI Model Analysis of Stability and Adaptability of Late Duration Finger Millet (*Eleusine coracana*) Genotypes

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Abstract: Multilocation yield trials on late duration (106-125 days) finger millet genotypes were conducted under early and late transplanting at Bhubaneswar and early direct-sown condition at Berhampur for three years 2004-2006, during *kharif* season. G×E interaction analysis of grain yield in AMMI (Additive Main and Multiplicative Interaction) model showed differential interaction of the genotypes in the 3 planting conditions. IPCA-1 explained 93% of G×E interaction. AMMI G×E interaction study showed that OEB 56, OEB 71 and VR 822 had high mean and positive interaction, while PES 110 had high mean and very low interaction. On basis of AMMI II predicted yield, the genotypes OEB 56 and OEB 71 were better suited for early transplanting at Bhubaneswar and early direct-sown condition at Berhampur indicating that the genotype would be suitable for early cropping, but not late cropping. The genotype PES 110 showed better adaptation to both early and late transplanting conditions at Bhubaneswar, indicating that the genotype is suitable for transplanting condition and not for direct-sown condition. Six other genotypes showed specific adaptation to single environment only, of which Chilika ranked first under late transplanting at Bhubaneswar and VR 822 ranked first under early direct-sown condition at Berhampur, indicating specific adaptation.

Key words: Finger millet · G×E interaction · AMMI analysis · Adaptability · Stability

INTRODUCTION

Finger millet is the most important of the small millets grown for food and among the course cereals and it accounts 7 % of the area 11 % of production in India [1]. 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, which is much lower than world average productivity. In Orissa State, the crop is generally grown under direct seeded condition in low rainfall zones and in transplanted condition in high rainfall zones. Lack of high yielding varieties adapted to diverse agro-ecological conditions is the major reason of low productivity of finger millet [1]. Evaluation of interaction of genotypes with locations and other agro-management conditions would help in getting information on adaptability and stability of performance of genotypes. The AMMI (Additive Main and Multiplicative Interaction) model suggested by Zobel *et al*. [2], Gauch [3] and Purchase [4] is considered to be a better model for analysis of G×E interaction in yield data of multilocation varietal trials. It not only gives estimate of total G×E interaction effect of each genotype but further partitions it into interaction effects due to individual environments. The present study in finger millet was undertaken to analyze G×E interaction using AMMI model and to evaluate stability and adaptability genotypes in different environments.

MATERIALS AND METHODS

Multilocation yield trial on 15 late duration (106-125 days) finger millet genotypes were conducted 3 environmental conditions: early and late transplanting at Bhubaneswar and early direct-sown at Berhampur for 3 years 2004-2006, during *kharif* season. Bhubaneswar (20^{O} 15’ N, 87^{O} 40’ E) represent high annual rainfall (1300-1700 mm) areas of the state where the crop is generally grown in transplanted condition. Berhampur (19^{O}18’ N, 84^{O}54’ E) represent low rainfall (1000-1300 mm) areas where the crop is grown in direct seeded condition. The 15 genotypes tested include five released varieties

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(PR 202, PES 110, Indaf 5, AKP 7 and Chilika) and 10 pre-release varieties (OEB 82, BEB 56, OEB 71, GPU 57, VR 849, VR 822, MR 33, VR 768, GPU 58 and OEB 52). 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. 21-25 days old seedlings were transplanted with 22.5 cm × 10 cm spacing. At Berhampur, the trials were conducted under early direct seeded condition and sowing was done in first week of July each year. Seeding was done in rows with 22.5 cm spacing between rows. All the nine trials were conducted in randomized block design with 3 replications and plot size was 2.25 × 3 m. Fertilizers were applied as: 50 kg N, 40 kg P_2O_5 and 25 kg K_2O per hectare. 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 1071, 1239 and 1367 mm for early planted crop and 914, 1068 and 1095 mm for late planted crop. At Berhampur the direct seeded crop received 762, 767 and 827 mm rainfall during 2004, 2005 and 2005. Grain yield data on 15 genotypes of the 9 environments was recorded and analyzed. The year component of the environment variables was eliminated by averaging over years and the G×E interaction was analyzed in Additive Main and Multiplicative Interaction-(AMMI) model [2,3] with a view to identify finger millet genotypes better adapted to different planting conditions.

RESULTS AND DISCUSSION

The fifteen late duration finger millet genotypes showed significant differences in grain yield in all the three environmental conditions in all the 3 years (Table 1). The average yield during the 3 years varied from 27.87 to 31.97 q/ha under early planting and from 27.68 to 29.46 q/ha under late planting at Bhubaneswar. Late transplanted crop did not show much reduction in yield due to fairly uniform distribution of rainfall during the cropping seasons., while yield level under direct seeded condition At Berhampur average grain yield varied between 15.69 and 18.66 q/ha and low yield level was due to low rainfall and the crop was grown under direct seeded condition. Ranking of the genotypes for yield in the different environments showed wide differences indicating interaction of genotypes with the environments.

The linear regression model of Eberhart and Russell [5] is most frequently used for G×E interaction study and in this model a stable genotype should have low deviation from regression (S^2_d). So many genotypes having very high yield potential often get rejected due to high S^2_d over the range of environments. Thus, a genotype showing high positive interaction at certain environments 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 for critical analysis of interaction of genotypes in specific environments and

Table 1: Grain yield (q/ha) of late duration finger millet genotypes in the three environmental conditions during 2004 to 2006

	Early transplantedBhubaneswar				Late transplantedBhubaneswar				Early direct-sownBerhampur				
Genotype	2004	2005	2006	Mean	2004	2005	2006	Mean	2004	2005	2006	Mean	Grand mean
1 OEB 82	33.34	21.34	25.68	26.79	25.35	24.06	22.38	23.93	21.27	15.02	19.45	18.58	23.10
2 OEB 56	36.30	36.86	27.82	33.66	28.97	23.32	30.45	27.58	20.77	19.65	26.23	22.22	27.82
3 OEB 71	32.22	36.51	29.30	32.68	32.92	22.57	26.50	27.33	16.81	25.54	22.53	21..63	27.21
4 PR 202	28.64	27.51	25.18	27.11	23.04	26.76	22.88	24.23	14.84	13.61	20.99	16.49	22.61
5 GPU 57	30.87	32.10	21.81	28.26	29.96	32.58	30.53	31.03	8.41	7.72	14.20	10.11	23.13
6 PES110	27.14	40.21	30.95	32.77	28.65	35.72	29.22	31.20	18.79	18.24	20.68	19.24	27.73
7 VR 849	28.64	34.92	31.28	31.61	26.01	29.89	33.25	29.72	13.85	18.24	22.53	18.21	26.51
8 VR 822	30.00	31.92	28.97	30.30	30.29	28.10	28.97	29.12	14.34	33.68	18.83	22.28	27.23
9 MR 33	25.68	34.39	29.14	29.74	28.97	33.78	31.03	31.26	8.90	9.75	14.51	11.05	24.02
10 VR 768	27.06	31.92	22.05	27.01	22.06	30.79	24.20	25.68	15.83	18.24	17.29	17.12	23.27
11 GPU 58	29.63	35.10	26.50	30.41	27.65	32.58	33.74	31.33	9.89	21.75	14.20	15.28	25.67
12 Indaf 5	28.64	28.75	32.10	29.33	26.66	27.95	33.33	29.31	18.30	19.22	18.83	18.78	25.98
13 AKP 7	31.11	24.52	28.65	28.09	25.68	28.25	32.10	28.68	20.77	16.49	18.21	18.49	25.09
14 OEB 52	30.80	32.10	29.63	30.84	28.64	24.21	28.73	27.19	20.77	27.36	12.96	20.37	26.13
15 Chilika	32.10	31.39	28.98	30.83	30.29	32.58	34.57	32.48	11.87	15.43	17.59	14.96	26.09
Average	30.15	31.97	27.87	30.00	27.68	28.88	29.46	28.67	15.69	18.66	18.60	17.65	25.44
CD (5%)	4.98	7.13	4.39	3.17	4.60	6.44	4.98	2.88	2.53	4.11	4.07	2.06	1.21

Table 2: AMMI ANOVA of late duration Finger millet genotypes for yield (q/ha) in the three environmental (planting) conditions

Source	df	SS	% of G-E SS	MS	F	% of G×E InteractionSS
Genotype (G)	14	136.15	7.88	9.73	5.91**	
Environments (E)	2	1377.45	79.69	688.72	418.45**	
G × E	28	214.98	12.43	7.68	4.67**	
IPCA 1	15	199.94	11.56	13.33	8.10**	93.00
IPCA 2	13	5.07	0.87	1.16	0.70	7.01
Residual	-	-0.03				-0.01
Error	252	414.77		1.65		

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, rained or irrigated etc.

AMMI analysis [2-4] gives estimate of total G×E interaction effect of each genotype and also further partitions it into interaction effects due to individual environments. Low G×E interaction of a genotype indicates stability of the genotype over the range of environments. A genotype showing high positive 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×E interaction of multilocation yield data in AMMI model have been reported by McLaren and Chaudhury [6], Ise *et al*. [7], Vijaykumar [8]; Asenjo *et al*. [9], Mahalingam *et al*. [10] and Naveed *et al*. [11] Das *et al.* [12] in rice, Tarakanovas and Ruzgas [13] and Mohammadi *et al*. [14] in wheat, Shinde *et al.* [15] in pearl millet, Hariprasanna *et al.* [16] groundnut and few other crops but such reports in finger millet is lacking. All these workers found significant G×E interaction for grain yield and stressed the usefulness of AMMI analysis for selection of promising genotypes for specific locations or environmental conditions.

AMMI analysis of variance of grain yield data of the 15 finger millet genotypes under three environmental conditions (Bhubaneswar-early planting, Bhubaneswar-late planting and Berhampur-early direct sown) showed that all three components-genotypes (G) and environment (E) and the G×E interaction, were highly significant (Table 2). The main effects of G and E accounted for 7.88 and 79.69 %, respectively and G×E interaction accounted for 13.43 % of the total variation in G×E data for grain yield. The G×E interaction effects of the genotypes in the three environmental conditions (Table 3) showed that the

Table 3: Interaction effects of late duration Finger millet genotypes for yield (q/ha) in different environmental conditions

		Environmental conditions		
Genotype		1. Early transplanted Bhubaneswar	2. Late transplanted Bhubaneswar	3. Early direct-sown Berhampur
1	OEB 82	-0.87	-2.40	3.27
2	OEB 56	1.28	-3.47	2.19
3	OEB 71	0.91	-3.11	2.20
4	PR 202	-0.05	-1.61	1.66
5	GPU 57	0.57	4.66	-5.23
6	PES 110	0.48	0.23	-0.71
7	VR 849	0.55	-0.03	-0.52
8	VR 822	-1.49	-1.35	2.84
9	MR 33	1.17	4.01	-5.18
10	VR 768	-0.81	-0.82	1.64
11	GPU 58	0.18	2.42	-2.61
12	Indaf 5	-0.70	0.11	0.59
13	AKP 7	-1.55	0.36	1.19
14	OEB 52	0.15	-2.17	2.02
15	Chilika	0.18	3.16	-3.34

genotypes had very small interaction effects (-1.55 to 1.28 q/ha) at Bhubaneswar under early planting. However, interaction effects of genotypes under late planting at Bhubaneswar was high varying from-3.47 to 4.66 q/ha and the genotypes GPU 57, OEB 82, Chilika showed high positive interaction, while OEB 56 and OEB 71 showed high negative interaction. The range of variation in interaction effects of genotypes at Berhampur under direct seeded condition was-5.24 to 3.27 q/ha and the genotypes OEB 82 and VR 822 showed high positive interaction, while GPU 57, MR 33, Chilika and VR 822 showed high negative interaction. Thus many of these genotypes showed differential performance under different planting conditions.

The G×E interaction was further partitioned into IPCA 1 and IPCA 2, of which IPCA 1 component was significant and accounted for 93 % of the total G×E interaction sum of squares (Table 2). The most powerful interpretive tool in analysis of G×E interaction in AMMI

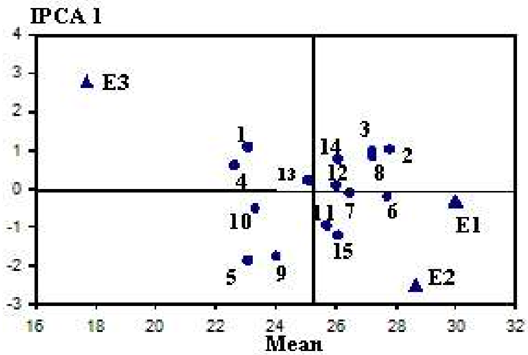

Fig. 1: AMMI I biplot of main effects and G×E interaction of 15 finger millet Genotypes in three Environments

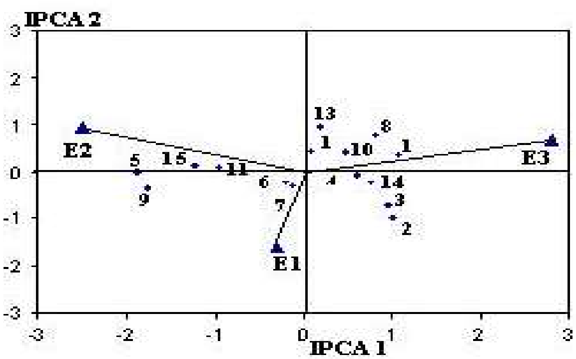

Fig. 2: AMMI II biplot of G×E interaction of 15 finger millet Genotypes in three Environments .
[Genotype and Environment names in Table 3 & 4]

model is the biplot analyses. The biplots permit 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 genotype and environments are plotted against each other. AMMI I biplot for grain yield of the 15 genotypes at 3 environmental conditions is presented in Fig. 1. The main effects (Genotypes and Environments) accounted for 87.57 % and IPCA 1 accounted for 11.56 % of total variation in G×L data and so the AMMI I biplot gave a model fit of 99.13 %.

The scatter of the genotype points in the AMMI 1 biplot (Fig. 1) showed five adaptive groups of genotypes. The genotypes OEB 71, VR 822 and OEB 56 formed an adaptive group with high mean accompanied with moderate positive interaction. The genotypes Indaf 5 and VR 849 and GPU 58 and Chilika formed two adaptive groups having moderately high mean but the former group had negligible interaction, while the latter group had moderate negative interaction. Genotypes OEB 82 and PR 202 and GPU 57 and MR 33 formed two adaptive groups having similar low mean but the former group had moderate positive interaction, while the latter had high negative interaction. The remaining four genotypes, which scattered singly in the biplot, differed from each other both in mean and interaction effects. Among the environmental conditions, both early and late plantings at Bhubaneswar had high mean but late planting showed high positive interaction, while early planting showed negligible interaction. Direct seeded condition at Berhampur showed very low mean effect and high positive interaction.

Fig. (2) Gives the AMMI II biplot for yield. The IPCA 1 component accounted for 93 % of G×L interaction, while IPCA 2 accounted for only 7 % (Table 2). Distribution of genotype points in the AMMI II biplot revealed that the genotypes PES 110, VR 849, GPU 58, Indaf 5, VR 768 and PR 202 scattered close to the origin, indicating minimal interaction of these genotypes with environments. The remaining 9 genotypes scattered away from the origin in the biplot indicating that the genotypes were more sensitive to environmental interactive forces. Interaction of genotypes with specific environmental conditions was judged by projection of genotype points on to environment spokes. On this basis, the genotypes OEB 56, OEB 71 and MR 33 had moderate positive interaction and VR 822 and AKP 7 had moderate negative interaction under early planting condition at Bhubaneswar.

Table 4: Predicted yield (q/ha) of late duration Finger millet genotypes in different environmental conditions in AMMI II model

Genotype		Environmental conditions		
		1. Early transplanted Bhubaneswar	2. Late transplanted Bhubaneswar	3. Early direct-sown Berhampur
1	OEB 82	25.79	23.93	18.58
2	OEB 56	33.66	27.58	22.22
3	OEB 71	32.68	27.33	21.63
4	PR 202	27.11	24.23	16.48
5	GPU 57	28.26	31.03	10.11
6	PES 110	32.76	31.20	19.24
7	VR 849	31.61	29.72	18.21
8	VR 822	30.30	29.12	22.28
9	MR 33	29.74	31.26	11.05
10	VR 768	27.01	25.68	17.12
11	GPU 58	30.41	31.33	15.28
12	Indaf 5	29.83	29.31	18.78
13	AKP 7	28.09	28.68	18.49
14	OEB 52	30.84	27.19	20.36
15	Chilika	30.83	32.48	14.96

Genotypes GPU 57, MR 33, Chilika and GPU 58 had high positive interaction and OEB 82, OEB 56, OEB 71 and OEB 52 had high negative interaction under late planting condition at Bhubaneswar and the interaction of these genotypes was just the reverse at Berhampur under direct seeded condition.

Predicted yield of the 15 finger millet genotypes in the 3 environmental conditions were estimated using AMMI II model (Table 4). The range of variation in the predicted yield of genotypes at Bhubaneswar was 26.79-33.66 q/ha under early planting and 23.93-32.48 q/ha under late planting, while that at Berhampur under direct sown condition was 10.11-22.28 q/ha. On the basis of AMMI-II predicted values, the four top ranking genotypes at the three environmental conditions were:

Bhubaneswar (Early planted):	OEB 56 (2), PES 110 (6), OEB 71 (3) and VR 849 (7)
Bhubaneswar (Late planted):	Chilika (15), GPU 58 (11), MR 33 (9) and PES 110 (6)
Berhampur (Direct sown):	VR 822 (8), OEB 56 (2), OEB 71(3) and OEB 52 (14)

The genotypes OEB 56, OEB 71 and PES 110 ranked among the top four in two of the three environmental conditions, while Chilika, VR 822, GPU 58, MR 33, VR 849 and OEB 52 ranked among the top four in only one environmental condition each.

Thus, the genotypes OEB 56 and OEB 71 were better suited for early planting at Bhubaneswar and early direct-sown condition at Berhampur indicating that the genotype would be suitable for early cropping, but not late cropping. The genotype PES 110 showed better adaptation to both early and late planting conditions at Bhubaneswar, indicating that the genotype is suitable for transplanting condition and not for direct-sown condition. Six other genotypes showed specific adaptation to single environment only, of which Chilika ranked first under late planting at Bhubaneswar and VR 822 ranked first under direct-sown condition at Berhampur, indicating specific adaptation.

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