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Genotype x environment interaction of near isogenic introgression lines (NIILs) under drought stress and non-stress environments in upland rice (*Oryza sativa* L.)

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Abstract

The superior NIILs selected for productivity under artificial drought condition were evaluated over three drought stress and three non-stress environments. AMMI based stability parameter; $ASTAB_i$ and Rao's Index of stability were utilized to interpret the stability among the NIILs under stress and non-stress environments. The grain yield was much sensitive and highly influenced by environment resulting in higher G x E interaction under stress environments. Pooled deviation was highly significant indicating the presence of non-predictable components for grain yield and yield related traits. Based on $ASTAB_i$, RF-55-254 was most stable genotype which was also the best for grain yield (6613 kg/ha) in non-stress environments, while it was unstable under stress environments. The genotype, RF-55-198 was superior for yield as well as stability in stress environments and for overall adaptability.

Key words: AMMI, $ASTAB_i$, drought tolerance, upland rice

Introduction

Rainfed rice is cultivated in around 50 per cent of total rice area, whereas it contributes only 25 per cent to production because of its poor productivity. Drought stress is the major constraint to rice production and yield stability in the rainfed regions [1]. There is high probability that a genotype performing well under non-stress conditions will also perform well under drought, even if the relative yield reduction is large, because of spillover effects of yield potential [2, 3]. However, high yielding varieties (HYVs) are inferior to traditional varieties under severe drought stress [4]. The traditional landraces on the other hand have poor yield potentiality although stable and better adaptable under harsh rainfed environment [5]. Therefore, stable genotypes which perform better under stress as well as under non-stress conditions are desirable in rainfed upland condition for sustainable rice production. The NIILs derived by introgressing drought tolerant land races, in the back ground of HYVs are expected to be high yielding, drought tolerant and stable in rainfed upland condition. The stability analysis proposed by Eberhart and Russel [6], the commonly used model can be useful in defining drought tolerance in terms of yield, provided the major component of variation in the environmental index is attributed to the moisture regimes [7]. But there is a large non-predictable component of genotype x environment interaction (GEI) as well as large error component in rainfed ecosystem [8]. The objective of multi-environment trials (METs) for a breeding program is to make accurate and precise predictions about the adaptation of breeding lines in target environments under rainfed conditions in which major components of GEI results from genetic variation for flowering time and stage of water deficits [9].

Several methods and techniques have been developed and reported to describe the responses of genotypes to variation in the environment. Each of these methods employs statistical parameters to measure genotypic stability or response to environments according to different concepts of stability. The most widely used method for identifying high yielding and stable genotypes, is the linear regression approach. Eberhart and Russell [6] used this approach along with deviation from the regression line (S^2d_i) as another stability parameter. In general, the regression models partition the overall response pattern into yield performance and stability. Analytical methods for examining the total behavior of a genotype across the tested environments which consider both yield and stability components simultaneously could be desirable for identifying the high yielding and stable genotypes [10, 11]. $ASTAB_i$ (AMMI based stability parameter) and Rao's index of stability [11] have been utilized in this

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study to interpret the stability among the NIILs under stress and non-stress environments and identify the stable genotype for rainfed upland condition of Karnataka.

Material and methods

Near Isogenic Introgression Lines (NIILs) derived by introgression of drought tolerant Iranian land race, Binam (*japonica*) in the background of IR-64 (irrigated wide adapted variety) and Teqing (upland adapted Chinese variety) were evaluated in artificial drought stress condition and selected for productivity. Eighteen superior NIILs selected based on *per se* performance, plant type and grain type along with recurrent parents and two checks Dodiga (a drought tolerant landrace) and MTU-1001 (a popular high yielding modern variety) were taken for this experiment. These 22 genotypes were evaluated in 6 different environments characterized by different locations, seasons and more importantly in different moisture regimes. The genotypes in all the six environments were evaluated under randomized complete block design with two replications. Each genotype was directly sown in four rows of four meter length with 20 cm row spacing in Mugad location, while it was transplanted with 25 days old seedlings in four rows of 4 m length with spacing of 20x10 cm at Siruguppa under irrigated conditions and at Sirsi under heavy rainfall conditions. Recommended package of practices for respective location was followed to raise a good crop. Days to 50% flowering, plant height at maturity, number of panicles per square meter, panicle length, panicle weight and grain yield (kg/ha) were recorded. The year and location combinations are considered as individual environments. The six environments were further sub-divided into non-stress and drought stress environments mainly based on moisture regimes as below:

Non-stress environments

1. Siraguppa, *Kharif* 2003 (irrigated condition)
2. Sirsi, *Kharif* 2004 (high rainfall condition).
3. Mugad, *Kharif* 2005 (sufficient rainfall condition)

Stress environments

1. Mugad, *Kharif* 2003 (severe stress)
2. Mugad, *Kharif* 2004-I (severe stress)
3. Mugad, *Kharif* 2004-II (moderate stress)

The three data sets *viz*. 1) three non-stress environments, 2) three drought stress environments and 3) overall six environments for grain yield and five yield related traits were subjected to pooled analysis of variance for working out the variance for stability [6].

ASTABi (an AMMI based stability parameter)

The additive main effect and multiplicative interaction (AMMI) method integrates analysis of variance and principal components into a unified approach [12]. The AMMI model for 't' genotypes and 'S' environments may be written as

$$Y_{ij} = \mu + g_i + e_j + \Sigma\lambda_n\alpha_{in}\gamma_{jn} + \varepsilon_{ij}$$

$$\varepsilon_{ij} \sim N(0, \delta^2);$$

$$i = 1, 2, \ldots, t; \qquad j = 1, 2, \ldots, s$$

Where, Y_{ij} is the yield of the i^{th} cultivar in j^{th} location, μ is over all mean, g_i is the i^{th} cultivar effect, e_j is the j^{th} location effect. $\sqrt{\lambda_n}\ \alpha_{in}$ and $\sqrt{\lambda_n}\ \gamma_{jn}$ are the principal component scores for i^{th} genotype and j^{th} environment respectively. Error $\varepsilon_{ij} \sim N(0, \delta^2)$ with $\Sigma_i\alpha^2_{in} = \Sigma_i \gamma_{jn} = 1$ and the multiplicative interaction term satisfy the constraints, $\lambda_1 > \lambda_{2} > \ldots > \lambda_n > 0$.

Biplots are commonly used to explain AMMI results considering one or two PCAs at a time. Plant breeders would like to identify varieties which are stable and high yielding when more than two PCA axes are retained in the AMMI model which cannot be explained with the help of biplots. Under such conditions Rao and Prabhakaran [11] proposed new stability statistics, ASTABi.

Let Z_{ij} be the interaction residuals of the i^{th} genotype in the j^{th} environment. The elements of Z matrix of the order t x s can be written as $[(Z_{ij})]$. Let the positive eigenvalues of ZZ' be $X_1, X_2, \ldots, X_N$; where N = rank (ZZ'). Let the eigen vectors of ZZ' be $\alpha_1, \alpha_2, \ldots, \alpha_n, \ldots, \alpha_N$ corresponding to eigen values $\lambda_1, \lambda_2, \ldots, \lambda_n, \ldots, \lambda_N$ where, α_n is a vector of order t x 1. Let $\alpha_n^* = \alpha_n\lambda_n$ be the genotypic scores corresponding to the axis n. Suppose n' of the N axes are retained in the AMMI model to explain GEI, then stability measure of i^{th} variety can now be determined as the end point of its vector $\alpha_{1i}^*, \alpha_{2i}^*, \ldots, \alpha_{ni}^*$ from the origin $0'_{n'x1}$. This can also be taken as the squared Euclidean distance between the vector $\gamma = (\alpha_{1i}^*, \alpha_{2i}^*, \ldots, \alpha_{ni}^*)$ from the origin in the n' dimensional Euclidean space.

$$ASTAB_i = di(\gamma, 0) = \sum_{n=1}^{n'} \lambda.\alpha^2_{ni}$$

A variety is considered as highly stable when the value of $ASTAB_i$ is small or closer to zero.

Rao's yield stability Index (Rao's I_2)

A new index for simultaneous selection of yield and stability, Rao's yield stability Index is measured as the ratio of the average performance of the i^{th} genotype to the overall mean performance of the genotypes under test and a stability component, measured as the ratio of stability information ($1/ASTAB_i$) of i^{th} genotype to the mean stability information of the genotype under test [11]. The expression of the index is given as:

$$\text{Rao's } I_2 = \frac{Y_{i.}}{Y} + \psi \frac{(1/ASTAB_i)}{[1/t\ (\Sigma_i 1/ASTAB_i)]}$$

Where, $Y_{i.}$ is the average performance by the i^{th} genotype, Y, the overall mean, ASTABi is estimate of stability parameter based on AMMI as explained previously and ψ is weight attached to stability component. The weight attached for stability in the present study was 0.25 which was considered practically acceptable [13].

Results and discussion

Genotypic differences were highly significant for days to 50% flowering, plant height, panicle length in non-stress environments (Table 1), while highly significant genotypic differences were observed for days to 50% flowering, plant height, panicle weight in stress environments (Table 2) indicating the importance of these traits under stress. Genotypic differences were highly significant for all the traits studied except panicle number per square meter over all six environments (Table 3). Higher genotypic coefficient of variance components were observed for days to flowering, panicle weight and grain yield under stress than non-stress environments. Genotypic differences for panicle weight, which were significant at 0.05 probability in non-stress environments turned highly significant (P<0.01) under stress environments. This indicated that genotypes respond differentially to drought with respect to panicle characters like panicle weight, grains per panicle, 1000 grain weight and ultimately productivity under stress.

Highly significant mean sum of squares (MSS) due to environments in respect of most of the traits in all three data sets indicate that the environments considered were highly diverse even within subsets and well suited to test for stability of a genotype. The environmental index ranged from –432 at Sirsi-2004 to 271 at Siraguppa-2003 among non-stress environments. It was –992 at Mugad-2003 to 1234 at Mugad-2004-I among stress environments. Environmental index over all the six environments ranged from –2311 at Mugad-2003 to 1590 at Siruguppa-2003. This supports the fact that the environments were highly diverse with non-stress and stress environments. The subset of non-

Table 1. Mean sum of squares for six productivity traits from pooled ANOVA over three non-stress environments

Source	df	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	Panicle no./ square meter	Panicle weight (g)	Grain yield (kg/ha)
Replications within environment	3	0.72	60.66	0.25	795.20	0.26	134852
Genotypes (G)	21	56.39**	361.94**	11.22**	2783.64	1.18*	2095054
Environments (E)	2	302.73**	1866.62**	29.64**	84757.06**	42.8**	3148399
G x E	42	36.43	37.27	4.14	1853.7	0.46	1249539
E + (G x E)	44	48.54*	120.42**	5.3	5622.04**	2.39**	1335851
G x E (Linear)	21	53.46*	37.7	4.59	1711.29	0.5	1406244
Pooled deviation	21	19.4++	36.83++	3.70++	1996.12++	0.43++	1092833.77++
Pooled error	63	0.76	12.92	1.41	638.05	0.12	146026.5
Total	131						
		Coefficients of variance components (%)					
Genotypes (G)		1.93	8.19	5.18	3.64	10.93	7.71
Environments (E)		2.6	7.18	3.63	12.68	30.94	4.27
G x E		4.46	3.88	5.57	7.2	13.01	15.25

* and ** = Significant at probability levels of 0.05 and 0.01 respectively against pooled deviation
\+ and ++ = Significant at probability levels of 0.05 and 0.01 respectively against pooled error

Table 2. Mean sum of squares for six productivity traits from pooled ANOVA over three stress environments

Source	df	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	Panicle no./ square meter	Panicle weight (g)	Grain yield (kg/ha)
Replications within environment	3	0.413*	64.075	3.230*	1025.901	0.026	138696.7
Genotypes (G)	21	58.87**	150.72**	1.66	1147.49	0.49**	685601
Environments (E)	2	298.03**	2866.71**	103.19**	35.82	1.00**	28212426.08**
G x E	42	5.58**	30.61	0.93	907.31	0.08	373617.6
E + (G x E)	44	18.88**	159.52**	5.58**	867.7	0.12	1543563.47**
G x E (Linear)	21	11.05**	27.8	0.83	352.37	0.08	214009.5
Pooled deviation	21	0.11	33.42+	1.03	1462.26++	0.09++	333225.77++
Pooled error	63	1.44	16.33	0.92	425.14	0.04	102575.8
Total	131						
Coefficients of variance components (%)							
Genotypes (G)		2.95	7.34	1.99	3.45	14.69	10.22
Environments (E)		2.55	13.17	8.68	1.2	8.12	35.64
G x E		1.42	4.38	0.4	8.47	7.95	16.49

* and ** = Significant at probability levels of 0.05 and 0.01 respectively against pooled deviation
+ and ++ = Significant at probability levels of 0.05 and 0.01 respectively against pooled error

Table 3. Mean sum of squares for six productivity traits from pooled ANOVA of over all six environments

Source	df	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	Panicle no./ square meter	Panicle weight (g)	Grain yield (kg/ha)
Replications within environment	6	0.564	62.365	1.742	910.553	0.142	136774.5
Genotypes (G)	21	84.85**	432.29**	8.06**	2688.90*	1.53**	2181703.95**
Environments (E)	5	505.04**	7388.97**	130.96**	201121.75**	30.43**	58493809.75**
G x E	105	22.89	43.22	2.99	1352.85	0.25	729052.6
E + (G x E)	110	44.80**	377.12**	8.81**	10433.25**	1.62**	3354723.40**
G x E (Linear)	21	42.72**	67.58*	3.1	1401.59	0.50**	621393.3
Pooled deviation	88	17.93++	37.13++	2.97++	1340.67++	0.19++	755967.44++
Pooled error	126	1.1	14.63	1.16	531.59	0.08	124301.1
Total	263						
Coefficients of variance components (%)							
Genotypes (G)		3.28	10.68	4.77	5.68	18.62	13.86
Environments (E)		3.38	17.14	8.85	25.64	33.4	32.26
G x E		3.37	5.02	4.96	7.71	11.76	15.48

* and ** = Significant at probability levels of 0.05 and 0.01 respectively against pooled deviation
+ and ++ = Significant at probability levels of 0.05 and 0.01 respectively against pooled error

stress environments had positive environmental indices based on all the six environments with mean index of 1320. The stress environments had negative environmental indices based over all the six environments with mean index of -1390. This indicated that the sub-set made represented well the non-stress and stress environments. The co-efficient of variation (CV) was higher in stress environments compared to non-stress environments indicating sensitivity of grain yield and differential response of genotypes for yield under stress.

Highly significant MSS due to E+ (G x E) for grain yield was noticed in stress environments and over all the six environments whereas, it was non-significant in non-stress environments. This is supported by considerably high proportion of variance components with respect to yield for environment and G x E (Table 1 to 3). These results indicated that, the grain yield was much sensitive and highly influenced by environment resulting in higher G x E interaction under stress as reported earlier [9, 14, 15]. The environmental component of variance for grain yield was more than that of G x E interaction in stress environments (Table 2) and overall six environments (Table 3). Jalaluddin and Harrison [16] also reported six time larger environmental variance component than G x E interactions in all the three data sets, which they studied for repeatability of stability estimators for grain yield in wheat. However, the G x E (linear) MSS was non-significant in all three data sets, when tested against pooled deviation in this study. This implies that regression responses of the individual genotypes did not contribute significantly to G x E interactions. However contrasting reports of significant G x E (linear) for grain yield have been reported indicating linear relationship in the expression of grain yield with different environments [17, 18]. These authors reported significance of MSS due to pooled deviation also indicating the presence of both predictable and non-predictable components of G x E interaction for grain yield. In the present study also pooled deviation tested against pooled error was highly significant indicating presence of non-predictable components for grain yield along with all yield related traits.

In AMMI ANOVA the G x E interaction was partitioned into two principal components axes (PCA) over three environments under both favourable and stress conditions, while it was partitioned into four PCA over all 6 environments (data not shown). First PCA was significant for days to 50% flowering and panicles per square meter under moisture stress condition, while it was non-significant for all traits under favourable condition. This indicated the additive nature of data in favourable condition and just Eberhert and Russel model of stability is sufficient to explain the variability. However, multiplicative nature data was found in stress and overall environments as indicated by significant PCA components (Tables 5 and 6). AMMI analysis is efficient to explain both additive and multiplicative variability present in diverse and complex environments. Two PCA together accounted for 99.9 % variability in favourable environments, whereas only 73.23% of G x E variability was explained in stress environments indicating its complex nature. Four PCA together accounted for 95.0% G x E variability in overall six environments.

The superior overall mean of a genotype indicates its superiority across environments. RF 55-254 and RF 55-198 ranked first and second in all the three environments indicating their stable performance in non-stress as well as stress conditions. However, actual mean yield has drawback of associated variance of yield across environments [19]. A high performance under non-stress environments will mask the poor performance under stress environments thus causing bias in favour of non-stress environments. For example, IR 64 a drought susceptible check ranked eighth in non-stress environments. However, it ranked 18th in stress environments. Because of superior performance (8th rank) in non-stress environments, it ranked ninth over all the six environments. Thus, poor performance of this variety under stress environments was masked by better performance under non-stress environment. It thus underlines the need to consider other stability parameters to assess the adaptability of a genotype.

ASTABi (an AMMI based stability parameter)

AMMI model also partitions the over all response pattern of a genotype into yield performance and stability similar to regression approach. Biplots are commonly used to interpret the AMMI analysis which considers yield in on axis and PCA scores on another axis or two PCA axes scores [20]. Whenever more than two axes are significant in the AMMI model, the biplot formulation of interaction is a failure. Rao and Prabhakaran [11] proposed a new stability measure ASTABi by considering all PCA axes in the AMMI model. A genotype is considered as highly stable, when the value of ASTABi is small or close to zero.

Based on ASTABi, RF 55-254 was the most stable genotype which was also the best for grain yield (6613 kg/ha) in non-stress environments (Table 4). However this genotype was unstable, although highest mean grain yield was recorded in stress environments. This is similar to the results obtained from Eberhart and Russel's [6] model in this study. RF 53-253-3-I turned out to be the most stable NIIL followed by RF 55-198, both of which were next to RF 55-254 for grain yield in stress environments.

Rao's index of stability

Rao and Prabhakaran [11] also proposed indices to combine both yield and stability in a similar approach as that of Bajpai and Prabhakaran [10]. Here they have

Table 4. The stability parameters for selected genotypes over three non-stress, three stress and over all six environment along with ranks

S.No	Genotype	Mean yield						AMMI-MODEL (ASTABi)						Rao's Index of stability (Rao's I)					
		3 non-stress environments		3 stress environments		Over all 6 environments		3 non-stress environments		3 stress environments		Over all 6 environments		3 non-stress environments		3 stress environments		Over all 6 environments	
		Mean	Rank	Mean	Rank	Mean	Rank	ASTABi	Rank	ASTABi	Rank	ASTABi	Rank	Rao's I	Rank	Rao's I	Rank	Rao's I	Rank
1	RF-55-18-3	5531	4	2614	4	4072	4	1422.68	22	345.70	19	1562.84	21	1.16	12	1.22	8	1.23	9
2	RF-55-82-3	4489	14	1903	16	3196	15	897.27	19	245.15	11	1091.67	19	0.96	18	0.93	20	1.02	19
3	RF55-155-I	4950	12	1980	15	3465	14	254.91	7	354.41	20	515.79	9	1.15	13	0.94	19	1.23	10
4	RF-55-29-2	4290	16	1810	20	3050	19	351.23	12	250.14	14	642.66	13	0.98	16	0.88	21	1.06	18
5	RF53-21-1-I	4074	19	2230	10	3152	16	298.46	9	74.81	7	581.36	12	0.95	19	1.24	7	1.11	16
6	RF-53-102-3	4954	11	2094	12	3524	11	53.42	3	119.97	8	189.71	1	1.67	3	1.09	13	1.69	3
7	RF-55-9	5275	9	2341	7	3808	6	806.31	18	249.20	12	861.04	17	1.13	14	1.12	11	1.23	12
8	RF55-237-4	4224	17	1532	22	2878	20	60.82	4	314.77	16	347.67	3	1.44	4	0.74	22	1.19	14
9	TEQING (RP)*	5574	3	2369	6	3971	5	638.94	17	318.53	17	926.15	18	1.20	10	1.12	12	1.26	7
10	RF-53-199-1-I	3330	22	1885	17	2607	21	583.03	16	174.42	9	574.87	11	0.74	22	0.95	17	0.96	20
11	RF-53-214	4947	13	2265	9	3606	10	1040.58	21	329.66	18	1442.51	20	1.05	15	1.07	14	1.11	17
12	RF-53-60-2-I	3460	21	1724	21	2592	22	559.08	15	64.37	6	819.64	16	0.77	21	1.05	15	0.89	22
13	RF-55-85-5-30	4189	18	2070	13	3129	17	89.01	5	249.34	13	358.24	4	1.25	7	1.00	16	1.25	8
14	RF-53-253-3-I	5520	5	2809	3	4164	3	418.23	13	9.99	1	424.98	8	1.22	9	3.08	1	1.48	4
15	RF-55-254	6613	1	3446	1	5029	1	20.93	1	369.69	21	368.89	5	3.02	1	1.59	3	1.77	1
16	RF-55-198	6051	2	3282	2	4666	2	321.95	10	32.05	2	326.14	2	1.35	5	2.04	2	1.72	2
17	RF-53-227-1-I	5187	10	1846	19	3516	12	333.34	11	35.66	4	547.49	10	1.17	11	1.34	5	1.23	11
18	RF-55-219	5418	7	2124	11	3771	7	247.83	6	32.57	3	389.90	6	1.25	6	1.51	4	1.40	5
19	RF-55-86	4414	15	2550	5	3482	13	548.99	14	278.94	15	796.54	15	0.97	17	1.21	9	1.15	15
20	IR-64 (RP)*	5412	8	1849	18	3631	9	260.29	8	39.85	5	709.40	14	1.24	8	1.28	6	1.21	13
21	MTU-1001 (HYV check)	5438	6	2055	14	3747	8	39.29	2	650.50	22	408.14	7	2.00	2	0.95	18	1.38	6
22	DODIGA (Landrace check)	3817	20	2332	8	3074	18	961.39	20	184.11	10	1828.93	22	0.82	20	1.14	10	0.94	21
Environmental Mean		4871		2232		3551													
C.V %		11.71		19.58		13.78													
C.D. (P = 0.05)		685		525		416													

*RP – Recurrent parent

used a new stability parameter, ASTABi, which was derived based on AMMI model considering all PCA components. In this study the weightage for yield and stability components were in the ratio of 1: 0.25 (ψ = 0.25) in estimating Rao's index of stability. Based on this index, RF 55-254 was found to be best NIIL for both yield and stability in non-stress and over all six environments. However, this NIIL was third best after RF 53-253-3-I and RF 55-198 in stress environments indicating its unstable nature in those environments. RF 55-198 which ranked second in stress environments as well as over all six environments indicates its superiority for adaptation to stress environments as well as overall adaptability. This genotype also possesses the desirable plant type and duration for upland situation of Karnataka and hence released as MGD-101 for this region during 2008 and well accepted by farmers.

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