



Stability analysis of Katarni rice (*Oryza sativa*) derived lines under different sowing dates

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ABSTRACT

Katarni is a non-basmati traditional aromatic rice (*Oryza sativa* L.) cultivar of Bhagalpur district of Bihar. This rice is weak strawed, traditionally tall type, late maturing and easily prone to lodging. Due to photosensitive nature, it matures very late only at the end of November and provide a narrow window for the sowing of wheat in farmers' field. An experiment was conducted at Bihar Agricultural University, Sabour, Bihar during 2018 and 2019 to develop a semi-dwarf and early maturing lines derived from crossing of Katarni with 3 semi-dwarf high yielding cultivars and were advanced to F₅ generation. In this study, 54 derived lines of Katarni in F₆ generation were studied on the basis of 14 morphological traits and yield stability was analysed in 4 environments. The environments were created by different sowing dates across two years (2018 and 2019) in a single location at Bihar Agricultural University, Sabour. Significant variability was found among the genotypes and four principal components (PC) identified, out of which two contributed 98.9% of total variation. Six advanced breeding entries were found to be significantly superior over parental checks for grain yield. Five Katarni derived were identified as highly stable genotypes on the basis of GGE and AMMI stability analysis. All four environments were constituted in two mega environments in which first one shared the best set of Katarni-derived lines. The promising advanced breeding lines with higher yield and stable performance can further be evaluated under multi-location testing for varietal release.

Keywords: AMMI, G × E interaction, Katarni rice, Stability, Sowing Date

Globally, more than 2.7 billion people depends on rice (*Oryza sativa* L.) (Tannidi *et al.* 2016) as it supplies 32 to 59% of the dietary energy in 39 consuming countries (Prabhu *et al.* 2017). Due to greater monetary profit to the farmers and consumer's preference, aromatic rice varieties are preferred over other rice genotypes. Although, lots of work has been done on enhancing the yield potential of long grained basmati rice, short-grained aromatic rice has gained less attention for yield improvement. Bihar state is known for producing medium slender grained aromatic non-basmati rice, popularly known as Katarni for its aroma and special grain and cooking qualities. Katarni rice is a tall (140–160 cm), late maturing (155–160 days), weak strawed and poor yielding (2.5–3.0 t/ha) rice (Smriti *et al.* 2016, Kumar *et al.* 2018). With an aim to develop a semi-dwarf statured early maturing Katarni retaining its aroma and exquisite qualities, a marker assisted breeding programme was initiated at Bihar Agriculture University, Sabour in

2013 and homogenous populations have been obtained in advanced generation.

There are many models for conducting G × E analysis whose applicability depends on the experimental data, the number of environments, and the accuracy of collected data with environmental information (Funga *et al.* 2017), but in many cases, the G × E analysis of variance resulted in wrong selection of genotypes for seed yield. One of the most applicable multivariate parameters, which have a high scientific validity, is additive main effects and multiplicative interactions (AMMI) method (Kanouni *et al.* 2015). AMMI model of analysis of G × E interaction includes sum of different multiplicative forms in different environments and analyses the stability of the genotypes across locations using principal components scores.

Like other traditional rice genotypes, Katarni is late maturing and photosensitive in nature and flowers in a specific daylength irrespective of date of sowing. In order to evaluate the different Katarni rice derived breeding lines under different sowing dates, the present study was carried out across four environments in two years created by altering the dates of sowing to identify high yielding stable lines using AMMI and GGE analysis.

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MATERIALS AND METHODS

Present study was carried out at the research farm of Bihar Agricultural University, Sabour, Bhagalpur, Bihar during 2018 and 2019. The experimental material comprised 54 Katarni derived lines which were in F_6 generation. Out of 54 lines, 43 lines were derived by crossing tall and photosensitive Katarni with Rajendra Sweta; 6 lines were generated by crossing Katarni with IR 64 and 5 lines were generated by crossing Katarni with MTU 7029. All 54 lines in F_6 generation, along with 6 checks (Katarni, Rajendra Sweta, IR 64, MTU 7029, Sabour Surbhit and Rajendra Suwasini) were grown in alpha lattice design in 2 replications at 4 different dates of sowing. For convenience, the derived lines of Katarni \times Rajendra Sweta, Katarni \times IR 64 and Katarni \times MTU 7029 were denoted as KRS, KIR and KMTU, respectively. Four environments were created by alterations in date of sowing in two consecutive years, viz. first sowing date, i.e. 15-06-2018 (EI), second sowing date 29-05-2019 (EII), third sowing date 15-06-2019 (EIII) and fourth sowing date 15-07-2019 (EIV). The raised seedlings were transplanted 25 days after sowing in each environment.

Yield/plant (g) were recorded on five randomly tagged plants of each line in each replication. Statistical analysis of additive main effects and multiplicative interactions AMMI analysis of variance for genotype (G), environment (E) and $G \times E$ interactions were done to identify stable genotype across the environments. The integrated analysis of variance (ANOVA) and principal component analysis (PCA) in AMMI analysis helped to estimate the main effect of genotypes as well as genotypic and environmental components of interaction, respectively. The AMMI model suggested by Thillainathan and Fernandez (2001) to investigate $G \times E$ interaction for seed yield in chickpea genotypes was used to estimate the $G \times E$ interaction in present study. The successive principal components were denoted as PC1, PC2, PC3 and PC4. The results of the AMMI model analysis were interpreted on the basis of AMMI biplot where the graph was plotted with the main effect and first multiplicative axis (PC1) and so on for both genotypes and environments to know the specific adaptation

of genotypes and facilitated the selection of most suited environments (Ebdon and Gauch 2002).

RESULTS AND DISCUSSION

The combined ANOVA for 54 breeding lines and checks over two years and four dates of sowing in AMMI model showed significant ($P < 0.01$) differences among environments, genotypes and $G \times E$ interactions (GEI) for grain yield per plant which indicated differential response of genotypes to different sowing dates over two years (Table 1). The $G \times E$ interaction was partitioned into three Interaction PCA (IPCA) which were highly significant and ordered according to their importance. The second column in Table 1 shows the per cent of GEI sum of squares explained by each AMMI term (PORCENT) while the third column had the cumulative per cent of GEI sum of squares explained until the i^{th} AMMI term (PORCENAC). The principal component analysis (PCA1) encompassed 95.4% of the GEI sum of squares. PCA1 had a significant mean square (21.316) at $P=0.01$ while PC3 had a non-significant mean square at 0.01 and contributed 100% of the entire GEI. The second principal component axis (PCA2) in turn explained 3% of GEI sum of squares. This observed variation can be useful while selecting these lines for use in aromatic rice breeding programme. High value of sum of squares for genotypes indicated that the genotypes were diverse, with large differences among genotypic means causing most of the variation in grain yield which is in congruity with the findings of Misra *et al.* (2009) and Fentie *et al.* (2013). Principal component analysis, done by Singh *et al.* (2020) reported five PCs (with eigen value >1.0) contributed 73.84% of cumulative variability in rice. Lingaiah *et al.* (2020) performed AMMI analysis in 7 rice genotypes during three seasons of 2014 and 2015 and found significant variance for GEI.

The AMMI biplot was conducted to know the most stable and wide adaptable genotype and most appropriate environment to select genotypes on the basis of yield. It depicts the relationships between the first interaction principal component axis (IPCA1) and genotype and environment

Table 1 Partitioning of the sum of squares (SS) and mean of squares (MS) from the AMMI analysis of Katarni derived lines and checks across three environments

| AMMI ANOVA | | | | | | | |
|------------|----|---------|----------|----------|-----------|----------|-------|
| | Df | Percent | Porcenac | Sum. sq | Mean. sq | F. value | Pr. F |
| PC1 | 61 | 95.4 | 95.4 | 1300.286 | 21.316162 | 1.56E+14 | 0 |
| PC2 | 59 | 3 | 98.4 | 40.45595 | 0.685694 | 5.03E+12 | 0 |
| PC3 | 57 | 1.6 | 100 | 21.79682 | 0.3824 | 2.81E+12 | 0 |
| PC4 | 55 | 0 | 100 | 0 | 0 | 0.00E+00 | 1 |
| GGE ANOVA | | | | | | | |
| PC1 | 61 | 91.5 | 91.5 | 8860.177 | 145.2488 | 1.07E+15 | 0 |
| PC2 | 59 | 7.9 | 99.4 | 765.3627 | 12.97225 | 9.52E+13 | 0 |
| PC3 | 57 | 0.4 | 99.8 | 39.99305 | 0.701632 | 5.15E+12 | 0 |
| PC4 | 55 | 0.2 | 100 | 21.78582 | 0.396106 | 2.91E+12 | 0 |

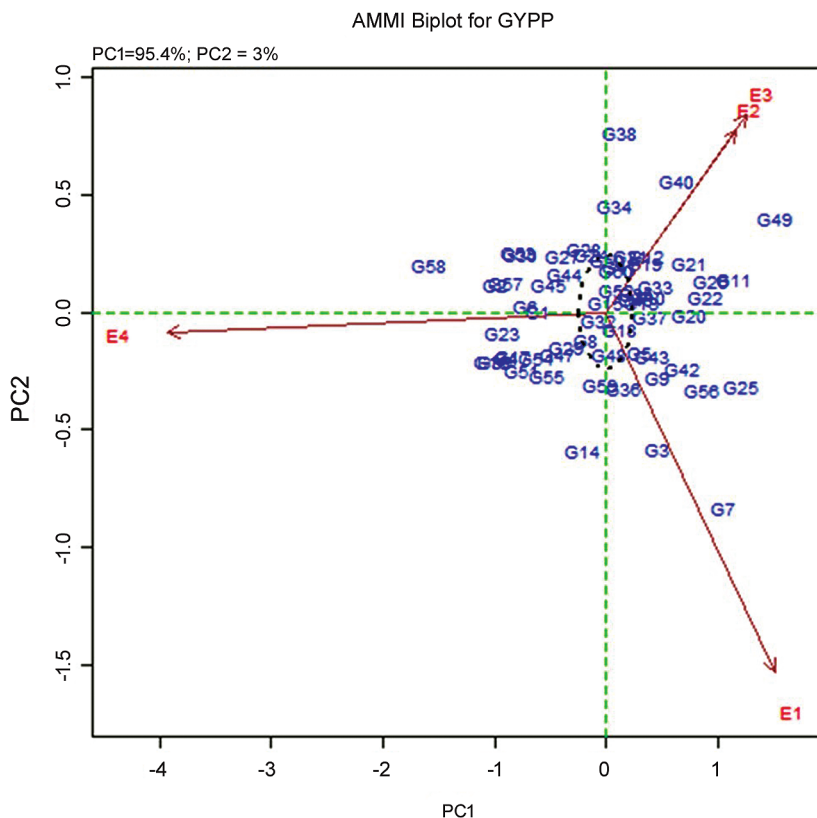


Fig 1 AMMI 1 biplot of main effects and G × E interaction for yield/plant of 54 Katarni derived lines and 6 checks across under four different environments.

means (Fig 1). The AMMI analysis done by the biplot method in Katarni derived lines revealed that entries like KRS-10, KRS-15, KRS-37, KRS-16, KMTU-52, KMTU-53, KRS- 20 and KRS-30 were located on the right side of the vertical axis and were considered as high yielding genotypes. Values closer to the origin of the axis (IPCA1) provided a smaller contribution to the G × E interaction than those that lied further away. Accordingly, the AMMI graph shows genotypes KRS-10, KRS-15 and KRS-30 stood out with the lowest IPCA1 scores. This indicated that these were least involved with the interaction and are therefore the most stable. On the other hand, Katarni derived lines like KIR-44, KRS-31, KRS-33, KRS-41 and KRS-4 were highly unstable with high genotype and environment interaction. The environment stood out with a small contribution to the interaction were EI and EII and with a high contribution were EIII and EIV (Fig 1). The most ideal genotype should combine high yield/plant (g) and stable performance across a range of production environments. In this way, Katarni derived lines like KRS-37 and KRS- 20 followed by KRS-10, KRS-15 and KRS-30 were

identified as stable genotypes, with high mean performance (Table 2) and with low absolute PC1 score but low yield/plant.

The GGE biplot was created by plotting the first two principal components (PC1 and PC2) and genotypes with better mean yield across test environments absolute performance stability are desirable for broad selection (Yan and Rajcan, 2002). In the GGE biplot analysis the PC-1 and PC-2 contributed 98.9% of total variation which justified the accuracy of GGE biplot analysis. Mean performance and stability of the genotype across the locations were graphically portrayed through “Average Environment Coordination”(AEC) view of the biplot (Fig 2). The single arrow head line in the graph known as “AEC abscissa” passing through biplot origin indicates higher mean yield of the genotypes. The double-headed line known as “AEC ordinate” points to greater variability (poorer stability) in either direction. The best performing stable genotypes would be those with higher yield performance and highest stability, i.e. projection on AEC close to 0 and absolute shorter length with

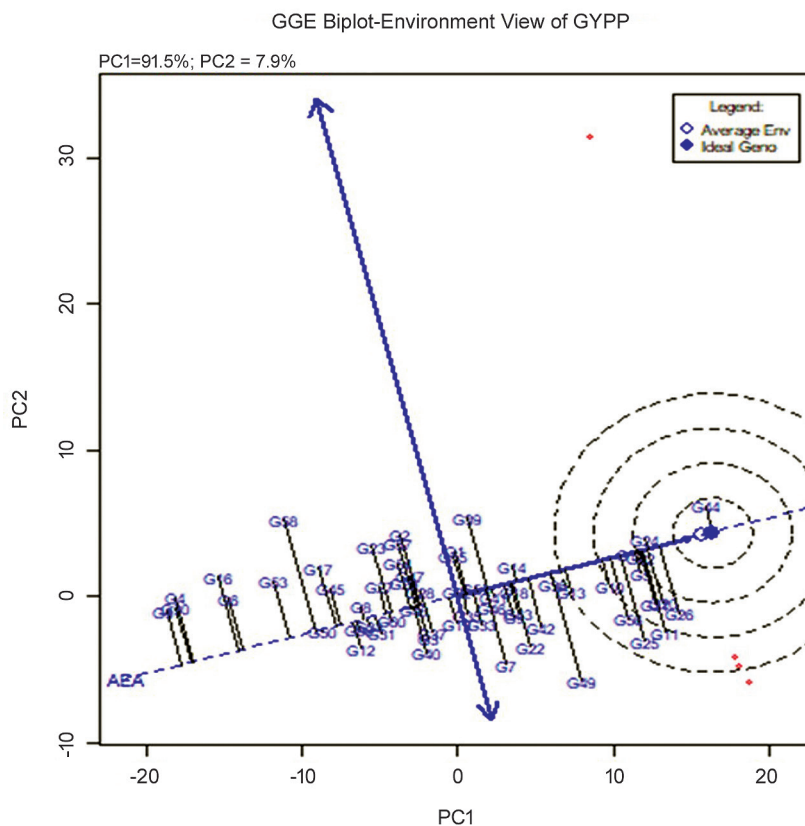


Fig 2 Mean vs Stability biplot for yield/plant (g) 54 Katarni derived lines and 6 checks across under four different environments.

Table 2 Mean performance of 54 Katarni rice derivatives and 6 checks for grain yield (g/plant)

| Genotype | EI | EII | EIII | EIV | Average | Genotype | EI | EII | EIII | EIV | Average |
|----------|-------|-------|-------|-------|---------|-------------|-------|-------|-------|-------|---------|
| KIR-44 | 29.20 | 27.10 | 28.00 | 13.90 | 24.55 | KRS-29 | 29.20 | 29.60 | 29.10 | 16.10 | 26.00 |
| KIR-45 | 18.80 | 18.50 | 18.72 | 12.35 | 17.09 | KRS-3 | 32.60 | 32.00 | 31.50 | 19.50 | 28.90 |
| KIR-46 | 35.40 | 35.10 | 34.70 | 21.70 | 31.73 | KRS-30 | 28.30 | 27.90 | 28.40 | 14.30 | 24.73 |
| KIR-47 | 20.30 | 20.90 | 20.40 | 13.10 | 18.68 | KRS-31 | 24.30 | 26.50 | 26.05 | 13.20 | 22.51 |
| KIR-48 | 32.80 | 30.30 | 30.35 | 13.50 | 26.74 | KRS-32 | 28.40 | 27.80 | 28.60 | 22.50 | 26.83 |
| KIR-49 | 25.50 | 25.70 | 24.90 | 14.80 | 22.73 | KRS-33 | 27.40 | 28.40 | 28.90 | 12.80 | 24.38 |
| KMTU-50 | 31.50 | 30.20 | 31.10 | 16.70 | 27.38 | KRS-34 | 29.70 | 30.20 | 30.20 | 17.70 | 26.95 |
| KMTU-51 | 34.05 | 34.00 | 34.25 | 20.30 | 30.65 | KRS-35 | 32.60 | 31.00 | 32.50 | 16.50 | 28.15 |
| KMTU-52 | 36.55 | 36.20 | 36.90 | 18.20 | 31.96 | KRS-36 | 31.50 | 30.60 | 31.20 | 17.10 | 27.60 |
| KMTU-53 | 25.50 | 25.50 | 26.50 | 12.05 | 22.39 | KRS-37 | 36.30 | 36.40 | 37.30 | 27.20 | 34.30 |
| KMTU-54 | 32.75 | 32.70 | 32.85 | 19.30 | 29.40 | KRS-38 | 23.80 | 24.00 | 24.60 | 15.50 | 21.98 |
| KRS-1 | 31.30 | 30.05 | 29.70 | 20.05 | 27.78 | KRS-39 | 30.00 | 30.10 | 30.10 | 16.90 | 26.78 |
| KRS-10 | 34.40 | 34.30 | 34.75 | 22.85 | 31.58 | KRS-4 | 27.00 | 26.60 | 26.80 | 17.70 | 24.53 |
| KRS-11 | 20.10 | 20.00 | 19.85 | 14.40 | 18.59 | KRS-40 | 27.60 | 26.60 | 27.65 | 15.50 | 24.34 |
| KRS-12 | 23.60 | 23.35 | 23.50 | 16.70 | 21.79 | KRS-41 | 33.70 | 34.00 | 34.50 | 13.60 | 28.95 |
| KRS-13 | 30.85 | 30.45 | 30.85 | 18.40 | 27.64 | KRS-42 | 23.90 | 24.60 | 24.40 | 12.55 | 21.36 |
| KRS-14 | 28.70 | 29.00 | 29.30 | 15.30 | 25.58 | KRS-43 | 18.70 | 18.60 | 18.10 | 11.30 | 16.68 |
| KRS-15 | 36.30 | 36.10 | 36.00 | 20.15 | 32.14 | KRS-5 | 34.70 | 35.20 | 34.70 | 22.70 | 31.83 |
| KRS-16 | 35.70 | 35.40 | 36.60 | 19.95 | 31.91 | KRS-6 | 21.40 | 22.20 | 22.50 | 15.00 | 20.28 |
| KRS-17 | 31.90 | 31.70 | 31.90 | 15.00 | 27.63 | KRS-7 | 26.40 | 26.30 | 26.00 | 18.30 | 24.25 |
| KRS-18 | 25.10 | 25.10 | 25.30 | 19.00 | 23.63 | KRS-8 | 28.50 | 28.00 | 28.00 | 19.70 | 26.05 |
| KRS-19 | 34.40 | 35.30 | 34.95 | 24.00 | 32.16 | KRS-9 | 35.80 | 34.80 | 34.60 | 18.50 | 30.93 |
| KRS-2 | 36.70 | 35.00 | 36.00 | 17.30 | 31.25 | IR-64 | 28.00 | 27.00 | 29.40 | 20.10 | 26.13 |
| KRS-20 | 36.80 | 36.70 | 37.00 | 19.70 | 32.55 | Katarni | 25.60 | 26.15 | 26.36 | 20.20 | 24.58 |
| KRS-21 | 25.30 | 25.90 | 26.25 | 16.40 | 23.46 | MTU 7029 | 25.60 | 26.40 | 26.10 | 19.60 | 24.43 |
| KRS-22 | 26.80 | 27.70 | 27.50 | 16.80 | 24.70 | R. Sweta | 21.05 | 21.70 | 22.50 | 19.30 | 21.14 |
| KRS-23 | 26.80 | 26.85 | 26.30 | 17.10 | 24.26 | R. Suwasini | 29.80 | 28.40 | 29.65 | 18.00 | 26.46 |
| KRS-24 | 18.20 | 18.60 | 19.60 | 11.60 | 17.00 | S. Surbhit | 26.30 | 26.50 | 27.00 | 14.40 | 23.55 |
| KRS-25 | 26.00 | 26.10 | 27.00 | 13.40 | 23.13 | Mean | 28.72 | 28.60 | 28.88 | 17.11 | 25.83 |
| KRS-26 | 28.70 | 28.50 | 28.80 | 17.40 | 25.85 | CD (0.05) | | | | | 2.8 |
| KRS-27 | 29.80 | 30.20 | 29.75 | 15.70 | 26.36 | CV (%) | | | | | 7.78 |
| KRS-28 | 25.10 | 25.90 | 26.60 | 13.70 | 22.83 | | | | | | |

Environment details are given under Materials and Methods.

high stability (Yan 2014). As evident from Table 2 and Fig 2, the genotype no. 49 (KRS-43) with lowest mean yield of 16.49 g/plant and genotype no. 42 (KRS-37) with highest mean yield of 34.3 g/plant lied farthest and closest, respectively with respect to the AEC.

Identification of ideal environment and relationship among four different environments (EI, EII, EIII and EIV) and interpretation was done with help of Discriminateness vs Representativeness biplot. The representative environment was identified by smaller angle between environments and AEC abscissa. This aided in identifying mega environment, whereas discrimination among the 54 Katarni derived lines including 6 checks was done on the basis of environmental vector, that is longest length of environment vector

represents a high ability to discriminate genotypes (Yan *et al.* 2011). In present experiment, EI environment was identified as most “discriminating environment” with longest length vector, whereas EII & EIII environments were identified as representative environments with less than 45° angle to AEC abscissa (Fig 3). Which-won-where graph of GGE was biplot used to identify rice Katarni derived lines specific for test environments. All the Katarni derived lines were placed within the polygon using symmetric scaling method in accord to and perpendicular lines were drawn known as equality line (Yan 2001). A mega environment is a group of locations that consistently share the best set of genotypes across environments. In this study, the four testing environments was grouped into two mega

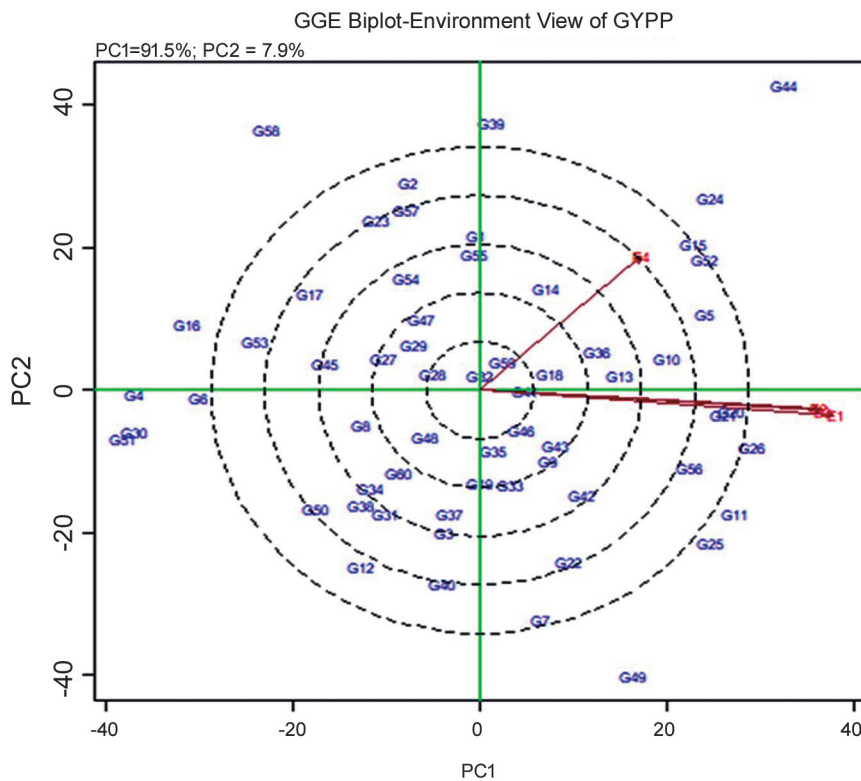


Fig 3 Discriminateness vs. Representativeness for Yield/plant (g) for 54 Katarni derived lines and 6 checks under four different environments.

environments, where (EI), (EII) and (EIII) constituted first Mega-environment-I (ME-I) and EIV environment into second Mega-environment-I (ME-II). Similar findings were reported by Aina *et al.* (2009), XuFei-fei *et al.* (2014), Akter *et al.* (2015). Sharifi *et al.* (2017) also used AMMI model for study of GE interaction effects of seven promising rice varieties with two checks in nine environments in three consecutive years.

Identifying stable lines across different environments is essential to obtain high yield irrespective of environment for which $G \times E$ interaction analysis is generally conducted to know the adaptability of the stable genotypes across environments. AMMI method of GEI analysis is most effective over other models because it uses ANOVA to analyse the main effects (additive part) and PCA to address the non-additive part. The ANOVA of AMMI and genotype main effect in addition to genotype by environment interaction (GGE) biplot analysis for 54 breeding lines and 6 checks over two years and four dates of sowing revealed three interaction principal component (IPAC) and there was highly significant variation among the genotypes.

Katarni is the ceremonial aromatic rice of Bihar which was tagged with Geographical Indication (GI) due to its territory specific unique cooking qualities. However, due to tall plant height and late maturity, farmers don't prefer to cultivate this genotype. The purpose of this study was to identify the high yielding genotype out of the isolated breeding lines of Katarni which give stable performance under different dates of sowing. Parental checks Katarni,

MTU 7029 and R. Suwasini recorded average grain yield of 24.5, 24.4 and 26.4 g/plant, respectively. Entries KIR-46, KMTU-52, KRS-10, KRS-15, KRS-16, KRS-19, KRS-2, KRS-20, KRS-37, KRS-5 and KRS-9 were found to be significantly superior over these checks (Table 2). Based on GGE and AMMI analysis, the five Katarni derived lines namely KRS-37 and KRS-20, KRS-10, KRS-15 and KRS-30 were identified as stable genotypes with high mean performance in all four environments. For the photosensitive varieties, 15th July is the normal sowing time while the sowing dates of photo insensitive early, medium and late maturing rice genotypes vary and ranges from last week of May to First week of July. Environment EI, EII and EIII constituted one Mega-environment-I (ME-I) that consistently shared the best set of Katarni-derived F_6 lines in present study and EIV environment into second Mega-environment-II (ME-II). Lingaiah *et al.* (2020) also performed what-won-where biplot and reported three environments to fall into two mega environments. Analysis of yield stability of 54 rice advanced breeding lines in four dates of sowing over two years through the AMMI model and its related parameters indicated that the sowing date played a major role in explaining the variations in the observed data. The identified high yielding genotypes with stable performance under different sowing dates can further be evaluated under multilocation testing for varietal release.

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