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*Research Article*

# Additive Main effect and Multiplicative Interaction (AMMI) model analysis for yield performance and G×E interaction in a multi-environmental trial of aromatic fine rice in Bangladesh

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## Abstract

**The problem of genotype-environment interaction (G×E) in interpreting multilocus trial analyses and predicting genotype performance can be mitigated by applying Additive Main effect and Multiplicative Interaction (AMMI) model analysis. The model AMMI was used in the present study to determine the effect of genotype, environment, and their interaction, to determine the extent of G×E interaction and to identify the factors contributing to G×E interaction for the best yielding aromatic fine rice genotype grown in four different districts in Bangladesh. Analysis of variance showed that the effect of genotypes, environments, G×E interactions were highly significant for plant height, days to maturity, panicles length, grain yield. Result showed grain yield had highly significant differences for environmental traits like (soil properties, phenological, genotypes) with their interactions which indicated that environments were different and changeability with the genotypes. Large variations in total P, Fe and rainfall identified as the main cause of the observed interaction. Here, Genotype BRRI Dhan34 had the highest mean grain yield values over four locations, respectively. In AMMI model, among four locations Dinajpur with Nilphamari were the majority responsive environments and Dinajpur was the most adjacent responsive location. Therefore, location Dinajpur with BRRI Dhan34 genotype could be considered as a better combination for higher grain yield among the ten aromatic fine rice genotypes.**

**Key Words:** AMMI model; G × E interaction; grain yield; PCA; aromatic fine rice

## 1. Introduction

Rice (*Oryza sativa* L.) is one of the most important staple foods for more than half of the world's population with a global production of more than 700 million tons per year area of 165 million hectares. (Nayak *et al.,* 2019). Local genotypes, including aromatic fine rice, occupied about 12.16% of the total rice area in Bangladesh (Akter *et al.,* 2020). All rice genotypes have different specialty while some are very prevalent for their aroma and scent. Many countries such as India, Thailand, Vietnam, USA, China, etc., are involved in developing special aromatic rice cultivars (Verma *et al.,* 2018). Although the productivity of aromatic fine rice is comparatively low, its demand for internal consumption for export is increasing gradually (Haque *et al.*, 2012).

In agricultural research testing a numerous genotype in several environments is called multi-environment trials (MET). MET is usually conducted to find superior genotypes for better cultivation in the future (Diyah and Hadi, 2016). A variety or genotype is more adaptable if it gives high average yield but has low variation in yielding ability when grown in different environments (Karim *et al.*, 2012). The use of genotype main effect (G) plus genotype-by-environment (GE) interaction (G+GE) AMMI analysis by plant breeders and other agricultural researchers has increased dramatically during the past 5 years for analyzing multi-environment trial (MET) data reported by (Yan *et al.*, 2007).

AMMI model has been expansively applied in the statistical analysis since large portion of the G×E interaction sum of squares visibly separates main and interaction effects which support a breeding program over the check locations (Ebdon and Gauch, 2013 and Rodrigues *et al.,* 2014). Therefore, estimation GEI by AMMI model is the best method stated by (Kindeya *et al.,* 2015).

AMMI model combines ANOVA for the G×E effects with the additive parameters of principal component analysis (PCA) reported by (Gauch and Zobel, 2006). Thillainathan and Femandez (2001) designated that the biplot display of PCA scores plotted against each other provides visual inspection and interaction components. Application of the AMMI model has performed normally throughout the previous two aeras namely (Eberhart and Russell, 1966), variance component methods (Shukla 1972; Gauch *et al.*, 2008; Yang *et al.*, 2009; Rodrigues *et al.,* 2014). With this background, the main objective of the current study was to identify the aromatic rice; perform G x E interaction and find out the influence of environmental components related to G x E interaction to better control the yield of aromatic rice.

## 2. Materials and Methods

### *2.1 Experimental plant materials*

The experimental plant materials *i.e.*, ten aromatic fine rice genotypes (Table 1) collected from different district of Bangladesh. Four locations differing in latitude, longitude and elevation from the sea level were in Dinajpur (25°37'38" N, 88°38'16" E and 42 m); in Thakurgaon (26°41'83" N, 88°42'16"E and 60 m); Panchagarh (26°20'00" N, 88°33'27" E and 79 m) and Nilphamari (25°48'27" N, 88°41'27" E and 40 m).Top of FormTop of Form The genotypes were evaluated in a RCBD with three replicates in a plot size of 4m×5m with a spacing of 30 cm between rows. Experiments related soil components were described in (Table 2). For the final setting of the experiment, 30-day-old seedlings were used, and one seedling was transplanted per hill. Adequate soil fertility was ensured by applying urea, Triple Super Phosphate (TSP), muriate of potash (MOP), gypsum, $ZnSO_4$ @ 250:130:120:50:10 kg/ha, respectively. Different agronomic actions namely, weed control overall completed by manually, insect and pests by the solicitation of 20 ml per 1 L Cypermethrin 10% w/v EC and 50 ml per 1 L Benfuracarb 20% w/v EC. At 30 days after planting urea fertilizer (46-0-0) was applied.

**Table 1:** Ten popular aromatic fine rice genotypes with place of collection in Bangladesh

| Sl No | Genotypes | Place of collection | Kernel size and shape | Yield (T/ha) |
|---|---|---|---|---|
| G1 | Kataribhog | Dinajpur | Short, medium Scented | 2.00 |
| G2 | Kalijira (medium grain) | BRRI | Short, medium Scented | 1.96 |
| G3 | Kalijira (long grain) | Khulna | Short, medium Scented | 2.11 |
| G4 | BRRI dhan34 | BRRI | Short, medium Scented | 2.66 |
| G5 | BRRI dhan37 | BRRI | Short, medium Scented | 1.92 |
| G6 | Chinigura | Sherpur | Medium, slender Scented | 1.21 |
| G7 | Basmati | Barguna | Short, bold Scented | 2.43 |
| G8 | Tulsimala | Sherpur | Short, bold Lightly scented | 1.95 |
| G9 | Badshabhog | Dhaka | Short, bold Scented | 1.35 |
| G10 | Gobindhabhog | Jessore | Short, medium Lightly scented | 2.38 |

### 2.2 Data collection

Yield contributing characters like plant height, days to maturity, panicles length, grain yield data was recorded using ten randomly selected plants in each replication and yield data were finally converted in to (t/ha).

### 2.3 Statistical analysis

Grain yield which was collected at 12% moisture level. Observations were recorded and the data were statistically analyzed. Here, the contribution of each genotype and environment to GEI is assessed by using the biplot plot in which mean yield values are plotted against scores of the first principal component interaction (PCA1). Correlation coefficient, analysis of variance (ANOVA) with Post Hoc also PCA (Principal Component Analysis) are using SPSS (ver 20) and XLSTAT (ver16).

### 2.4 Additive main effect and multiplicative interaction (AMMI) method for RCBD analysis

The AMMI method was applied with additive effects to 10 genotypes in three environments, and multiplicative was used for G×E interaction. It affords a symbolic view of the transformed G×E interaction for any interpretation (Kempton, 1984) based on the following AMMI equation:

Where, = Yield for genotype g, environment e and replication r; μ = Grand mean value for trait; = Mean deviations for genotype (genotype means minus grand mean); = Mean deviation for environment; n = PCA axis number reserved in the model; = Singular value for PCA axis n; = Genotype eigenvector values for PCA axis n; = Eigenvector for environment; = Residuals and = Error is used

**Table 2:** Physico-chemical characteristics of initial soils in the different experimental fields

| Soil characteristics | Locations | | | |
|---|---|---|---|---|
| | Dinajpur | Thakurgaon | Panchagarh | Nilphamari |
| Soil texture | Sandy clay loam | Loomy | Sandy clay loam | Sandy clay loam |
| pH | 5.25 | 5.1 | 5.7 | 5.21 |
| Organic carbon (%) | 0.81 | 0.55 | 0.79 | 0.79 |
| Total N (%) | 0.08 | 0.07 | 0.08 | 0.08 |
| Available P (mg/kg soil) | 120.34 | 98.99 | 121.44 | 120.00 |
| Exchangeable K (cmol/kg) | 0.151 | 0.055 | 0.141 | 0.171 |
| Available S (mg/kg soil) | 14 | 24 | 14 | 13 |

## 3. Results and discussions

### 3.1 Analysis of variance result including the partitioning of the G×E interaction of aromatic fine rice

The analysis of result showed significant differences for plant height, days to maturity, panicle length and grain yield for genotype, environment, G x E interaction. The highly significant effect on environment indicates high differentiation of genotypic responses in different environments and existence of wide range of diversity among genotypes (Kulsum *et al.*, 2012). Analysis of variance based on the AMMI model for grain yield is shown in Table 3 indicating that genotype performance was more influenced than environmental factors. The genotype × environment effect interaction could be divided into two components, namely IPCA1 and IPCA2. All significant differences were found for grain yield, indicating that the components of G×E interaction affected the yield of genotypes in different environments and the environments were different. Kumar *et al* (2012) reported the result for hybrid rice at different locations in Bangladesh.

**Table 3:** Analysis of variance including the partitioning of the G×E interaction of aromatic fine rice

| Source of variation | df | Mean sum of squares | | | |
|---|---|---|---|---|---|
| | | Plant height | Days to maturity | Panicle length | Yield (t/ha) |
| Genotype (G) | 9 | 45.22** | 69.88** | 1.756** | 2.22** |
| Environment (E) | 3 | 263.33** | 533.77* | 11.26** | 1.80** |
| Replication (R) | 2 | 22.01** | 4.82** | 1.00* | 0.065* |
| Interaction (G×E) GEI | 36 | 5.033* | 2.11** | 0.56* | 0.142** |
| AMMI component 1 | 12 | 11.65** | 3.44** | 0.89* | 0.32** |
| AMMI component 2 | 11 | 5.67** | 2.45** | 0.76* | 0.14** |
| Error | 18 | 3.66 | 0.567 | 0.578 | 0.89 |

Here * $p < 0.05$, ** $p < 0.01$

### *3.2 Analysis of variance result for grain yield with soil, climatic and phenological properties*

Based on ANOVA result, the average highest grain yield (2.66 t/ha) was found from G4 (BRRI dhan 34) genotype and comparatively low (1.95 t/ha) for G8 (Tulsimala) genotype. High variations occurring in this result were caused by several factors such as soil properties like Fe, total phosphorus, Ca as well as rainfall (Eberhart and Russell, 1966). Changeable environmental features such as rainfall through a single situation can underscore dissimilarity of genotypes in relation to environment across locations. For the different location trials, the location in which the field trials were undertaken showed geographical and environmental dissimilarities (Islam *et al.*, 2020) .The soil properties showed that the highest variation occurred phenological traits like plant height, days to maturity, panicles length showed highest variation. All the findings shown in (Table 4).

**Table 4:** Summary statistics of grain yield, soil, climatic and phenological properties of ten aromatic fine rice genotypes in 4 locations of Bangladesh

| Variables | Sum | Average | Variance | Variables | Sum | Average | Variance |
|---|---|---|---|---|---|---|---|
| G1 | 8.012 | 0.200 | 0.530 | **Fe** | **1068.77** | **26.71** | **7138.41** |
| G2 | 3.800 | 0.096 | 0.115 | CEC | 16.05 | 0.40 | 1.521 |
| G3 | 8.420 | 0.211 | 0.578 | pH | 19.95 | 0.49 | 2.297 |
| G4 | 10.63 | 0.266 | 0.972 | EC | 93.76 | 2.34 | 52.197 |
| G5 | 7.68 | 0.192 | 0.504 | T_max | 142 | 3.55 | 116.36 |
| G6 | 4.84 | 0.121 | 0.187 | T_min | 99 | 2.48 | 56.61 |
| G7 | 9.70 | 0.243 | 0.681 | **Rainfall** | **465.8** | **11.65** | **1254.83** |
| G8 | 3.81 | 0.095 | 0.121 | Humidity | 339 | 8.48 | 663.54 |
| G9 | 5.41 | 0.135 | 0.211 | PH | 523.2 | 13.08 | 1622.24 |
| G10 | 9.51 | 0.238 | 0.703 | DM | 2743.2 | 68.58 | 5300.17 |
| N | 3.78 | 0.332 | 0.675 | PL | 103.6 | 2.59 | 63.15 |
| OC | 4.44 | 0.111 | 0.115 | - | - | - | - |
| **Total_P** | **726.84** | **18.17** | **3226.57** | | | | |
| Available_P | 29.36 | 0.73 | 5.892 | - | - | - | - |
| K | 125.02 | 3.12 | 91.79 | - | - | - | - |
| Ca | 335.15 | 8.37 | 664.58 | - | - | - | - |

Here, N=Total Nitrogen, OM=Organic Matter, OC=Organic Carbon, Total P=Total phosphorus, FG=Filled grains (no), SW=Seed weight (gm), Available P = Available Phosphorus, K=Potassium, Ca=Calcium, Fe=Iron, CEC= Cation Exchange Capacity, pH=pH level, EC=Exchangeable Cation, Tmax=Temperature Maximum, Tmin=Temperature Minimum, PH=Plant Height (cm), PL=Panicles Length (cm) bold letters indicate correlation is significant at the 0.01% level

### *3.3 Principal Component Analysis (PCA)*

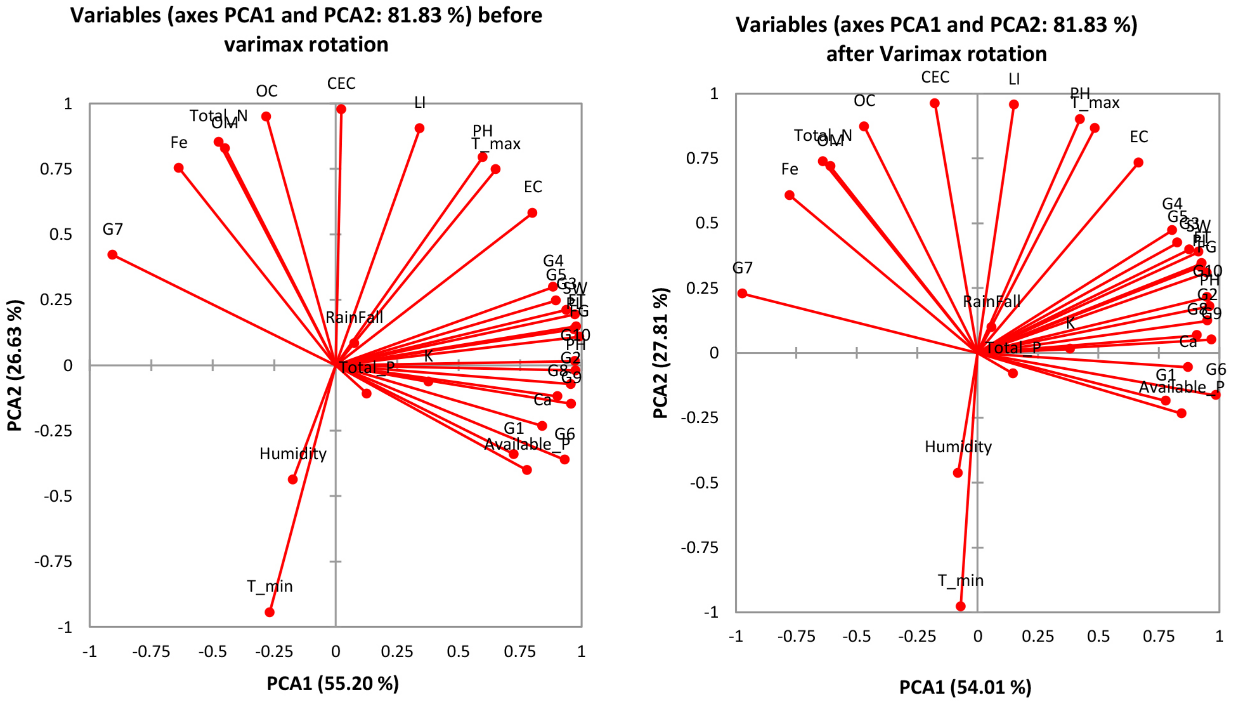
The AMMI biplot provides a visual expression of the relationships between the IPCA1 and IPCA2 with the mean of the genotypes and environments. Principal Component Analysis is a multivariate technique that detects figure arrangements with correspondences and differences between variables set up and arranged in a systematic multivariate system (Islam *et al.*, 2020). Tables 5 and 6 showed that the output of PCA analysis exposed the relation between retained factors and the variables before and after rotation. Figure 1 is the map titled correlation circle (below on axes PCA1 as well as PCA2) showing a projection of the primary variables into the factors planetary. If two variables were away from the center (Xlstat, 2017) but variables were close to each other then they were significantly positively correlated (r near 1). Besides, remained orthogonal, then they do not exist correlated (r near 0); if they were on the opposite side of the center, then they remained significantly negatively correlated (r near -1). From the plot of the component loadings gave a visual representation schemed in planetary that showed exactly how closely related the items to each other as well as with the components.

**Table 5:** Outputs of PCA analysis between variables and factors before Varimax rotation

| Variables | PCA1 | PCA2 | Variables | PCA1 | PCA2 |
|---|---|---|---|---|---|
| G1 | 0.725 | -0.340 | Fe | -0.637 | 0.753 |
| G2 | 0.957 | -0.073 | CEC | 0.024 | 0.977 |
| G3 | 0.839 | 0.211 | PH | 0.598 | 0.795 |
| G4 | **0.885** | **0.299** | EC | 0.802 | 0.582 |
| G5 | **0.876** | **0.247** | T_max | 0.652 | 0.748 |
| G6 | 0.932 | -0.361 | T_min | -0.267 | -0.944 |
| G7 | -0.906 | 0.421 | Rainfall | 0.077 | 0.084 |
| G8 | 0.903 | -0.119 | Humidity | -0.174 | -0.437 |
| G9 | 0.958 | -0.147 | PH | 0.977 | -0.020 |
| G10 | 0.974 | -0.016 | PL | 0.971 | 0.137 |
| Total_N | -0.475 | 0.853 | MD | 0.343 | 0.905 |
| OM | -0.449 | 0.828 | - | - | - |
| OC | -0.281 | 0.949 | - | - | - |
| Total_P | 0.127 | -0.108 | - | - | - |
| Available_P | 0.779 | -0.401 | - | - | - |
| K | 0.378 | -0.063 | - | - | - |
| Ca | 0.841 | -0.232 | - | - | - |

In the current study Fig 1(a) the first principal component axis (PCA1) illustrated 55.20% of entire variation while PCA2 explain 26.63%. Therefore, the two axes together explained 81.83% of the G×E interaction for grain yield with other traits and Fig 1(b) also support the same G×E interaction. Figure 1(a) showed that all the variables have strong relationships with some of the environmental parameters before rotation. Therefore, genotypes were closed with their related environmental traits. Table 4 indicated that most of the genotypes with very strong PCA1 values G1 (0.725), G2 (0.957), G3 (0.839), G4 (0.885), G5 (0.876), G6 (0.932), G8 (0.903), G9 (0.958) and G10 (0.974) appeared with Available_P (0.779), Ca (0.841), EC (0.802), PH (0.977), PL (0.971) in PCA1. On the other hand, in PCA2 only OM (0.828) and OC (0.949) closed to each other. This finding very much similar with (Poramate and Anchalee, 2015).

Although some of the traits shown strong relationship values but they were not closed to each other. Table 6 showed that after rotation the PCA values between factors and the variables changed to some extent. Figure 1(b) also supported the relationships. The correlation round also useful in understanding the significance of the axes. Following this research, the parallel axis link by means of Total_P, Available_P, K, Ca, EC, PH, PL, FT and the vertical axis with Total_N, OM, OC, Fe, CEC, PH, Temp_max, Temp_min, Rainfall, Humidity and LI. These trends revealed that a variable is well linked with an axis.




1a 1 b

Fig 1: AMMI model based on environments focused scaling for comparison the genotypes with the ideal genotype on grain yield. a) before rotation b) after rotation

**Table 6:** Outputs of PCA analysis between variables after Varimax rotation

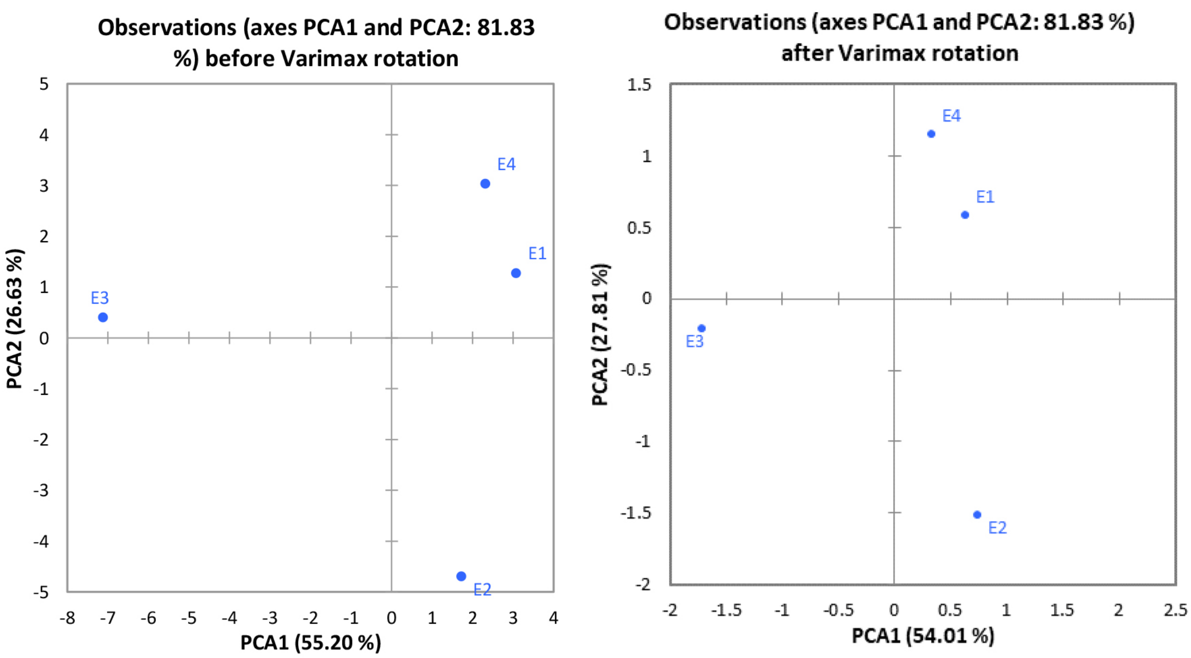
| Variables | PCA1 | PCA2 | Variables | PCA1 | PCA2 |
|---|---|---|---|---|---|
| G1 | 0.779 | -0.185 | Fe | -0.777 | 0.607 |
| G2 | 0.652 | -0.124 | CEC | -0.176 | 0.961 |
| **G3** | **0.800** | **0.398** | PH | 0.424 | 0.900 |
| **G4** | **0.806** | **0.473** | EC | 0.666 | 0.733 |
| **G5** | **0.807** | **0.424** | T_max | 0.486 | 0.865 |
| G6 | 0.986 | -0.164 | T_min | -0.069 | -0.979 |
| G7 | -0.973 | 0.228 | Rainfall | 0.058 | 0.098 |
| G8 | 0.909 | 0.068 | Humidity | -0.081 | -0.464 |
| G9 | 0.968 | 0.051 | PH | 0.961 | 0.179 |
| G10 | 0.751 | -0.214 | PL | 0.922 | 0.332 |
| Total_N | -0.639 | 0.738 | MD | 0.151 | 0.956 |
| OC | -0.469 | 0.872 | GY | 0.949 | 0.309 |
| Available_P | 0.845 | -0.234 | - | - | - |
| K | 0.383 | 0.015 | - | - | - |
| Ca | 0.871 | -0.056 | - | - | - |

### *3.4 Analysis of variance result for grain yield in four locations*

There had a significant effect of environmental parameters for grain yield with four locations. As shown (Table 7), the Tukey's HSD (Honestly Significantly Different) test smeared to wholly pairwise variances among mean values. The risk of 5% chosen values used to define the critical value F, which compared to the standardized difference between the means. Only three pairs appeared significantly different (E1, E3), (E4, E3) and (E2, E3). The means and the groups then categorized founded on this analysis. In conclusion, four location's different environmental parameters showed significantly effects on the yield of genotypes. Based on the result of Table 7, Fig 2 showed the eventual objective of the Principal Component Analysis. Where E1 and E4 environment nearer to the central point was nearer with similar yield and E1 devoured higher yield than E4. After that E3 and E4 took very low yield comparing to other environments. In this case the best environment was E1 (Dinajpur). It was enabled the observations on a two-dimensional map and to identify links that exists grain yield Dinajpur, Thakurgaon, Panchagarh and Nilphamari locations were unique. It showed that every geographical location had its own environmental characteristics and those characteristics had different impact upon the genotypes.

**Table 7:** Environment /Tukey (HSD)/ ANOVA Analysis of the differences between grain yield with four locations in Bangladesh

| Contrast | Difference | Standardized difference | Critical value | Pr > Diff | Significant |
|---|---|---|---|---|---|
| E1 vs E3 | 2.061 | 4.335 | 2.693 | 0.001 | Yes |
| E1 vs E2 | 0.670 | 1.409 | 2.693 | 0.502 | No |
| E1 vs E4 | 0.403 | 0.848 | 2.693 | 0.831 | No |
| E4 vs E3 | 1.658 | 3.487 | 2.693 | 0.007 | Yes |
| E4 vs E2 | 0.267 | 0.562 | 2.693 | 0.943 | No |
| E2 vs E3 | 1.391 | 2.925 | 2.693 | 0.029 | Yes |
| | Tukey's d critical value: | | 2.868 | | |




**2a** **2b**

Fig 2: AMMI observation study for comparison of the locations a) before rotation b) after rotation

## 4. Conclusion

In summary, the statistical model AMMI was used to determine the G×E interaction pattern of grain yield of ten promising aromatic fine rice cultivars. ANOVA showed that significant differences among genotypes, soil properties and phenological traits indicated the presence of large variability among genotypes and locations for yield, with G4 (BRRI Dhan34) and G7 (Tulshimala) being the first and second high yielding genotypes corresponding to environments E1, E2, E3 and E4. The maximum yielding genotypes G4, G7, G10, G3, G1, G5 and G6, G2, G8 were the low yielding genotypes with wide adaptation. The analysis of the four environments showed that there were significant differences between E1 vs. E3, E3 vs. E4, and E2 vs. E3. PCA analysis also showed that location E1 (Dinajpur) was found to be optimum selection site for identification of broad and adaptive genotype of aromatic rice and for other improvement work on aromatic fine rice.

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## Compliance with ethical standards

NA

## Conflict of Interest

Authors declare that they have no conflict of interest

## Author contributions

Conceptualization of research and designing of experiments (SSI, ), Conduction of experiment (SSI, AKH, ABMK), Preparation of manuscript (SSI, AKH, ABMK,NN).

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