Genotype x environment interaction of rice genotype

T Sitaresmi, U Susanto, E F Pramudyawardani, Nafisah, Y Nugraha, P Sasmita

Indonesian Center for Rice Research
Jalan Raya 9 Sukamandi, Ciasem, Subang, West Java, Indonesia 41256

Email: triassitaresmi@gmail.com

Abstract. Grain yield was influenced by genotype, environment and, genotype x environment interaction, so the maximum potential of rice will appear when planted in a suitable environment. The study aims to estimate grain yield stability of 20 genotypes of rice in dry season of 2014 in three locations. The experimental design used was a randomized complete block design with three replications. The average grain yield of the three locations ranged from 5.60 to 7.89 ton/ha. Based on the combined analysis of variance, the interaction between the genotype x environment was significant. Six lines have grain yield were not significantly different from Ciherang, which were BP5168F-KN-16-3, BP4114-7f-Kn-22-2-KLT-2*B-SKI-1*B, BP5168f-kn-16-3-KLT-2*B-SKI-1*B, BP11282f-Kn-4-3-KLT-2*B, BP5478-1f-Kn-19-1-2-KLT-2*B-SKI-1*B, and HHZ12-SAL2-Y3-Y1. Only OBS 8412 which has grain yield higher than Ciherang. Based on the coefficient of regression and coefficient of variability, HHZ12-SAL2-Y3-Y1 and OBS 8412 were stable and have general adaptability in Cilacap, Sukabumi, and Kebumen. BP12244-20-3-1-3 and HHZ12-SAL8-Y1-Y2 were specifically adapted in the low yielding environment. BP5480-3f-Kn-4-1-KLT-2*B, Ciherang, and INPARI 32 HDB were specifically adapted in high yielding environment.

1. Introduction
Previously, plant breeding programs mostly focused on developing high yielding varieties. Recently, stable and sustainable yields under various environmental conditions have consistency gained importance over only increased yield. The development of varieties, which are adapted to a wide range of diversified environments, is the important aim of breeders in a crop improvement program [1].

The selection of genotypes in breeding programs and making varieties recommendations to farmers is complicated by genotype-by-environment interaction (GxE). The problem lies in the fact that genotypes that are superior across all locations are rare. How to integrate GxE and performance to make selections has been the source of considerable research, but despite its importance, the optimal method using GxE information is unclear [2].

The GE interaction is the response of each genotype to variations in the environment and it has been one of the principal subjects of study in plant breeding, allowing the generation of different methodologies for genetic improvement and recommendation of stable genotypes [3]. The presence of GE interaction for quantitative traits such as yield performance has led to the development of several statistical methods for stability analysis that can be used to identify genotypes with consistent performance across environments.

Crop performance tests at multiple locations and possibly in multiple years are executed to generate experimental data for measuring genotype. Due to the complexity of field trials and various definitions of yield stability, many different statistical methods for measuring stability have been proposed [4, 5,
These methods can be clustered into two basic categories: variation-based [7, 8, 9, 10] and regression-based [11, 12, 13]. Both variation and regression-based methods are more focused on yield consistency across environments. It appears more appropriate that genotype yield performance and yield stability be considered simultaneously [14, 15, 16]. These statistics, advantages and, disadvantages, as well as the relationships between them have been reviewed previously [17, 4, 18, 19, 20].

The main type of stability analysis was joint regression analysis or joint linear regression (JLR) [21]. It involves the regression of the genotypic means on an environmental index. Joint regression analysis provides a means of testing whether the genotypes have characteristic linear responses to changes in environments. Joint regression analysis was first proposed by Yates and Cochran (1938) and then widely used and reviewed by various authors [12, 11, 13, 22, 23, 24, 25, 22, 23, 24, 21, 17, 25, 26]. Our objective was to evaluate rice genotypes under different environments; and to estimate the genotype x environment interaction of rice genotypes, giving emphasis to grain yield.

2. Materials and Method
The experiments were conducted on dry season 2014 in three locations that were Cilacap, Kebumen, and Sukabumi. Plant materials used were 20 rice genotypes including 16 lines and 4 check varieties (Ciherang, INPARI 28, INPARI 32 HDB, and INPARI 33). The genotypes were develop/breed for main pest and diseases resistance, that were bacterial leaf blight, tungro, brown planthopper, and blast. The experiment used a randomized complete block design with three replication at each location. The response of plants to growth environment was measured on grain yield (ton/ha). Data were analysed using a single analysis of variance, combined analysis of variance [38], and stability analysis based on regression [12], and coefficient of variability [7]. All statistical procedure was performed by SAS and Ms excel.

The two important indices in stability analysis based on reference [12] are the regression coefficient and the variety mean yield overall environments. Regression coefficients approximating to 1.0 indicating average stability. When this is associated with high mean yield, varieties have general adaptability; when associated with low mean yield, varieties are poorly adapted to all environments. Regression values increasing above 1 describe varieties with increasing sensitivity to environmental change (below average stability), and greater specificity of adaptability to high-yielding environments. The regression coefficient decreasing below 1 provides measure of greater resistance to environmental change (above average stability), and therefore increasing specificity of adaptability to low-yielding environments.

3. Result and Discussion
Analysis of variance of grain yield in each location showed that genotype significantly affected grain yield. This means that there were differences in grain yield among the genotypes so it revealed variations on this character. Source of variance of replication in Cilacap and Kebumen did not affect variation of grain yield, so that experimental design of RAL can be considered in the next experiment.

| Source of Variance | Df | Cilacap | Kebumen | Sukabumi |
|--------------------|----|---------|---------|----------|
|                    |    | MS      | Prob    | MS       | Prob    |
| Replication        | 3  | 2.670   | 0.063   | 1.296    | 0.072   | 5.263   | 0.000   |
| Genotype           | 19 | 3.335   | 0.000   | 0.953    | 0.045   | 0.913   | 0.000   |
| Error              | 57 | 1.042   |         | 0.529    |         | 0.206   |         |
| Corrected total    | 79 | 1.655   | 0.660   | 0.568    |         |         |         |
Table 2. Grain yield of rice in three locations

| No | Genotypes | Grain yield (t/ha) | Mean (t/ha) |
|----|-----------|--------------------|-------------|
|    |           | Cilacap | Kebumen | Sukabumi |
| 1  | BP12244-20-3-1-3 | 5.34    | 6.12    | 5.36     | 5.60 |
|    | BPT164C-68-7-3-2/2*Ciherang | 7.23    | 6.36    | 5.64     | 6.41 |
| 2  | BP13106-1d-1-2-3 | 7.70    | 6.20    | 6.05     | 6.65 |
|    | Way Apo Buru/Tukad Unda |         |         |          |      |
| 3  | BP5168F-KN-16-3 | 6.70    | 6.45    | 5.54     | 6.23 |
|    | IR69020-81-1-2-3-3-1-2/2*Ciherang |         |         |          |      |
| 4  | BP7528-3F-7-1 | 7.50    | 6.37    | 6.01     | 6.63 |
|    | Ciherang/Kalimas |         |         |          |      |
| 5  | BP4114-7f-Kn-22-2-KLT-2*B-SKI-1*B | 7.72    | 6.22    | 5.82     | 6.59 |
|    | Way Apo Buru/Tukad Unda |         |         |          |      |
| 6  | BP5168f-Kn-16-3-KLT-2*B-SKI-1*B | 6.65    | 6.71    | 6.34     | 6.57 |
|    | IR69020-81-1-2-3-3-1-2/2*Ciherang |         |         |          |      |
| 7  | BP7528-3f-7-1-KLT-2*B-SKI-1*B | 7.36    | 6.12    | 6.47     | 6.32 |
|    | Cigeulis/IRBB 4 |         |         |          |      |
| 8  | BP9444-1f-Kn-1-3-KLT-2*B | 6.41    | 6.12    | 5.94     | 6.16 |
|    | IR66169-121-4-5-3/Tukad Balian |         |         |          |      |
| 9  | BP11282f-Kn-4-3-KLT-2*B | 6.65    | 6.71    | 6.34     | 6.57 |
|    | Ciherang/IRBB 52//IRBL 20 |         |         |          |      |
| 10 | BP5478-1f-Kn-19-1-2-KLT-2*B-SKI-1*B | 7.72    | 6.74    | 6.06     | 6.84 |
|    | Ciherang/IRBB 52//Cigerang |         |         |          |      |
| 11 | BP5480-3f-Kn-4-1-KLT-2*B-SKI-1*B | 7.67    | 6.14    | 5.25     | 6.35 |
| 12 | HHZ8-SAL6-SAL3-Y2 | 6.86    | 6.34    | 5.94     | 6.38 |
| 13 | HHZ12-SAL2-Y3-Y1 | 7.83    | 7.66    | 6.46     | 7.32 |
| 14 | HHZ12-SAL8-Y1-Y2 | 5.10    | 6.85    | 6.76     | 6.23 |
| 15 | IR83832-26-2-1-2-SKI-4 | 7.33    | 6.16    | 5.85     | 6.45 |
| 16 | OBS 8412 | 8.55    | 7.80    | 7.32     | 7.89 |
| 17 | Ciherang | 8.52    | 6.94    | 6.12     | 7.19 |
| 18 | INPARI 28 | 6.91    | 6.30    | 6.11     | 6.44 |
| 19 | INPARI 32 HDB | 8.42    | 6.92    | 5.93     | 7.09 |
| 20 | INPARI 33 | 7.11    | 6.44    | 6.04     | 6.53 |
|    | LSD 5% | 1.45    | 1.03    | 0.64     | 0.62 |
|    | CV (%) | 14.1    | 11.1    | 7.6      | 11.67 |

The overall means of grain yield in three locations show that Ciherang was not significantly different from INPARI 32 HDB. INPARI 28 and INPARI 33 were lower than Ciherang. Based on the grain yield, Ciherang was used as check varieties compared to the lines. The overall means of grain yield of all genotypes tested in Cilacap higher than in other locations. Grain yield in Cilacap was higher than in other locations.
ranged from 5.10 to 8.55 ton/ha. There were 10 lines having grain yield > 7 ton/ha were not significantly different from Ciherang. The lines were BP13106-1d-1-2-3, BP5168F-KN-16-3, BP4114-7f-Kn-22-2-KLT-2*B-SKI-1*B, BP5168f-Kn-16-3-KLT-2*B-SKI-1*B, BP7528-3f-7-1-KLT-2*B-SKI-1*B, BP5478-1f-Kn-19-1-2-TLC-2*B-SKI-1*B, BP5480-3f-Kn-4-1-KLT-2*B-SKI-1*B, HHZ12-SAL2-Y3-Y1, IR83832-26-2-1-2-SKI-4, and OBS 8412 (Table 2).

Grain yield in Kebumen was ranged from 6.12 to 7.80 ton/ha. Ciherang has a grain yield of 6.94 ton/ha. All lines tested were not significantly with Ciherang. Nevertheless, there were two lines that have grain yield above 7 ton/ha, which were HHZ12-SAL2-Y3-Y1 (7.66 ton/ha) and the OBS 8412 (7.80 ton/ha). Grain yield in Sukabumi was ranged from 5.25 to 6.34 ton/ha. Twelve lines were not significantly different from Ciherang, and only one line was higher than Ciherang, namely OBS 8412 (7.32 ton/ha). The overall means of grain yield of the three locations ranged from 5.60 to 7.89 ton/ha. Six lines showed grain yield which not significantly different from Ciherang, that were BP5168F-KN-16-3, BP4114-7f-Kn-22-2-KLT-2*B-SKI-1*B, BP5168f-kn-16-3-KLT-2*B-SKI-1*B, BP11282f-Kn-4-3-KLT-2*B, BP5478-1f-Kn-19-1-2-KLT-2*B-ski-1*B, and HHZ12-SAL2-Y3-Y1. OBS 8412 was higher grain yield than Ciherang.

A combined analysis of variance showed the interaction of genotype x location was significant. It was indicated that there was a genotype that has different ranked across locations. Location was significant indicating location was the effect on grain yield variation. This may be caused by differences in altitude. Sukabumi is ± 600 m, Cilacap is ± 400 m, and Kebumen is ± 200 m above sea level. Genotype was significantly different, it means that genotype effect on grain yield variation.

**Table 3.** Combined analysis of variance of grain yield of rice in three locations

| Source of variance       | Df | SS   | MS   | F value | Probability |
|--------------------------|----|------|------|---------|-------------|
| Locations                | 2  | 60.76| 30.38| 9.88    | 0.0054      |
| Replication( Location)   | 9  | 27.68| 3.08 | 5.19    | <.0001      |
| Genotype                 | 19 | 54.78| 2.88 | 2.49    | 0.0083      |
| Location*Genotype        | 38 | 44.03| 1.16 | 1.96    | 0.002       |
| Error                    | 171| 101.26| 0.59|         |             |
| Corrected total          | 239| 288.51|     |         |             |

**Figure 1.** Response of grain yield of 20 rice genotype in three locations
The plot of genotype x environment interaction showed that BP12244-20-3-1-3 and HHZ12-SAL8-Y1-Y2 have similar response patterns which high in Kebumen (2) and then declined in Sukabumi (3). This response was different from other genotypes so it revealed the intersection graph of interaction. INPARI 32 HDB and BP11282f-Kn-4-3-KLT-2*B similar response with others, but they decreased slightly from Kebumen (2) to Sukabumi (3), so revealed interaction with other genotypes. Reference [11] suggested that a stable genotype is genotype having a coefficient of regression equal to one and deviation of regression is not different from zero. The stable genotype is widely adaptation [12]. The stability is based on the linear components from the effects of the interaction, so when the pattern of genotype x environment interaction is not linear it will leave large variation [28].

**Table 4. Stability analysis of rice-based on Finlay and Wilkinson**

| No | Genotype       | Mea | bi | SDi | R   | r   | Cii | CVi |
|----|----------------|-----|----|-----|-----|-----|-----|-----|
| 1  | BP12244-20-3-1-3| 5.60| 0.07| 0.623| 0.009| 0.095| 1.317| 7.90 |
| 2  | BP13106-1d-1-2-3| 6.41| 1.29| 0.008| 1.000| 1.000| 1.317| 19.72|
| 3  | BP5168F-KN-16-3 | 6.65| 1.38| 0.475| 0.865| 0.930| 1.317| 23.67|
| 4  | BP7528-3F-7-1   | 6.23| 0.92| 0.322| 0.861| 0.928| 1.317| 15.76|
| 5  | BP4114-7f-Kn-22-2 | 6.63| 1.23| 0.247| 0.949| 0.974| 1.317| 22.25|
| 6  | BP5168f-Kn-16-3-KLT- | 6.59| 1.57| 0.364| 0.934| 0.967| 1.317| 23.77|
| 7  | BP7528-3F-7-1-KLT-2*B | 6.32| 1.55| 0.151| 0.988| 0.994| 1.317| 20.55|
| 8  | BP9444-1f-Kn-1-3-KLT-2*B | 6.16| 0.39| 0.024| 0.995| 0.997| 1.317| 11.67|
| 9  | BP11282f-Kn-4-3-KLT-2*B | 6.57| 0.24| 0.186| 0.550| 0.742| 1.317| 18.20|
| 10 | BP5478-1f-Kn-19-1-2-KLT- | 6.84| 1.35| 0.045| 0.999| 0.999| 1.317| 25.23|
| 11 | BP5480-3f-Kn-4-1-KLT-2*B | 6.35| 1.97*| 0.151| 0.992| 0.996| 1.317| 24.03|
| 12 | HHZ8-SAL6-SAL3-Y2 | 6.38| 0.74| 0.008| 1.000| 1.000| 1.317| 16.51|
| 13 | HHZ12-SAL2-Y3-Y1 | 7.32| 1.08| 0.479| 0.794| 0.891| 1.317| 30.43|
| 14 | HHZ12-SAL8-Y1-Y2 | 6.23| 1.40*| 0.671| 0.767| 0.876| 1.317| 20.05|
| 15 | IR83832-26-2-1-2-SKI-4 | 6.45| 1.23| 0.283| 0.935| 0.967| 1.317| 20.09|
| 16 | OBS 8412       | 7.89| 1.00| 0.058| 0.996| 0.998| 1.317| 36.33|
| 17 | Cihera         | 7.19| 1.96*| 0.199| 0.987| 0.993| 1.317| 31.90|
| 18 | INPARI 28      | 6.44| 0.66| 0.134| 0.948| 0.974| 1.317| 17.11|
| 19 | INPARI 32 HDB  | 7.09| 2.04*| 0.092| 0.997| 0.999| 1.317| 31.19|
| 20 | INPARI 33      | 6.53| 0.87| 0.058| 0.994| 0.997| 1.317| 19.23|

bi = coefficient of regression; *) significant at α=0.05; SDi = Deviation of mean square GxE interaction; CVi = Coefficient of variability

The stability analysis method based on regression showed there were two genotypes have a regression coefficient less of than one (b < 1). The genotype were BP12244-20-3-1-3 and HHZ12-SAL8-Y1-Y2. This means that the genotypes were specifically adapted to low yielding environment and less responsive to environmental improvement. The location which was adapted for the genotypes maybe Kebumen, because both genotypes have a higher yield in this location. BP5480-3f-Kn-4-1-KLT-2*B, Cihera, and INPARI 32 HDB have a regression coefficient of more than one (b> 1), it was mean that the genotypes responsive to environmental improvement and adapted in the high yielding environment. Based on the grain yield, the three genotypes may be specifically adapted in Cilacap. Fifteen other genotypes had regression coefficients were not significantly different from one
(b ≈ 1). The grain yield of 9 genotypes was tested ranged from 6.16 - 7.89 ton/ha. Two of them have grain yield more than 7 ton/ha, that was HHZ12-SAL2-Y3-Y1 and OBS 8412. It means that the genotype was classified as a stable genotype and have general adaptability in three locations tested.

As mentioned by reference [1], the results and conclusions are dependent on the environments and genotypes used in trials since environmental indices are used for regression analyses. Having common genotype checks grown in different years will help in making decisions based on performance. In addition, the number of environments used in regression-based stability analysis should be enough so as to provide accurate predictions. If the number of environments is small, examining G×E interaction effects [29, 30, 31] or using the AMMI approach [32] might represent useful alternatives.

The problem in the regression technique is the choice of measure of the environment. It is highly desirable to measure the environment by something unrelated to the organism under study to fulfill the basic assumption of independence of the regression analysis. Stability based on regression enable to eliminate of varieties that are responsive to the productive environment (b> 1), while the grain yield is above average. Reference [28] suggested Finlay and Wilkinson stability based on linear component of an interaction effect, so when the response of genotype x environment interaction is not linear, the variance of the error is great.

One of stability analysis which rapidly growing is AMMI. Many researchers used AMMI to estimate the stability of genotype from multi-locational yield trial [33, 34, 35, 36]. AMMI analysis of variance described components interactions on bilinear model, while the combined analysis of variance of regression was calculated based on the linear component of the interaction effect. AMMI analysis is more accurate in estimating response of genotype x environment interactions compared with linear regression analysis [37].

The Analysis of stability for Francis and Kannenberg (1978)

Francis and Kannenberg used the coefficient of variance (CVi) for each genotype as parameter stability and variation of genotypes against to environment. Criteria of coefficient variation values according to Moedjiono and Mejaya (1994), that is lowest (0 < x <25%), moderate-low (25% < x <50%), moderate-high (50% < x <75%), and highest (75% < x <100%). Based on these criteria, BP5478f-Kn-19-1-2-KLT-, HHZ12-SAL2-Y3-Y1, OBS 8412, Ciherang, and INPARI 32 HDB were moderate-low. Other genotypes had the lowest variability. It means that all genotypes tested were quite stable based on Francis and Kannenberg.

4. Conclusion

There was an interaction between the rice genotype x environment (different elevation) significantly. The average grain yield of the three locations ranged from 5.60 to 7.89 ton/ha. Six lines have grain yield were not significantly different from Ciherang, which were BP5168f-KN-16-3, BP4114-7f-Kn-22-2-KLT-2*B-SKI-1 * B, BP5168f-kn- 16-3-KLT-2*B-SKI-1*B, BP11282f-Kn-4-3-KLT-2*B, BP5478f-Kn-19-1-2-KLT-2*B-SKI-1*B, and HHZ12-SAL2-Y3-Y1. Only OBS 8412 which has grain yield higher than Ciherang. Based on the coefficient of regression and coefficient of variability, HHZ12-SAL2-Y3-Y1 and OBS 8412 were stable and have general adaptability in Cilacap, Sukabumi, and Kebumen. BP12244-20-3-1-3 and HHZ12-SAL8-Y1-Y2 were specifically adapted in the low yielding environment. BP5480-3f-Kn-4-1-KLT-2*B, Ciherang, and INPARI 32 HDB were specific adapted in high yielding environment.

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