Yield stability analysis of rice mutant lines using AMMI method

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Abstract. The development of the rice cultivation area is needed to increase rice productivity through expanding of marginal land especially in high-elevation areas of Indonesia. Temperature, solar radiation and rainfall influence rice yield by directly affecting the physiological processes involved in grain production. The effects of abiotic stress on grain yield and yield components vary with the growth stage, depending on variety and weather conditions. The major constraint of rice cultivation in high elevation areas is the lack of cold tolerance varieties. The objective of this research was to obtain the information on the stability of rice genotypes to be adapted in highland across three different high-elevations (700, 900 and 1200 m above sea level). The rice genotypes derived from mutation induction and hybridization treatment were cultivated in the dry season and rainy season. The AMMI analysis revealed KN-10-111, KN-20-124 and RB-10-98 mutant lines were the most stable genotypes across environments evaluated. KK-10-249 mutant line was specific in 900 m above sea level area, C4-30-21, RB-10-95 and KN-20-127 mutant lines adapted in 700 m above sea level area (dry season) whereas B-30-82, IPB117-F-20 and C3-10-171 lines specified in the rainy season. PK-20-133 mutant line had stability in 1200 m above sea level area (rainy season) while OS-30-199 and Sarinah genotypes more stable in the dry season with low temperatures stress conditions. The stable and promising mutant lines could be released and developed a new variety to improve the yield of rice highland adapted.

1. Introduction
Increasing staple food needed especially rice, is a problem that has yet to be overcome. The success of rice cultivation is determined by the type of cultivar used and the planting area. Both of these factors play an important role in efforts to increase productivity. Based on rice productivity data, in 2007 productivity reached 4.71 tons ha⁻¹, in 2008 to 2010 increased to 4.89 tons ha⁻¹, 4.99 tons ha⁻¹ and 5.02 tons ha⁻¹, but in 2011 has decreased with the productivity of 4.94 tons ha⁻¹ [2].

Environmental conditions in Indonesia, especially air temperatures have differences based on altitude. The minimum temperature ranges from 12.8°C - 16.6°C at an altitude of 1000 m ASL, while at an altitude of 900 m ASL the minimum temperature ranges between 14.4°C - 21.0°C [4]. A decrease in temperature of 0.6 °C per 100 m height increase [13]. Rice plants have critical temperatures ranging from 10 °C - 20 °C, especially at the time of the anthesis and in the microsporogenesis phase [3]. Besides being influenced by temperature, highland rice grows as rain-dependent agriculture, requires rainfall of more than 750 mm over a 3-4 month period and does not tolerate drought. In Southeast Asia the average water requirement for rice irrigation is 1200 mm per crop or 200 mm of rainfall per month [5].
The effect of low-temperature stress on rice plants has differed within regions. As in Korea, low-temperature stresses affect the seedling and ripening phases, in Nepal and India low temperatures affect the number of tillers and flowering phases. In tropical countries where planting is done terracing, the temperature difference depends on the altitude. Therefore it is necessary to develop location-specific highland rice varieties due to the variety of damage caused by low-temperature stress in various growth phases which has an impact on yield reduction [8].

In Indonesia, planting some rice varieties at an altitude of 700-1000 m above sea level, has low yields with high sterility caused by low-temperature stress during the pregnant and flowering phases [5]. Different levels of low-temperature stress will affect yields and components of rice grown in various environmental conditions, especially with varying low temperatures [7].

The effect of temperature stress on several altitudes in the highlands can significantly differ in the production rate for each line. This is an essential factor to be studied more deeply in the framework of producing highland rice varieties at all levels of specific altitude and altitude to obtain optimal results through sub-optimal land use.

Stability is the ability of plants to maintain their yield on changes in environmental conditions. Yield stability is a character inherited through the competitiveness of genetically heterogeneous populations [19]. GxE interactions are complex because of the varied components of environmental factors [9].

The interaction of genotype x environment (G x E) indicates the failure of genotypes tested showed relatively similar performance from one environment to another [16]. Information about GxE is very useful in determining whether it is possible to develop a cultivar in all desired environments or the need to develop specific cultivars for a specific target environment [6].

The AMMI (Additive Main Effects and Multiplicative Interaction) model combines the analysis of various additives for the main effect of the treatment with the analysis of the double main component with the binary modeling for the effect of the interaction. The AMMI model can be used to analyze multiple location experiments. The assumptions underlying this test are additive treatment and environment, homogeneous variety and error-free [11]. Akter et al. (2014) used the AMMI model by stating a stable genotype based on a combination of analysis of variance and principal component analysis. Stable genotypes can be described by biplot models [20].

The main objective of this study was to study the stability of highland rice lines and obtain information about the adaptability of the highland rice genotypes at three altitude levels.

2. Methodology
The first planting season was carried out in two locations namely Banjaran District, Bandung Regency, West Java with an altitude of 700 m above sea level, and in Bayongbong District, Garut Regency, West Java with a height 1200 m above sea level (ASL). The second planting season was carried out in rainy season in three locations namely Banjaran District (700 m ASL), Ciburuy District (900 m ASL) and Bayongbong District (1200 m ASL).

The genetic materials used consist of twenty-five genotypes there were fifteen highland rice mutants namely C4-30-21, C8-10-25, RB-30-82, RB-10-95, RB-10-98, KN-10-111, KN-20-124, KN-20-127, PK-30-131, PK-20-133, C3-10-171, KN-30-186, OS-30-199, KK-10-249, CM- 20-251, five lines of crossing results, namely IPB117-F-20, IPB117-F-80-2, IPB117-F-7-7, IPB117-F-15-4 and IPB97-F-13 as well as three local rice and one national variety as a comparison namely Padi Kuning, Kuriek Kusuik, Randah Batu Hampa and Sarinah.

The experiment was conducted using a Complete Randomized Block Design with 3 replications while genotype as treatment. The experimental unit was a plot measuring 2 m x 5 m. Planting was with a spacing of 25 cm x 25 cm when the seedlings old 21 days old. Seedlings are planted as one seed per hole. Plant maintenance was carried out in accordance with the conditions and needs of planting in the field. Harvesting the plants was conducted after ripe physiologically.

Data analysis conducted included analysis of variance for each location, followed by a combined analysis of variance after the homogeneity of variance tests. Dunnet test was performed at $\alpha$ 0.05 level.
Estimation of stability parameters was done using AMMI (Additive Main Effect Multiplicative Interaction) analysis.

3. Result and Discussion
Grain yield was mainly influenced by environmental conditions. The frequency distribution of grain yield for all genotypes tested was normally distributed at an altitude of 700 m ASL on the rainy season (RS), and at an altitude of 1200 m ASL on the dry season and rainy season (Figure 1). The distribution with the highest frequency at an altitude of 700 m above sea level in the dry season (DS) can be interpreted that the product reaches an optimal value in the dry season. A decrease in grain yield at an altitude of 700 m above sea level during the rainy season.

An increase in grain yield in rainy season at an altitude of 1200 m above sea level with increasing temperature, but with distribution were almost the same as dry season due to genotype diversity that could affect the production of grain yield. The distribution frequency of grain yield with the highest average value in the rainy season is at an altitude of 900 m above sea level followed by an altitude of 700 m above sea level and 1200 m above sea level.

![Figure 1. Frequency of distribution highland rice genotype production in five environments.](attachment:image.png)
Limbongan (2008) reported that the existence of G x E interactions was characterized by the responses of a different cultivar in each environment. In the interaction of G x E, the relative order of a variety will change from a certain location and season. A genotype will be able to grow and produce equally well in various locations or growth environments if there is no G x E, therefore the lines can be stable. Stable varieties are needed to reduce risks due to unpredictable environmental changes such as soil fertility, striking weather changes and pest and disease attacks.

The effect of rice genotypes on grain yield in the five test environments varied greatly (Figure 2). The IPB117-80-2 has the lowest range of grain yield. The C3-10-171 mutant line has a high diversity of grain yield with the moderate average value. Padi Kuning and OS-30-199 mutant lines have stable production values in five environments and have the highest production in certain environments. The

![Figure 2](https://example.com/figure2.png)

**Figure 2.** Results of grain yield of rice genotypes in five test environments.

The AMMI model is able to explain stability by combining the analysis of various additives for the main effect of treatment with the analysis of multiple main components with binary modeling for interaction effects [12]. The AMMI model can predict the magnitude of the influence of the genotype components, location and interactions of G x E, so that the stability and adaptability of a genotype can be seen through the AMMI biplot [17].

Analysis of the AMMI variance of 20 genotypes in five test environments showed that all major influences (genotype and environment) had a significant effect, as the effects of their interactions. This shows the existence of different responses from a genotype in different environments (Table 1). Contributions to the diversity of each component consisting of the environment (49.23%), genotype (10.61%) and GxE interactions (23.91%) have a real chance value of 0.00; 0.002 and 0.02. This shows that the environment has the largest diversity contribution, followed by the interaction of G x E and genotype.
The contribution of the diversity of G x E interaction effects that can be explained by each component was 43.65%; 28.71%; 19.46%; and 8.19%. AMMI analysis results showed that there were two real components with an F value of 3.88 and 2.80. These showed that the grain yield data of rice genotypes in this study could be explained using the AMMI model. The AMMI model was able to explain the diversity of interaction effects by 72.36%.

Table 1. Variation analysis of AMMI in rice genotypes in five environments.

| Source of variation | DF | SS     | MS     | F value | P value | Contribution to variation (%) | Contribution to GxE (%) |
|---------------------|----|--------|--------|---------|---------|------------------------------|------------------------|
| Environment         | 4  | 310,14 | 77,53  | 78,35*  | 0,000   | 49,23                        |                        |
| replication/        | 10 | 9,89   | 0,99   | 1,28    | 0,317   | 1,57                         |                        |
| environment         |     |        |        |         |         |                              |                        |
| Genotype            | 19 | 66,84  | 3,52   | 4,56*   | 0,002   | 10,61                        |                        |
| Genotype/           | 76 | 150,63 | 1,98   | 2,57*   | 0,019   | 23,91                        |                        |
| environment         |     |        |        |         |         |                              |                        |
| IAKU1               | 22 | 65,75  | 2,99   | 3,88*   | 0,004   | 43,65                        |                        |
| IAKU2               | 20 | 43,24  | 2,16   | 2,80*   | 0,020   | 28,71                        |                        |
| IAKU3               | 18 | 29,32  | 1,63   | 2,11    | 0,069   | 19,46                        |                        |
| IAKU4               | 16 | 12,33  | 0,77   |         |         | 8,19                         |                        |
| Error               | 190| 92,41  | 0,49   |         |         | 14,67                        |                        |
| Total               | 299| 629,92 |        |         |         | 100                          | 100                    |

Note: SS = Sum of Squares, MS = Middle Squared, df = degree of freedom, Value of P = Opportunity, *) significant effect at 5% level, IAKU = Interaction Analysis of Main Components.

Analysis of variance components that affect the interaction of GxE and the environment has also been reported by Rasyad et al. 2012, on several local rice cultivars to see the stability of yields in different environments. Genotype was classified to be stable if it is near the coordinate axis or zero points (0,0). Genotypes were far from the axis but close to the location line were classified as location-specific genotypes because they are able to adapt to that location. KN-10-111, KN-20-124 and RB-10-98 lines were stable lines because they were able to maintain results in five test environments (Figure 3). KK-10-249 was adaptive lines at an altitude of 900 m above sea level. The C4-30-21, RB-10-95 and KN-20-127 specific lines at an altitude of 700 m above sea level in DS, while in the rainy season the RB-30-82, IPB117-F-20 and C3-10-171 lines had more adaptability. The PK-20-133 line can adapt well at an altitude of 1200 m ASL on RS. While the OS-30-199 and Sarinah lines were stable in the lowest temperature environment at an altitude of 1200 m above sea level in the DS.
According to Poli et al. (2018), that genotype and environment interactions can be used to measure the stability of a genotype, because the stability of appearance in a range of environments depends on the magnitude of the interaction. Yield test stability indicated that the interactions between the lines and the environment often occur. This difference can result in changes in the yield between one place and another. Since the differences in yield were strongly influenced by genetic and environmental differences, it is necessary to choose superior lines with stable results [18]. GxE interactions were very useful in determining whether it is possible to develop a cultivar in all desired environments or the need to develop specific cultivars for a specific target environment [4]. The importance of GxE interactions instability analysis had been reported in cereal plants [21].

4. Conclusion
The diversity of interaction effects can be explained using the AMMI2 model of 72.36% and illustrates that the KN-10-111, KN-20-124 and RB-10-98 mutant lines were stable lines. KK-10-249 line is adaptive at an altitude of 900 m above sea level. C4-30-21, RB-10-95 and KN-20-127 mutant lines were specific to the altitude of 700 m above sea level in DS, whereas in the rainy season RB-30-82, IPB-117-F-20 and C3-10-171 had better adaptability. The PK-20-133 mutant line was stable at an altitude of
1200 above sea level in RS while the OS-30-199 mutant line and the Sarinah were stable in the environment with the lowest temperature at DS.

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