Grain yield stability analysis of Jembar local rice mutant lines generated from mutation breeding

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Abstract. In breeding program to successfully develop cultivars that are well-adapted to growing regions, it is fundamental that candidate promising lines are tested in across different environments and that the data are analysed for grain yield stability. The objective of this study was to determine the stability parameters of grain yield of rice mutant lines across sixteen different environments and to select lines having wide and/or specific adaptation to environment. The research was conducted from January 2013 until January 2014 at the lowland rice experimental station under diverse environments at sixteen locations. The experiment used randomized complete block design (RCBD) with three replications. The 21-day-old seedlings were planted with spacing of 25 cm x 25 cm with a plot size of 4 m x 5 m. The ten promising rice mutant lines and two rice varieties (Jembar and Ciherang) as parents control were used in this experiment for multi-location yield trials. Yield stability of genotypes was estimated by using regression lines proposed by Finlay and Wilkinson. The result of yield stability analysis indicated that five mutant lines were OBS 1901/Psj, OBS 1904/Psj, OBS 1906/Psj, OBS 1907/Psj, and OBS 1908/Psj having wide adaptability to the environment. All rice mutant lines had highest yield compared than parent and check varieties with mean yield ranged from 7.54 t ha$^{-1}$ to 7.89 t ha$^{-1}$. Finally, regarding both mean yield and most of stability characteristics, genotypes OBS 1901/Psj and OBS 1908/Psj were found to be the most stable genotypes.

1. Introduction

Rice (Oryza sativa L.) is the most important food crops in Indonesia and is grown throughout the country under different agro-ecosystems from lowland to upland and irrigated to rain fed situations. Rice plays an important role in providing food and nutritional security and eradicating poverty. The average of total rice growing area is 14 million hectares with 73 million tons of rice production [1]. For sustainable production and face increasing population, rice production must increase at rates unseen to feed the fast growing population in Indonesia. Development and adoption of improved rice varieties has significantly contributed to the increase of rice production in Indonesia. Therefore, broadening the genetic base of rice is an essential requirement for a rice improvement program, considering conventional techniques have not been able to resolve these problems due to its narrow genetic base. The shortest possible method is induced mutation technique [2].

In plant breeding mutation induction has become an effective way of supplementing existing germplasm and development of new varieties by generating and utilizing genetic variability through chemical and physical mutagenesis [3]. The most important thing in mutation breeding is the process of identifying individuals with a target mutation, specifically in mutant screening and mutant confirmation [4]. Currently, the increase in the genetic diversity of rice varieties by way of ionizing...
radiation has become a great choice by plant breeders. Among physics mutagens, gamma rays have drawn the attention as a rapid method to improve the qualitative and quantitative characters for many crops. Induce mutations for factors that govern the heredity of quantitative characters a promising tool for creating new genotypes. Mutagen causing mutation in major genes and at loci governing quantitative characters. These micro-mutations can be detected in the form of increasing variance of \( \text{M}_2 \) generation [5]. Irradiating seeds with a suitable dose of gamma rays produces physiological and/or genetical changes in plant tissue that may be affected the yield of plant [6].

From a number of studies that have been conducted show mutation techniques are very useful in improving rice plants, especially for characters controlled by closely linked genes that are difficult to break by gene recombination [5]. Induced mutation has been used in rice more than any other crop as confirmed by for over 815 rice mutant varieties listed in the FAO/IAEA Mutant Varieties Database [7].

Rice breeding using induced mutations in Indonesia was initiated in 1966 and the first mutant rice variety Atomita 1 developed through gamma irradiation was released in 1982. Since then, there are a total of 22 mutant rice varieties which have been officially released [8]. In Indonesia, the use of mutation induction techniques has been focusing on new variety development through improving characters of direct importance for a new mutant variety. Yield and adaptability trials in the fields constitute an integral part of varietal evaluation before any new breeding lines are released as varieties to farmers including mutant lines developed from mutation breeding programs. Unless they possess all the important morpho-agronomic and quality traits. Mutant lines would not be released for commercial planting [9].

It is obligatory to examine the yield stability of rice mutant lines and to obtain mutant lines having high yield stability across different environmental conditions. Genotype and environment (G x E) interactions greatly affect the phenotype of a variety, so the stability analysis is required to characterize the performance of varieties in different environments, to help plant breeders in selecting varieties. Instability is the result of cultivars response in different environments, which usually indicates a high interaction between genetic and environmental factors [10, 11].

The analytical method that is often used in determining grain stability is the Finlay-Wilkinson method through the bi value approach [12]. For determining stability and adaptability of genotypes in this method, parameters like mean genotype yield, regression coefficient \((b_i)\) and variance of deviation from regression \((S^2 d_i)\) are used. Relationship between the yield at each location and the location index was expressed to a straight line (regression line) for each genotype and for mean yield of all genotypes. Then the regression lines for the yield of each genotype were compared with that for the mean yield of all genotypes over all locations to estimate the yield stability of each genotype.

This research was conducted to determine the stability parameters of grain yield of rice mutant lines across different environments and to study the relationship between yield-related traits.

2. Materials and Methods
2.1. Genetic materials
The dry seed (contains 14 percent moisture) of Jembar traditional rice variety was exposed to mutagenic treatments with irradiated to 0.20 kGy doses of gamma rays (\(^{60}\)Co source). Based on mutant selection with desirable yield and yield component traits at \( \text{M}_2 \) – \( \text{M}_3 \) generation and yield potential trials up to \( \text{M}_8 \) generation has acquired ten of promising mutant lines. The ten promising rice mutant lines and two rice varieties (Jembar and Ciherang) as parents control were used in this experiment for multi-location yield trials.

2.2. Field experiment
Multi-location yield trials of 12 rice genotypes were conducted at sixteen different locations over two years during rainy and dry season (2013-2014). The design used was randomized complete block design (RCBD) with three replications. A seeding of 21-day-old was planted per hole with spacing 25 cm x 25 cm. with a plot size of 4 m x 5 m so that there were 320 plants per plot. Fertilizer rate was 250
kg ha\(^{-1}\) N. 100 kg ha\(^{-1}\) P\(_2\)O\(_5\). 100 kg ha\(^{-1}\) K\(_2\)O. At flowering and maturity stages. Observations were recorded on six characters for plant height (cm) days to 50% flowering, the number of productive tillers per hill, the number of filled grains per panicles. 1000-grain weight (g) were collected from 10 randomly chosen plant from each plot. Grain yield (kg plot\(^{-1}\) ) was measured from each plot.

2.3. Data analysis

Data were analysed combined with variance. Differences among treatment means were compared using the Duncan’s Multiple Range Test (DMRT) at the 0.05 level of probability. Regression linear analysis was calculated using Equation 1 as suggested by Finlay and Wilkinson [12].

\[
Y_{ij} = \mu + g_i I_j + \sigma_{ij}
\]

Where:
\(Y_{ij}\) : Yield mean of a genotype i at the j location
\(\mu\) : Population mean
\(g_i\) : Regression coefficient of the i genotype
\(I_j\) : Environmental index of the j location
\(\sigma_{ij}\) : Regression deviation of the i genotype at the j location

Finlay and Wilkinson used the regression coefficient parameter \((b_i)\) between the average of a genotype with the general average of all genotypes tested and all test environments. Genotypes with \(b_i\) values > 1, \(b_i = 1\), and \(b_i < 1\) have stability below average, average on average, and above average respectively.

3. Results and discussion

The combined analysis of variance was conducted to determine the effect of genotype by environment interaction (G x E). An environmental factor in this experiment is a combination of location and year or the planting season. Results of the combined analysis of variance showed highly significant interaction effect of both mutant lines, environment, and the interaction between mutant line and environment (G x E) (Table 1). Significant G x E interaction shows that the relative performances of the genotypes were significantly affected by the varying environmental conditions. There were differences between yield and appearance of the mutant lines in each environment. Means of mutant lines varied considerably at different environment. The similar result also reported by Lestari et al. [10] and Asad et al. [13] in rice genotypes at different sites in Indonesia and Fehr [14] mentioned that yield and yield components of a crop are influenced by genotype (G), environment (E), and their interaction (G x E). Every factor of the environment has a potential to cause differential associated with G x E interaction.

Table 1. Combined variance analysis for grain yield from 12 rice genotypes in 16 test locations.

| Source of variation         | Degree of freedom (df) | Sum square | Mean square (MS) | F-value |
|-----------------------------|------------------------|------------|------------------|---------|
| Environment (E)             | 15                     | 695.39     | 46.36            | 130.12 **|
| Replication/environment     | 32                     | 67.38      | 2.10             | 5.91 ** |
| Genotype (G)                | 11                     | 185.27     | 16.84            | 47.27 **|
| G x E                       | 165                    | 185.99     | 16.84            | 3.16 ** |
| Error                       | 353                    | 125.41     | 1.13             |         |

** Significant at 1% level.

3.1. Grain yield and yield components

Table 2 shows the plant height, days to 50% flowering, the number of panicles plant\(^{-1}\), the number of filled grains and 1.000-grain weight respectively of each genotypes at each environment. The mean
values varied among genotypes in plant height. All the mutant lines had lower plant height compared to the parent variety. Mutant lines mean plant height ranged from 110.65 cm to 115 cm.

The day to 50% flowering was significantly different among genotypes. OBS 1906/PsJ mutant line had the shortest days to 50% flowering (79.31 day). On the other hand, OBS 1903/PsJ mutant line had the longest days to 50% flowering (88.66 day). Plant age observed in this study was on days to 50% flowering. This is done to avoid the appearance of plant age data less accurate when using the data harvesting, considering the time of harvest is often done when the rice grains on a panicle has exceeded physiologically mature age. When using days to 50% flowering data, the estimated age of the harvest is 30 days after flowering 50% in the dry season, or 35 days after flowering 50%. The plant height of OBS 1901/PsJ had lower plant height compared with other mutant lines during the rainy season. However, all mutant lines have a longer flowering dates compared to its parent variety. Differences in flowering date for up to 5 days, basically no difference by age class, because flowering unanimity on all plants individual generally occur within a period of one week.

Table 2. The mean of yields component from rice genotypes were evaluated in 16 environments.

| No | Genotypes     | Plant height (cm) | days to 50% flowering (day) | panicles plant⁻¹ | Filled grains (g 1000) | Grain weight (g 1000) |
|----|---------------|------------------|-----------------------------|------------------|------------------------|-----------------------|
| 1. | OBS 1901/PsJ  | 110.65           | 82.69                       | 16.14            | 146.59                 | 29.44                 |
| 2. | OBS 1902/PsJ  | 115.00           | 87.08                       | 15.12            | 138.83                 | 28.18                 |
| 3. | OBS 1903/PsJ  | 112.78           | 88.66                       | 15.65            | 146.30                 | 29.28                 |
| 4. | OBS 1904/PsJ  | 112.74           | 87.75                       | 15.78            | 145.69                 | 28.91                 |
| 5. | OBS 1905/PsJ  | 110.99           | 83.47                       | 15.16            | 141.39                 | 28.68                 |
| 6. | OBS 1906/PsJ  | 112.43           | 79.31                       | 15.50            | 146.43                 | 29.02                 |
| 7. | OBS 1907/PsJ  | 112.75           | 86.41                       | 14.79            | 145.74                 | 29.48                 |
| 8. | OBS 1908/PsJ  | 112.28           | 81.52                       | 14.83            | 145.87                 | 28.95                 |
| 9. | OBS 1909/PsJ  | 111.77           | 83.45                       | 15.31            | 137.35                 | 28.70                 |
| 10.| OBS 1910/PsJ  | 111.93           | 81.79                       | 14.87            | 147.29                 | 28.69                 |
| 11.| Jembar        | 134.34           | 79.75                       | 15.72            | 133.96                 | 25.69                 |
| 12.| Ciherang      | 103.85           | 79.54                       | 14.76            | 140.23                 | 27.66                 |

The number of panicles plant⁻¹ was different among genotype. The lowest number of panicles plant⁻¹ was observed in OBS 1907/PsJ mutant line reached 14 panicles and the highest was observed in OBS 1901/PsJ mutant line reached 16 panicles.

The number of filled grains was different among genotype. Genotypes mean number of filled grain ranged from 137-147 grains per panicle. The highest number of filled grain was observed in OBS 1910/PSJ mutant line reached 147.29 grains and followed by OBS 1901/PSJ mutant line reached 146.59 grains and OBS 1906/PSJ mutant line reached 146.43 grains respectively. Jembar as parent variety reached 133.96 grains and Ciherang only reached 140.23 grains.

Grain weight (1.000-grain weight) of a genotype serves as an indicator to the end product like grain yield. The result showed that all mutant lines had the highest grain weight compare to Jembar and Ciherang as check varieties. Mutant lines mean grain weight ranged from 8.18 grams to 29.48 grams. The highest grain weight was observed in OBS 1907 / PSJ mutant line reached 29.48 grams and OBS 1901/PSJ mutant line reached 29.44 grams respectively.

Grain yield of the mutant lines varied when planted in different environmental conditions. All rice mutant lines give mean yield results across all locations is higher than Ciherang as the check variety and Jembar as the parent variety. All rice mutant lines showed the average production of over 7 t ha⁻¹, with mean yield ranged from 7.54 t ha⁻¹ to 7.89 t ha⁻¹, while the mean yield of Jembar variety only 5.75 t ha⁻¹ and 7.28 t ha⁻¹ for Ciherang variety. The highest mean yield across all environment was observed
in OBS 1908/PsJ mutant line reached 7.89 t ha\(^{-1}\) and the lowest was observed in OBS 1910/PsJ mutant line reached 7.54 t ha\(^{-1}\).

Variations in the character of yield and yield components of mutant lines can be caused by changes in the genotype due to radiation treatment and also the interaction of genotype and environment. Greater role of GE interaction may suggest that the genotypes performed differently under diverse environments and their performance was unpredictable across environments as stated by Ceccarelli et al [15].

3.2. Yield stability

Stability analysis is an important and efficient tool for the plant breeders to evaluate and select the most stable high performing genotypes that are best suitable under a given set of environmental conditions before a new improved genotype is released for production to farmers. Assessment of lines stability and adaptability were tested following the test method of Finlay-Wilkinson [12], based on regression coefficient (\(b_i\)) and the general mean.

Regression coefficient (\(b_i\)) of three mutant lines was significantly different from one, they were OBS 1902/Psj, OBS 1903/Psj, and OBS 1909/Psj, was only adapted to optimum environmental conditions (Table 3). Those lines were sensitive to environmental changes and adapted only to specific environments which is favourable to the genotype. While, parent variety (Jembar) and check variety (Ciherang) were classified as kind of genotype is less sensitive to environmental changes and adaptable to marginal environments.

| No. | Genotype       | Mean yield \((t \text{ ha}^{-1})\) | \(b_i\)     | \(Sdi\) | Explanation |
|-----|----------------|----------------------------------|------------|--------|-------------|
| 1.  | OBS 1901/Psj   | 7.82                             | 1.00 ns    | 0.09   | Stable      |
| 2.  | OBS 1902/Psj   | 7.83                             | 1.18 *     | (0.06) | Unstable    |
| 3.  | OBS 1903/Psj   | 7.85                             | 1.22 *     | 0.01   | Unstable    |
| 4.  | OBS 1904/Psj   | 7.86                             | 1.11 ns    | (0.02) | Stable      |
| 5.  | OBS 1905/Psj   | 7.56                             | 1.13 ns    | (0.04) | Stable      |
| 6.  | OBS 1906/Psj   | 7.77                             | 1.09 ns    | (0.09) | Stable      |
| 7.  | OBS 1907/Psj   | 7.61                             | 1.09 ns    | (0.04) | Stable      |
| 8.  | OBS 1908/Psj   | 7.89                             | 1.07 ns    | 0.04   | Stable      |
| 9.  | OBS 1909/Psj   | 7.87                             | 1.22 *     | 0.07   | Unstable    |
| 10. | OBS 1910/Psj   | 7.54                             | 0.98 ns    | (0.05) | Stable      |
| 11. | Jembar         | 5.75                             | 0.24 *     | 1.23   | Unstable    |
| 12. | Ciherang       | 7.42                             | 0.67 *     | 0.08   | Unstable    |
|     | Average        | 7.56                             |            |        |             |

Note: ns = not significantly different from bi = 1; * = significantly different from bi = 1

In this study, based on the value of \(b_i\) and yield averages of 10 mutant lines, there were five lines having wide adaptability to the environment because they had a \(b_i\) values equal to one and the average yield is higher than the average yield of all genotypes in all environments. Those mutant lines were OBS 1901/Psj, OBS 1904/Psj, OBS 1906/Psj, OBS 1907/Psj, and OBS 1908/Psj, with the change of environment those mutant lines had only a few changes in yield. It could be seen from the average value of mutant lines yield, which have a high yield (>7.56 ton ha\(^{-1}\)) in all environments. These mutant lines were stable and have wide stability. Our study showed that 2 mutant lines namely OBS 1905/Psj and OBS 1910/Psj, which had a value close to \(b_i\) or not significantly different from one (\(b_i = 1\)) but the average yield was below the general average. Those lines were classified as poorly adapted in all environments and sensitive to environmental changes so it should be used only in specific locations. Based on agronomic performance for high yielding, high yield components, and high yield stability,
two mutant lines OBS 1901/Psj and OBS 1908/Psj (Figure 1) are considered as prospective lowland rice mutant lines having high yielding ability, high yield stability and wide adaptability.

![Figure 1. The architectural appearance of parent variety (A) and the OBS 1908/Psj mutant lines (B).](image)

4. Conclusion
From the present study it is concluded that yield stability across different environments varied among genotypes. Some mutant lines had high yield stability and wide adaptability to all environments and others had high adaptability to specific location. All rice mutant lines had highest yield compare than parent and check varieties, with mean yield ranged from 7.54 t ha$^{-1}$ to 7.89 t ha$^{-1}$. Two mutant lines namely OBS 1901/Psj and OBS 1908/Psj were found to be the highest yield stable genotypes and are thus recommended for commercial release.

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