Comparative study on the stability and adaptability of different methods to developed a high yield Inbred Lines from landraces rice varieties

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Determination of stability through different methods to developed high yield Inbred Lines from landraces rice varieties

Reny Herawati[1*], Angelita Puji Lestari[2], Atra Romeida[1], Bilman Wilman Simanihuruk[1], and Helfi Eka Saputra[1]

[1]Department of Crop Production, Faculty of Agriculture, University of Bengkulu. Jl. WR. Supratman, Kandang Limun, Bengkulu Province, Indonesia, 38122

[2]Indonesian Center for Rice Research (ICRR), Jl. Raya Ciapus No. 25A Bogor, West Java, Indonesia, 16610

Corespondence Author, email: reny.herawati@unib.ac.id
ORCID:0000-0003-1093-6681

Abstract: *Fourteen genotype from inbred line Bengkulu landraces rice varieties were evaluated in five environments from January 2019 to November 2020. The experiment was conducted using a complete randomized block design with two replications. The estimation of yield stability was based on the parametric and non-parametric stability tests, and GGE biplot. There was a strong and positive correlation (r = 1.00) between the mean yield (Yi) with YSi, s2di with Di, and Wi2 with StabVar. Meanwhile, the TOP has a positive correlation of 0.78, indicating a suitable stability parameter to identify high yield lines. There were consistently stable lines based on parametric and non-parametric stability analyzes, namely G10(BKL2-B3-264-6), G7(BKL1-B3-261-3), G13(BKL4-B1-268-10), and G5(BKL1-B1-259-1), while the GGE approach methods showed consistent stability, namely the lines G13(BKL4-B1-268-10), G10(BKL2-B3-264-6), G5(BKL1-B1-259-1), G7(BKL1-B3-261-3), and G6(BKL1-B2-260-2) have high yield potential, wide adaptation and stability, and are recommended to be tested more widely as candidates for new varieties.*

Keywords: inbred line rice; landraces; parametric stability; non-parametric stability; GGE biplot

INTRODUCTION

Rice cultivation in Indonesia is an important part of the national economy. It is spread out at an altitude of relatively 0 to 1,450 m above sea level (asl), therefore the availability of suitable varieties in this diverse location-specific agroecosystem is indispensable. Bengkulu Province is in the southern part of the island of Sumatra, Indonesia, where the cultivation of local rice varieties still quite extensive with various types and it contributes significantly to rice production. Local varieties (landraces) have the advantage that they are more resistant to local pests, but generally have a long maturity, taller, and poor grain yield. However, efforts to enhance production are realized through plant breeding programs. The breeding program has been carried out since 2010 by crossing landrace varieties namely Sriwijaya and Bugis with drought tolerant lines (IR148 and IR7858-1) to obtained new type rice lines tolerance to drought and blast disease (Herawati et al. 2017, Herawati et al. 2021).

The success of these studi depends on two factors, the accuracy of the estimated results related to the experiment and the environmental effects at the location in respect to the forecasting capability of the new area (Fasahat et al. 2014). The recommendations for the development of new high yielding varieties requires reliable and accurate predictions of yield (Alam et al. 2015, Ikmal et al. 2020). Multilocation experiments are relevant to obtain genotypes that specifically adapt to a certain location or tend to be stable under various environmental conditions (Gauch 2006, Ponnuswamy et al. 2018).

Multilocation trials are important in plant breeding and other studies carried out in the agronomy field. The combination of agronomy and plant breeding is needed to improve plant characteristics and stability tests before releasing new varieties. This information can be obtained from several experiments. A single stability analysis method may not be sufficiently representative to determine the stability performance of genotypes across environments. Because it will give different results, which sometimes lead to wrong decisions about genotype stability. Breeders usually using several methods to determine genotype adaptation and stability, and the interpretation of genotype stability for variety release recommendations. The use of several stability methods helps them make the right decision about the stability of a genotype by comparing the statistical relationships between them (Shukla et al. 2015; Goksoy et al. 2019).

Parametric and non-parametric approaches are used to analyze the stability of genotypes. Several previous studies investigated the adaptability and stability of a plant genotype (Abdipour et al. 2017, Goksoy et al. 2019). The use of a non-parametric approach is based on the phenotype rank in each test environment with a stable genotype. The concept of non-parametric stability, relating to the use of a phenotype rank in each environment, refers to a homeostatic G x E interaction theory. This involves the stability of a genotype in all environments (Huehn 1990). Nassar and Huhn (1987) stated that non-parametric analyses are unbiased and need not consider the type of data distribution. Furthermore, Yue et al. (1997) stated that the non-parametric stability analysis serves as an alternative to the parametric approach, although it is unable to explain the adaptability of the lines. However, based on the reasons, the non-parametric method is usually utilized as reported by Huehn (1990), it is the appropriate approach used to estimate the G x E interaction.

Analyze mega-environments used GGE biplot to study the stability of a genotype (Akter et al. 2015, Balakrishnan et al. 2016, Shahriari et al. 2018). It is an interactive analysis technique consisting of the main effect of the genotype (G) and the GxE interaction (Yan and Kang 2003). GGE is constructed using 2 main components, namely PC1 and PC2, which are derived from single value decomposition (SVD) with data obtained through multi-location experiments. Biplots are multi-dimensional, however the 2 dimensions of PC1 and PC2 are the most common.

This study aims to obtain information on yield potential, adaptability, and stability of superior lines resulted from inbred landraces with superior varieties, so that these lines are recommended to be widely adapted to the environment of rainfed lowland, irrigated rice, and dry land.

MATERIALS AND METHODS

The experiment was conducted from January 2019 to November 2020, in five environments in Bengkulu Province, namely Aur Gading (North Bengkulu), Talang Benih (Rejang Lebong), Sawah Dendam (Bengkulu City), Sungai Serut (Bengkulu City), and Desa Semarang (Bengkulu City). Environmental characteristics are presented in Table 1. The genotypes used were 14 superior inbred lines from Bengkulu local rice varieties (Sriwijaya and Bugis) with superior drought tolerant lines (IR7858-1 and IR148), and two check namely Inpago 12 and Rindang 2 (Table 2).

The study was carried out using a completely randomized block design with two replications. The experimental plot was 5 mx 5 m in size. The first fertilization was 20 kg of manure by spreading it and mixing it with the soil. Planting is carried out a week after applying manure with a spacing of 20 cm x 20 cm. A week after planting, each plot was fertilized with 400 g of urea, 200 g SP-36, and 200 g KCl.

The variables observed were plant height, number of productive tillers, panicle length, number of filled grains/panicles, percentage of empty grain, 1000 grain weight, grain weight per hill, and grain weight per plot. Harvesting was carried out using physiological ripening criteria marked by 80% yellowish panicles in one plot. Furthermore, the grain was dried until they reached a moisture content of ± 14%. The grain yield per hectare is derived from the conversion of grain weight per plot.

The yield component variables were analyzed using combined variance analysis and the least significant difference test (LSD) at a 5% level according to Steel and Torrie (1980). The estimation of yield adaptability and stability is based on the coefficient of variance (CVi) (Francis and Kannenberg 1978), regression (Finlay and Wilkinson 1963, Eberhart and Russell 1966), Wricke'secovalence (Wi2), Hanson genotypic stability (Di), and Shukla's stability variance (σ2) tests. Non-parametric stability parameters include Kang's yield and stability index (YSi) (Kang 1988) as well as several others proposed by Nassar and Huehn (1987), Fox et al. (1990), as well as the correlation between their parameters. The stability analyzes were based on the main components of GGE biplot. All data were analyzed using PBSTAT-GE software (www.pbstat.com).

RESULTS AND DISCUSSION

Agronomic performance of inbred Lines

One of the methods used to obtain superior varieties is testing several potential lines in various environments. Therefore, the mechanisms and physiological adaptations of each line need to be tested under various environmental conditions. The results of the combined variance analysis showed that interactions between the environment, and genotype had a significant effect. The differences in environmental conditions of the genotypes tested led to dissimilarities in grain yield.

The yield response is a combination of yield components, namely plant height, panicle length, number of productive tillers, number of filled grains, 1000 grain weight, and grain weight per hill (Table 2). The genotype agronomic characters' appearance showed that the plant heights ranged from

99.65 to 130.66 cm. Some were insignificantly different from the check varieties, namely G12(BKL3-B3-267-9), G13(BKL4-B1-268-10), and G1(BKL3-RS1-1-253-18). The panicle length is relatively 24.85 to 27.04 cm, which is insignificantly different from Rindang 2 variety. Furthermore, the number of productive tillers ranges within 9.68 to 15.22, significantly different from Rindang except for G1(BKL3-RS1-1-253-18), while G7(BKL1-B3-261-3) surpassed Inpago 12 check varieties. The number of filled grains per panicle and percentage of empty grains ranges from 112.99 to 151.57, and 14.65-25.75 respectively. The weight of 1000 grains was quite low, relatively between 26.45 and 28.52. On the contrary, the weight of filled grain per hill ranges from 22.46 g (G1(BKL3-RS1-1-253-18)) to 42.82 g (G11(BKL3-B1-265-7)), as shown in Table 2.

All genotypes tested in Aur Gading had a mean yield of 4.52 tonnes/ha, while G9(BKL2-B2-263-5), had the highest value of 6.41 tonnes/ha, as shown in Table 3. However, this was the least compared to other environments. It is because the irrigation system relies only on the rainfed, and farmers usually cultivate this grain once a year. However, these results are encouraging because some of the genotypes tested in this environment were above the average yield of the Rindang 2 check variety. Therefore, this line can be considered as a potential line for cultivation as upland rice or in rainfed systems. This differs from the Sungai Serut and Talang Benih environment, which are supported by a technical irrigation system with a mean grain yield of 12.65 tonnes/ha and 9.82 tonnes/ha. The highest yield grouping comprised G13(BKL4-B1-268-10), G10(BKL2-B3-264-6), G7(BKL1-B3-261-3), and G5(BKL1-B1-259-1), was found in the Sungai Serut.

Some of the lines tested had a yield potential of over 5 tonnes/ha, and some genotypes even exceeded the check varieties, namely Inpago 12 and Rindang 2. Furthermore, G10(BKL2-B3-264-6), G13(BKL4-B1-268-10), G5(BKL1-B1-259-1), and G7(BKL1-B3-261-3) have a potential yield of > 10 tonnes/ha, thereby exceeding the check varieties of 7 tonnes/ha and 5 tonnes/ha, as shown in Table 3. Furthermore, the representative agronomic characters is an ideal line that needs to be developed into new superior varieties, with moderate plant height (IRRI 2014). of relatively 100 to 127 cm, total productive tillers > 13, total filled grain > 126 grains, or panicle, and the percentage of empty grain in respect to IRRI (2014), which is less than 19 percent per panicle, as shown in Table 2.

Parametric Stability Analysis

The results of the parametric stability analysis showed that G10(BKL2-B3-264-6), G13(BKL4-B1-268-10), G5(BKL1-B1-259-1), G7(BKL1-B3-261-3), and Inpago 12 had variance coefficient (CVi) values of 34.61%, 35.49%, 37.68%, and 32.64%, and environmental variance (Si2) of 3.13, 5.48, 4.51, 1.74, respectively, as shown in Table 4. These genotypes are stable because the 2 values are relatively close to 0. Based on the variance coefficient and environmental variance values, they are classified as genotypes with static stability (Becker and Leon 1988). Genotypes G10(BKL2-B3-264-6), G13(BKL4-B1-268-10), G5(BKL1-B1-259-1), and G7(BKL1-B3-261-3), have bi values of 1.02, 1.05, 1.06, and 1.42, and grain productivity of 10.47, 11.14, 10.31, 10.2 tonnes/ha relatively above the total mean, respectively, as shown in Table 4. According to Finlay and Wilkinson (1963), a genotype with a regression coefficient (bi) of 1 and a mean yield greater than the total mean is regarded as stable with high adaptability to all the environments.

Wricke (1962) developed the ecovalence method (Wi2), which measures the contribution of each genotype with respect to the total square of the genotype x environment interactions. A genotype is considered stable, assuming it has a low ecovalence value. The analysis showed that the stable genotypes were G10(BKL2-B3-264-6), G2(BKL4-RS1-1-256-21), G7(BKL1-B3-261-3), and Inpago 12 with low ecovalence values of 10.19, 5.93, 9.48, and 9.56, respectively (Table 4).

The stability evaluation method applied by Hanson (1970) was used to investigate the total genotype in few environments with respect to Di parameters. The stable genotypes such as G2(BKL4-RS1-1-256-21), G7(BKL1-B3-261-3), Inpago 12, and Rindang 2 had low Di values of 6.69, 6.65, 6.83, and 6.56, respectively (Table 4).

The stability parameter designed by Shukla (1972) is based on the concept that genotypes with the smallest Stab Var (σ^2) are the most stable compared to the others. G10(BKL2-B3-264-6) (4.97), G2(BKL4-RS1-1-256-21) (2.53), G7(BKL1-B3-261-3) (4.56), Inpago 12 (4.61) (Table 4) were the most stable lines, while G4(BKL4-RS1-3-258-23) and G1(BKL3-RS1-1-253-18) were the most unstable. The results obtained using these both methods (CVi and σ^2) show that G10(BKL2-B3-264-6) and G7(BKL1-B3-261-3) are the most stable lines.

Non-parametric Stability Analysis

The non-parametric stability method is based on the ratio of the genotype rank to each environment. A genotype is stable, assuming it ranks the same in several environments (Kang 1988, Ketata et al. 1989, Nassar and Huehn 1987, Fox et al. 1990, Huehn 1990). The Kang yield and stability index (YSi) combined the genotype yield and Shukla stability variance into one statistical test. Kang and Pham's (1991) stated that rank-sum is another non-parametric stability statistic regarded as yield, and Shukla's (1972) stability variance was used as selection criteria. This analysis realized a score of one for yield and stability, thereby permitting s the identification of stable genotypes. Furthermore, the genotypes with the maximum and minimum yields were both assigned to rank 1. The ranks based on yield and stability variance were attached to each genotype. The genotype with the minimum rank-sum was the most desirable one. Moreover, when a genotype has an YSi> mean, then the YSinya is selected. The genotypes with (+), namely G10(BKL2-B3-264-6), G13(BKL4-B1-268-10), G5(BKL1-B1-259-1), G6(BKL1-B2-260-2), G7(BKL1-B3-261-3), G8(BKL2-B1-262-4), and G9(BKL2-B2-263-5), were selected based on YSi, as shown in Table 5.

The two stability methods designed by Nassar and Huehn (1987) are S1 and S2. Moreover, both methods are based on the ranking of the genotypes in the number of environments. Genotypes with slight changes in rank are more stable (Becker and Leon 1988). The variance of S1 and S2 (Zi (1) as well as Zi (2)) is smaller than the value of table Z (Tables Chi-sq Zi (1), Zi (2)), which implies that the genotype is stable. The Sum of Zi (1) = 16.63 and Zi (2) = 8.73 are smaller than the Chi-sq Sum Zi (1) table. However, when Zi (2) = 26.29, it indicates that the stability ratings of the tested genotypes were insignificantly different. Fox et al. (1990) stated that a non-parametric superiority measure for general adaptability used graded ranks from cultivars. The ranking was carried out at each location. Besides, the number of sites where the genotypes occurred in the upper, middle, and lower third of the rankings was calculated. Furthermore, those that occurred mostly in the upper third are considered widely adapted cultivars. Based on Fox et al. (1990), those discovered in the top three ranked environments tested were identified as properly adapted genotypes. In accordance with the analysis G5(BKL1-B1-259-1), G10(BKL2-B3-264-6), G13(BKL4-B1-268-10), G7(BKL1-B3-261-3), and G9(BKL2-B2-263-5) properly adapted to these environments, unlike the others, as shown in Table 5. Genotypes with small NPi (1), NPi (2), NPi (3), and NPi (4) values are considered to be more stable. Based on these values, G2, G5, , G11, G8(BKL2-B1-262-4) and Inpago 12 are more stable than others, as shown in Table 5.

Parametric and non-parametric methods have their advantages and disadvantages, each method describes a certain way of looking at the GE interaction phenomenon. Each of these approaches complemented each other for interpreting GE interactions, so it was finally decided that a clear picture of the interaction as a genotype was differential sensitive to the environment (Dehghani et al. 2016).. Correlation analysis is very helpful for breeders to interpret the results of both methods.

Correlation of the relationship between stability parameters

The regression coefficient bi was correlated with Yi (0.59), and all stability parameters were tested. YSi negatively correlates with Si (6) (- 0.68), NPi (2) (- 0.72), NPi (3) (- 0.76), and NPi (4) (-0.75). There was a strong and positive correlation (r = 1.00) between the mean yield (Yi) and YSi, S2di, and Di, as well as W21 and Stabvar, while TOP had a positive correlation of 0.78 (Table 6).

The Spearman correlation analysis of the stability parameters indicated that Yi, YSi, TOP, and bi, had a positive correlation, as shown in Table 6. This is consistent with the studies carried out by Becker and Leon (1988) and Mut et al. (2010), which stated that there was a correlation between Yi and the TOP stability parameter. The selection to improve yield is expected to change the grain yield stability by increasing the TOP parameter (Abdipour et al. 2017, Goksoy et al. 2019). This was directed towards the development of site-specific genotypes by optimizing environmental conditions. Genotypes tend to produce poor yields when planted in a less optimal environment and and will produce high yields when planted in optimal environmental. The regression coefficient bi correlates with Yi and all the tested stability parameters. YSi negatively correlates with Si (6), NPi (2), NPi (3), NPi (4). Similarly, there is a strong and positive correlation (r = 1.00) between the mean results and YSi, S2di, and Di, as well as W21 and Stabvar. Furthermore, TOP has a positive correlation of 0.78, indicating a stability parameter suitable for identifying high-yield genotypes (Mut et al. 2010; Abdipour et al. 2017).

The main component analysis that correlates the genotype with the yield and stability parameters is shown in Figure 1. Genotypes that are close to the stability parameter are considered "stable" or "good." The results of the biplot analysis stated that G13(BKL4-B1-268-10), G10(BKL2-B3-264-6), G5(BKL1-B1-259-1), G7(BKL1-B3-261-3), and G9(BKL2-B2-263-5) had the highest stable yields based on the TOP stability parameters and strongly correlate with Ysi and bi (Figure 1, Table 6). This is easily understood because TOP is calculated based on the number of locations where the genotypes had the highest yield rank.

GGE biplot analysis

Biplot analysis is used to interpret the AMMI model as indicated by AMMI1 and AMMI2. The AMMI1 biplot is a plot of the main effect (yield) and the score for the first principle component (PC1). On the contrary, the AMMI2 biplot is a plot of the first (PC1) and the second (PC2) principle component scores. The results of the AMMI variance analysis show that the interaction with the main component 1 (PC1) is significant at the probability level of less than 1% (Table 7). The effective breakdown of the genotype x environment interaction into 4 main components shows that there are 3 important components. Besides, the first 2 PCs were obtained as 85.7% from the G x E interaction (Table 7). The GGE biplot is more advantageous than the AMMI, for example, the GGE biplot graph is better than the AMMI in the mega-environmental analysis for evaluating genotypes. This is due to the fact that the GGE biplot is more descriptive on G + GE, and comprises the productive part of the biplot properties. GGE biplot was used to analyze mega-environments (Kebede et al. 2017; Zulqarnain et al. 2017), genotype evaluation (Islam et al. 2020), evaluation of environmental trials (Tekdal S and Kendal 2018), and the analysis of heterotic patterns (Kannababu et al. 2017), whose applications are becoming popular in quantitative analysis and plant breeding. The polygon visualization in the GGE biplot is effective and elegant. This method divides the environment into several groups and predicts the ideal genotype (Yan and Kang 2003).

The results of discriminativeness and the representativeness of the Environments produced genotype rankings relatively close to the mean. In the Desa Semarang and Sawah Dendam, G13(BKL4-B1-268-10) had the highest yield, followed by G10(BKL2-B3-264-6), G5(BKL1-B1-259-1), G7(BKL1-B3-261-3), and G6(BKL1-B2-260-2), as shown in Figure 2. These results were consistent when analyzed based on the highest mean grain yield ratings tested in the 5 environments (Figure 3). The genotype determined using the biplot in respect to the longest vector was combined with G × E = 0, and represented by dots and arrows. This shows that it is a stable and high yield genotype. Fortunately, G13(BKL4-B1-268-10), G10(BKL2-B3-264-6), and G7(BKL1-B3-261-3) are ideally stable because their projections in AEA are close to zero. However, those close to the ideal genotype are G5(BKL1-B1-259-1) and G6(BKL1-B2-260-2). The poor yield genotypes were Rindang 2,

G1(BKL3-RS1-1-253-18), G2(BKL4-RS1-1-256-21), G3(BKL4-RS1-2-257-22), and G12(BKL3-B3-267-9) because it was located far from the ideal ones.

The polygon is drawn from the position of the point farthest to the axis (0, 0), which then forms an angle. Therefore all genotypes are present in the polygon. Subsequently, a perpendicular line is drawn from the axis (0, 0) to each side of the polygon, thereby dividing the location into sectors, with each having a different genotype angle. Apparently, in each sector, the genotype suited at the top of the polygon was identified as the best in all the locations (Yan and Kang 2003). In this results showed that 7 genotypes were located at the top of the polygon, namely G5(BKL1-B1-259-1), G13(BKL4-B1-268-10), G11(BKL3-B1-265-7), G12(BKL3-B3-267-9), Rindang 2, G1(BKL3-RS1-1-253-18), and G4(BKL4-RS1-3-258-23) (Figure 4). Irrespective of the fact that the genotypes were spread across 7 sectors, only 2 provided a suitable environment for the genotypes to be tested. The first sector, which comprises G7(BKL1-B3-261-3), G10(BKL2-B3-264-6), G13(BKL4-B1-268-10), is properly adapted to the Sungai Serut, Aur Gading, Semarang Village, and Sawah Dendam environments. Furthermore, the second sector is G6(BKL1-B2-260-2), and G5(BKL1-B1-259-1), which properly adapted to the environment in Talang Benih.

Stability analysis using several methods helps breeders make decisions easily and comprehensively to obtain stable superior genotypes. This can be done by comparing the results of the statistical relationship between them (Shukla et al. 2015; Goksoy et al. 2019). We compared the results of several methods to determine the yield stability of the lines (Table 8). Overall, the results of this study indicated that there were four consistently stable lines based on parametric and non-parametric stability analyzes, namely G10(BKL2-B3-264-6), G7(BKL1-B3-261-3), G13(BKL4-B1-268-10), and G5(BKL1-B1-259-1). The GGE approach methods showed consistent stability, namely the lines G13(BKL4-B1-268-10), G10(BKL2-B3-264-6), G5(BKL1-B1-259-1), G7(BKL1-B3-261-3), and

G6(BKL1-B2-260-2) have high yield potential, wide adaptation and stability, and are recommended to be tested more widely as candidates for new varieties.

CONCLUSION

The highest yield grouping based on GxE heat-map describes the average yield of 14 genotypes tested in 5 environments, namely genotypes G13(BKL4-B1-268-10), G10(BKL2-B3-264-6), G7(BKL1-B3-261-3), and G5(BKL1-B1-259-1), found in the Sungai Serut. The interaction of GxE, parametric, and non-parametric stability showed that there was a strong and positive correlation (r = 1.00) between the mean yield with YSi, S2di with Di, and W21 with Stabvar, while with TOP had a positive correlation (0.78), which demonstrated a suitable stability parameter to identify high yield genotypes. The analysis of GGE obtained two sectors that provide a suitable environment for the genotype tested. The first sector, namely the genotype G7(BKL1-B3-261-3), G10(BKL2-B3-264-6), G13(BKL4-B1-268-10), adapted well to the Sungai Serut, Aur Gading, Desa Semarang, and Sawah Dendam, the second sector was the genotype G6(BKL1-B2-260-2), and G5(BKL1-B1-259-1) provided a good environment for Talang Benih. The results of this study indicated that there were five consistently stable lines based on parametric, non-parametric stability analyzes, and GGE approach methods, namely the genotypes G13(BKL4-B1-268-10), G10(BKL2-B3-264-6), G5(BKL1-B1-259-1), G7(BKL1-B3-261-3), and G6(BKL1-B2-260-2) have high yield potential, wide adaptation and stability, and are recommended to be tested more widely as candidates for new varieties.

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Table 1. Characteristics of 5 environments trial in Bengkulu Province

Enviroment	Year	Soil Type	Altitude (m)	Rainfall (mm)	Temperature (° C)		Irrigation Type
					Min	Max	
Sungai Serut (SS)	2019	Ultisol	60	101	26	34	semi technical
Desa Semarang (DS)	2019	Ultisol	50	112	26	34	semi technical
Talang Benih (TB)	2019	Andosol	300	118	26	34	technical
Sawah Dendam (SD)	2020	Ultisol	50	277	26	32	technical
Aur Gading (AG)	2020	Ultisol	100	215	26	32	rainfed

Tabel 2. Agronomic performance of inbred line from Bengkulu local rice varieties tested in different location yield trials

Lines Number	Accesian number	Pedigree	Plant height (cm)	Panicle length	Number of Productive Tiller per hill	Filled grain per panicle	Unfilled grain per panicle (%)	1000-grain Weight (g)	Grain weight per (g)
G1	BKL3-RS1-1-253-18	Sriwijaya x IR148	125.33^{a}	27.04^{a}	9.68^{gh}	120.22^{efg}	25.75^{bc}	27.01^{defg}	22.46^{i}
G2	BKL4-RS1-1-256-21	Sriwijaya x IR7858-1	107.99^{bcd}	25.51^{cde}	10.17^{g}	112.99^{h}	23.46^{cd}	27.22^{cdef}	24.98^{hi}
G3	BKL4-RS1-2-257-22	Sriwijaya x IR7858-1	112.71^{bc}	26.36^{b}	10.09^{g}	119.73^{fg}	22.38^{de}	27.86^{b}	28.53^{fg}
G4	BKL4-RS1-3-258-23	Sriwijaya x IR7858-1	103.89^{cd}	25.97^{bc}	10.39^{fg}	118.33^{fgh}	19.11^{fg}	26.91^{defg}	31.30^{ef}
G5	BKL1-B1-259-1	Bugis x IR7858-1	99.91^{d}	24.85^{f}	13.59^{d}	129.27^{bc}	15.65^{hi}	27.35^{bcde}	38.69^{bc}
G6	BKL1-B2-260-2	Bugis x IR7858-1	99.65^{d}	25.01^{ef}	13.53^{d}	126.87^{bcd}	14.94^{i}	26.45^{g}	37.25^{cd}
G7	BKL1-B3-261-3	Bugis x IR7858-1	103.91^{cd}	26.00^{bc}	15.63^{a}	129.49^{bc}	17.47^{gh}	26.52^{g}	41.87^{ab}
G8	BKL2-B1-262-4	Bugis x IR148	104.91^{cd}	25.62^{cd}	13.74^{cd}	121.42^{defg}	22.45^{de}	27.63^{bc}	35.44^{cd}
G9	BKL2-B2-263-5	Bugis x IR148	106.04^{cd}	26.04^{bc}	15.43^{ab}	123.72^{cdef}	19.81^{fg}	27.50^{bcd}	42.37^{a}
G10	BKL2-B3-264-6	Bugis x IR148	106.12^{cd}	25.23^{def}	13.78^{cd}	126.41^{bcde}	14.65^{i}	28.52^{a}	41.50^{ab}
G11	BKL3-B1-265-7	Sriwijaya x IR148	115.06^{b}	25.90^{bc}	15.22^{ab}	115.09^{gh}	18.30^{fg}	27.18^{cdef}	42.82^{a}
G12	BKL3-B3-267-9	Sriwijaya x IR148	130.66^{a}	25.83^{bc}	11.85^{e}	131.48^{b}	20.43^{ef}	26.58^{g}	34.50^{de}
G13	BKL4-B1-268-10	Sriwijaya x IR7858-1	127.75^{a}	25.93^{bc}	13.07^{d}	151.57^{a}	18.63^{fg}	26.69^{fg}	42.27^{a}
G14	BKL4-B3-270-12	Sriwijaya x IR7858-1	112.25^{bc}	25.87^{bc}	11.14^{ef}	130.34^{b}	23.65^{cd}	27.01^{defg}	35.32^{cd}
ıpago 12	Elite variety	-	124.47^{a}	22.71^{g}	14.62^{bc}	120.36^{defg}	27.44^{b}	23.29^{h}	34.69^{de}
indang 2	Elite variety	-	132.15^{a}	26.32^{b}	9.07^{h}	116.77^{gh}	32.66^{a}	26.87^{efg}	26.25^{gh}
	LSD 5%		8.84	0.55	0.93	6.52	2.48	0.59	3.48
	CV		8.83	2.43	8.34	5.87	13.24	2.46	11.16

Note: Numbers in one column followed by the same letter show no significant difference based on the LSD test at 5%; CV=Coeficient of variance

Table 3. Means of grain yield (tonnes/ha) in 5 environments of 14 genotypes

Genotype	Grain yield (tonnes/ha)					Mean
	Aur Gading (AG)	Desa Semarang (DS)	Sawah Dendam (SD)	Sungai Serut (SS)	Talang Benih (TB)	
G1	3.18	4.76	4.58	5.57	11.52	5.92
G10	4.97	9.55	11.82	14.85	11.18	10.47
G11	3.85	5.50	6.60	17.37	6.79	8.02
G12	4.15	4.48	4.48	15.96	5.40	6.89
G13	4.57	11.38	12.22	15.24	12.29	11.14
G14	3.85	6.34	6.25	15.73	6.56	7.74
G2	3.28	4.34	4.69	8.84	9.14	6.06
G3	5.21	4.14	4.36	9.01	10.93	6.73
G4	4.39	4.32	5.09	7.51	15.10	7.28
G5	5.19	8.14	10.16	13.11	14.96	10.31
G6	4.93	5.93	7.18	13.52	13.76	9.06
G7	4.37	7.47	10.33	16.31	12.52	10.20

G8	4.55	5.93	7.26	15.21	7.39	8.07
G9	6.41	5.84	7.43	16.84	7.26	8.76
Inpago 12	5.07	7.36	7.82	12.07	7.05	7.87
Rindang 2	4.37	4.30	6.40	5.29	5.29	5.13
Mean	4.52	6.23	7.29	12.65	9.82	8.10
LSD 0.05	1.12	0.80	0.56	0.56	2.49	0.57
CV (%)	14.10	7.33	4.22	2.52	14.48	9.40

Table 4. Parametric stability analysis: coefficient of variability, environmental variability, regression coefficient and regression deviation, and stability in 14 lines and 2 checks in 5 environments

Lines number	Y_i (t Ha^{-1})	CV_i	bi	P_b_i	s^2d_i	$P\_s^2d_i$	W_i^2	D_i	StabVar (σ^2)
G1	5.97	53.89	0.51**	0.006	9.96***	0.000	40.34	8.45	22.2
G10	10.47	34.61	1.02 ns	0.899	3.11***	0.000	10.19	7.12	4.97
G11	8.02	66.73	1.51**	0.004	7.19***	0.000	32.86	7.94	17.93
G12	6.89	73.88	1.35*	0.044	9.50***	0.000	34.41	8.36	18.81
G13	11.14	35.49	1.06 ns	0.744	5.46***	0.000	17.36	7.6	9.06
G14	7.74	59.36	1.28 ns	0.106	5.65***	0.000	21.04	7.64	11.17
G2	6.07	44.88	0.79 ns	0.231	1.11***	0.004	5.93	6.69	2.53
G3	6.73	45.48	0.73 ns	0.125	4.94***	0.000	18.57	7.5	9.76
G4	7.28	62.65	0.79 ns	0.230	18.97***	0.000	59.53	9.92	33.16
G5	10.31	37.68	1.06 ns	0.707	4.50***	0.000	14.53	7.41	7.45
G6	9.06	46.92	1.24 ns	0.161	2.90***	0.000	11.95	7.08	5.97
G7	10.2	45	1.42*	0.017	0.48 ns	0.053	9.48	6.55	4.56
G8	8.06	51.51	1.20 ns	0.258	3.37***	0.000	12.52	7.18	6.3
G9	8.76	52.13	1.21 ns	0.227	7.70***	0.000	25.74	8.03	13.86
Inpago 12	7.87	32.64	0.71 ns	0.094	1.74***	0.000	9.56	6.83	4.61
Rindang 2	5.13	16.7	0.11***	0.000	0.54*	0.040	34.93	6.56	19.11

Y: overall mean of yield. LSD 0.05: 0.17; CVi: coefficient of variability (Francis and Kannenberg); b: coefficient of regression to index of environment (Finlay and Wilkinson; Eberhart and Russel). Stable (a=0.05): 0.9 - 1.1
P_bi : P-value for b with null hypothesis b=1; s^2d: deviation of regression (Eberhart and Russel); P_s^2di: P-value for s^2d with null hypothesis s=0; W_i^2 : Wrickeecovalence; D: Hanson's parameter stability; StabVar : Shukla *stability variance* (σ^2)

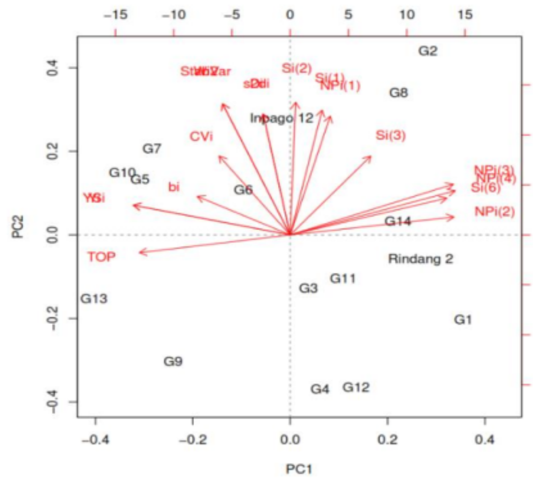

Figure 1. Maping of PCA biplot of 14 genotype and stability parameters.

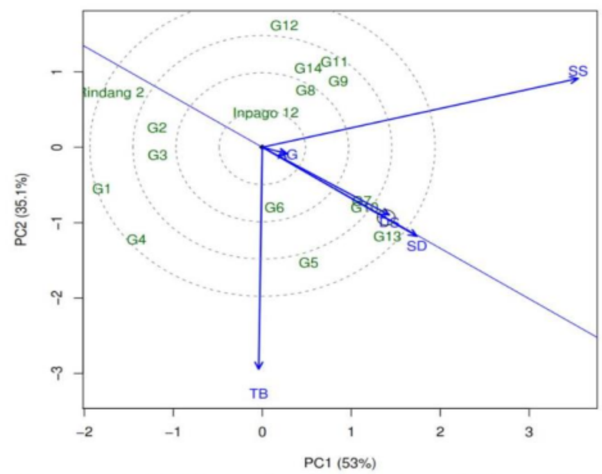

Figure 2. Biplot showing the discriminating ability and the representativeness of environments from 14 genotypes and 5 environment trials

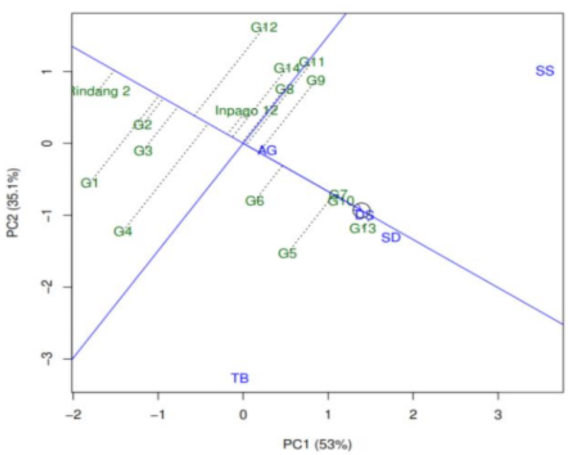

Figure 3. Mean versus stability biplot for grain yield showing the stability and performance of each genotypes

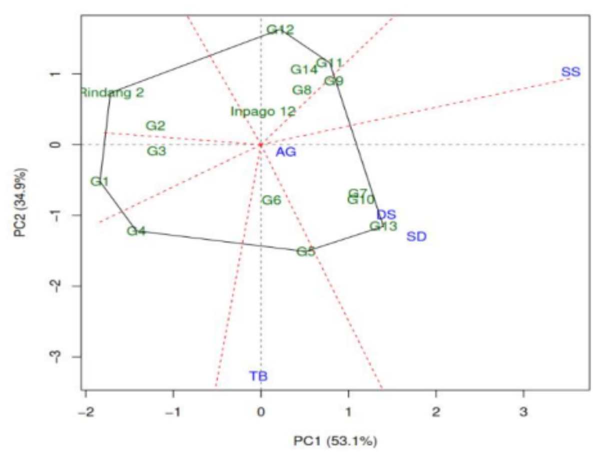

Figure 4. GGE biplot with mega-environment sectors: which won where biplot for grain yield showing identification of winning genotypes and their related mega-environments

Table 5. The result of analysis non-parametric stability

Genotype	YSi	Si(1)	Zi(1)	Si(2)	Zi(2)	Si(3)	Si(6)	TOP	NPi(1)	NPi(2)	NPi(3)	NPi(4)
G1	-9	6.20	0.35	27.80	0.37	5.15	1.21	0	3.40	0.26	0.39	0.51
G10	10 +	6.20	0.35	24.70	0.10	6.42	2.33	2	3.60	0.72	0.93	1.29
G11	0	5.40	0.00	25.70	0.17	10.52	1.83	1	2.80	0.28	0.49	0.59
G12	-6	7.90	2.95	41.25	3.43	7.00	1.31	0	5.10	0.43	0.50	0.68
G13	11 +	7.40	1.92	35.30	1.69	8.00	3.00	2	4.40	0.88	1.33	1.85
G14	-2	4.80	0.12	15.00	0.34	7.40	1.80	0	3.00	0.27	0.35	0.48
G2	-8	3.60	1.29	8.50	1.39	1.63	0.59	0	2.20	0.17	0.20	0.28
G3	-7	6.80	0.97	31.30	0.87	13.04	2.15	1	4.20	0.35	0.46	0.63
G4	-4	6.80	0.97	35.30	1.69	11.80	2.00	1	4.00	0.33	0.53	0.68
G5	9 +	4.60	0.22	13.30	0.54	9.36	2.55	3	2.80	0.93	0.74	1.05
G6	6 +	6.40	0.52	26.00	0.19	3.21	1.27	1	3.80	0.54	0.69	0.97
G7	8 +	5.80	0.10	22.50	0.01	8.20	2.29	2	3.60	0.90	0.87	1.18
G8	1 +	2.80	2.78	5.00	2.27	0.75	0.50	0	1.60	0.20	0.25	0.35
G9	5 +	7.20	1.57	34.80	1.58	12.90	2.97	2	4.70	0.78	0.91	1.24
Inpago 12	-1	4.80	0.12	14.50	0.39	7.73	2.22	0	2.80	0.56	0.46	0.65
Rindang 2	-10	7.20	1.57	36.70	2.05	2.67	0.96	0	4.40	0.29	0.40	0.53

YS: Kang's yield and stability index; '+': selected genotypes having YSi> mean of 8.10; Si(1), Si(2), Si(3), Si(6): Nassar and Huehn's nonparametric stability parameters; SumZi(1) : 16.63; SumZi(2) : 17.61; Chi-sqtabelZi(1), Zi(2): 8.73; Chi-sqtabelSumZi(1), SumZi(2): 26.29; TOP : Fox's TOP - Number of sites at which the genotype occurred in the top third of the ranks; NPi(1), NPi(2), NPi(3), NPi(4): Thennarasu's nonparametric stability parameters

Table 6. Spearman correlation between stability parameters.

	Yi	CVi	bi	s2di	Wi2	Di	StabVar	YSi	Si(1)	Si(2)	Si(3)	Si(6)	TOP	NPi(1)	NPi(2)	NPi(3)
Yi																
CVi	0.25															
bi	0.59*	0.24														
s2di	0.14	0.76**	0.01													
Wi2	0.46	0.54*	0.40	0.76**												
Di	0.14	0.76**	0.01	1.00**	0.76**											

StabVar	0.46	0.54*	0.40	0.76**	1.00**	0.76**										
YSi	1.00**	0.25	0.59*	0.14	0.46	0.14	0.46									
Si(1)	0.10	0.11	0.19	0.38	0.57*	0.38	0.57*	0.10								
Si(2)	0.24	0.20	0.30	0.44	0.70**	0.44	0.70**	0.24	0.97**							
Si(3)	-0.22	0.20	0.01	0.42	0.25	0.42	0.25	-0.22	0.29	0.28						
Si(6)	-0.68**	-0.27	-0.36	0.12	-0.13	0.12	-0.13	-0.68**	0.27	0.15	0.73**					
TOP	0.78**	0.22	0.46	0.00	0.19	0.00	0.19	0.78**	-0.15	-0.06	-0.59*	-0.82**				
NPi(1)	0.08	0.09	0.15	0.33	0.51*	0.33	0.51*	0.08	0.98**	0.93**	0.32	0.30	-0.20			
NPi(2)	-0.72**	-0.40	-0.27	-0.15	-0.25	-0.15	-0.25	-0.72**	0.30	0.16	0.50*	0.86**	-0.81**	0.36		
NPi(3)	-0.76**	-0.19	-0.36	0.09	-0.06	0.09	-0.06	-0.76**	0.48	0.36	0.50*	0.84**	-0.88**	0.50	0.88**	
NPi(4)	-0.75**	-0.26	-0.36	0.03	-0.13	0.03	-0.13	-0.75**	0.48	0.35	0.46	0.84**	-0.83**	0.51*	0.92**	0.99**

Table 7. Analysis of variance of AMMI model.

Source of variance	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Environment (E)	4	1296.28	324.07	158.27	0.00
Replication/E	5	10.24	2.05	3.53	0.01
Genotype (G)	15	454.38	30.29	2.53**	0.01
GxE	60	717.73	11.96	20.61**	0.00
PC1	18	497.07	27.62	47.58**	0.00
PC2	16	117.91	7.37	12.70**	0.00
PC3	14	93.29	6.66	11.48**	0.00
PC4	12	10.17	0.85	1.46*	0.16
Residuals	73	42.37	0.58		

Table 8. The analysis results in parametric, non-parametric, and GGE models to determine the yield stability of the lines

Methods	Parameters	Stability	Stability Lines
Parametric stability			
Regression	bi	b=1	**G10**, **G13, G5, G7**
	bi and S2di	b=1; S2di=0	**G10, G5, G6, G7**, G8
Variace	Wi2	Low	**G10**, G2, **G7**, Inpago 12
	σ2	Low	G10, G2, **G7**, Inpago 12
	Di	Low	G2, **G7**, Inpago 12, Rindang 2
	CVi	Low	**G10, G13, G5, G7**, Inpago 12
Non-parametric stability			
	Ysi	YSi> mean	**G10,G13, G5, G6**, **G7**, G8, G9
	Si(3), Si(6)	Zi< Chi-sq-table	all genotipe
	Si(1), Si(2)	Zi< Chi-sq-table	all genotipe
	NPi(1), NPi(2), NPi(3), NPi(4)	Low	G2, **G5**, G8, G11, Inpago 12
	TOP	Top third of the ranks	**G13, G10, G5, G7**, G9
GGE biplot models			
	discrimitiveness vs. representativenes		**G13, G10, G5, G7, G6**
	mean vs. stability		**G13, G10, G5, G7, G6**
	which−won−where		**G13, G10, G5, G7, G6**

Determination of stability through different methods to developed high yield Inbred Lines from landraces rice varieties

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