AGRIVITA Journal of Agricultural Science. 2023. 45(1): 163–172

AGRIVITA
Journal of Agricultural Science
www.agrivita.ub.ac.id

Genotype by Environment Interaction of IPB New Plant Type Rice Lines in Three Irrigated Lowland Locations

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ARTICLE INFO

Keywords:
G×E interaction
Rice breeding
Stability analysis

Article History:
Received: January 18, 2022
Accepted: March 7, 2023

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ABSTRACT

One essential objective of rice breeding is to obtain high-yielding varieties. This study aimed to (1) determine the effect of genotype (G), environment (E), and genotype by environment (G×E) interaction on agronomic traits and yield of 12 lowland rice genotypes, (2) estimate variance components and repeatability (3) identify promising rice genotypes with good agronomic performance and high yield potential. The trials were conducted in three irrigated lowland locations from June to November 2020, using a randomized complete block design with three replications. The results showed that the G×E interaction effect was significant on days to flowering, days to harvest, plant height, number of tillers, and panicle length. The genotype's main effect was significant on yield. Four IPB lines (IPB189-F-13-1-1, IPB189-F-23-2-2, IPB193-F-17-2-3, and IPB193-F-30-2-1) had a higher average yield than Ciherang and Inpari 32 varieties. The IPB189-F-23-2-2 had a panicle length stability across the three test locations and a higher average yield than the checks.

INTRODUCTION

Rice (*Oryza sativa* L.), belonging to the Gramineae family, is one of the leading food crops in the tropics and subtropics (Mackill et al., 2012). However, in 2019, Indonesia's rice production decreased by 7.75% from the previous year (Statistics Indonesia, 2020). One of the current main factors impacting the low productivity of rice is climate change, including the shifting of the beginning of the rainy and dry seasons (Sudewi, Ala, Baharuddin, & Farid, 2020).

Increasing crop production is of utmost importance to fulfil peoples' needs. Thus, strategies are needed to meet the demand for rice worldwide. Several ways have been carried out to increase crop yield, including breeding superior varieties, utilizing the available agricultural land, and preventing the conversion of agricultural land to non-agriculture use. Additionally, scientists have been taking approaches to develop types and cultivation techniques (Yang et al., 2014).

Conventional plant breeding has a long history of increasing crop productivity, food protection, and safety (Kaiser et al., 2020). Its activities include hybridization to form a base population, selecting the desired lines and plants, and testing the yield and adaptation of the promising lines produced before being released as new varieties (Breseghello & Coelho, 2013). Germplasm collections are required for developing base populations. Indonesia's germplasm potential is large and varied, especially in local rice varieties.

In addition to increasing yields, breeding rice varieties is also carried out to obtain varieties tolerant of environmental conditions that significantly affect productivity (Chattopadhyay et al., 2017; Heidari et al., 2016). Genotype stability in various environmental conditions, which is the ability of plants to maintain yields when environmental conditions change, is also an important consideration (Torres & Henry, 2018). Agronomic traits and yield potential are observed to understand the differences between the tested lines and select plants that have the potential to be cultivated (Senguttuvel et al., 2021). The combined effects of genotype (G), environment (E), and the

ISSN: 0126-0537

Cite this as: Rahim, S., Suwarno, W. B., & Aswidinnoor, H. (2023). Genotype by environment interaction of IPB new plant type rice lines in three irrigated lowland locations. *AGRIVITA Journal of Agricultural Science*, *45*(1), 163–172. http://doi.org/10.17503/agrivita.v45i1.3685

interaction between genotype and environment (G×E) may affect the performance of each trait (Blanche et al., 2009). The G×E interaction typically has a significant effect on yield. The G×E interaction can produce various responses according to the ability of the genotype used and the environmental conditions in which cultivation is carried out (Sharifi et al., 2017).

The presence of a suitable genotype in a specific environment is indicated by a significant G×E interaction (He et al., 2017). This interaction demonstrates that changes in environmental conditions affected the response of each genotype for a particular trait (Jayaningsih et al., 2020; Satoto et al., 2016; Sharifi et al., 2017). Testing the physiological adaptation of each line in different environments is one way to identify superior varieties. When planted in other locations, biologically stable genotypes are characterized by constant responses (Kartahadimaja et al., 2019).

The concept of the characteristics of a new type of rice was developed at IRRI. This type of rice has dense panicles with fewer but productive tillers (Peng et al., 1994). The IPB University has been conducting new plant-type rice breeding, and nine varieties have been released for different agroecosystems, i.e., lowland, upland, and tidal swamps. A national consortium released one high-yielding upland rice variety of IPB, IPB 9G (Hairmanisis et al., 2019). New plant-type rice research at IPB is ongoing, and recent advances included understanding correlations between panicle branching traits (Hastini et al., 2019), elucidating genotypic responses to various nitrogen doses (Rahayu et al., 2018) and different seasons (Hastini et al., 2020).

This study aimed to (1) determine the effect of genotype (G), environment (E), and genotype by environment (G×E) interaction on agronomic traits and yield of 12 lowland rice genotypes, (2) estimate variance components and repeatability (3) identify promising rice genotypes with good agronomic performance and high yield potential.

MATERIALS AND METHODS

Experimental Sites and Plant Materials

The experiment was carried out from June to November 2020. The trials were conducted in three irrigated lowland locations, namely (1) Tongkoseng Village, Tontonunu District, Bombana Regency, Southeast Sulawesi (4°42'45"S 121°41'50"E, 27 m asl), (2) IPB University experimental station in Babakan Village, Dramaga District, Bogor Regency, West Java (6°33'49"S 106°44'06"E, 180 m asl), (3) Tanjungsari Village, Rowosari District, Kendal Regency, Central Java (6°56'31"S 110°3'43"E, 9 m asl). These irrigated lowland locations were selected as they are assumed suitable for the genotypes. The average temperature, relative humidity, and rainfall of each area are shown in Table 1.

The plant materials used were 12 IPB New Plant Type advanced rice lines and two national rice varieties as checks. Fertilizers applied were urea, Phonska (15% N, 15% P_2O_2, 15% K_2O), and KCl at a dose of 200 kg/ha urea, 350 kg/ha Phonska, and 50 kg/ha KCl. Insecticides with chlorpyrifos 500 g/l, molluscicide with niclosamide 250 g/l, and herbicide with active ingredient isopropyl amine glyphosate 480 g/l was applied.

Experimental Design and Data Analysis

The experiment was conducted using a randomized complete block design with a single factor of genotype and three replications in each location. The genotype factor had 14 levels consisting of 12 IPB rice lines and two check varieties, so there were 42 experimental units in each area. The plot size was 5 × 4 m^2. Seeds were planted, and 15 days-old seedlings were transplanted to the experimental plot, with a plant spacing of 20 × 20 cm. Traits measured included plant height, stem length, number of tillers, panicle length, number of filled grains per panicle, number of empty grains per panicle, the weight of 1000 grains, and yield. The yield was measured on a plot basis and then converted to t/ha at the moisture content of 14%.

Table 1. Average temperature, relative humidity, rainfall, and sowing date in the test locations

Location	Temperature (°C)	Relative humidity (%)	Rainfall (mm/day)	Sowing date
Bombana	27.815	77.373	7.759	9 July 2020
Bogor	26.435	80.356	12.995	16 July 2020
Kendal	28.713	78.340	1.862	15 June 2020

The combined analysis of variance over locations was conducted using the following model as stated by Mattjik & Sumertajaya (2013):

$$Y_{ijk} = \mu + E_i + B_{k(i)} + G_j + (GE)_{ij} + \varepsilon_{ijk} \text{.........1)}$$

Where: Y_{ijk}: response to environment-*i*, genotype-*j*, and block-*k*, μ: general mean, E_i : effect of environment-*i*, i = 1, 2, 3, $B_{k(i)}$: effect of block-*k* within environment-*i*, k = 1, 2, 3, G_j : effect of genotype-*j*, j = 1, 2, 3, …., 14, $(GE)_{ij}$: interaction effect of the environment-*i* and genotype-*j*, ε_{ijk}: effect of the experimental error on environment-*i*, genotype-*j*, and block-*k*.

Following the ANOVA, the Dunnett t-test at the 5% level was conducted to compare the test genotypes to the checks. Stability analysis was performed using the Francis-Kannenberg (Francis & Kannenberg, 1978), Wricke's ecovalence (Wricke, 1962), Kang's yield and stability index (Kang, 1993), and additive main effect and multiplicative interaction (AMMI) (Gauch, 1988). The phenotypic correlation coefficients were calculated following Gomez & Gomez (1984).

AMMI analysis was performed by partitioning the G×E interaction into several principal components. The F tests were conducted to identify significant main components. Furthermore, the AMMI biplot was drawn based on PC1 on the X-axis and PC2 on the Y-axis. This biplot may help determine stable genotypes across all sites and genotypes adapted to specific areas (Mattjik & Sumertajaya, 2013). According to Shafii & Price (1998), the AMMI model can be formulated as follows:

$$y_{ijk} = \mu + \gamma_i + \epsilon_j + b_{jk} + \sum_{t=1}^{m} \lambda_t \upsilon_{ti} \nu_{tj} + p_{ij} + e_{ijk} \text{.....2)}$$

Where: : response to the environment *i*, genotype *j*, and block *k*, μ: general mean, : effect of environment-*i*, *i* = 1, 2, 3, ϵ_j: effect of genotype-*j*, *j* = 1, 2, 3, ..., 14, b_{jk}: effect of replication-*k* in environment-*i*, k = 1,2,3, λ_t: singular value for the bilinear component *n*, $\lambda_1 \geq \lambda_2 \geq \ldots \geq \lambda_n$,$\upsilon_{ti}$: multiplicative effect of environment-*i* through the bilinear component-*t*, v_{jn}: multiplicative effect of genotype-*j* through bilinear component-*t*, p_{ij} = random error, e_{ijk}: experimental error on environment-*i*, genotype-*j*, replication-*k*, m: number of axes retained.

RESULTS AND DISCUSSION

Combined Analysis Across Locations

The genotype and environment main effects were significant on all traits, and the G×E interaction effect was significant on plant height, the number of tillers, and panicle length (Table 2). The significance of the G×E indicates that the responses of the genotypes for these traits varied with changing locations. Jayaningsih et al. (2020) also reported that the panicle length is affected by the G×E interaction. As for the character of stem length, number of filled grains per panicle, empty grain per panicle, 1000-grain weight, and yield, the G×E effect was insignificant, and environmental rather than genotypic factors more influenced phenotypic variability. The coefficient of variability was less than 20% for all traits observed except for empty grain per panicle (Table 2), indicating that the experiment was reliable. Khairullah et al. (2019) reported a significant G×E where some rice lines adapted quite well at specific locations but not at others. Jayaningsih et al. (2020) also mentioned that the rank changes of genotypes could occur in the presence of G×E interaction.

The characters of plant height, the number of filled grains per panicle, 1000-grain weight, and yield had repeatability more than 80%. In comparison, the number of empty grains per panicle had the lowest repeatability (60.25%) (Table 2). In breeding programs, the selection of superior entries should consider the heritability or repeatability of the traits of interest. A high heritability or repeatability indicates that the genetic influence on the variability of the trait is greater than the GxE influence (Hasan-Ud-Daula & Sarker, 2020). Analysis of variance components for these characters also shows that the genetic variance is greater than the GxE variance. For traits with high repeatability, the genotypes may have consistent performance across environments, and therefore selection may be performed in any environment.

Agronomic Performance and Yield Potential

Some of the tested genotypes had a higher average plant height, stem length, panicle length, number of filled grains, and 1000-grain weight than check varieties (Table 3). Most of the test genotypes had a smaller average number of tillers (14.2 - 17.5) than the check varieties (20.8 and 21.6), with a difference of 3-7 tillers per hill. However, two genotypes had a similar number of tillers to the check varieties, namely IPB187-F-37-1-2 (18.8) and IPB187-F-43-1-2 (17.9). Furthermore, four genotypes, namely IPB189-F-13-1-1, IPB189-F-23-2-2, IPB193-F-17-2-

3, and IPB193-F-30-2-1, yielded significantly higher than both check varieties.

The study results agreed with Jayaningsih et al. (2020) that the test lines performed differently against the check varieties used. According to Kartahadimaja & Syuriani (2020), too many tillers may reduce the harvest index and rice quality because the panicles may not ripen simultaneously.

Table 2. Mean squares, variance components, and repeatability for agronomic traits and yield

Source or parameter	PH	SL	NT	PL	FG	EG	WG	Y
MS E	892.55**	1249.27**	1275.75**	431.71**	17167.46**	286.06*	237.57**	23.14**
MS G	289.54**	149.14**	45.52*	36.14**	4540.89**	245.25**	27.21**	3.77**
MS G×E	36.12*	36.48ns	16.49*	12.14*	774.21ns	94.63ns	4.91ns	0.55ns
CV (%)	4.04	6.32	17.44	9.44	18.25	46.27	5.97	7.39
σ^2_g	28.16	12.52	3.23	2.67	416.38	16.32	2.48	0.36
σ^2_{ge}	5.37	2.93	2.54	1.82	18.74	11.34	0.55	0.05
σ^2_e	20.01	27.70	8.88	6.67	719.20	62.90	3.27	0.40
σ^2_p	32.17	16.57	5.06	4.02	502.53	27.09	3.02	0.42
R (%)	87.52	75.54	63.77	66.42	82.86	60.25	81.95	85.34

Remarks: E=environment, G=genotype, CV=coefficient of variation, σ^2_g=genotypic variance, σ^2_{ge}=G×E interaction variance, σ^2_e=environment variance, σ^2_p=phenotypic variance, R=repeatability, PH=plant height, SL=stem length, NT=number of tillers, PL=panicle length, FG=number of filled grain per panicle, EG=number of empty grain per panicle, WG=weight of 1000 grains, Y=yield, * =significant at 5% level, **=significant at 1% level, ns=not significant.

Table 3. Means of agronomic traits and yield of 12 rice genotypes and two check varieties

Genotype	PH	SL	NT	PL	FG	EG	WG	Y
IPB187-F-37-1-2	110ab	82	18.8	27.5b	139	20	30.0a	8.31
IPB187-F-43-1-2	108ab	81	17.9	26.5	137	16	29.4	8.83
IPB187-F-65-1-2	106b	78	16.8ab	28.2ab	169ab	17	30.6a	8.37
IPB187-F-88-1-3	112ab	82	14.5ab	29.1ab	183ab	30ab	29.9a	7.64
IPB189-F-13-1-1	112ab	85ab	14.7ab	26.5	165ab	13	32.5ab	9.30ab
IPB189-F-23-2-2	116ab	87ab	15.8ab	29.6ab	158ab	16	32.6ab	9.64ab
IPB191-F-27-1-3	110ab	83b	16.1ab	26.9b	120	14	30.7ab	8.23
IPB193-F-17-2-3	118ab	89ab	14.2ab	29.5ab	174ab	14	33.5ab	9.54ab
IPB193-F-30-2-1	119ab	89ab	17.0ab	29.7ab	161ab	16	31.2ab	9.31ab
IPB194-F-39-1-2	111ab	83b	17.0ab	28.0b	143b	17	29.2	8.62
IPB194-F-74-3-1	114ab	86ab	17.5a	28.1ab	145b	21	29.7a	8.14
IPB194-F-77-1-1	112ab	86ab	16.2ab	25.9a	141	25ab	30.0a	7.65
Ciherang	102	78	21.6	24.2	119	11	27.1	8.30
Inpari 32	100	76	20.8	23.1	106	11	28.0	8.43

Remarks: Numbers followed by letters a and b were significantly different from Ciherang and Inpari 32 varieties, respectively, based on Dunnett's t-test at 5% level, PH=plant height, SL=stem length, NT=number of tillers, PL=panicle length, FG=number of filled grain per panicle, EG=number of empty grain per panicle, WG=weight of 1000 grains, Y=yield.

Stability Analysis on Panicle Length

A rice breeding program aims to obtain varieties with a high and stable yield across various environments. In this study, we found that the effect of G×E interaction was insignificant on yield, indicating that all genotypes had a similar response to environmental changes. Therefore, the stability analysis was not performed on yield but on the panicle length affected by G×E. Parimala et al. (2019) suggested that stability tests were not carried out for characters that did not have G×E interactions.

Wricke (1962) proposed ecovalence (W_i) as a dynamic or agronomic stability parameter. According to this method, genotypes with smaller W_i had a relatively stable panicle length. Such genotypes were IPB187-F-88-1-3, IPB189-F-23-2-2, IPB187-F-65-1-2, IPB193-F-17-2-3, IPB187-F-43-1-2, IPB193-F-30-2-1 and IPB194-F-39-1-2. Sabaghnia et al. (2014) mentioned that genotypes with dynamic stability responded positively to the environment and can perform above or below the average in different environments. Dynamic stability is the ability of a genotype to adjust yields based on environmental conditions (Becker & Leon, 1988; Lin et al., 1986).

Francis & Kannenberg (1978) mentioned that a genotype having a high yield and low coefficient of variation (CV_i) is considered stable. Genotypes with a high CV_i but below-average yields are undesired. Lin et al. (1986) studied nine stability parameters and classified those into four groups. Group A and B are based on the sum of squares, group C is based on the regression coefficient, and group D is based on regression deviation. Group A involved the deviation from the average genotype effect, and group B used the GxE interaction term. They categorized the Francis-Kannenberg stability parameter as static or biological stability. Stable genotypes according to this method were Ciherang, IPB194-F-77-1-1, IPB187-F-37-1-2, IPB187-F-43-1-2, IPB193-F-17-2-3, IPB187-F-65-1-2 and IPB189-F-23-2-2.

Kang (1993) proposed selecting genotypes based on yield and stability using the yield stability index (YS_i). In this study, the YS_i was calculated based on the ranks of average panicle length and Shukla's stability variance of this trait. Genotypes with a higher YS_i than the average are considered potential, and therefore genotypes IPB193-F-30-2-1, IPB189-F-23-2-2, IPB193-F-17-2-3, IPB187-F-88-1-3, IPB187-F-65-1-2, IPB189-F-23-2-2 were selected based on this method (Table 4).

Table 4. Stability parameters of 12 rice genotypes and two check varieties

Genotype	PL (cm)	CV_i	W_i^2	YS_i
IPB187-F-37-1-2	27.52	8.07	5.67	8+
IPB187-F-43-1-2	26.50	8.17	2.24	3
IPB187-F-65-1-2	28.24	8.47	1.33	11+
IPB187-F-88-1-3	29.12	11.79	0.56	12+
IPB189-F-13-1-1	26.54	16.60	7.44	4
IPB189-F-23-2-2	29.58	9.30	0.93	15+
IPB191-F-27-1-3	26.88	21.46	16.74	1
IPB193-F-17-2-3	29.51	8.42	1.93	14+
IPB193-F-30-2-1	29.74	12.42	3.17	16+
IPB194-F-39-1-2	28.01	16.57	4.20	9+
IPB194-F-74-3-1	28.15	25.46	33.41	2
IPB194-F-77-1-1	25.86	7.28	4.24	2
Ciherang	24.17	3.98	16.19	-4
Inpari 32	23.12	14.93	7.13	-2
Average	27.35	12.35	7.51	7

Remarks: PL=Panicle length, CV_i=Francis and Kannenberg's coefficient of variation, W_i^2=Wricke's ecovalence, YS_i=Kang's yield and stability index, +=selected genotypes having YS_i greater than the average

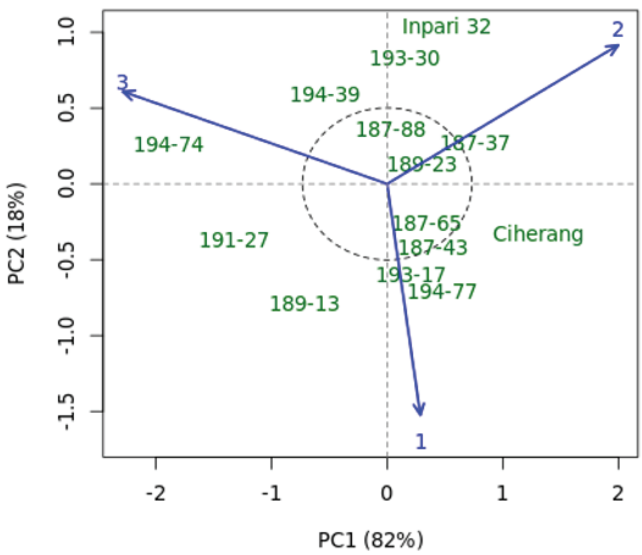
Three stability methods identified several stable genotypes at the three test locations, namely IPB187-F-65-1-2, IPB189-F-23-2-2, and IPB193-F-17-2-3. The selected genotype has an ecovalence and CV_i than the average. Genotypes IPB189-F-23-2-2 and IPB193-F-17-2-3 had higher yields than the check varieties. This study found no significant correlation between yield and panicle length stability based on CV (r=-0.09, p=0.76) and ecovalence (r=-0.30, p=0.30). Still, yield tended to be correlated with the index of average panicle length and stability (YS_i) (r=0.48, p=0.08).

AMMI analysis revealed that the G×E interaction effect could be explained by two principal components (PCs), each accounting for 82% and 18% of the G×E variability. The first main component is significant at the 0.01 level, and the second is insignificant (Table 5). These two PCs can fully explain the G×E interactions because the number of test environments was three. The AMMI biplot could therefore indicate a genotype having a positive GxE effect in a particular location or relatively stable across the three sites.

Kumar et al. (2016) and Sheelamary & Karthigeyan (2021) reported that the use of AMMI biplot was effective for evaluating lines in various environments because the results of the tests they had carried out identified stable genotypes and high yields. Aryana & Wangiyana (2016) mentioned that AMMI analysis required a significant G×E interaction. Akter et al. (2016) explained that the G×E interaction is divided into several principal components. The F tests were used to select the number of principal components explaining the G×E interaction from the available principal components. The research by Kartina et al. (2019) reported that if the GxE interaction variance explained by AMMI PCs is more significant than the unexplained. Genotypes adapted to one environment or stable across environments could be identified.

Chandrashekhar et al. (2020) state that biplots can facilitate genotype evaluation. Genotypes near one of the environments are usually called site-specific genotypes, while those near the midpoint are called stable lines across all test locations. Stable lines in several areas can be seen as the genotypes within the circle at the center of the biplot (Amzeri et al., 2020). Khairullah et al. (2019) mentioned that promising genotypes that have good adaptability at a particular test location could be recommended for development.

Genotypes IPB194-F-77-1-1 and IPB193-F-17-2-3 have a positive GxE with location 1 (Bombana) for panicle length. IPB187-F-37-1-2, IPB193-F-30-2-1, and the Inpari 32 variety responded well when planted in location 2 (Bogor). IPB194-F-39-1-2 and IPB194-F-74-3-1 had a good response in location 3 (Kendal). IPB187-F-43-1-2, IPB187-F-65-1-2, IPB187-F-88-1-3, and IPB189-F-23-2-2 have relatively stable panicle lengths in all three test environments (Fig. 1).



Remarks: 1=Bombana, 2=Bogor, 3=Kendal

Fig. 1. AMMI biplot of panicle length

The check varieties used in this study have been widely cultivated in Indonesia. The Ciherang check variety has the lowest CV stability parameter (3.98%) (Table 4), indicating that this variety has Type 1 (biological) stability. The panicle length means of Ciherang in locations 1, 2, and 3 were 23.1, 24.8, and 24.7 cm, respectively (data not shown), showing a relatively consistent performance across environments. This variety was bred from the IR64 variety, which was a mega-variety in Indonesia and other countries in Southeast and South Asia (Mackill and Khush, 2018).

The insignificance of the G×E effect on yield might be due to the limited number of environments in this study, which was only three. However, as mentioned above, this study found a significant G×E effect on panicle length. As the three locations belong to the same agroecosystem, i.e., irrigated lowland, this study may provide insight into the stability of the tested genotypes across these locations. Evaluating the genotypes in more areas would likely give better information on GxE.

Correlations Among Agronomic Traits

The weight of 1000 grains has a highly significant positive correlation with yield (r=0.67, p<0.01), while the number of empty grains has a significant negative correlation with yield (r=-0.59, p<0.05) (Table 6). The 1000-grain weight reflects the grain size, and therefore in the present research, the genotypes with larger grain size tended to have high yield, and vice versa. Also, this study revealed that panicle length had a highly significant positive correlation with plant height (r=0.86, p<0.01), indicating that tall genotypes tended to have long panicles. Furthermore, a longer panicle may have more filled grains, as shown by a highly significant positive correlation between the two (r=0.81, p<0.01). A negative and highly significant correlation between panicle length and the number of tillers in this study (r=-0.73, p<0.01) might be due to the contrasting plant architecture, where some new plant-type rice lines tested had higher yield but fewer tillers than the check varieties.

Table 5. AMMI analysis of variance on rice panicle length across three locations

Source of variation	df	SS	MS	F	% GxE explained
Environment (E)	2	863.43	431.72	205.52**	
Replication/E	6	12.60	2.10	0.31	
Genotype (G)	13	469.79	36.14	2.98**	
G×E	26	315.55	12.14	1.82*	
PC1	14	258.67	18.48	2.77**	82.00
PC2	12	56.88	4.74	0.71	18.00
Error	78	520.55	6.67		

Remarks: df=degrees of freedom, SS=sum of square, MS=mean square

Table 6. Correlation among agronomic traits of 14 genotypes across three locations

Trait	PH	SL	NT	PL	FG	EG	WG
SL	0.97**						
NT	-0.77**	-0.71**					
PL	0.86**	0.71**	-0.73**				
FG	0.68**	0.55*	-0.80**	0.81**			
EG	0.31	0.23	-0.42	0.40	0.47		
WG	0.78**	0.75**	-0.82**	0.69**	0.68**	-0.01	
Y	0.46	0.46	-0.26	0.38	0.28	-0.59*	0.67**

Remarks: *, **=significantly different from zero at the 5% and 1% levels, respectively, PH=plant height, SL=stem length, NT=number of tillers, PL=panicle length, FG=number of filled grain per panicle, EG=number of empty grain per panicle, WG=weight of 1000 grains, Y=yield.

Indirect selection for yield could be performed using secondary traits with high heritability and correlated with yield (Bhargava et al., 2021). Hastini et al. (2020) suggested that panicle traits indirectly affect rice production. Rahayu et al. (2018) mentioned that panicle length was correlated with yield; however, such a correlation was not significant in this study (r=0.38, p>0.05) (Table 6). Kartahadimaja et al. (2019) stated that panicle length was correlated with the number of grains per panicle and the weight of 1000 grains. As mentioned above, the latter has a positive and highly significant correlation with yield (Table 6). Therefore, based on these studies, it could be assumed that genotypes with a longer panicle have the potential to have a higher yield. However, it may be essential to consider that genotypes with long and heavy panicles should have sturdy stems to prevent lodging.

CONCLUSION

Environment and genotype main effects significantly influenced rice's agronomic and yield traits. The G×E interaction significantly affected plant height, number of tillers, and panicle length. Plant height, number of filled grains per panicle, the weight of 1000-grains, and yield had high repeatability of greater than 80%. Four genotypes had a significantly higher yield than the check varieties, namely IPB189-F-13-1-1, IPB189-F-23-2-2, IPB193-F-17-2-3, and IPB193-F-30-2-1. The IPB189-F-23-2-2 line also expressed stability for panicle length across the three irrigated lowland locations.

ACKNOWLEDGEMENTS

The research was supported by Ministry of Research and Technology - National Research and Innovation Agency of the Republic of Indonesia, Grant/Award Number: 1/AMD/E1.KP.PTNBH/2020 and IPB Internal Funding through IPB Action Research Grant 2022 [grant number 10287/IT3.L1/PT.01.03/P.B/2022].

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