Journal of Tropical Crop Science Vol. 13 No. 2, June 2026
www.j-tropical-crops.com

Received 9/23/2025; Revised 4/2/2026; Accepted 5/13/2026
https://doi.org/10.29244/jtcs.13.02.467-478

Combined Tall and Short Genotypes Performance of Multi-canopy Rice in Dry and Wet Planting Seasons

Dea Puspamiya Rahayu[1], Willy Bayuardi Suwarno[2], and Hajrial Aswidinnoor*[2]

[1] Plant Breeding and Biotechnology Study Program, Graduate School, IPB University, Indonesia
[2] Department of Agronomy and Horticulture, Faculty of Agriculture, IPB University, Indonesia

*Corresponding author; email: hajrial@apps.ipb.ac.id

Abstract

The productivity of existing rice varieties has plateaued, while the area of rice fields continues to decline and the population continues to grow. Efforts to develop higher-yielding rice varieties have been made, one of which is the development of the multi-canopy rice system. This study aimed to assess the agronomic performance of tall and short rice genotypes in a multi-canopy (MC) system across two planting seasons. This study evaluated 22 MC combinations and two monoculture checks ('Inpari 32' and 'Ciherang') using a randomized complete block design with 3 replications, across dry and wet seasons at IPB University's Babakan station. The results of the study showed that a significant C×S interaction was found only for the number of filled grains (NFG) trait. A better performance is generally observed in the dry season. The best performing combination was D15 (IPB200-F-60 and IPB200-F-12), which produced the highest grain yield of 7.27 tons/ha, outperforming the check varieties. Total number of tillers (TNT), number of productive tillers (NPT), and number of filled grains (NFG) were positively and significantly correlated with yield. MGIDI analysis identified multi-canopy combinations D15, D6, D20, D19, D1, D12, and D9 as potential based on six traits. These combinations should be tested across a wider range of environments to further elucidate the effect of genotype-by-environment interaction.

Keywords: combined analysis, cropping system, MGIDI, multi-canopy, rice breeding

Introduction

Rice (*Oryza sativa* L.) is the staple food for more than 50% of the world's population (Muthayya et al., 2014) and is one of the main food commodities for the Indonesian population. The lack of rice production in Indonesia remains an issue that requires attention (Uwiringiyimana & Antriyandarti, 2025). This is because the area of land available for rice cultivation, particularly the lowland rice ecosystem, is rapidly decreasing. Rice-producing countries face various threats, such as land shortages and environments that are unsuitable for rice growth. Consequently, these countries suffer losses due to declining incomes. According to the Statistic Indonesia (2025), Indonesia's rice production in 2024 reached 53.14 million tons, a decrease of 1.55% compared to 2023.

Considering Indonesia's relatively high population growth rate and the increasing demand for rice, this level of production is worrisome compared with other countries (Fitrawaty et al., 2023; Rozaki, 2020). This continues to drive efforts to increase rice productivity to meet food needs. The stagnation in production growth can be overcome by developing innovations for sustainable rice production, as well as new superior rice varieties to maintain food security in Indonesia (Abdelrahman et al., 2022; Omar et al., 2019; Samsuddin et al., 2023).

The multi-canopy rice system is an innovative breakthrough that focuses on a planting pattern for rice, which is a special version of a varietal mixture involving the simultaneous cultivation of both tall and short genotypes.

Received 9/23/2025; Revised 4/2/2026; Accepted 5/13/2026
https://doi.org/10.29244/jtcs.13.02.467-478

Consequently, the tall and short rice genotypes form tiered canopy strata, resulting in two panicle strata within a single plot. This approach aims to utilize the vertical space above the field, thereby increasing the yield per unit area of land (Hidayah et al., 2022; Widyastuti et al., 2020).

The factors that significantly influence rice productivity include genotype, environment, and the interaction between genotype and environment (G×E). However, rice yield is also affected by agroecosystems and agroclimates. G×E interaction occurs when the responses of genotypes to different levels of environmental stress are inconsistent and can be identified using procedures that evaluate genotypes across multiple environments (Blanche et al., 2009; Sharifi et al., 2017).

Interaction analysis is an approach used to measure the level of genotype response to environmental changes. This is important for further evaluating whether a variety can be recommended for a particular region (Gupta et al., 2022; Saltz et al., 2018; Smith et al., 2021). G×E interaction analysis is generally independent among growth traits and often focuses solely on grain yield per hectare (Brown et al., 2020; Hilmarsson et al., 2021; Roy et al., 2022; Yang, 2014).

G×E interactions can produce diverse responses depending on the capabilities of the genotypes used and the environmental conditions of the cultivation site; the presence of suitable genotypes in a particular environment is indicated by significant G×E interactions. Previous studies have focused on grain yields in different environments. A limited number of studies have reported that G×E interactions indicate that changes in environmental conditions influence each genotype's response to specific traits (He et al., 2017; Jayaningsih et al., 2020; Satoto et al., 2016; Sharifi et al., 2017). This study aimed to evaluate the agronomic performance of selected tall and short rice genotypes in a multi-canopy system to identify potential combinations across two planting seasons.

Materials and Methods

This study was conducted at the Sawah Baru IPB Experimental Farm, Babakan Village, Dramaga District, Bogor. Planting season one was carried out from April 2024 to July 2024 (dry season), and planting season two was carried out from October 2024 to January 2025 (wet season). The research materials consisted of 11 tall and 8 short rice genotypes, along with 2 check varieties, 'Ciherang' and 'Inpari 32', planted in monoculture. These two check varieties were used because they are known to be broadly adaptable across lowland agroecosystems in Indonesia (Sitaresmi et al., 2025).

Tall plants comprised 11 genotypes, and 8 short genotypes resulted in 22 multi-canopy combinations. This study was conducted using a randomized complete block design with 3 replications, plot size of 1.2 × 5 m², (four rows with 20 plants per row). The pairs of multi-canopy rice genotypes used in this study were selected randomly (Table 1). The single factor, genotype, consisted of 22 rice lines planted in a multi-canopy system and 2 check varieties planted in a monoculture system. Thus, there were 72 experimental units. From each experimental unit, 5 plants of each short and tall genotype were sampled.

The experiment involved soil preparation, plowing, harrowing, leveling, and labeling. Before sowing, the seeds were selected by soaking them, and then the selected seeds were planted in seedbeds. Transplanting was carried out when the seedlings were 18-21 days old after sowing (DAS). Seedlings are planted at a spacing of 30 cm × 25 cm (Figure 1). The spacing between tall and short plants in the multi-canopy system is 10 cm. Each planting hole contains 1 seedling. The first fertilization is carried out using a dose of 75 kg/ha urea and 150 kg/ha NPK. The second fertilization is done using a dose of 125 kg/ha of urea and 100 kg/ha of NPK. Seedling thinning is done at 7-14 days after transplanting (DAT). Pest and disease control is done based on symptoms and intensity in the field. During the generative phase, bird netting is installed in the planting area. Harvesting is done after 90%

Received 9/23/2025; Revised 4/2/2026; Accepted 5/13/2026
https://doi.org/10.29244/jtcs.13.02.467-478

of the panicles in a plot have turned yellow and the grains have hardened, followed by threshing and drying.

Data analysis includes a combined analysis of variance over seasons (Sharma, 2003). Post-hoc tests used Tukey's HSD test at a significance level of 0.05. Further analysis included estimation of variance and heritability, phenotypic correlation analysis between traits, and simultaneous selection using the Multi-trait Genotype-Ideotype Distance Index (MGIDI) (Olivoto & Nardino, 2021). Data analysis were performed using Microsoft Excel 2019, SAS On-Demand for Academics (welcome.oda.sas.com), and R-Studio.

Observations were made on the agronomic traits, yield components, and production. Agronomic traits and yield components were recorded from five sampled plants of each plot, whereas production was measured from the whole plot. The total yield was calculated by adding up the total yield of tall and short plants in each plot, then weighing and measuring the moisture content using the following formula:

$$\mathrm{GY} = \frac{\left(\frac{10000}{\mathrm{PS}}\,\mathrm{x}\,\mathrm{GW}\right)\mathrm{x}\left(\frac{100-\mathrm{GMC}}{100-14}\right)}{1000}$$

Where GY is grain yield (tons/ha), PS is plot size (m^2), GW is grain weight per plot (kg), GMC is grain moisture content at harvest (%), and 14 is the final adjustment of 14% grain moisture content.

The observed traits are: (1) grain yield (GY), (2) total number of tillers (TNT), (3) number of productive tillers (NPT), (4) number of filled grains (NFG), (5) total number of grains (TNG), and (6) percentage of empty grains (PEG). For the multi-canopy combination data, GY, TNT, and NPT are the sums of tall and short genotypes, whereas for the traits, NFG, TNG, and PEG are the averages of tall and short genotypes.

Results and Discussion

Combined Analysis of Variance Across Seasons

The results of the combined analysis of variance for tall and short multi-canopy rice genotype combinations planted in two growing seasons are presented in Table 2. Traits that showed significant differences due to season were observed in grain yield (GY), total number of tillers (TNT), number of productive tillers (NPT), number of filled grains (NFG), and percentage of empty grains (PEG). For the total number of grains (TNG) trait, there was no significant effect with respect to the difference in growing seasons, indicating that this trait will produce similar results whether planted in the wet or dry season.

Genotype combinations had significant effects on all observed traits ($p < 0.05$), suggesting genetic variation in multi-canopy rice, with different genotype pairings yielding different yield performance. Combination × season interactions (C×S) were only significant for the NFG trait, indicating that the response of genotype combinations to the season for that trait is inconsistent. Significant C×S effects show that a superior genotype in one season may not necessarily perform well in the other season, or that genotype rankings for certain traits may differ across environments (Jayaningsih et al., 2020). The coefficient of variation (CV%) for multi-canopy genotype combinations ranged from 13.82% to 25.14%.

Replication within the season had a highly significant effect on the number of productive tillers (NPT), the total number of tillers (TNT), and grain yield (GY). This indicates variation among blocks within a season, which could be due to differences in drainage, soil fertility, or other factors. In contrast, the block effect is not significant for the total number of grains (TNG), number of filled grains (NFG), and percentage of empty grains (PEG).

Effects of Season on Agronomic Traits and Yield

The average performance of multi-canopy rice genotypes across planting seasons is shown in Table 3. Almost all traits, except for the total number of grains (TNG), exhibit significant differences ($p < 0.05$) between seasons. The

Received 9/23/2025; Revised 4/2/2026; Accepted 5/13/2026
https://doi.org/10.29244/jtcs.13.02.467-478

average trait values in the dry season are generally higher than in the wet season. Productivity during the rainy season (4.04 tons/ha) was lower than during the dry season (7.04 tons/ha) (Table 3). Higher grain yield observed in the dry season was mainly associated with increased solar radiation and more favorable conditions for photosynthesis, thereby enhancing assimilate production and grain-filling efficiency (Yoshida, 1981). This contrasts with the statements of Sution et al. (2019), who state that the dry season tends to increase environmental stress, which can affect grain filling and reduce yield. In contrast, excessive rainfall during the rainy season likely reduced tiller formation and grain filling by lowering radiation. The total number of grains (TNG) traits showed no significant differences between environments, as indicated

Table 1

The Multi-Canopy Rice Genotype Pairs Used in the Experiment

Combination	Genotype pairs		Combination	Genotype pairs	
	Short	Tall		Short	Tall
D1	IPB201-F-2	PB187-F-40	D12	IPB203-F-3	IPB202-F-3
D2	IPB203-F-2	IPB187-F-40	D13	IPB200-F-43	IPB200-F-19
D3	IPB200-F-60	IPB200-F-46	D14	IPB201-F-2	IPB200-F-19
D4	IPB201-F-1	IPB200-F-46	D15	IPB201-F-2	IPB200-F-12
D5	IPB200-F-60	IPB200-F-48	D16	IPB201-F-1	IPB200-F-12
D6	IPB202-F-1	IPB200-F-48	D17	IPB203-F-1	IPB197-E-1
D7	IPB201-F-1	IPB200-F-51	D18	IPB203-F-2	IPB197-E-1
D8	IPB200-F-43	IPB200-F-51	D19	IPB203-F-1	IPB200-F-13
D9	IPB203-F-1	IPB200-F-52	D20	IPB203-F-3	IPB200-F-13
D10	IPB202-F-1	IPB200-F-52	D21	IPB202-F-1	IPB200-F-20
D11	IPB201-F-2	IPB202-F-3	D22	IPB200-F-43	IPB200-F-20

Note. D1-D22 = multi-canopy combination pairs, short and tall genotypes.

Table 2

Mean Squares From the Combined Analysis of Variance of Multi-Canopy Rice in Two Planting Seasons

Source	df	Traits					
		Grain yield	Total number of tillers	Number of productive tillers	Total number of grains	Number of filled grains	Percentage of empty grains
Seasons (S)	1	319.40^{**}	291.69^{*}	281.96^{*}	1307.45^{ns}	87583.44^{**}	0.03^{*}
Replications/S	4	12.09^{**}	20.97^{*}	15.93^{*}	545.95^{ns}	330.04^{ns}	0.00^{ns}
Combination (C)	23	3.00^{*}	14.58^{**}	13.10^{**}	2973.88^{**}	1012.46^{**}	0.01^{**}
C × S	23	1.95^{ns}	6.00^{ns}	5.85^{ns}	547.17^{ns}	700.50^{*}	0.00^{ns}
Error	92	1.62	6.20	6.23	541.01	353.26	0.00
CV%		22.88	15.28	15.75	13.82	21.63	25.14

Notes. df = degrees of freedom, CV = coefficient of variation, * = significant at the 0.05 level, ** = significant at the 0.01 level, ns = not significant.

Received 9/23/2025; Revised 4/2/2026; Accepted 5/13/2026
https://doi.org/10.29244/jtcs.13.02.467-478

by the use of the same letter notation. Based on these results, it can be assumed that the total number of grains exhibited similar performance between the wet and dry seasons.

Estimation of Genetic Variance and Heritability in Multi-canopy Rice

Heritability is used to estimate the proportion of genetic variation in a trait's total phenotypic variation (Shrestha et al., 2021). The magnitude of the heritability value is a key determinant of the success of a selection program and an indicator of the potential for genetic gain in a specific trait (Zobel & Talbert, 1984). Heritability values are also needed to determine whether a trait is influenced by genetic factors or by environmental factors. Estimated heritability values are categorized as low ($H < 0.20$), medium ($0.20 < H < 0.50$), and high ($H > 0.50$) (Stansfield, 1991).

Based on the analysis of the multi-canopy rice traits observed in Table 4, the evaluated traits showed medium to high heritability, with values ranging from 0.49 to 0.83. This indicates that genetic factors play a dominant role in controlling the phenotypic variation of these traits. These heritability estimates are consistent with the findings of Sholehah et al. (2024), who reported that the number of productive tillers, total tillers, filled grains, and total grains have high heritability values in multi-canopy environments. These results are also consistent with other studies on multi-canopy rice by Riswanto et al. (2025), in which the traits of yield, total tiller number, productive tiller number, total grain number, filled grain number, and percentage of empty grains also exhibit high heritability values. All multi-canopy rice traits observed in Table 4 show high heritability and can be utilized in plant breeding programs, especially in multi-canopy rice, to improve desired traits, particularly the

Table 3

Average Performance of Multi-Canopy Rice Genotype Combinations in Each Planting Season

Environments	Traits					
	Grain yield (tons/ha)	Total number of tillers	Number of productive tillers	Total number of grains	Number of filled grains	Percentage of empty grains
Dry season	7.04^a	17.73^a	17.73^a	171.21^a	111.54^a	0.37^a
Rainy season	4.04^b	14.88^b	14.88^b	165.18^a	62.21^b	0.34^b

Note. Values followed by the same letter in the same column are not significantly different based on the *F* test.

Table 4

Estimation of Variance Components and Broad-Sense Heritability in Multi-Canopy Rice

Traits	σ^2_g	σ^2_{ge}	σ^2_p	σ^2_e	h^2
Grain yield	1.70	1.40	3.49	1.63	0.49
Total number of tillers	10.58	3.94	16.69	6.21	0.63
Number of productive tillers	9.20	3.78	15.25	6.23	0.60
Total number of grains	2609.10	366.84	3153.19	541.01	0.83
Number of filled grains	545.46	582.75	1072.34	353.26	0.51
Percentage of empty grains	0.02	0.00	0.02	0.01	0.69

Notes. σ^2_g= genetic variance, σ^2_{ge}= genotype × environment variance, σ^2_p= phenotypic variance, σ^2_e= environmental variance, h^2 = broad-sense heritability on entry-mean basis. Values followed by the same letter in the same column are not significantly different based on the HSD test at the 0.05 level.

traits of total number of tillers (TNT), number of productive tillers (NPT), total number of grains (TNG), and number of filled grains (NFG).

Performance of Multi-canopy Rice Genotype Combinations in Two Seasons

The mean values of 22 multi-canopy rice genotype combinations and two monoculture check varieties across two planting seasons are shown in Table 5, revealing significant differences and variability among the multi-canopy rice genotype combinations. Combination D15 shows the highest genotype combination for the grain yield (GY) (7.27 tons/ha), while the lowest value is found in combination D4 (4.34 tons/ha).

The trait of total tiller number (TNT) is highest in combinations D3 (19.26) and D15 (19.16), and the lowest in D2 (13.80) and D17 (13.80). The productive tiller number trait also records the highest values in D3 (18.86) and D15 (18.63), with the lowest in D2 (13.13), D17

Table 5

Average Performance of Multi-Canopy Rice Genotype Combinations Across Two Planting Seasons

Genotype combination	Traits					
	Grain yield (tons/ha)	Total number of tillers	Number of productive tillers	Total number of grains	Number of filled grains	Percentage of empty grains
D1	5.56^{ab}	16.16^{ab}	15.93^{ab}	199.69^{ab}	106.45^{ab}	0.42^{ab}
D2	5.15^{ab}	13.80^{b}	13.13^{b}	223.53^{a}	120.38^{a}	0.40^{ab}
D3	6.02^{ab}	19.26^{a}	18.86^{a}	132.29^{e}	70.04^{b}	0.32^{ab}
D4	4.34^{b}	16.80^{ab}	16.06^{ab}	155.71^{bcde}	77.72^{b}	0.34^{ab}
D5	4.88^{ab}	16.50^{ab}	15.96^{ab}	145.16^{cde}	69.80^{b}	0.36^{ab}
D6	5.70^{ab}	18.47^{ab}	17.16^{ab}	168.49^{bcde}	90.74^{ab}	0.39^{ab}
D7	5.58^{ab}	15.13^{ab}	14.70^{ab}	184.46^{abcd}	98.02^{ab}	0.45^{a}
D8	6.00^{ab}	15.26^{ab}	15.76^{ab}	172.71^{bcde}	94.90^{ab}	0.39^{ab}
D9	5.12^{ab}	17.10^{ab}	16.80^{ab}	196.25^{ab}	97.17^{ab}	0.37^{ab}
D10	6.95^{ab}	16.90^{ab}	16.03^{ab}	137.88^{de}	68.53^{b}	0.38^{ab}
D11	4.73^{ab}	14.50^{ab}	14.40^{ab}	176.42^{abcde}	87.42^{ab}	0.31^{ab}
D12	5.25^{ab}	17.30^{ab}	16.80^{ab}	168.51^{bcde}	85.95^{ab}	0.41^{ab}
D13	5.53^{ab}	16.93^{ab}	16.81^{ab}	159.95^{bcde}	83.43^{ab}	0.36^{ab}
D14	6.28^{ab}	15.20^{ab}	14.40^{ab}	178.18^{abcde}	91.23^{ab}	0.29^{ab}
D15	7.27^{a}	19.16^{ab}	18.63^{a}	152.16^{bcde}	67.82^{b}	0.32^{ab}
D16	5.75^{ab}	15.00^{ab}	14.73^{ab}	150.15^{bcde}	77.12^{b}	0.29^{ab}
D17	5.29^{ab}	13.80^{b}	13.46^{ab}	193.26^{abc}	98.47^{ab}	0.38^{ab}
D18	5.48^{ab}	14.63^{ab}	13.96^{ab}	186.56^{abcd}	93.87^{ab}	0.36^{ab}
D19	5.99^{ab}	17.03^{ab}	16.50^{ab}	177.28^{abcde}	96.18^{ab}	0.39^{ab}
D20	5.73^{ab}	17.13^{ab}	16.20^{ab}	171.69^{bcde}	85.84^{ab}	0.46^{a}
D21	5.55^{ab}	16.90^{ab}	16.36^{ab}	160.35^{bcde}	83.28^{ab}	0.27^{ab}
D22	5.69^{ab}	17.76^{ab}	17.36^{ab}	161.98^{bcde}	89.84^{ab}	0.28^{ab}
INP 32	4.61^{ab}	14.33^{ab}	14.33^{ab}	145.62^{cde}	78.91^{b}	0.23^{b}
CHG	4.38^{b}	16.26^{ab}	15.70^{ab}	138.35^{de}	71.90^{b}	0.30^{ab}

Note. Values followed by the same letter in the same column are not significantly different based on the HSD test at the 0.05 level.

Received 9/23/2025; Revised 4/2/2026; Accepted 5/13/2026
https://doi.org/10.29244/jtcs.13.02.467-478

(13.46), and D18 (13.96). Combinations D3 and D15 show high values for both the total number of tillers (TNT) and the number of productive tillers (NPT), indicating that a high number of tillers correlates with a high number of productive tillers in these genotypes, suggesting they may be high-yielding.

Combination D2 has the highest value for total grain number (TNG) (223.53) and number of filled grains (NFG) (120.38). The lowest values are found in D3 (132.29) and D15 (67.82). The percentage of empty grains (PEG) is highest in combination D20 (0.46) and lowest in the check variety 'Inpari 32' (0.23).

Yield of Tall and Short Genotypes in Two Seasons

Figure 2 presents the average productivity data for short genotypes, tall genotypes, and multi-canopy combinations. The short genotypes (IPB203-F-1, IPB201-F-2, IPB203-F-2, IPB203-F-3, IPB202-F-1, IPB201-F-1, IPB200-F-60, and IPB200-F-43) show productivity variations ranging from 1.96 tons/ha to 3.76 tons/ha in two planting seasons.

The tall genotypes (IPB187-F-40, IPB200-F-46, IPB200-F-48, IPB200-F-51, IPB200-F-52, IPB202-F-3, IPB200-F-19, IPB200-F-12, IPB197-E-1, IPB200-F-13, and IPB200-F-20) have a higher productivity range than the short genotypes, ranging from 2.38 to 4.47 tons/ha. This is assumed to be due to taller plants' greater ability to capture sunlight compared to shorter genotypes. Optimal canopy structure can increase light interception, thus increasing photosynthetic capacity (Cao et al., 2021). The best performing short genotype is IPB202-F-1 in combination D10 (3.76 tons/ha), while the best performing tall genotype

Figure 1

Illustration of Multi-Canopy Rice Planting (A) and Monoculture (B)

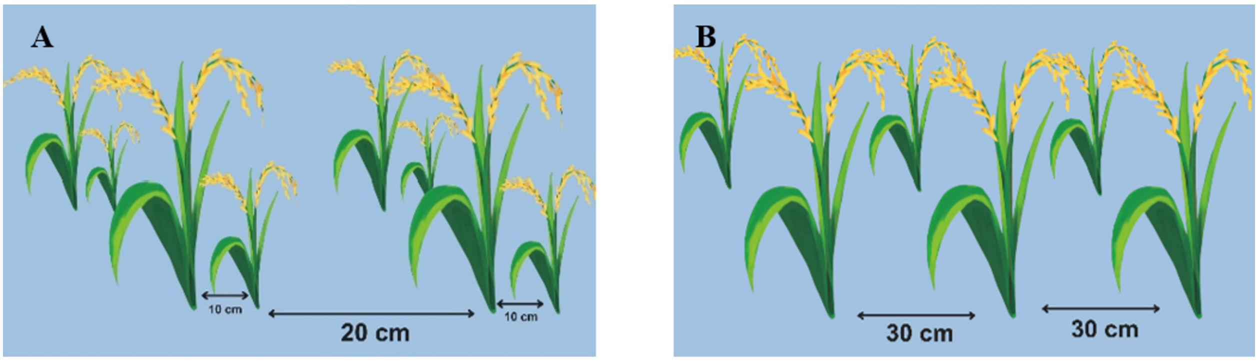
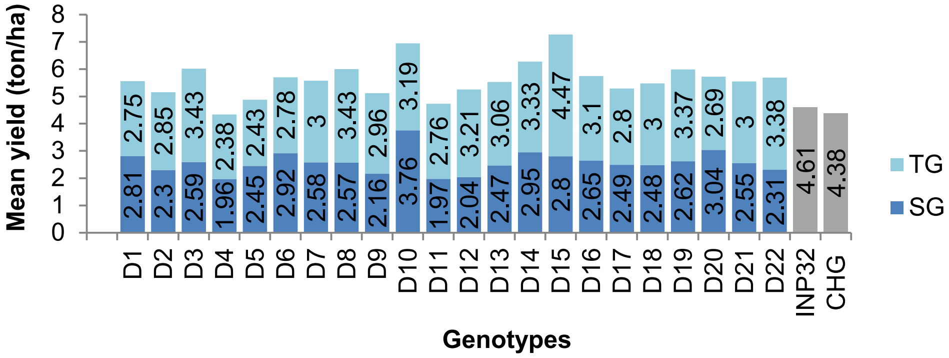


Figure 2

Grain Yield of Short Genotype (SG) and Tall Genotype (TG) of Multi-Canopy Rice as Compared with Two Check Varieties ('Inpari 32' and 'Ciherang') in Monoculture



Received 9/23/2025; Revised 4/2/2026; Accepted 5/13/2026
https://doi.org/10.29244/jtcs.13.02.467-478

is IPB200-F-12 in combination D15, with an average productivity of 4.47 tons/ha.

The best multi-canopy combination is D15, with an average yield of 7.27 tons/ha, the highest among the combinations. When compared to the productivity of the monoculture control varieties ('Inpari 32' at 4.61 tons/ha and 'Ciherang' at 4.38 tons/ha), the multi-canopy combinations generally outperform the controls. The multi-canopy system has significant potential to increase yields, but this depends on the genotype combinations used. Multi-canopy cultivation also enables short plants to absorb adequate light beneath the tall genotypes, while tall plants continue to perform optimally above, meaning tall genotypes achieve high productivity without inhibiting the short ones, and short genotypes can still photosynthesize efficiently in the shade below (Widyastuti et al., 2020).

Correlation Among Traits in Multi-canopy Rice

Correlation analysis aims to understand the relationships among the observed traits. The results of the correlation analysis also serve as a reference for determining selection traits. Correlations among traits can help explain how improving one trait can lead to simultaneous changes in others (Shrestha et al., 2021). The results of the phenotypic correlation analysis presented in Figure 3 demonstrate highly significant correlations between total tiller number (TNT), productive tiller number (NPT), and filled grain number (NFG) and grain yield (GY), ranging from 0.47 to 0.56. Traits with high and significant correlation coefficients with grain yield (GY) should be considered in trait selection.

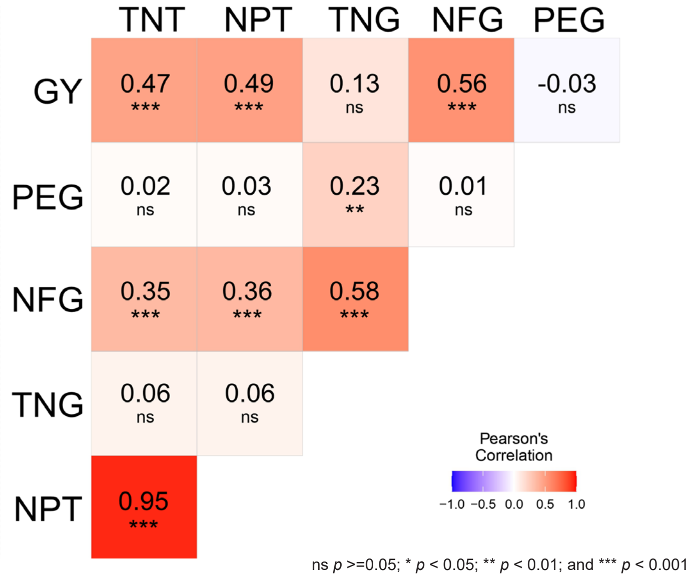
Selection will be more effective when the correct selection traits are used and when there is a significant relationship among those traits (Aryana, 2009). Traits that are significantly or highly correlated with grain yield (GY) can be considered when selecting traits, as it is expected that selected genotypes will have high yields and good performance and yield components.

Multi-trait Selection of Multi-canopy Combinations

The Multi-trait Genotype-Ideotype Distance Index (MGIDI) is a method for

Figure 3

Phenotypic Correlation Among Traits in Multi-Canopy Rice



	TNT	NPT	TNG	NFG	PEG
GY	0.47 ***	0.49 ***	0.13 ns	0.56 ***	-0.03 ns
PEG	0.02 ns	0.03 ns	0.23 **	0.01 ns	
NFG	0.35 ***	0.36 ***	0.58 ***		
TNG	0.06 ns	0.06 ns			
NPT	0.95 ***				

ns p >=0.05; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$

Notes. GY = grain yield, PEG = percentage of empty grains, NFG = number of filled grains, TNG = total number of grains, NPT = number of productive tillers.

Received 9/23/2025; Revised 4/2/2026; Accepted 5/13/2026
https://doi.org/10.29244/jtcs.13.02.467-478

selecting the best genotypes across multiple traits by comparing them to an ideal ideotype or desired ideal genotype. Specifically, MGIDI ranks genotypes based on their Euclidean distance from an ideal ideotype, which is defined by combining desirable values across multiple traits (Olivoto & Nardino, 2021). Each genotype is evaluated simultaneously for all traits, and genotypes with shorter distances to the ideotype are considered more desirable. This approach allows for the selection of genotypes with balanced and superior multi-trait performance rather than optimization of a single trait (Debnath et al., 2024). The MGIDI selection results are presented in Figure 4.

The results of the MGIDI analysis present genotype rankings based on trait values described in the ideotype. This selection is expected to yield plant ideotypes with a high total number of tillers, a large number of productive tillers, a high number of filled grains, a high total number of grains, high productivity, and a low percentage of empty grains. Through selection with MGIDI, seven genotypes have been identified with traits closest to the ideotype: D15, D6, D20, D19, D1, D12, and D9. The genotypes

Figure 4

Multi-trait Selection of Genotype Combinations and Check Varieties Using MGIDI

Received 9/23/2025; Revised 4/2/2026; Accepted 5/13/2026
https://doi.org/10.29244/jtcs.13.02.467-478

selected in two seasons indicate that they have good yield and agronomic performance under both wet and dry conditions. The selected multi-canopy combinations have productivity ranging from 5.12 to 7.27 tons/ha. The productivity of these selected genotype combinations is higher than that of the check varieties, which have an average productivity of 4.38 to 4.61 tons/ha. The yield potential of these multi-canopy combinations is considered promising for further development, as they can compete with or perform as well as the widely cultivated check varieties in Indonesia.

The MGIDI method allows the interpretation of the strengths and weaknesses of the selected genotypes. The closer a factor line is to the outer edge, the less proportion it explains and the closer it is to the desired ideotype (Nardino et al., 2022). The factor contribution plot (Figure 4) is used to evaluate the strengths and weaknesses of each genotype as well as the proportion of each factor in the MGIDI value for each multi-canopy genotype combination. Genotypes with the lowest contribution are considered the best because they most closely resemble the desired ideotype. Factor analysis showed that factor 1 (FA1) consists of the traits total number of tillers (TNT), number of productive tillers (NPT), and grain yield (GY). Factor 2 (FA2) consists of the traits number of filled grains (NFG), total number of grains (TNG), and percentage of empty grains (PEG). Factor 1 (FA1) shows strengths in the D15 combination. This indicates that the variety performs well in the traits TNT, NPT, and GY. Factor 2 (FA2) shows strengths in the D1 combination, indicating that this genotype performs well on the traits NFG, TNG, and PEG.

This study provides evidence that combining genotypes with contrasting canopy architectures can improve yield performance. Although this study was conducted on rice, the multi-canopy system may be applicable to other crops. These factors still need to be considered, such as light interception, canopy stratification, and competitive interactions among genotypes. However, further studies are required to validate these responses in different crops and environments.

Conclusions

The D15 combination (IPB200-F-60 & IPB200-F-12) emerged as the highest-yielding genotype, with the highest productivity reaching 7.27 tons/ha. Estimates of heritability were categorized as high for all traits. Correlation analysis identified the total number of tillers (TNT), the number of productive tillers (NPT), and the number of filled grains (NFG) as traits influencing productivity. Multi-trait selection using MGIDI placed the multi-canopy combinations D15, D6, D20, D19, D1, D12, and D9 as the closest to the desired ideotype, with strengths in productivity traits and yield components.

Acknowledgement

The works supported by the Directorate General of Higher Education, Research, and Technology of the Ministry of Education, Culture, Research, and Technology, Republic of Indonesia, contract number 027/E5/PG.02.00.PL/2024, and the National Research and Innovation Agency (BRIN) and LPDP of the Republic of Indonesia through the RIIM BATCH III, under grant number 4/IV/KS/05/2023 and 13955/IT3/PT.01.03/P/B/2023, as part of the first-year funding. Data analysis and manuscript preparation were supported by the second-year funding of the same grants, awarded to HA.

References

Abdelrahman, M. A. E., Engel, B. S. M., Eid, M. M., & Aboelsoud, H. (2022). A new index to assess soil sustainability based on temporal changes of soil measurements using geomatics: An example from El-Sharkia, Egypt. *All Earth, 34*(1), 147–166. https://doi.org/10.1080/27669645.2022.2103953

Aryana, I. G. P. M. (2009). Adaptasi dan stabilitas hasil galur-galur padi beras merah pada tiga lingkungan tumbuh. *Indonesian Journal of Agronomy, 37*(2), 95–100.

Blanche, S. B., Utomo, H. S., Wenefrida, I., & Myers, G. O. (2009). Genotype ×

Received 9/23/2025; Revised 4/2/2026; Accepted 5/13/2026
https://doi.org/10.29244/jtcs.13.02.467-478

environment interaction of hybrid and varietal rice cultivars for grain yield and milling quality. *Crop Science, 49*(6), 2011–2018.

Brown, D., Van den Bergh, I., De Bruin, S., Machida, L., & Van Etten, J. (2020). Data synthesis for crop variety evaluation: A review. *Agronomy for Sustainable Development, 40*(6), 1–20. https://doi.org/10.1007/s13593-020-00630-7

Cao, Y. J., Wang, L. C., Gu, W. R., Wang, Y. J., & Zhang, J. H. (2021). Increasing photosynthetic performance and post-silking N uptake by moderately decreasing the leaf source of maize under high planting density. *Journal of Integrative Agriculture, 20*, 494–510. https://doi.org/10.1016/S2095-3119(20)63378-0

Debnath, P., Chakma, K., Bhuiyan, M. S. U., Thapa, R., Pan, R., & Akhter, D. (2024). A novel multi-trait genotype ideotype distance index (MGIDI) for genotype selection in plant breeding: Application, prospects, and limitations. *Crop Design, 3*(4), 1–10. https://doi.org/10.1016/j.cropd.2024.100074

Fitrawaty, Hermawan, W., Yusuf, M., & Maipita, I. (2023). A simulation of increasing rice price toward the disparity of income distribution: Evidence from Indonesia. *Heliyon, 9*(3), 1–14. https://doi.org/10.1016/j.heliyon.2023.e13785

Gupta, V., Kumar, M., Singh, V., Chaudhary, L., Yashveer, S., & Sheoran, R. (2022). Genotype by environment interaction analysis for grain yield of wheat (*Triticum aestivum* L.) genotypes. *Agriculture, 12*(7), 1–15. https://doi.org/10.3390/agriculture12071002

He, D., Wang, E., Wang, J., & Lilley, J. M. (2017). Genotype × environment × management interaction of canola across China: A simulation study. *Agricultural and Forest Meteorology, 247*, 424–433. https://doi.org/10.1016/j.agrformet.2017.08.027

Hidayah, U. F., Suwarno, W. B., & Aswidinnoor, H. (2022). Genotype by environment analysis on multi-canopy cropping system in rice: Effects of different types of flag leaves. *Agronomy Journal, 114*(1), 1–10. https://doi.org/10.1002/agj2.20959

Hilmarsson, H. S., Rio, S., & Sánchez, J. I. (2021). Genotype by environment interaction analysis of agronomic spring barley traits in Iceland using AMMI, factorial regression model and linear mixed model. *Agronomy, 11*(3), 1–15. https://doi.org/10.3390/agronomy11030499

Listiyanto, R. (2023). *Uji daya hasil pendahuluan 35 galur padi (Oryza sativa L.) generasi F5 dan F6 sebagai genotipe pendek galur multikanopi* [Skripsi, IPB University] IPB University Repository.

Muthayya, S., Sugimoto, J. D., Montgomery, S., & Maberly, G. F. (2014). An overview of global rice production, supply, trade, and consumption. *Annals of the New York Academy of Sciences, 1324*(1), 7–14. https://doi.org/10.1111/nyas.12540

Olivoto, T., Diel, M. I., Schmidt, D., & Lucio, A. D. (2022). MGIDI: A powerful tool to analyze plant multivariate data. *Plant Methods, 18*(121), 1–13. https://doi.org/10.1186/s13007-022-00952-5

Olivoto, T., & Nardino, M. (2021). MGIDI: Toward an effective multivariate selection in biological experiments. *Bioinformatics, 37*(10), 1383–1389. https://doi.org/10.1093/bioinformatics/btaa981

Omar, S. C., Shaharudin, A., & Tumin, S. A. (2019). *The status of the paddy and rice industry in Malaysia*. Khazanah Research Institute.

Riswanto, A. (2025). *Analisis daya pasang genotipe dan seleksi multi-karakter pada padi multi-kanopi* [Undergraduate thesis, IPB University]. IPB University Repository.

Roy, D., Gaur, A. K., & Pandey, I. D. (2022). Estimation of G×E interaction by AMMI model in 'antenna panel' genotypes of rice (*Oryza sativa* L.). *Brazilian Archives of Biology and Technology, 65*, 1–14. https://doi.org/10.1590/1678-4324-2022220202

Rozaki, Z. (2020). COVID-19, agriculture, and food security in Indonesia. *Review of Agricultural Science, 8*, 243–261. https://

Received 9/23/2025; Revised 4/2/2026; Accepted 5/13/2026
https://doi.org/10.29244/jtcs.13.02.467-478

doi.org/10.7831/ras.8.0_243

Saltz, J. B., Bell, A. M., Flint, J., Gomulkiewicz, R., Hughes, K. A., & Keagy, J. (2018). Why does the magnitude of genotype-by-environment interaction vary? *Ecology and Evolution, 8*, 6342–6353. https://doi.org/10.1002/ece3.4128

Samsuddin, S. S., Abdul Maulud, K. N., Sharil, S. A., Karim, O., & Pradhan, B. (2023). Monitoring of three stages of paddy growth using a multi-spectral vegetation index derived from UAV images. *Egyptian Journal of Remote Sensing and Space Science, 26*(4), 989–998. https://doi.org/10.1016/j.ejrs.2023.11.005

Satoto, Rumanti, I. A., & Widyastuti, Y. (2016). Yield stability of new hybrid rice across locations. *Agrivita Journal of Agricultural Science, 38*(1), 33–39. https://doi.org/10.17503/agrivita.v38i1.675

Sharifi, P. H., Aminpanah, R., Erfani, A., Mohaddesi, A., & Abbasian. (2017). Evaluation of genotype × environment interaction in rice based on the AMMI model in Iran. *Rice Science, 24*(3), 173–180. https://doi.org/10.1016/j.rsci.2017.05.002

Shrestha, J., Subedi, S., Subedi, N. R., Subedi, S., Kushwaha, U. K. S., Maharjan, B., & Subedi, M. (2021). Assessment of variability, heritability, and correlation in rice (*Oryza sativa* L.) genotypes. *Natural Resources for Sustainable Development, 11*(2), 181–192. https://doi.org/10.31924/nrsd.v11i2.077

Sholehah, M., Suwarno, W. B., Hapsari, V. P., Sulistyo, N. N., Marwiyah, S., & Aswidinnoor, H. (2024). Rice breeding for multi-canopy system: Estimations of genetic parameters and response to selection. *Agronomy Journal, 116*(5), 2129–2140. https://doi.org/10.1002/agj2.21629

Sitaresmi, T., Barokah, U., Mulyani, E., & Nugroho, R. J. (2025). Growth responses of superior varieties of rice in South Coast of Kebumen Regency. *Akta Agrosia, 28*(1), 1–7. https://doi.org/10.31186/aa.28.1.1-7

Smith, A., Norman, A., Kuchel, H., & Cullis, B. (2021). Plant variety selection using interaction classes derived from factor analytic linear mixed models: Models with independent variety effects. *Frontiers in Plant Science, 12*, 1–17. https://doi.org/10.3389/fpls.2021.737462

Stansfield, W. (1991). *Schaum's outline of theory and problems of genetics* (3rd ed.). McGraw-Hill.

Statistic Indonesia. (2025). *Luas panen dan produksi padi Indonesia 2024*. BPS-Statistics Indonesia. https://www.bps.go.id/id/pressrelease/2025/02/03/2414/pada-2024-luas-panen-padi-mencapai-sekitar-10-05-juta-hektare-dengan-produksi-padi-sebanyak-53-14-juta-ton-gabah-kering-giling-gkg-.html

Sution, S., Sugiarti, T., Hartono, H., & Lehar, L. (2019). Pengaruh dua musim tanam berbeda dan beberapa varietas terhadap pertumbuhan dan produktivitas padi gogo. *Agriekstensia, 18*(1), 24–31. https://doi.org/10.34145/agriekstensia.v18i1.24

Uwiringiyimana, X., & Antriyandarti, E. (2025). Declining rice production in Indonesia: A case study of Central Java, challenges and food security strategies. *Journal of Scientific Reports, 9*(1), 177–192. https://doi.org/10.58970/JSR.1103

Widyastuti, L. P. Y., Suwarno, W. B., & Aswidinnoor, H. (2020). Genotype by environment analysis on a multi-canopy cropping system towards vertical harvest space in rice. *Agronomy Journal, 112*(6), 4568–4577. https://doi.org/10.1002/agj2.20405

Yang, R. C. (2014). Analysis of linear and non-linear genotype × environment interaction. *Frontiers in Genetics, 5*, 1–7. https://doi.org/10.3389/fgene.2014.00227

Yoshida, S. (1981). *Fundamentals of rice crop science*. International Rice Research Institute.

Zobel, B. J., & Talbert, J. T. (1984). *Applied forest tree improvement*. John Wiley & Sons.