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Yield stability potential of IPB 9G and IPB 3S varieties in paddy and dry systems

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ABSTRACT
Limited water availability due to climate change significantly challenges the increase in rice production. One effective way to address this issue is by selecting rice varieties that thrive under well-watered and water-scarce conditions. This study aimed to determine the morphophysiological responses and yield of rice varieties in paddy and dry cultivation systems. The experiment involved cultivating rice using two different systems: paddy and dry systems. A one-factor randomized complete block design was employed, with three replications. Lowland and upland rice varieties (IPB 3S and IPB 9G) were used. These varieties were planted in both paddy fields and dryland. IPB 3S and IPB 9G had different responses to the conditions of the paddy field and dry systems. The dry system decreased morphological, physiological, and crop yield characteristics compared to the paddy field system. IPB 3S had a higher photosynthesis rate, and IPB 9G had a higher crop yield. IPB 3S and IPB 9G were moderately drought-tolerant varieties, with drought sensitivity index values of 0.69 and 0.71, respectively. They also demonstrated yield stability, with values of 0.67 for IPB 3S and 0.68 for IPB 9G. Overall, IPB 3S and IPB 9G have the potential to produce high and stable yields in both paddy and dry systems.

Keywords: Climate change, Drought stress, Rice production.

Potencial de estabilidade de produção das variedades IPB 9G E IPB 3S em sistemas de arroz irrigado e sequeiro

RESUMO
A disponibilidade limitada de água devido às mudanças climáticas desafia significativamente o aumento da produção de arroz. Uma maneira eficaz de abordar esse problema é selecionar variedades de arroz que prosperam em condições irrigadas ou não irrigadas. Esta pesquisa teve como objetivo avaliar as respostas morfofisiológicas e os rendimentos das variedades de arroz em sistemas de cultivo de arroz irrigado e sequeiro. O delineamento em blocos casualizados completos (RCBD) de um fator foi empregado para o estudo, com três repetições. Variedades de arroz de terras baixas e altas (IPB 3S e IPB 9G) foram usadas. Essas variedades foram plantadas em campos de arroz irrigado e em áreas não irrigadas. As variedades IPB 3S e IPB 9G responderam diferentemente às condições testadas. As características morfológicas, fisiológicas e de rendimento da cultura em cultivo de sequeiro foram piores em comparação ao sistema irrigado. IPB 3S apresentou a maior na taxa de fotossíntese, enquanto IPB 9G obteve o maior rendimento. IPB 3S e IPB 9G são variedades moderadamente tolerantes à seca, com valores de índice de sensibilidade à seca (DSI) de 0,69 e 0,71, respectivamente. Elas também demonstraram valores de estabilidade de rendimento com IPB 3S em 0,67 e IPB 9G em 0,68. No geral, IPB 3S e IPB 9G têm o potencial de produzir rendimentos altos e estáveis nos sistemas de cultivo de arroz testados.

Palavras-chave: Mudança climática, Estresse por seca, Produção de arroz.

1. Introduction

Rice (*Oryza sativa* L.) is a vital food crop consumed by nearly all Indonesians and over half of the world's population. In Indonesia, rice consumption reaches approximately 22,639,224 tons annually, translating to a per capita consumption of 81.23 kg annually in 2023 (BPS, 2024). As the population continues to grow, rice productivity must also increase. However, this productivity is often hampered by environmental stress, particularly water scarcity, which is exacerbated by various factors, including climate change. Driven by global climate change, water shortages in agriculture significantly impact crop yields (Zhang et al., 2022). One of the most effective strategies for addressing this issue is the selection of rice varieties that can adapt to a range of land conditions, whether in rice paddies or drylands. There is a pressing need for varieties that exhibit stable high yields and adaptability across diverse environments, particularly in countries with high rice consumption (Akter and Hassan, 2014).

Indonesia has a total of 7.43 million hectares of rice fields, including 4.1 million hectares of irrigated rice and 3.3 million hectares of rainfed rice fields, encompassing 0.7 million hectares of tidal and 0.4 million hectares of lowland areas (Mulyani et al., 2022). Furthermore, there are approximately 144.7 million hectares of dry land, although its utilization remains suboptimal (BRIN, 2024). Most rice production originates from rice fields, with only 1.5% produced from dry land (BPS, 2022). Effective rainfed and dry land management is essential for boosting food production, particularly rice, and for supporting the national rice self-sufficiency initiative. Both rainfed rice fields and dry land hold significant potential for enhancing rice production (Hussain et al., 2021).

Water deficit considerably impacts the morphology, physiology, and molecular activities of rice plants, resulting in delayed flowering, reduced distribution and allocation of dry matter, and decreased photosynthetic capacity due to stomatal closure (Farooq et al., 2009). An early indicator of diminishing soil water content is leaf rolling, which decreases the solar radiation captured by the leaves. IPB 3S and IPB 9G are rice varieties developed by Institut Pertanian Bogor University, both of which have received distribution permits from the Indonesian Minister of Agriculture. IPB 3S is characterized as lowland rice, whereas IPB 9G is an amphibious variety that thrives on dry land but can also be cultivated in paddy fields. Understanding the morphological and physiological responses of these varieties in paddy and dry systems is crucial for evaluating their production potential in these environments. This study aimed to analyze the morphological, physiological, and yield responses of these rice varieties in different growing systems and identify their capacities for stable yields under both paddy and dry cultivation systems.

2. Material and Methods

This research was conducted in Lampung Province, Indonesia, from December 2022 to April 2023. The location is at 5° 21′ 47.96″ S, 105° 13′ 4.41″ E. The soil is classified as ultisol. Soil analysis was performed in rice fields, showing a total organic matter of 14.7%, available phosphorus of 675.55 mg/kg, available potassium of 459.22 mg/Kg, total nitrogen of 0.15%, and a soil pH of 6.48. Dry land revealed the following properties: total organic matter, 13.36%; available phosphorus, 616.88 mg/kg; available potassium, 188.02 mg/kg; total nitrogen, 0.16%; and soil pH, 7.33.

The rice varieties used in the study were IPB 3S and IPB 9G. Fertilization was carried out using urea, super phosphate-36, and potassium chloride fertilizers. Table 1 presents the environmental conditions during the study period. The average temperature and relative humidity were suitable for plant growth. However, the rainfall was insufficient compared to the plants' needs, indicating a water shortage in the research location, which operated under a dry system.

The experiment involved cultivating rice using two different systems: paddy fields and dry systems. A one-factor randomized complete block design was employed for the study, focusing on rice varieties with three replications. The planting distance was set at 20 × 25 cm in the paddy field system and 50 × 10 cm for the dry system. The transplanting method was utilized in the paddy field system, with two 19-day-old rice seedlings placed in each planting hole. In contrast, the dry system employed direct seed planting, with five rice seeds per hole. The paddy fields used were artificial, consisting of ponds with tarpaulin bases filled with soil and irrigated with water from the irrigation system. The dry land used was a former corn field without irrigation water that relies solely on rainwater as its water source. The distance between the rice fields and dry land was approximately 100 m.

Fertilization was conducted using 250 kg ha^{-1} urea fertilizer, 100 kg ha^{-1} super phosphate, and 100 kg ha^{-1} potassium chloride, following the recommendations of Balitbangtan (2020). All doses of super phosphate-36 (36% of P_2O_5) and potassium chloride fertilizers (60% of K_2O) and half a dose of urea (46% of N) were applied at 7 days after transplanting (DAT) or 28 days after sowing (DAS). The dry system was fertilized 21 days after planting (DAP). Subsequent fertilization was carried out using half a dose of urea at 28 DAT or 47 DAS for the paddy field system and at 47 DAP for the dry system.

Table 1. Weather conditions at the experimental site on December 2022–April 2023.

Weather Parameter	Dec 22	Jan 23	Feb 23	Mar 23	Apr 23
Temperature Max (°C)	29.0	28.2	28.4	28.7	28.9
Temperature Min (°C)	23.8	23.8	23.7	24.1	24.4
Temperature (°C)	26.0	25.7	25.8	26.1	26.3
Relative Humidity (%)	84.3	86.9	85.8	86.7	86.5
Precipitation (mm/month)	215.5	310.5	205.4	261.3	107.1
Precipitation (mm/day)	6.95	10.0	7.3	86.6	3.5

Source: NASA Power Project (2025).

Rice plants were sprayed five times with Fastac and Amistartop pesticides. Rice was harvested when rice grains were 90% ripe.

This study assessed morphological characteristics, including plant height, total number of tillers, productive tiller ratio, and flowering age. Physiological traits, such as photosynthesis rate, transpiration rate, stomatal conductance, and plant growth rate, and yield variables, such as panicle length, number of grains per panicle, 1000-grain weight, percentage of empty grains, harvest yield, and non-structural carbohydrate (NSC) content, were measured. Physiological variables were measured using a LICOR 6800 XT between 09:00 AM and 11:00 AM (Western Indonesian Time), specifically on the most optimally growing part of the leaf at 60 DAP. Harvest measurements were conducted. NSC analysis was performed at 60 DAP following the method outlined by Longland and Byrd (2006).

The drought sensitivity index (DSI) was calculated using the formula developed by Fischer and Maurer (1978) as follows:

$$\mathrm{DSI} = \frac{(1 - \frac{Y}{Yp})}{(1 - \frac{X}{Xp})}$$

Where:
DSI: drought sensitivity index
Y: genotype with drought
Yp: genotype without drought
X: all genotypes with drought
Xp: all genotypes without drought

The criteria for determining the level of tolerance to drought stress were as follows: DSI ≤ 0.5 indicates that the variety is tolerant; 0.5 < DSI ≤ 1.0 indicates moderate tolerance; and DSI > 1.0 indicates sensitivity.

The estimation of adaptability and yield stability was calculated based on the regression coefficient of Finlay and Wilkinson (1963), as follows:

$$\mathrm{bi} = \frac{\sum j\,(Yij - Yi.)(Y.j - Y)}{\sum j\,(Y.j - Y)2}$$

Where:
bi: regression coefficient
Yij: average yield of variety i in environment j
Yi.: average yield of variety i in all environments
Y.j: average of all varieties in environment J
Y: average of all environment indexes

The values bi = 1, bi < 1, and bi > 1 indicate average, high, and low stability. Varieties with regression coefficient values approaching or equal to 1 and a higher average yield than the general average indicates that the variety adapts to all environments.

The dataset was analyzed using an independent t-test at a significance level of 5% ($p < 0.05$) to compare rice characteristics between paddy fields and dry lands. Data analysis was performed using the R studio application version 4.5.0.

3. Results and Discussion

Morphological and physiological responses of the IPB 9G and IPB 3S rice varieties are presented in Table 2. Both varieties showed a significantly reduced plant height under dry conditions, as indicated by the t-test. The decrease in plant height for IPB 3S was 19.56%, compared to a 16.85% reduction for IPB 9G. This aligns with the findings of Vatanee et al. (2023), who reported that all rice varieties grown in dry land exhibited a reduction in height. Pratiwi et al. (2018) noted that differences in plant genotype affect plant height. Each genotype responds differently to water scarcity, leading to varying height reductions among varieties. The lower decrease in plant height observed in IPB 9G suggests that it may be more tolerant to water stress. However, the reductions in height in this study were still less severe than the 31.8% decrease observed in mutant rice plants subjected to drought stress, as reported by Huang et al. (2019).

A significant decrease occurred in the ratio of productive tillers to total tillers in the two rice varieties in the dry system compared to the paddy system. This ratio decreased by 30% in IPB 3S and by 20.3% in IPB 9G. IPB 3S showed a higher decrease than IPB 9G. The number of productive tillers is important because it is correlated with yield. Water shortages in dry lands cause a significant decrease in tillers (Konate et al., 2022). When rice experiences water shortage, there is a decrease in the number of productive tillers and panicles (Gaballah et al., 2022).

Varieties IPB 3S and IPB 9G significantly delayed flowering. Flowering age was delayed in the dry system compared to the paddy system. IPB 9G had a longer delay than IPB 3S, with delays of −11.86 and −8.73%, respectively. According to Huang et al. (2019), the SN265 variety delayed flowering by 8.8% during drought. The flowering delay was due to a lack of water during the growth period. Fischer and Fukai (2003) stated that rice flowering was delayed by 2–3 weeks during drought, and no flowers appeared. Flowering delay can be used as an indication of tolerance in rice varieties. The avoidance mechanism in drought is usually indicated by faster or timely flowering. High-yielding rice genotypes are those with fast flowering ages (Sujinah et al., 2020). Plant growth is disrupted due to limited plant water absorption (Bhandari et al., 2023).

The photosynthesis rate is closely related to rice production. Even under water shortage conditions, a high photosynthesis rate indicates that these varieties have potential stable productivity. IPB 9G has a higher photosynthesis rate than IPB 3S in the rice field system. However, IPB 9G significantly decreased the rice field system by 17.04%, while IPB 3S did not show a significant difference in the t-test. Photosynthesis in plants produces a plant dry weight that is closely related to yield.

Figure 1 shows the increase in dry weight in IPB 3S and IPB 9G at each plant phase. IPB 9G showed lower dry matter gain compared to IPB 3S.

Under drought conditions, the drought-resistant PR-115 genotype demonstrated the highest photosynthesis rate (Khan et al., 2022). Drought can lead to changes in chlorophyll content due to chloroplast damage caused by the regeneration of reactive oxygen species during dry periods (Salsinha et al., 2020). Chlorophyll levels are crucial for efficiently capturing light, which is necessary for photosynthesis. Vatanee et al. (2023) noted that photosynthesis rates and stomatal conductance decreased under dryland conditions compared to flooded rice fields. Photosynthesis decreased by 64% under various water deficits (Zhang et al., 2022). Reducing stomatal conductance is a strategy used by plants to minimize excessive water loss, thereby maintaining optimal water status within plant cells based on their needs. High-yielding, drought-resistant upland rice exhibited maximum rates of photosynthesis, transpiration, and stomatal conductance compared to low-yielding varieties (Boy et al., 2020). As the soil water content falls below field capacity, stomatal conductance decreases. Stomata play a critical role in regulating the release of water vapor (H_2O) and the entry of carbon dioxide (CO_2) into leaves.

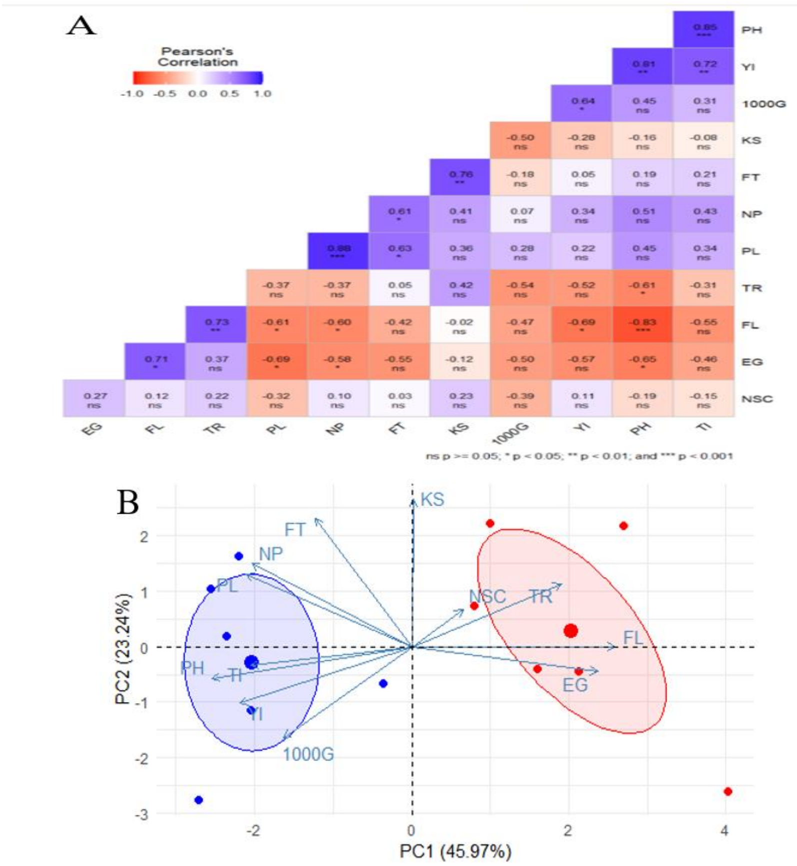

Figure 1. Pearson correlation matrix (A) and principle component analysis plot (B). Note: EG = empty grain, FL = flowering date, TR = transpiration rate, PL = panicle length, NP = number of grains per panicle, FT = photosynthesis rate, KS = stomatal conductance, 1000G = 100-grain weight, Yi = yield, PH = plant height, TI = tiller number, NSC = nonstructural carbohydrate content.

Table 2. Differences in morphological and physiological responses of IPB 3S and IPB 9G in paddy and dry systems.

Parameters	IPB 3S		Decreased by (%)	IPB 9G		Decreased by (%)
	Paddy	Dry		Paddy	Dry	
Plant height (cm)	147.93a	119.00b	19.56*	140.46a	116.80b	16.85*
Tiller ratio	0.88a	0.61b	30.7*	0.79a	0.63b	20.3*
Flowering age (days after planting)	84.0b	91.3a	-8.73*	84.3b	94.3a	-11.86*
Photosynthesis rates (µmol CO_2 m^{-20} s^{-1})	20.10a	21.04a	-4.71^{ns}	21.97a	18.22b	17.04*
Transpiration rates (mmol H_2O m^{-2} s^{-1})	0.0059b	0.0073a	-24.29*	0.0064b	0.0071a	-10.88*
Stomatal conductance (mol H_2O m^{-2} s^{-1})	0.7544b	0.9708a	-24.70*	0.9556a	0.8285b	11.62*

Note: Numbers in the same row followed by the same letter are not significantly different according to the t-test at $p< 0.05$. ns: not significant, *significantly different according to the t-test at $p< 0.05$.

The number of tillers affects the growth rate of plants by increasing the total leaf area, which in turn contributes to the total biomass accumulation. This occurs because tillers actively increase the total leaf area of the plant, significantly contributing to the total biomass accumulation. One of the results of photosynthesis is plant growth. Table 3 shows the increased plant growth rate at each growth phase. The paddy system exhibits a higher plant growth rate at each growth phase compared to the dry system. Both varieties consistently exhibited plant growth rates from 45 to 60 DAP but showed no significant difference from 60 to 85 DAP. The growth rate of plants was higher in the paddy system than in the dry system.

All varieties decreased significantly in panicle length based on the t-test (Table 4). The panicle length decreased by 2.93% in IPB 3S and by 12.24% in IPB 9G, which showed a higher decrease. The number of grains per panicle was also the same. The highest decrease in the number of grains per panicle was shown by IPB 9G with 27.11% compared to IPB 3S with only 10.85%.

Regarding the 1000-grain weight, IPB 3S was superior to IPB 9G and the percentage of empty grain increased in both varieties in the dry system. IPB 9G achieved a decrease of -104.45% or increased by about 2 times. a high value compared to IPB 3S, which showed a decrease of -17.78%. The yield also significantly decreased in the dry system. The highest decrease in yield occurred in IPB 3S (38.60%), compared to IPB 9G (37.41%). Irrigation factors influence the percentage of empty grain more than the rice genotype (Pratiwi et al., 2018). Caine et al. (2019) stated that reduced water availability had a detrimental effect on rice harvest yields. In this study, the lowest decrease in rice production occurred in IPB 9G, which is an upland rice. Upland rice tends to be more resistant to water shortage conditions. The yield decline in 12 rice varieties planted under water stress and normal conditions ranged from 27.31 to 67.5% or around 1.36 to 5.53 tons per hectare (Kumar et al., 2015). Zhou et al. (2021) stated that the number of grains per panicle decreased when rice was continuously irrigated without flooding.

Table 3. Growth rate of IPB 3S and IPB 9G in paddy and dry systems.

Growth rate (g m day^{-1})	IPB 3S		Decreased by (%)	IPB 9G		Decreased by (%)
	Paddy	Dry		Paddy	Dry	
45–60 DAP	42.7a	30.8b	27.9^{*}	43.9a	7.1b	80.4*
60–85 DAP	17.9a	16.2a	10.0^{ns}	16.8a	20.0a	17.3^{ns}

Note: Numbers in the same row followed by the same letter are not significantly different according to the t-test at $p< 0.05$. ns: not significant, *significantly different according to the t-test at $p< 0.05$.

Kumar et al. (2015) found that rice planted without irrigation produced more empty grains than rice planted with sufficient water. Drought is the most important limiting factor to rice plant growth and production (Ahmadikhah and Marufinia, 2016; Pharmawati et al., 2017).

The smallest decline in rice production per hectare occurred in the IPB 9G variety, which is a type of upland rice. Upland rice is drought-tolerant but has a low yield potential (Heryani et al., 2020). However, IPB 9G showed a yield potential unlike that of upland rice, which generally has a low yield. IPB 9G showed a yield per hectare of 6.9 tons in a dry system, which is as high as the average yield of paddy rice usually planted by farmers.

Drought refers to a reduction in soil moisture in the root zone, which can hinder the physiological functions of plants. The response of rice plants to drought varies depending on the drought severity and duration, the growth phase, and the genotype. During the vegetative phase, drought can inhibit plant height growth, the number of leaves, and the number of tillers. In contrast, during the reproductive phase, drought can lead to an increased percentage of empty grains and reduced grain weight (Bouman and Tuong, 2001).

Estimating a rice variety’s adaptability and suitability to its growing environment is crucial for its development. Adaptation testing enables breeders to evaluate a genotype's compatibility with specific environments and stability across different conditions (Seeraj et al., 2011).

Table 4. Yield and its components of IPB 3S and IPB 9G in paddy and dry systems.

Parameters	IPB 3S		Decreased by (%)	IPB 9G		Decreased by (%)
	Paddy	Dry		Paddy	Dry	
Panicle length (cm)	30.45a	29.56b	2.93*	29.87a	26.22b	12.24*
Number grains per panicle	259.50a	231.33b	10.85*	288.1a	210.03b	27.11*
1000-grain weight (g)	29.94a	28.19b	5.84*	28.58a	26.25b	8.16*
Percentage of empty grains (%)	22.23b	26.18a	-17.78*	21.46b	43.88a	-104.45*
Yield (kg ha^{-1})	10,543a	6,473b	38.60*	11,083a	6,937b	37.41*
Nonstructural carbohydrate (%)	2.02b	2.64a	-30.69*	4.7a	4.05b	13.83*

Note: Numbers in the same row followed by the same letter are not significantly different according to the t-test at $p < 0.05$. ns: not significant, *significantly different according to the t-test at $p < 0.05$.

Stability analysis assesses a genotype's performance in various environments, helping breeders select superior varieties. Understanding the stability and adaptability of a candidate variety is essential, as farmers in diverse environments will cultivate these varieties; therefore, a stable variety is necessary for achieving high yields across various conditions.

IPB 9G scored a DSI of 0.69, while IPB 3S scored 0.71 (Table 5). Both IPB 9G and IPB 3S were classified as moderately tolerant to drought. Although IPB 3S is a lowland rice variety, it performs well in upland planting systems, which do not have standing water. The regression coefficient scores were 0.67 and 0.68, indicating that IPB 3S and IPB 9G are stable varieties. Stability analysis also showed that both varieties maintained consistent yields in paddy and dry systems, incating that both varieties achieve optimal yields under paddy and dry conditions.

Table 5. Drought sensitivity index and yield stability of IPB 3S and IPB 9G in paddy and dry systems.

Variety	Yield (kg ha^{-1})			Drought sensitivity index		Yield stability	
	Paddy	Dry	Mean (kg ha^{-1})	DSI	Category	bi	Category
IPB 3S	10.543	6.473	9.525	0.71	Moderately tolerant	0.67	Stable
IPB 9G	11.083	6.936	10.046	0.69	Moderately tolerant	0.68	Stable
Mean	11.174	5.092	8.133				

Note: bi= regression coeficient.

Figure 1 shows that yield had a strong positive correlation with plant height, the number of productive tillers, and the 1000-grain weight. These characteristics significantly influence the yield under sufficient and limited water conditions; generally, higher values correspond to greater yields. Conversely, flowering age demonstrated a negative correlation with yield, and a later flowering age tended to reduce the yield.

Additionally, plant height, harvest age, the number of productive tillers, and grain length exhibited positive correlations with the yield of hybrid rice (Thorat et al., 2019). Rice yield is a complex polygenic trait influenced by various other factors. Principal component analysis (PCA) results showed that the measured parameters' responses clustered according to the two treatment conditions. In the dry system, flowering age, transpiration rate, percentage of empty grains, and NSC content were located in the red quadrant. In contrast, plant height, productive tiller ratio, photosynthesis rate, panicle length, the number of grains per panicle, and 1000-grain weight were positioned in the purple quadrant, representing the rice field system.

Thus, in the dry system, characteristics that can be enhanced to improve yield stability include flowering age, percentage of empty grains, transpiration rate, and NSC content. The PCA score value, which was relatively low at 69.21%, may result from the variability in plant responses despite consistent environmental conditions.

4. Conclusions

IPB 3S and IPB 9G responded differently to the conditions in paddy fields compared to dry systems. In the dry system, there was a decline in the morphological, physiological, and yield characteristics of both varieties compared to the paddy field system. The IPB 3S variety showed a higher rate of photosynthesis, while IPB 9G achieved a higher yield. IPB 3S and IPB 9G were moderately drought-tolerant varieties, with DSI values of 0.69 and 0.71, respectively. They also demonstrated the highest yield stability (bi) values, with IPB 3S at 0.67 and IPB 9G at 0.68. Overall, IPB 3S and IPB 9G have the potential to produce high and stable yields in both paddy fields and dry systems.

Authors' Contribution

All authors contributed to this manuscript. Suhadi Sapto Yuwono conducted the experiment, collected the data and writing the manuscript. Iskandar Lubis and Munif Ghulamahdi performed data analysis and interpretation. Endah Retno Palupi conducted the textual review.

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