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Research Article

Agronomical Performances of Gajah Mungkur Mutant Rice Varieties Under Drought Stress

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ABSTRACT

The productivity of the rice plant is commonly influenced by both genotype and environmental factors. One common environmental factor that leads to harvest failure is drought, often caused by low rainfall. Therefore, the development of drought-tolerant varieties should be implemented to obtain optimum productivity under an unfavorable environment. One of the canonical approaches for achieving this is genetic manipulation, such as by gamma radiation-induced mutation. This study aimed to determine the drought tolerance and quantitative characteristics of mutant rice varieties generated from gamma radiation. The methodology used was a split-plot design with two factors, including drought as the first factor consisting of three groups namely control, mid-level, and high-level. The second factor was rice genotypes, which consisted of six genotypes comprising PMG 07/PsJ, PMG 08/ PsJ, and PMG 09/ PsJ (mutant varieties), Gajah Mungkur (parental background), Limboto (drought-tolerant), and IR 20 (drought-susceptible). The data were statistically examined using Analysis of Variance (ANOVA) and further analyzed with Duncan's Multiple Range Test (DMRT) with a significance level of 5%. The results showed that high-level drought significantly affected plant height during both the vegetative and mature stages. Among the mutants, PMG 08/PsJ exhibited better vegetative growth under dry conditions, retaining a relatively higher height. Drought also had a negative impact on the number of tillers and productive tillers. The PMG 08/PsJ mutant had a slightly higher number of tillers under drought cultivations. On the other hand, PMG 09/PsJ was found to have a relatively more filled grain number per panicle. Leaf rolling and dryness index showed similar trends in all varieties, while drought treatments imposed a delay on the flowering and harvesting age. Although the results demonstrated no substantial improvement over the parental lines, the selected mutant lines provided several beneficial agronomical features such as maintenance of plant height, tiller number, and shorter life cycles under severe drought. These characteristics could serve as valuable genetic resources for breeding programs focused on developing drought-resistant rice varieties for challenging environments.

Keywords: Agronomical traits, Drought, Gamma radiation, Mutant variety, Rice

Introduction

The increasing consumption of rice is directly correlated with annual human population growth. As one of the main staple foods in Indonesia, rice production reached 54.42 million tons in 2021, indicating a decrease of approximately 0.99% or 230 thousand tons compared to the 2020 production of 54.65 million tons [1]. Improving agricultural practices is essential to obtain an optimum rice crop yield, and this can be achieved by expanding the planting area, including the utilization of dry lands, which generally have characteristics of low fertility. According to a previous study [2], dry lands are classified as entisol soil type with low pH, C-organic, organic matter, phosphorus, and

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potassium. Low organic matter potentially causes poor water storage, thereby affecting plant growth and productivity.

Rice growth and productivity are influenced by several factors including planting and harvesting age, pests, diseases, as well as climate [3, 4]. Additional factors include the genetic background, fluctuations in environmental conditions, and the interaction between the two [3]. Drought is a primary environmental factor that leads to harvest failure in rice cultivation. It is caused by low rain intensity and potentially results in decreased crop yields [5, 6]. Rice plants respond to drought stress with physiological adjustments, such as reducing transpiration rates to save water by closing the stomata and minimizing surface area by leaf rolling. These physiological responses can impede the exchange of CO_2 and O_2 from plant tissue to the atmosphere and minimize solar capture radiation. These activities lead to a decrease in photosynthesis rate and harvest yield. Furthermore, rice varieties, with their extensive genetic diversity, exhibit various ranges of tolerance against drought or dry conditions. This diversity is a crucial growth characteristic for optimizing cultivation on dry lands. One of the efforts to obtain optimum productivity is by using drought-tolerant rice varieties. Gajah Mungkur was produced from crossing IR64 x IRAT112 varieties, possessing the ability to maintain growth under drought-stress conditions. Therefore, its utilization as a parental background will facilitate the generation of drought-tolerant varieties with valuable agronomical traits [7].

Improvements in rice varieties can be achieved by modifying the genetic composition using mutagens such as gamma radiation. A report by [8] showed that the use of gamma-ray irradiation provided a wide range of sensitivity and tolerance towards certain growth conditions and stresses. Therefore, this study aimed to examine the tolerance level and the quantitative characteristics of rice mutant varieties cultivated under drought stress conditions using mutant collections previously generated by the Center for Isotope and Radiation Application (BATAN) from gamma irradiation processes.

Material and Methods

Plant materials

The rice plant used was generated and cultivated at the Center for Isotope and Radiation Application (BATAN), Cilandak-South Jakarta. A total of six genotypes were utilized consisting of three mutant varieties (PMG 07/PsJ, PMG 08/PsJ, and PMG 09/PsJ), Gajah Mungkur (mutant background), Limboto (drought-tolerant), and IR 20 (drought-sensitive control).

Cultivation and drought stress treatment

Rice varieties were cultivated in planting media and maintained during the growing period at Experimental Greenhouse, Center for Isotopes and Radiation Application (BATAN), Cilandak-South Jakarta. The planting media was prepared using a mixture of soil and manure with a ratio of 2:1. To support the plant growth, fertilizers comprising Urea 3.45 g, SP-36 1.43 g, and KCl 1.15 g were applied to approximately 23,69 kg of each planting media. All fertilizers were applied once except for Urea, which was dispersed in three portions, with 25% applied before sowing, 41% at 14 days after planting (DAP), and 34% between 24-26 DAP. Insecticides consisting of Furadan 3GR, Prevathon 50 SC, and Regent, as well as a common fungicide (Antracol) were applied to control pests and diseases. Seeds were directly planted in planting media under moist conditions. A total of six varieties were cultivated with two rows of eight individual plants per variety.

On 14 days after planting (DAP), three types of drought stress treatments were imposed on the plants, including regular watering throughout the growing period (Control), as well as every four days (Medium/Mid-Level Drought) and eight days (High/Hi-level drought). In all treatment groups, water was added and allowed to settle 5 cm from the media surface. A repeated cycle of dry and watering conditions of mid-level and high-level drought was maintained throughout the growing period. Furthermore, the three treatments were designed to reach a field capacity of approximately 80% (Control), 60% (Mid-level), and 20% (High-level) according to [9]). Observations were subsequently performed on both the qualitative and quantitative agronomical characteristics. The qualitative characteristics were indicated by the leaf rolling (Table 2) and dryness index (Table 3) according to [9]. On the other hand, the quantitative parameters of plant growth included 1) plant height, 2) the number and productivity of tillers, 3) the age of flowering, 4) the age of harvesting, and 5) the number of grains and filled grains per panicle.

Experimental design and data analyses

A split-plot design was implemented with two factors namely genotypes and drought. Genotypes consisted of six rice varieties, while drought treatment comprised three conditions. Table 1 showed the combination of the experiment, and each treatment was repeated three times. The statistical data were analyzed using Analysis of Variance (ANOVA). When significant differences were observed, the data were further analyzed with Duncan's Multiple Range Test (DMRT) with a significance level of 5%.

Table 1. Design of the experiments

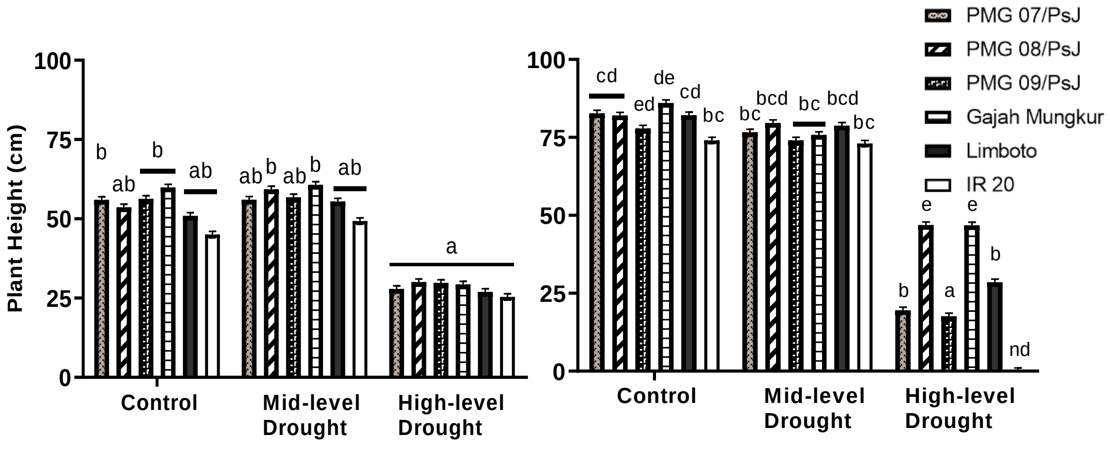
No	Genotypes	Drought stress treatments
1.	PMG 07/PsJ	Control
2.	PMG 08/PsJ	
3.	PMG 09/PsJ	
4.	Gajah Mungkur	
5.	Limboto	
6.	IR 20	
7.	PMG 07/PsJ	Mid-level drought
8.	PMG 08/PsJ	
9.	PMG 09/PsJ	
10.	Gajah Mungkur	
11.	Limboto	
12.	IR 20	
13.	PMG 07/PsJ	High-level drought
14.	PMG 08/PsJ	
15.	PMG 09/PsJ	
16.	Gajah Mungkur	
17.	Limboto	
18.	IR 20	

Results and Discussion

Effect of drought on plant heights

Plant height is an important agronomic trait in rice, playing a crucial role in determining yield as it affects the length of panicles and tillering capacity, as well as provides a strong posture against environmental changes [10]. Environmental factors such as drought stress are immensely known for their effect on the vegetative and generative (mature) growth of various rice genotypes [10, 11]. This study examined the growth responses of six rice varieties under control, mid-level, and high-level drought conditions. Among the tested varieties were PMG 07 to 09/PsJ (mutant), Gajah Mungkur (parental background), Limboto, and IR20 (tolerant and susceptible). The results showed that drought treatment had negative effects on plant height at vegetative and mature growth stages.

The control and mid-level drought had a less distinct effect, while the high-level treatment led to retarded growth in all rice varieties, resulting in lower plant heights (Figure 1a). This condition persisted not only in the vegetative stage but also in the mature phase (Figure 1b). The plant height significantly decreased across all varieties grown under high-level drought conditions. The PMG 07 to 09 /PsJ mutant varieties demonstrated similar plant height with Gajah Mungkur, Limboto, and IR20 in both control and mid-level drought conditions. Based on the results, IR20 did not survive in high-level drought conditions, while PMG 08/PsJ and Gajah Mungkur exhibited the lowest



a b

Figure 1. The average plant height of six rice varieties under drought stress conditions at the vegetative state (14 DAP) (a) and mature stage (b). Different letters above the bars show significant differences (*) according to Duncan's Multiple Range Test (DMRT) levels of 5%. Nd = not detected.

plant height decrease compared to other varieties grown under high-level drought conditions.

Plants require sufficient water for growth and development, while drought conditions result in lower soil water content, which can potentially reduce height [12]. This reduction may be due to a decline in net photosynthesis, the inhibition of cell elongation, and limitations in nutrient uptake [13, 14]. Lack of water can impair physiological, morphological, biochemical, and ecological processes [15]. Furthermore, plants have the ability to adjust their growth and reduce resource utilization to cope with adverse environmental conditions [16]. These results were consistent with a previous study performed by [11], which demonstrated a significant decrease in rice plant height cultivated under drought stress treatments across different varieties. Another study [11] also reported that drought stress significantly affected plant height at 30, 60, and 90 days after planting. Although the three mutant lines did not show significant improvements in plant height compared to Gajah Mungkur at vegetative (Figure 1a) and mature stages (Figure 1b), the maintenance of plant height exhibited by PMG 08/PsJ under high-level drought conditions is a particularly interesting subject for further study. This variety showed superior growth, potentially indicating a greater resilience to drought conditions compared to other mutant lines, Limboto, and IR20. A study by [17] demonstrated that the ideal plant height would offer a strong phenotype and optimum grain yield. It was also reported that the increment of rice plant height correlated with the grain yield [18], while a reduction corresponded to the lower grain yield [19]. This presumably suggested that maintaining plant height could serve as a means of water conservation under drought conditions. Therefore, the consistent plant height exhibited by PMG 08/PsJ remains a valuable resource for drought-resistant traits in future studies and breeding programs.

Effect of Drought on Tiller and Productive Tiller Number

The tiller number is important in determining rice architecture and contributes to yield components [20]. A higher tiller count in a variety typically results in more panicles, which in turn leads to increased grain production. However, an excessive tiller number could also sequester the supply of nutrition for reproductive organs, necessitating the need for balance between the total number and productive tillers [10]. Productive tillers are capable of bearing panicles and ultimately producing grains. According to a study [21], tiller outgrowth initiates at the early stage of rice growth and depends strongly on internal factors such as genetic interaction, hormones, as well as external factors. Environmental factors including water scarcity in soil could have potential detrimental effects on tiller developments. Consequently, plants respond with physiological adaptations to either retain or inhibit tiller growth, depending on their survival needs.

The different response mechanisms of each mutant variety under drought stress were predominantly determined by genetic factors [5]. In this study, at the end of the vegetative phase (50 DAP), the tillering capacity varied across rice varieties. Under normal conditions, the tiller number of PMG 07/PsJ, PMG 08/PsJ, and PMG 09/PsJ did not indicate any differences compared to Gajah Mungkur and Limboto with 2 to 2.14 tillers per clump. Meanwhile, the tiller number of IR20 exceeded those of the other five varieties, reaching 3.53 tillers per clump (Figure 2a). In mid-level drought conditions, the three mutant varieties, along with Gajah Mungkur and Limboto, developed only 1.77 to 1.93 tillers per clump. Compared to the five rice varieties, IR20 exhibited an increased number of tillers, up to 4.14 tillers per clump. This phenotype shows that IR20 despite being a common drought-susceptible check variety, possesses the ability to produce numerous tillers [23]. Under high-level drought conditions, all rice varieties experienced a substantial reduction in tiller number (Figure 2). IR20 did not survive and subsequently failed to produce tillers in these growing conditions. PMG 07/PsJ, PMG 08/PsJ, and PMG 09/PsJ produced 1,02, 0,88, and 0,80 tillers per clump, respectively. These differences imply that although IR20 had more capacity to develop numerous tillers, the three mutant varieties demonstrated a stronger capacity to maintain their growth under drought conditions. This resilience is likely due to the genetic inheritance of the drought tolerance mechanism from Gajah Mungkur, which serves as the parental line for these mutants [23–25].

Productive tillers determine the number of potential panicles that can be generated during one growing period. In this study, under normal conditions, the number of productive tillers for PMG 07/PsJ, PMG 08/PsJ, and PMG 09/PsJ were slightly lower than that of the Gajah Mungkur parental line, although the difference was not considered significant. The three mutant varieties also exhibited a slightly higher number of productive tillers compared to Limboto, reflecting their larger grain-filling capacity, while Limboto had a relatively higher number of tillers. Similarly, IR20 in normal growing conditions had the highest number of productive tillers, although the result was not significantly different from others. Under mid-level drought, the number of productive tillers was also statistically insignificant. PMG 07/PsJ, PMG 08/PsJ, and PMG 09/PsJ shared a similar number of tillers with Gajah Mungkur parental lines and Limboto drought-tolerant variety. Meanwhile, IR20 showed a higher number of productive tillers, although the difference was not statistically significant (Figure 2b).

The discriminative effect of high-level drought treatment was observed in the number of productive tillers across the six rice varieties. The results demonstrated that there was no substantial improvement in the number of tillers and productive tillers between the mutants and Gajah Mungkur parental lines. However, PMG 08/PsJ exhibited a slightly higher number of tillers than Limboto and IR20 under high-level drought conditions. This was attributed to the prolonged severe drought experienced from the vegetative stage, which significantly impacted the number of productive and ineffective tillers, particularly during the tiller formation stage [22]. Therefore, aside from considering yield features in rice varieties, it is essential to focus on maintaining tillers under drought conditions as a promising trait for inclusion in drought-resistant breeding programs. The tillers play a crucial role as a panicle-bearing organ, ultimately influencing yield outcomes [20, 21]. In comparison to the control and mid-level drought conditions, the high-level drought condition had a significant effect on reducing the number of productive tillers (Figure 2b). This response is consistent with other members of the grass family, which tend to suppress their tiller productivity to basal level when subjected to stress conditions [27]. Plants have various signaling pathways and respond by changing their growth pattern under drought stress [28]. Furthermore, drought tolerance mechanisms are often manifested in morphological adaptation, such as reduced tiller number and leaf size to keep water loss at a minimum level. Physiological adaptations include increased osmolyte content, antioxidant, and enzymatic protection against oxidative damage [29]. These survival mechanisms underscore the importance of maintaining strong growth under limited conditions, as tiller development can only occur in favorable environments [5, 16, 28].

Leaf responses on drought treatment

Leaves play a vital role in food assimilation within plants, with photosynthesis primarily taking place in these organs. By converting light energy into food, leaves facilitate the exchange of gas and water through the stomata. When water stress occurs, plants respond within the leaves in a wide range of forms such as changes in photosynthetic rate, suppression of expansion, stomatal

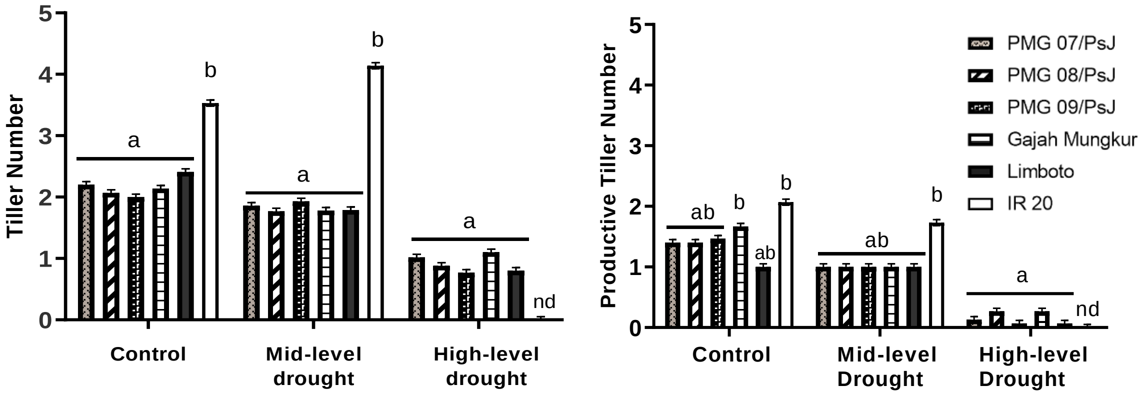


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Figure 2. The average tiller number (a) and productive tiller number (b) of six rice varieties under drought stress conditions were measured at 50 DAP. Different letters above the bars show significant differences (*) according to Duncan's Multiple Range Test levels of 5%. nd = not detected.

Table 2. Leaf rolling index [10]

Score	Symptoms
0	Healthy leaves
1	Leaves starting to curl (shallow V
3	shape)
5	Leaves curl (deep V shape)
7	Leaves curl (curved U shape)
9	Leaves curl where leaf edges touch (O shape)
	Leaves fully rolled

Table 3. Leaf dryness index [10]

Score	Symptoms
1	Healthy leaves
3	Dry tips of the leaves
5	$^1/_4$ - $^1/_2$ Dry tips of the leaves
7	$^1/_2$ – $^2/_3$ Dry tips of the leaves
9	Dry leaves

closure, and rolling responses [28–32]. Leaf rolling responses are recognized as one of the mechanisms that precede or accompany stomatal closure. It could also serve to minimize the transpiration rate by reducing the leaf area directly exposed to sunlight [27]. In this study, the leaf rolling and dryness index were used in line with a previous study [28] to elucidate drought responses from six rice varieties (Table 3). For this observation, the leaf rolling index was recorded after the drought period, while the dryness index was measured after the recovery (watering). Table 3 shows normal (a) and rolled leaves (b) at 21 DAP and the scores of both indexes are provided in Table 2 and Table 3.

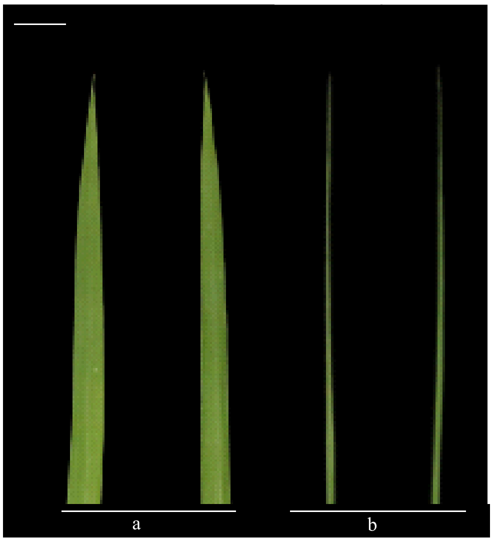

Figure 3. (a) normal leaves and (b) rolled leaves observed at vegetative stages at 21 DAP, scale bar = 10 mm.

Table 4 showed that under normal conditions, all rice varieties used in this study were healthy, as indicated by both leaf rolling and dryness indexes of 0. The symptoms started to appear in the mid-level drought treatments. Among the rice varieties, the leaf rolling index at this level ranged from 4.00 to 5.67 while the dryness index spanned from 3.00 to 3.50. At the high-level drought stress, all genotypes showed rolling leaf symptoms (Figure 3 and Table 4) where the edges touched each other to form an O shape with a score of 7, while the leaf drought index was 9. According to previous reports, a wider dry area on leaves indicates a high sensitivity to drought stress [33]. Drought tolerance in plants is characterized by the recovery ability which is marked by the leaves turning green after being watered [34].

Leaf rolling is a physiological response in plants aimed at conserving water by reducing the transpiration rate through stomata closure and decreasing the surface area [35]. This phenomenon is frequently used for discriminating drought-tolerant and susceptible varieties. However, this study showed that even at high-level drought conditions, the leaf rolling index of PMG 07/PsJ, PMG 08/PsJ, and PMG 09/PsJ mutant varieties did not significantly differ from Gajah Mungkur, Limboto, and IR 20 (Table 4). This result is consistent with previous reports [10, 36, 37] stated that the leaf rolling index parameter is less sensitive for examining drought sensitivity levels among various rice genotypes. It is commonly perceived as an early symptom of drought-susceptible varieties or a coping mechanism of drought-tolerant varieties to conserve water during stress periods [10, 33]. Therefore, the use of other physiological parameters might better help plant breeders in selecting and deselecting varieties for drought-tolerant breeding purposes [32].

Effect of drought on flowering and harvesting age

The sensitivity of rice towards drought conditions extended from the vegetative to the generative phase. Specifically, the development and maturation of reproductive organs were extremely susceptible to water scarcity [38], thereby inducing a reduction in grain number and filling rate [39]. This study observed the effect of drought on the flowering and harvesting age (Table 5), as well as the number of grains among six rice varieties (Table 4). Based on the results, drought stress had

Table 4. Average leaf rolling and dryness index for mutant varieties under drought stress

Drought Treatment	**Genotypes**	**Leaf rolling Index**	**Tolerance level**	**Leaf dryness Index**	**Tolerance level**
Control	PMG 07/PsJ	0.00 a	-	0.00 a	-
	PMG 08/PsJ	0.00 a	-	0.00 a	-
	PMG 09/PsJ	0.00 a	-	0.00 a	-
	Gajah Mungkur	0.00 a	-	0.00 a	-
	Limboto	0.00 a	-	0.00 a	-
	IR20	0.00 a	-	0.00 a	-
Mid-level Drought	PMG 07/PsJ	4.50 b	Rather Sensitive	3.33 b	Tolerant
	PMG 08/PsJ	4.50 b	Rather Sensitive	3.00 b	Tolerant
	PMG 09/PsJ	4.00 b	Rather Sensitive	3.17 b	Tolerant
	Gajah Mungkur	4.17 b	Rather Sensitive	3.33 b	Tolerant
	Limboto	5.67 b	Rather Sensitive	3.33 b	Tolerant
	IR20	5.50 b	Rather Sensitive	3.50 b	Tolerant
Hi-Level Drought	PMG 07/PsJ	7.00 c	Sensitive	9.00 c	Sensitive
	PMG 08/PsJ	7.00 c	Sensitive	9.00 c	Sensitive
	PMG 09/PsJ	7.00 c	Sensitive	9.00 c	Sensitive
	Gajah Mungkur	7.00 c	Sensitive	9.00 c	Sensitive
	Limboto	7.00 c	Sensitive	9.00 c	Sensitive
	IR20	7.00 c	Sensitive	9.00 c	Sensitive

*Numbers followed by different letters show significant differences according to Duncan’s Multiple Range Test level of 5%.

Table 5. Average flowering and harvest age of rice mutants under drought stress

Drought Treatment	**Genotypes**	**Flowering age (day)**	**Harvest age (day)**
Control	PMG 07/PsJ	62,00 a	76,00 a
	PMG 08/PsJ	62,00 a	76,00 a
	PMG 09/PsJ	62,00 a	76,00 a
	Gajah Mungkur	62,00 a	76,00 a
	Limboto	79,00 bcd	94,00 b
	IR20	84,00 e	108,00 d
Mid-level Drought	PMG 07/PsJ	64,33 a	81,00 a
	PMG 08/PsJ	64,33 a	81,00 a
	PMG 09/PsJ	64,33 a	81,00 a
	Gajah Mungkur	64,33 a	81,00 a
	Limboto	79,00 bcd	101,00 c
	IR20	84,00 e	115,00 d
Hi-Level Drought	PMG 07/PsJ	75,00 a	115,00 d
	PMG 08/PsJ	77,00 ab	115,00 d
	PMG 09/PsJ	75,00 a	115,00 d
	Gajah Mungkur	75,00 a	115,00 d
	Limboto	104,00 d	129,00 e
	IR20	nd	nd

*Numbers followed by different letters show significant differences according to Duncan’s Multiple Range Test level of 5%. nd = not detected

a significant effect on the age of flowering and harvesting. Mutant varieties PMG 07/PsJ, PMG 08/PsJ, and PMG 09/PsJ started to bloom at 62 DAP, 64 DAP, and 75-77 DAP under normal, mid-level, and high-level drought stress conditions respectively. This exerted a delay in harvesting time from 76 DAP to 81 DAP and 115 DAP. The flowering and harvesting age of the three mutant varieties was similar to the parental Gajah Mungkur, which started to bloom and was harvested on the same days after planting at all planting conditions. Meanwhile, the flowering age of Limboto was not significantly affected by mid-level drought. Under normal and mid-level drought, this variety began to bloom at 79 DAP but in terms of the harvesting age, there was a delay from 94 DAP to 101 DAP. In the high-level drought, Limboto extended its flowering and harvesting age to 104 DAP and 129 DAP respectively. The IR20 variety under normal and mid-

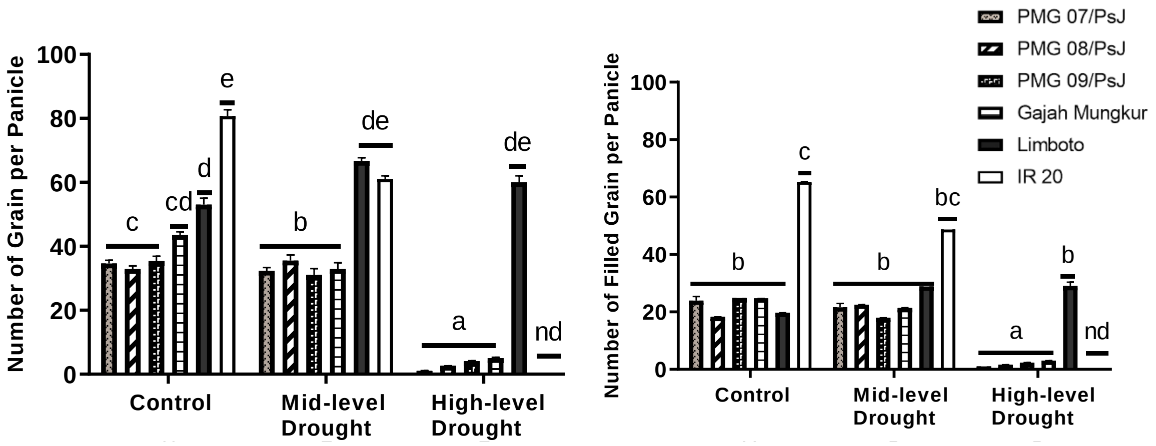

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Figure 4. The average number of grains per panicle (a) and filled grain per panicle (b) of six rice varieties under drought stress conditions were measured after harvesting. Different letters above the bars show significant differences (*) according to Duncan's Multiple Range Test (DMRT) levels of 5%. Nd = not detectedcted.

level conditions exhibited late blooming at 84 DAP. There was also a delay in harvesting time from 108 DAP to 115 DAP. Moreover, this variety showed strong sensitivity in the form of delayed blooming and harvest under high-level drought conditions (Table 5).

This study observed that the harvest age of the rice was also influenced by the flowering age, wherein the longer the flowering time, the longer the harvest time. High levels of drought stress led to longer harvest ages spanning from 115 to 129 DAP across varieties, causing a delay of 35-39 days (Table 4). Based on the results, PMG 07/PsJ, PMG 08/PsJ, and PMG 09/PsJ exhibited earlier flowering compared to Limboto and IR20. Consequently, under normal to high-level cultivation, these mutant varieties were able to be harvested at an earlier time (Table 5). This is in line with the breeding goal of developing varieties that can thrive under drought conditions. Early flowering is one of the desired features of rice breeding programs, as this feature saves production time, conserves water resources, and adapts to multiple crop cultivation systems, specifically under constraining environments such as drought conditions [41]. Additionally, given the increasing water scarcity, planting early flowering varieties during an initial period of drought may enable farmers to harvest earlier and circumvent the potential harsh impacts [42]. The extent of delay in flowering characteristics differed among genotypes under drought-stress conditions. This is consistent with [43] stating that the diverse tiller capacity among upland rice varieties represents a valuable resource for various agronomic traits, specifically drought tolerance and resistance.

The age of flowering is also affected by water availability, as rice spikelets require an ample supply of water for opening. The swelling of the lodicule and anthers as well as the elongation of the filament depends on the availability of water [44]. A previous study [45] reported that drought stress at the flowering stage significantly reduced grain yield. This phenomenon reduces the number of spikelets opened, decreases leaf water potential, and increases tissue temperature in the panicle, elevating the percentage of sterile spikelets [44]. The morphological and physiological responses to these conditions are influenced by the severity level of drought stress and the degree of tolerance [24, 35]. The genetic background of each variety played a crucial role in how plants responded to stress conditions. Previous studies [24, 25, 43] demonstrated that rice varieties such as IR64 were stable under drought stress, despite being known to thrive only in flooded conditions.

Effect of drought on grain filling

One of the most crucial agronomical traits affecting the yield component of rice is the number of grains and filled grains per panicle. In this study, both variables decreased with increasing levels of drought across all tested varieties. Under normal conditions, PMG 07/PsJ, PMG 08/PsJ, and PMG 09/PsJ had approximately 32.87 to 35.54 grains per panicle and 18.2 to 24.87 filled grains per panicle. Although the number of grains per panicle for Gajah Mungkur was only slightly higher compared to those of the mutant varieties. There was no difference in the number of filled grains per panicle between Gajah Mungkur and Limboto. IR20 had the highest values in terms of both parameters under normal conditions as shown in (Figure 4a & b).

Under mid-level drought conditions, the number of grains and filled grains for PMG 07/PSJ, PMG 08/PSJ, PMG 09/PSJ, and Gajah Mungkur did not significantly differ. Meanwhile, the Limboto variety experienced an increase from 53.07 to 66.74 grains per panicle, and IR20 decreased from 81.93 to 61 (Figure 4a). Interestingly, although an increase in the number of grains was observed in Limboto, the number of filled grains per panicle did not experience a similar increase. At the same time, IR20 decreased from 65.33 to 48.73 (Figure 4b). This phenomenon indicates that the two varieties' response and tolerance to drought stress conditions differ.

Under high-level drought conditions, the number of grain and filled grain per panicle for PMG 07/PsJ, PMG 08/PsJ, PMG 09/PsJ, and Gajah Mungkur experienced a severe decline. The impact on IR20 was even more severe, as this variety did not generate any tiller (Figure 2a), leading to zero grains, while Limboto experienced a mild change in both parameters. Despite producing less number of grains per panicle, the mutant varieties still yielded a significant amount of tillers compared to Gajah Mungkur and Limboto. These results imply that drought treatments substantially impact the number of grains per panicle and rice grain filling. According to previous studies [28, 29, 39], water regulates grain rice filling. The reproductive phase is susceptible to water stresses, which affect spikelet formation, pollination, and grain-filling stages. Extended drought conditions from the vegetative to the reproductive stage could lead to the formation of sterile spikelets and empty grains (Figure 4a & b).

This study underscored the potential of three rice mutants as genetic resources to develop drought-tolerant varieties. Although drought stress affected several agronomical traits, each mutant showed superior characteristics in certain traits than the others. For example, PMG 08/PsJ was distinct in maintaining plant height, indicating its potential to maintain vegetative growth under drought conditions. Regarding plant tiller number, PMG 07/PsJ performed slightly better than the other two mutants. Although a severe effect was observed in the number of grains per panicle among the three mutants, PMG 09/PsJ exhibited a relatively higher value. There were no marked differences in leaf rolling responses or flowering and harvesting age.

In summary, although the mutant lines might not significantly improve all agronomic traits, several potential benefits were established. These include the maintenance of plant height under drought stress by PMG 08/PsJ, the preservation of tiller number by PMG 07/PsJ and PMG 08/PsJ, and earlier flowering in the three mutant lines than Limboto. Therefore, future breeding programs that develop drought-tolerant varieties should consider other agronomical aspects that sustain the rice life cycle, such as organ growth maintenance and life cycle adjustments. The results provide information on genetic resources and their potential use in drought-environment breeding purposes. Future investigations are needed to examine the mutants under a broader range of environmental conditions and explore crossbreeding with other varieties to comprehend their potential for various breeding purposes fully.

Conclusion

In conclusion, this study provided insights into the vegetative and generative characteristics of three rice mutant varieties cultivated under drought stress. Based on the result, the treatments affected their agronomical performance in various ways. PMG 08/PsJ showed enhanced vegetative growth compared to the other two mutants by maintaining taller plant height under high-level drought conditions. PMG 07/PsJ had a more significant number of tillers, and PMG 09/PsJ was found to have a higher number of grains per panicle, although both parameters were insignificant in mutants. There were no significant differences in the leaf rolling and dryness index, while the flowering and harvesting age was delayed in a drought-level dependent manner. Despite only showing slight improvements compared to the Gajah Mungkur parental line, these mutants exhibited agronomical uniqueness that could be incorporated into rice breeding programs for drought-resistant varieties.

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