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The Effect of Fertilization Combination and Paclobutrazol Concentrations on the Productivity of Rice Plants (*Oryza sativa* L.)

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ABSTRACT

Rice (Oryza sativa L.) is a key agricultural commodity and represents the primary carbohydrate source for the Indonesian population. Despite its importance, national rice productivity is still relatively low compared to other major rice-producing countries. This study aimed to evaluate the most suitable combination of paclobutrazol concentration and N, P, K fertilization to optimize rice growth and yield performance. The research was conducted from December 2024 to February 2025 in Ngraho Village, Bojonegoro Regency, East Java. A Split Plot Design was employed, involving two factors: paclobutrazol concentration as the subplot factor and fertilizer combination as the main plot factor. In total, 16 treatment combinations were arranged with three replications, resulting in 48 experimental units. The best performance was obtained from the combination of Urea (600 kg/ha), SP36 (300 kg/ha), KCl (200 kg/ha), and paclobutrazol at 600 ppm, which improved multiple growth and yield parameters. The treatment showed statistically significant effects and is recommended for implementation in rice cultivation under similar agroclimatic environments. Further investigations in different regions and planting periods are necessary to assess the stability of these outcomes.

1. INTRODUCTION

In Indonesia, rice (*Oryza sativa* L.) functions as both a major agricultural commodity and the primary source of carbohydrates. However, the country's rice productivity is still lagging behind that of other rice-producing regions. According to data from Statistics of Indonesia, rice production decreased by 767,984 tons of dry unhusked grain (DUG) in 2023 compared to 2022 (BPS, 2026). The use of high-yielding varieties, optimal fertilization, and the application of Plant Growth Regulators (PGRs) are among the efforts to increase rice productivity (Hamdani & Haryati, 2021; Sembiring *et al*., 2021; Fitri *et al*., 2018). Optimal fertilization can enhance crop productivity by fulfilling nutrient requirements. The proper use of N, P, K and micronutrient fertilizers has been proven to improve plant productivity (Masruroh *et al*., 2017; Sukmawati *et al*., 2021; Siregar *et al*., 2023). The use of paclobutrazol as a PGR can reduce vegetative growth and accelerate the generative phase in plants. Research conducted by Novita *et al*. (2025) showed that the application of paclobutrazol could increase rice production by up to 13% compared to rice grown without paclobutrazol application.

Plant Growth Regulators (PGRs) play various roles, such as stimulates root initiation, shoot multiplication, stimulate primordium growth, breaking seed dormancy, prevent leaf senescence, etc (Mishra *et al*., 2024). Paclobutrazol is a type of PGR with a growth-inhibiting or retardant mechanism that has been widely applied to ornamental and fruit plants to stimulate flowering (Rugayah *et al*., 2020). Furthermore, according to Runtunuwu *et al*. (2019), the application of paclobutrazol can increase chlorophyll content, thereby enhancing photosynthetic capacity.

The mechanism of vegetative growth inhibition occurs due to early suppression of growth, which leads to carbohydrate accumulation and a reduction in nitrogen levels at the terminal shoot. This helps maintain the C : N ratio in the buds, which is a key factor in flowering induction (Ningsih & Rahmawati, 2017). Research by Rombon *et al*. (2019) and Fauziah *et al*. (2024) demonstrated that the application of paclobutrazol at a concentration of 600 ppm can increase grain weight per clump and the number of grains per clump.

Nitrogen (N), Phosphorus (P), and Potassium (K) fertilizer plays an essential role in plant growth. Nitrogen stimulating vegetative growth and increasing the rate of photosynthesis through the production of nucleic acids and chlorophyll (Nuraeni *et al*., 2019). Phosphorus stimulates root elongation, plant maturation, helps assimilation and respiration (Lisdiyanti *et al*., 2018). Potassium regulates cell growth, nutrient transport, and response to stress (Sardans & Penuelas, 2021). The combination of potassium fertilization and paclobutrazol has been shown to accelerate the flowering time of sweet corn at specific concentrations (Usmadi *et al*., 2023). Additionally, the combination of paclobutrazol and urea fertilizer has been proven to increase the number of flowers and total pod weight in long bean plants (Safitri, 2023). However, combining fertilizers and paclobutrazol requires careful consideration to avoid disrupting the plant's nutritional needs. Adjusting the fertilizer ratio and paclobutrazol concentration is necessary to optimize yield and crop quality. Accordingly, this research was conducted to determine the most effective combination of paclobutrazol concentration and N, P, K fertilizers in enhancing rice growth and yield. The results are intended to provide useful information regarding the response of rice plants to paclobutrazol as well as nitrogen, phosphorus, and potassium inputs.

2. MATERIALS AND METHODS

2.1. Time and Location of Study

The study was conducted from December 2024 to February 2025 in Ngraho Village, Bojonegoro Regency, East Java, Indonesia. The experimental site, situated at an altitude of 25–500 meters above sea level, is characterized by dry to muddy soil conditions, average temperatures of 27–38 °C, annual precipitation ranging from 1,500 to 2,500 mm, and relative humidity between 65% and 90%.

2.2. Tools and Material

The tools used in this research are a tractor, hoe, measuring tape, hand sprayer, and digital scale. The materials used in this research include Inpari 32 rice seeds, urea fertilizer (N), SP36 fertilizer (P), KCl fertilizer (K), Landep 450 SL insecticide, Antracol 70 WP fungicide, and paclobutrazol Gobest 250 SC.

2.3. Research Design

The study utilized a Split-Plot Design (SPD) consisting of two factors. Paclobutrazol concentration (P) was assigned to subplots with four treatment levels: 0 ppm (P0), 600 ppm (P1), 800 ppm (P2), and 1000 ppm (P3). Fertilizer combinations (N), applied as the main plot factor, also included four levels: urea 650 kg/ha + SP36 225 kg/ha + KCl 150 kg/ha (N1), urea 400 kg/ha + SP36 200 kg/ha + KCl 200 kg/ha (N2), urea 500 kg/ha + SP36 200 kg/ha + KCl 150 kg/ha (N3), and urea 600 kg/ha + SP36 300 kg/ha + KCl 200 kg/ha (N4). A total of 16 treatment combinations were established, each with three replications, resulting in 48 experimental units (Figure 1).

2.4. Research Procedure

Seeds were immersed in water for 24 hours, followed by draining and a further 24-hour incubation period until radicle emergence occurred. The field was prepared one week prior to transplanting using a tractor, and then divided into plots measuring 2.25 m in length and 2 m in width, with a 50 cm spacing between plots. Transplanting was done at a spacing of 25 cm × 25 cm using three seedlings per planting hole. Fertilization was carried out in stages at 7, 28, and 42 days after transplanting (DAT) by broadcasting the fertilizer onto the field under saturated soil conditions. Paclobutrazol was applied twice at 21 and 35 DAT by evenly spraying it onto the leaves. Rice harvesting was conducted when 90–95% of the grains had turned yellow, the flag leaves had aged and turned yellow, and the rice plants had reached 100 DAT.

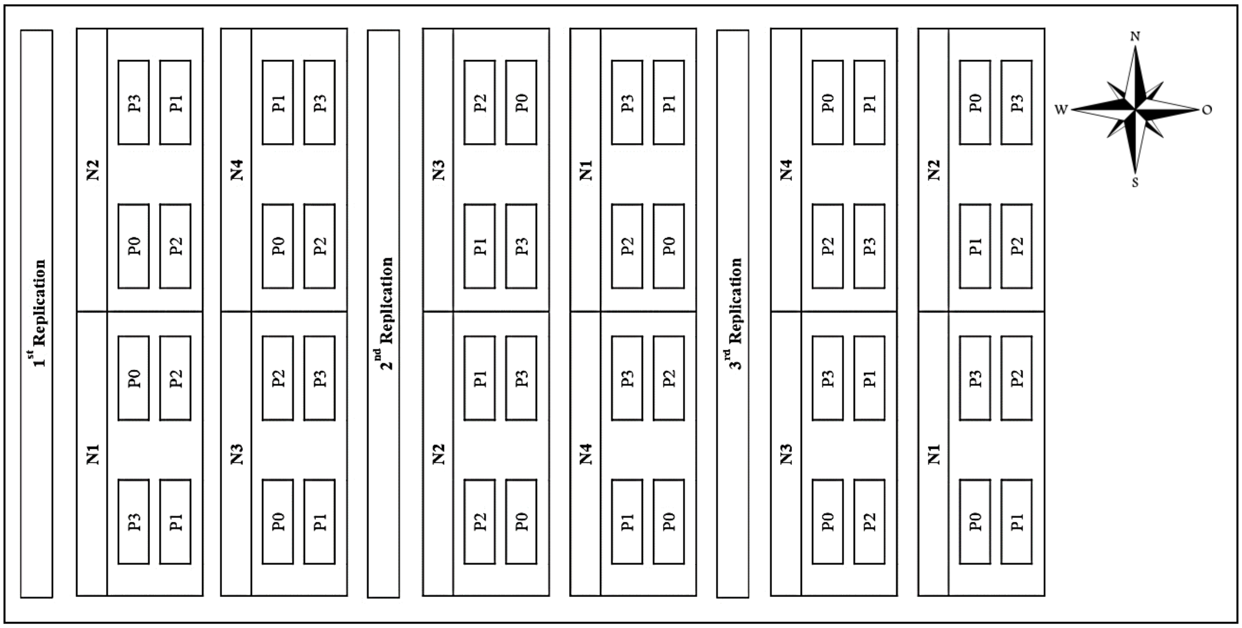

Figure 1. Layout of the experiment and treatment combinations (plot length: 2.5 m; plot width: 2 m; distance between plots: 50 cm; distance between subplots: 25 cm; distance between rows: 25 cm; in row spacing: 25 cm; P: Paclobutrazol; N: Fertilizer combination).

2.5. Data Analysis

Observed variables consisted of plant height, leaf number, flowering time, panicle number, and dry weight per hectare. Plant height and leaf number were assessed at 28, 35, 42, 49, and 56 DAT, while panicle number and yield were measured at harvest. The collected data were analyzed using analysis of variance (ANOVA) to determine treatment effects. In cases where significant differences were found, a follow-up test using the Honestly Significant Difference (HSD) at the 5% level was performed.

3. RESULTS AND DISCUSSION

3.1. Analysis of Variance

Table 1. Results of analysis of variance for each observed parameter

Parameter	Paclobutrazol concentration (P)			Fertilizer combination (N)			P × N		
	F-count	F-table	Sig.	F-count	F-table	Sig.	F-count	F-table	Sig.
Plant height (28 DAT)	32.13	3.01	*	21.76	4.76	*	2.53	2.30	*
Plant height (35 DAT)	13.30	3.01	*	18.33	4.76	*	4.97	2.30	*
Plant height (42 DAT)	25.65	3.01	*	4.82	4.76	*	5.71	2.30	*
Plant height (49 DAT)	34.52	3.01	*	113.14	4.76	*	12.12	2.30	*
Plant height (56 DAT)	28.04	3.01	*	50.01	4.76	*	4.98	2.30	*
Number of leaves (28 DAT)	9.45	3.01	*	5.19	4.76	*	2.53	2.30	*
Number of leaves (35 DAT)	7.40	3.01	*	7.69	4.76	*	2.36	2.30	*
Number of leaves (42 DAT)	10.89	3.01	*	4.80	4.76	*	4.88	2.30	*
Number of leaves (49 DAT)	10.63	3.01	*	5.51	4.76	*	4.36	2.30	*
Number of leaves (56 DAT)	3.33	3.01	*	14.09	4.76	*	3.12	2.30	*
Days of flowering	4.81	3.01	*	4.86	4.76	*	1.94	2.30	ns
Number of panicles	79.33	3.01	*	4.98	4.76	*	3.36	2.30	*
Grain yield	4.23	3.01	*	6.03	4.76	*	3.60	2.30	*

Note: * = significant; ns = not significant

ANOVA results indicated that both plant height and leaf number across all observation periods were significantly affected by paclobutrazol concentration, fertilizer combination, and their interaction. Similar significant effects were observed for panicle number and grain yield. In contrast, flowering time was not significantly affected by the interaction between treatments. The significance of each treatment effect was determined through comparison between the calculated F statistic and the critical F value. When the computed F value exceeded the critical value, the effect was considered significant; otherwise, it was regarded as non-significant. A significant effect implies that, in addition to uncontrolled factors, the treatment factors contributed to the observed parameters, whereas a non-significant effect suggests that result from observed parameters was predominantly attributable to uncontrolled or random factors.

3.2. Plant Height

ANOVA analysis indicated that the interaction between N, P, and K fertilizer treatments and paclobutrazol concentration significantly influenced plant height at 28, 35, 42, 49, and 56 DAT (F value > F table) (Table 1). The data in Table 2 show that the highest average plant height at 28, 35, 42, and 49 DAT was found in the treatment combination of N4P1. At 56 DAT, the highest plant height was recorded in the N4P0 treatment. The lowest plant height at all observed ages was recorded in the treatment combination of N1P0. The combination of N, P, K fertilizer with paclobutrazol creates optimal conditions for the plants. The macronutrients from N, P, K support leaf and root growth, while paclobutrazol inhibits excessive stem elongation, thus creating a balance between plant development and height. This result is consistent with the statement of Tristanti *et al*. (2018), which suggests that the application of N, P, K and inorganic fertilizers can significantly affect plant height and the number of leaves. The application of paclobutrazol at high concentrations at certain fertilizer doses can inhibit vegetative plant growth. This may be caused by inhibiting the synthesis of the hormone gibberellin, which is responsible for cell elongation. This is in line with Sugiharto *et al*. (2022), who found that paclobutrazol inhibits gibberellin synthesis, which ultimately leads to a decrease in gibberellin concentration.

Table 2. Effect of treatments on the average plant height of rice

Age (DAT)	Paclobutrazol Concentration	Plant Height (cm)			
		NPK Fertilizer			
		N1	N2	N3	N4
28	P0	39.49 a	47.22 bc	42.36 ab	41.97 ab
	P1	46.67 bc	47.05 bc	43.06 ab	48.53 c
	P2	43.47 ab	43.78 b	40.68 ab	47.03 bc
	P3	43.00 ab	40.44 ab	45.83 bc	44.28 b
	HSD 5 %	4.23			
35	P0	41.97 a	46.52 bc	48.53 c	47.50 bc
	P1	45.91 bc	46.71 bc	47.03 bc	48.69 c
	P2	44.94 b	45.94 bc	46.01 bc	48.50 c
	P3	43.98 ab	44.04 ab	44.28 ab	47.41 bc
	HSD 5 %	3.41			
42	P0	48.75 a	55.38 c	56.53 c	57.36 c
	P1	53.51 bc	54.56 bc	55.10 c	57.50 c
	P2	52.62 bc	53.34 bc	54.94 c	49.83 a
	P3	52.39 b	52.33 b	53.54 bc	54.50 bc
	HSD 5 %	2.60			
49	P0	50.43 a	62.27 bc	62.99 c	62.02 bc
	P1	59.65 b	61.60 bc	61.60 bc	63.30 c
	P2	60.22 bc	61.20 bc	61.60 bc	61.60 bc
	P3	53.53 b	60.08 bc	60.39 bc	60.93 bc
	HSD 5 %	3.24			
56	P0	58.22 a	69.63 c	66.28 bc	72.40 c
	P1	66.43 bc	67.87 bc	67.55 bc	70.49 c
	P2	66.02 bc	66.33 bc	68.38 bc	69.30 bc
	P3	65.07 b	66.02 bc	59.22 a	68.81 bc
	HSD 5 %	4.50			

Note: Means sharing the same letter within a given observation time do not differ significantly based on the 5% HSD test; DAT refers to Days after transplanting.

3.3. Number of Leaves

Based on ANOVA, a significant effect of the combined application of N, P, and K fertilizers and paclobutrazol concentration on plant height was observed at 28, 35, 42, 49, and 56 DAT (F value > F table) (Table 1). The highest number of leaves at all observed ages/times occurred in the treatment combination of N4P1. The N1P0 combination resulted in the lowest number of leaves, showing a trend comparable to that observed in plant height (Table 3). A study by Sugiharto *et al*. (2022) showed that paclobutrazol concentrations at certain ages of tomato plants can cause a decrease in leaf number. However, as the tomato plant ages, paclobutrazol concentrations have no effect on leaf number and are more influenced by fertilizer dosage. However, this finding does not align with the results presented by Fathurrahman *et al*. (2022) on *Albizia saman*, where paclobutrazol application resulted in a smaller number of leaves. However, when considering the results as a combination treatment, paclobutrazol application at certain fertilizer dosages produced more varied result.

Table 3. Effect of treatments on the number of leaves of rice

Age (DAT)	Paclobutrazol Concentration	Number of Leaves (blades)			
		NPK Fertilizer			
		N1	N2	N3	N4
28	P0	32.08 a	37.44 ab	34.00 a	36.11 ab
	P1	32.72 a	38.39 ab	34.67 a	42.33 b
	P2	35.89 ab	32.78 a	35.33 ab	41.22 b
	P3	38.00 ab	35.89 ab	35.78 ab	41.22 b
	HSD 5 %	6.48			
35	P0	42.00 a	49.00 b	51.44 bc	52.33 bc
	P1	46.00 a	52.67 bc	54.33 c	55.00 c
	P2	50.67 bc	51.67 bc	53.44 bc	53.33 bc
	P3	51.11 bc	52.78 bc	54.67 c	51.78 bc
	HSD 5 %	4.87			
42	P0	57.33 a	68.89 b	71.44 bc	72.33 bc
	P1	65.33 a	71.56 bc	73.22 c	73.67 c
	P2	70.11 bc	72.89 c	73.22 c	72.33 bc
	P3	71.11 bc	73.33 c	73.67 c	70.78 bc
	HSD 5 %	3.55			
49	P0	80.25 a	81.00 ab	84.11 ab	91.78 b
	P1	83.33 ab	81.00 ab	86.22 ab	91.89 b
	P2	83.61 ab	83.61 ab	89.00 ab	90.33 b
	P3	90.39 b	90.72 b	90.67 b	88.00 ab
	HSD 5 %	9.90			
56	P0	84.00 a	98.78 b	96.67 b	98.78 b
	P1	85.44 ab	98.78 b	99.22 b	101.11 b
	P2	87.11 ab	99.33 b	99.11 b	97.33 b
	P3	95.77 b	99.89 b	99.44 b	98.44 b
	HSD 5 %	10.81			

Note: Mean values followed by the same letter within the same observation age are not significantly different based on the HSD test at the 5% significance level; DAT: Days after Transplanting.

3.4. Days to Flowering

The ANOVA analysis revealed no significant effect of the combined application of N, P, and K fertilizers and paclobutrazol concentration on flowering time. However, the single factor, paclobutrazol concentration nor fertilizer combination, had a significant effect (Table 1). The earliest average flowering time was observed in the treatment of N4, which was 61.44 DAT, while the slowest flowering age occurred in the treatment of N2, which was 62.22 DAT. For the paclobutrazol treatment, the fastest average flowering age was observed at a concentration of P1, which was 61.19 DAT. The slowest flowering age occurred at P0, which was 62.58 DAT (Table 4).

Table 4. Effect of NPK and Paclobutrazol concentration on the days to flowering

NPK	Flowering Age (DAT)
N1	63.37 b
N2	62.22 ab
N3	61.47 a
N4	61.44 a
HSD 5 %	1.90

NPK	Flowering Age (DAT)
P0	62.58 b
P1	61.19 a
P2	62.42 ab
P3	61.33 ab
HSD 5 %	1.28

Note: Mean values followed by the same letter within the same observation age are not significantly different based on the HSD test at the 5% significance level; DAT: Days after Transplanting

The fertilization treatments showed that the application of fertilizers at the appropriate doses could accelerate the time to flowering. This indicates that N, P, K fertilization plays a crucial role in promoting the plant's physiological the transition from the vegetative stage to the reproductive stage. According to Gunardi *et al*. (2023), nitrogen (N) plays a role in chlorophyll formation and protein synthesis, which supports vegetative growth. However, when applied at appropriate levels and in balance with other macronutrients, nitrogen can also promote the development of reproductive structures such as panicles and flowers. On the other hand, phosphorus (P) is important for cell division and energy production required to initiate flowering. Additionally, potassium (K) supports enzyme regulation, photosynthate transport, and tissue formation. Meanwhile, the application of paclobutrazol can accelerate generative growth by altering the distribution of photosynthetic assimilates to the plant's generative organs (Aldini *et al*., 2022). Inappropriate fertilizer dosages may lead to nutrient deficiencies or toxicity in plants, which can slow growth and, in severe cases, cause plant death (Sukarminingsih *et al*., 2017). According to Krasilnikov *et al*. (2022), improper fertilization will cause a decline in soil quality, increased pest attacks, and a decrease in beneficial organisms, which will result in a decrease in plant growth and yields.

3.5. Number of Panicles per Clump

The results of the ANOVA showed that the combination of N, P, and K fertilizer treatments and paclobutrazol concentration significantly affected the number of panicles per clump (F value > F table) (Table 1). The data in Table 5 indicate that the greatest average panicle number per clump was obtained under the N4P1 treatment, amounting to 40.67 panicles. The lowest number of panicles per clump occurred in the treatment combination of N1P0, which was 29.11 panicles. The application of paclobutrazol has been shown to increase the number of panicles both in dry and flooded conditions (Azarcon *et al*., 2022). The Urea dose of 600 kg/ha provides sufficient nitrogen to increase the number of potential tillers per clump. In contrast SP-36 and KCl at high doses of 300 and 200 kg/ha, respectively, can enhance plant vigor, resulting in more uniform panicle formation and improved stem quality and strength. This allows the plants to support a greater number of panicles. By suppressing the biosynthesis of gibberellins, paclobutrazol slows stem growth but enhances the shift toward the generative phase. As a result, the plants have more uniform panicles because the controlled vegetative growth enables resources to be directed toward flower and seed formation. The combination of high macronutrient fertilization and hormonal balance regulation through paclobutrazol creates an ideal physiological environment for the plants to maximize panicle number. This is in line with research by Syahputra *et al*. (2016), where increasing the concentration of paclobutrazol to 600 ppm was able to significantly increase the number of panicles.

Table 5. Effect of treatments on the average number of panicles per clump

Paclobutrazol Concentration	Number of Panicles per Clump (Panicles)			
	NPK Fertilizer			
	N1	N2	N3	N4
P0	29.11 a	29.87 a	32.67 b	33.00 b
P1	34.00 bc	37.22 d	33.00 b	40.67 e
P2	33.44 bc	35.11 c	35.28 c	33.33 bc
P3	35.55 cd	29.67 a	36.22 cd	35.67 cd
HSD 5 %	1.79			

Note: Mean values followed by the same letter within the same observation age are not significantly different based on the HSD test at the 5% significance level; DAT: Days after Transplanting

3.6. Grain Yield per Hectare

The results of the ANOVA showed that the combination of N, P, and K fertilizer treatments and paclobutrazol concentration significantly affected the grain yield per hectare (F value > F table) (Table 1). As presented in Table 6, the highest average dry grain weight per hectare of rice was found in the treatment combination of N4P1, which was 9.11 tons. The lowest dry grain weight per hectare occurred in the treatment combination of N1P0, which was 6.21 tons. The nutrient content of N, P, and K can optimally enhance both vegetative and generative growth in rice plants. The combination of optimal macro-nutrient availability with hormonal regulation by paclobutrazol creates a balance between the energy needs for growth and reproductive processes. The elements N, P, and K support the availability of energy and physiological processes, while paclobutrazol directs the use of this energy toward the optimal formation and maturation of panicles. This promotes an increase in generative component yield. However, excessive nitrogen application beyond the optimal dose will hinder the absorption of other nutrients, thus reducing growth and yield, and may increase the number of empty grains (Ambarita *et al*., 2017).

Table 6. Effect of treatments on the dry unhusked grain weight per hectare

Paclobutrazol Concentration	**Dry Unhusked Grain (ton/ha)**			
	NPK Fertilizer			
	N1	**N2**	**N3**	**N4**
P0	6.21 a	6.40 a	7.29 b	7.46 b
P1	7.38 b	6.93 ab	6.27 a	9.11 c
P2	7.81 bc	7.28 b	6.34 a	7.26 b
P3	8.59 c	8.40 c	7.81 bc	7.77 bc
HSD 5 %	0.77			

Note: Mean values followed by the same letter within the same observation age are not significantly different based on the HSD test at the 5% significance level.

Paclobutrazol has been shown to increase stomatal conductance, which is the leaf's ability to capture CO_2. This increase in conductance results in wider stomatal openings and a greater number of stomata, which indirectly improves photosynthetic efficiency by enhancing CO_2 flow and regulating the rate of transpiration. Rombon *et al*. (2019) support this statement, noting that the application of paclobutrazol can increase chlorophyll a content, which contributes to the increase in dry grain weight. Furthermore, according to Palupi *et al*. (2025), the paclobutrazol application can enhance photosynthate utilization efficiency, leading to an increase in harvest index. Thus, paclobutrazol treatment not only functions to control plant growth but is also effective in increasing dry grain weight. The application of paclobutrazol can enhance root development, leading to higher harvest yields (Kamran *et al*., 2018). At the correct concentration, paclobutrazol has a positive effect. However, at too high a dose, the plant may experience stress or excessive growth suppression, which could decrease plant growth. Conversely, too low a dose may not effectively suppress apical dominance. Therefore, using the optimal concentration of 600 ppm is crucial for maximizing productivity.

4. CONCLUSION

The best treatment combination was obtained from the combination of Urea (600 kg/ha) + SP36 (300 kg/ha) + KCl (200 kg/ha) + 600 ppm paclobutrazol, which showed the best results for plant height, number of leaves, and dry grain weight per hectare. High-dose NPK fertilization (Urea 600 kg/ha, SP36 300 kg/ha, KCl 200 kg/ha) and 600 ppm paclobutrazol accelerated flowering and resulted in the highest number of panicles. The balanced fertilization combination and hormonal regulation effectively promoted the generative phase of rice plants. The treatments applied showed significant effects across all parameters, suggesting that this combination of fertilizer and plant growth regulators can be applied in rice cultivation activities in the field, especially in areas with similar agro-climatic conditions. To ensure result stability, the treatments need to be evaluated under different environmental conditions and planting seasons.

AUTHOR CONTRIBUTION STATEMENT

Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
FR	✓	✓				✓		✓	✓					
AS				✓			✓			✓		✓		
PN				✓			✓			✓		✓		

C: Conceptualization	Fo: Formal Analysis	O: Writing - Original Draft	Fu: Funding Acquisition
M: Methodology	I: Investigation	E: Writing - Review & Editing	P: Project Administration
So: Software	D: Data Curation	Vi: Visualization	
Va: Validation	R: Resources	Su: Supervision	

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