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Modulation of Biomass Accumulation and Yield Traits in *Vigna sinensis* L. Under Paclobutrazol and NPK Phonska Plus (15:15:15) Treatments

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Abstract

Background: *The productivity of long beans (Vigna sinensis L.) in Indonesia remains low due to an imbalance between vegetative and generative growth, with long bean production experiencing significant fluctuations between 2017 and 2022, dropping to 352,700 tons in 2019 and rising again to 360,674 tons in 2022. Research on the use of paclobutrazol and NPK fertilizer on long beans is generally conducted separately, so information regarding their interaction on fruit set and productivity remains limited. Therefore, this study aims to evaluate the interaction between paclobutrazol concentration and Phonska Plus NPK fertilizer dose on the growth and yield of long beans (V. sinensis L.), as well as to determine the most effective treatment combination for improving the plants' generative performance.* **Methodology:** *The study employed a two-factor randomized block design (RBD) with four levels of paclobutrazol (0, 100, 150, 200 ppm) and four levels of Phonska Plus NPK fertilizer (250, 300, 350, 400 kg/Ha), each replicated three times. Data were analyzed using analysis of variance (ANOVA) and followed by a BNJ test at the 5% level if significant effects were found.* **Findings:** *The results showed significant interactions for plant height at 14 and 56 days after sowing (DAS), pod number in the 2nd and 3rd weeks of harvest, pod weight per plot, and fruit set. The combination of 150 ppm paclobutrazol and 400 kg/Ha NPK Phonska Plus yielded the highest fruit set at 86.92% and high pod weight. Physiologically, a moderate dose of paclobutrazol effectively suppressed vegetative growth in a controlled manner, allowing for more efficient distribution of photosynthates to the generative organs, while sufficient levels of N, P, and K enhanced photosynthetic activity and the pod-filling process.* **Contributions:** *This study demonstrates the synergy between hormonal regulation and balanced fertilization in enhancing the generative performance of long beans, and provides recommendations for effective dose combinations to support more efficient and targeted productivity improvements.*

Keywords: *Fruit set; Growth–yield interaction; NPK fertilization; Paclobutrazol; Vigna sinensis*

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INTRODUCTION

Long bean production in Indonesia has fluctuated, dropping to 352,700 tons in 2019 before rebounding in 2022. These production fluctuations indicate that long bean productivity remains unstable over time. Meanwhile, population growth has led to increased consumption, necessitating more efficient cultivation strategies to ensure sustainable production. This situation underscores the need for efforts to increase long bean production sustainably. The decline in production is not in line with the increase in public consumption, which rose from 2,238 kg/capita/year in 2021 to 2,275 kg/capita/year in 2022 (Central Statistics Agency, 2022). Low productivity is influenced by an imbalance between vegetative and generative growth, limited soil fertility, and low nutrient availability. One improvement strategy involves the use of the growth regulator paclobutrazol, which inhibits gibberellin synthesis, suppresses vegetative growth, and redirects the plant's energy toward flower formation and pod filling (Utami et al., 2018).

In addition, fertilization plays a crucial role in supplying macro- and micronutrients. Phonska NPK fertilizer contains N, P, K, Zn, and S, which support vegetative and generative growth. Previous research has shown that a dose of 200 kg/ha of Phonska NPK has a significant effect on the growth and yield of long beans (Supandji et al., 2021). Paclobutrazol also plays a role in the allocation of photosynthates to reproductive organs, while NPK Phonska enhances nutrient uptake (Yusran, 2024). Several previous studies have examined the effects of paclobutrazol and NPK fertilizer, both individually and in combination; however, most were conducted on other crops such as tomatoes, chili peppers, watermelons, and peanuts. Fitriana (2024) reported that applying 150 ppm paclobutrazol increased long bean yields to 44.16 tons/ha, while Widad et al., (2021) demonstrated that the combination of paclobutrazol and NPK fertilizer synergistically enhances flower and fruit formation in chili plants. However, research specifically on the combination of paclobutrazol and NPK Phonska in long beans remains limited. Most previous studies have focused on single treatments or were conducted on crops other than long beans, thus failing to provide a comprehensive picture of the potential synergy between these two treatments.

The novelty of this study lies in the evaluation of the interaction between various concentrations of paclobutrazol and doses of Phonska NPK fertilizer on growth, flowering, pod number, pod weight, and yield per hectare in long bean plants. This study also examines the effects of these treatments on important parameters such as fruit set and pod development, which have not been extensively studied previously. Through this approach, it is hoped that recommendations can be obtained regarding the most effective paclobutrazol concentration and Phonska NPK fertilizer dose to enhance the growth and yield of long beans. This study aims to determine the effects of paclobutrazol growth regulator concentrations and Phonska Plus NPK fertilizer doses, both individually and in interaction, on the growth and yield of long bean plants, and to identify the optimal treatment combination to achieve maximum productivity.

METHOD

This study was conducted from May 2025 on land in Medokan, Medokan Asri Utara, and Medokan Ayu, Rungkut District, Surabaya. This land, owned by the Surabaya City Food Security and Agriculture Agency (DKPP), is located at an elevation of approximately 5 meters above sea level, with an average minimum temperature of 23 °C and a maximum temperature of 34 °C. The average annual rainfall is approximately 165.3 mm, and relative humidity ranges from a minimum of 50% to a maximum of 92%.

Materials and Equipment

The tools used in this study included mulch, a hoe, a trowel, a measuring cup, an analytical balance, wool thread, raffia twine, a sprayer, a knife, stakes, a bucket, a hand sprayer, a measuring tape, labels, a ruler, writing utensils, and a camera. The materials used in this study were Katon Tavi long bean seeds, goat manure, Curacron insecticide, Antracol fungicide, Phonska Plus NPK fertilizer, and Golstar 250 SC paclobutrazol plant growth regulator.

Data Collection

This study was a factorial experiment consisting of two treatment factors and designed according to the principles of a Randomized Block Design (RBD). Factor 1 was the concentration of Paclobutrazol Golstar (P), and Factor 2 was the application rate of Phonska Plus NPK fertilizer (N), each consisting of four treatment levels: P0 = 0 ppm; P1 = 100 ppm; P2 = 150 ppm; P3 = 200 ppm. Factor 2 is Phonska Plus NPK fertilizer, consisting of 4 application levels: N1 = 250 kg/ha; N2 = 300 kg/ha; N3 = 350 kg/ha; and N4 = 400 kg/ha. Based on these two factors, 16 treatment combinations were obtained. The determined treatment combinations were repeated three times, resulting in 48 experimental units. There were 8 plant populations with 4 sample plants each, resulting in a total population of 384 plants.

Land Preparation

Preparation of the planting site for long beans begins with soil cultivation by turning the soil over with a hoe to loosen it. The next step is to spread dolomite evenly over the entire soil surface and let it sit for 2 days. The following step involves creating raised beds 1 meter wide, spaced 1 meter apart, and 30 cm high. The next step involves adding base fertilizer, goat manure, NPK, and dolomite lime in sequence, spreading them evenly across each raised bed. Once completed, Black-Silver Plastic Mulch (MPHP) is installed on each prepared raised bed, secured using stakes on each side of the bed. Holes are punched in the mulch according to the predetermined planting spacing. Holes in the mulch are made using a used milk can that has been heated and then pressed against the plastic mulch. Mulch installation is done during the day so that the mulch can expand quickly, ensuring it covers the beds properly.

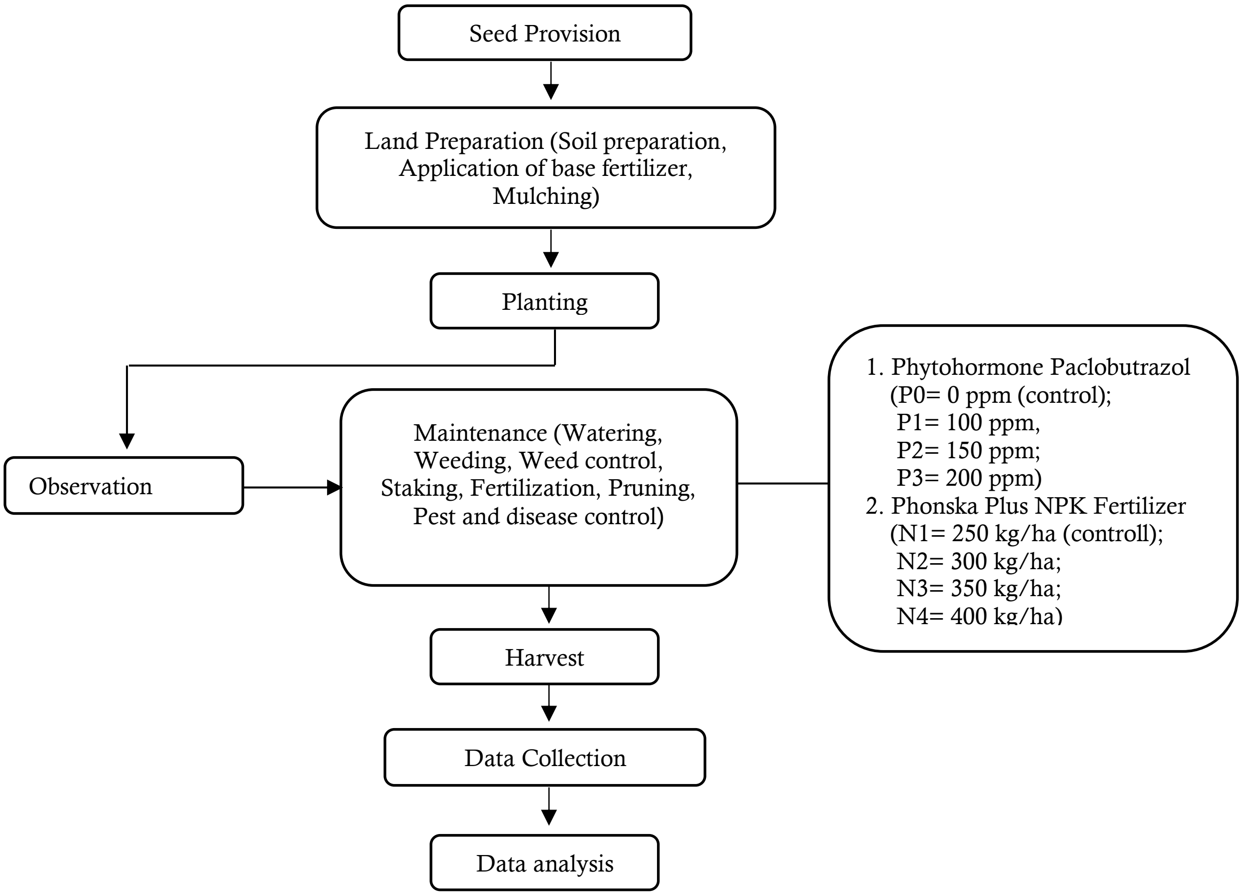

Figure 1. Research Implementation Flowchart

Planting

Planting is done in the morning; long bean seeds are planted by making holes 2–3 cm deep. Each hole is filled with two seeds, then lightly covered with soil. The planting spacing for long beans is 40 cm × 60 cm, with eight plants per plot, plus plants serving as an outer border. At 7 days after sowing (DAS), thinning is performed by leaving the best plant per planting hole, cutting the others above ground level. Watering is done after planting if the soil is too dry.

Fertilization

NPK Phonska Plus fertilization for long beans was carried out in the afternoon using the hole-digging method, approximately 6 cm from the planting hole, and was conducted in three stages: initial fertilization, first top-dressing, and second top-dressing. Initial fertilization was performed during land preparation using 2 kg/m² of goat manure, and at planting, NPK Phonska Plus was added at ¼ of the treatment dose. The first follow-up application is given at 14 and 28 days after sowing (DAS) with NPK Phonska Plus at ¼ of the dose each, while the second follow-up application is carried out at 42 and 56 DAS with the dose increased to ½ of the dose for each application. The NPK Phonska Plus dosage was adjusted according to the treatment, namely 250 kg/ha (control), 300 kg/ha, 350 kg/ha, and 400 kg/ha.

Application of The Plant Growth Regulator Paclobutrazol

Paclobutrazol was applied to long bean plants three times when the plants were 20, 27, and 34 days after sowing, based on the indeterminate plant type. The application of the paclobutrazol plant growth regulator (PGR) Golstar was carried out by applying concentrations corresponding to the treatment levels, namely four treatment levels: 0 ppm, 100 ppm, 150 ppm, and 200 ppm, which were sprayed evenly onto the leaves of the long bean plants until the plants were wet. This application of paclobutrazol can be performed in the morning.

Maintenance

Maintenance of long bean plants includes regular watering 1–2 times a day in the morning or evening depending on soil conditions, replanting of plants that have not sprouted by 7 days after sowing using reserve seedlings from polybags, and manual weeding about once a week to prevent competition for nutrients. Plants are also provided with a trellis made of bamboo stakes approximately 2 m tall and 3 cm wide at 14 days after sowing (DAS) or 25 cm tall to support vertical growth, air circulation, and ease of maintenance. Vine pruning is performed on the 1st–3rd nodes at 15–20 DAS before flowering to enhance flowering and pod development. Pest and disease control is carried out through field sanitation, routine monitoring, manual control, and chemical control when infestation intensity is high, such as using the insecticide Curacron at 3 ml/L for whiteflies and armyworms, and the fungicide Antracol at 3 g/L for leaf spot disease caused by Cercospora sp., with spraying beginning 2 weeks after planting and repeated every week. Harvesting is done by cutting the base of the pods at approximately 45 days after sowing (DAS) or 14 days after flowering, every other day throughout the week, with the criteria being firm pods of a fresh green color to ensure quality is maintained.

Observation Parameters

The observed parameter was plant height, measured by calculating the distance from the soil surface to the tip of the longest shoot using a measuring tape. The number of pods per plant was recorded from the first harvest until the end of the harvest period by counting all pods on the sample plants. The number of pods per plant was recorded from the first harvest until the end of the harvest period by counting the number of pods on each sample plant. Pod weight was measured during each harvest period from the beginning to the end of the harvest period, with measurements taken every two days. Measurements were taken by weighing all the pods on each plant sample using an analytical balance.

Pod weight per hectare is calculated by converting the long bean harvest yield to hectares. This data is collected by summing the total weight of long bean pods for each harvest period from the beginning to the end of the harvest period; the total weight of the long bean pods is determined using an analytical balance and then converted to tons. Fruit set is calculated by determining the percentage of flowers that have successfully developed into long bean pods on a single plant, using the formula referenced by Triani & Sulistyono (2023). The calculation formula 1 is as follows:

$$\frac{Number\ of\ pods\ harvested}{total\ interest} \times 100\% \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

Data Analysis

Data analysis was performed on the experimental results using analysis of variance (ANOVA) in accordance with the experimental design used, namely the Randomized Block Design (RBD). This study is a factorial experiment consisting of two factors. The first factor is the concentration of Paclobutrazol Golstar (P), which consists of four treatment levels, and the second factor is the application rate of NPK Phonska Plus fertilizer (N), which consists of four treatment levels. All data obtained were then statistically analyzed using analysis of variance (ANOVA) to determine the presence of significant interactions or real effects between treatments. The results of the data analysis will indicate whether there is a significant effect or no significant effect. Results showing a significant effect will undergo further analysis using the 5% BNJ test using Microsoft Excel 2013.

RESULTS AND DISCUSSION

Plant Height (cm)

Statistical analysis of plant height showed that the combination of paclobutrazol and Phonska NPK fertilizer had a significant effect on plant height at 14 and 56 days after sowing (Figure 2). Table 1 shows that the single treatment with paclobutrazol had a significant effect at 28–49 DAS, and the single treatment with Phonska Plus NPK fertilizer had a significant effect at 42 DAS and 49 DAS. The mean values for plant height at 14 and 56 DAS are presented in Figure 2, and the mean values for plant height from 21 to 49 DAS are presented in Table 1.

The results of the analysis show that the interaction between paclobutrazol and Phonska NPK fertilizer on the length of long beans had a significant effect at 14 and 56 days after sowing. At 14 DAP, the combination of 200 ppm paclobutrazol and 250 kg/ha NPK resulted in the best plant height of 14.34 cm, while the combination of 0 ppm paclobutrazol and 300 kg/ha NPK yielded a lower height of 7.50 cm. This indicates that a moderate dose of paclobutrazol does not inhibit growth but rather enhances photosynthetic efficiency and nutrient uptake, while NPK provides sufficient nitrogen and phosphorus for early growth.

At 56 days after sowing, the combination of 0 ppm paclobutrazol and 400 kg/ha NPK yielded the best plant height of 296.75 cm, whereas the combination of 100 ppm paclobutrazol and 350 kg/ha NPK resulted in a lower height of 115.25 cm. These results indicate that a high dose of paclobutrazol suppresses gibberellin biosynthesis, thereby inhibiting stem elongation, whereas a high dose of NPK fertilizer enhances vegetative tissue formation through the availability of N, P, and K, which support photosynthetic activity.

Table 1. Average Length of Long Bean Plants Under Single Treatments of Paclobutrazol Concentration and Phonska Plus NPK Fertilizer Dosage

Paclobutrazol Concentration (ppm)	**Average Plant Height (cm)**				
	HST				
	21	**28**	**35**	**42**	**49**
0	94.00 ± 26.54	186.9 ± 36.86^{c}	208.74±41.24^{c}	228.06±49.52^{c}	244.43± 49.01^{c}
100	79.54 ± 26.79	113.29 ± 47.53^{b}	132.11±57.58^{b}	157.39±62.07^{b}	167.00± 68.58^{b}
150	73.99 ± 23.19	97.73 ± 34.18^{a}	112.58±37.13^{a}	142.52±46.33^{ab}	150.83± 44.37^{a}
200	71.91 ± 33.10	90.03 ± 46.01^{a}	99.63± 47.54^{a}	129.69± 56.33^{a}	136.03± 52.18^{a}
BNJ 5%	tn	12.92	14.47	15.72	15.52
NPK Phonska Fertilizer Dosage (kg/ha)					
250	84.50± 26.37	115.54± 51.38	130.51± 55.11	150.42± 55.56^{ab}	157.44± 62.53^{a}
300	81.02± 27.75	129.78± 50.15	148.70± 59.24	162.75± 57.41^{b}	174.23± 58.66^{b}
350	69.50± 28.30	116.77± 64.87	130.61± 71.03	144.86± 75.19^{a}	156.41± 77.03^{a}
400	84.42± 30.82	125.85± 61.77	143.23± 67.79	199.63± 62.55^{c}	210.22± 63.76^{c}
BNJ 5%	tn	tn	tn	15.72	15.52

Note: Mean values followed by the same letter and corresponding to the same treatment and age group indicate no significant difference in the BNJ test at the 5% level; ns = not significant.

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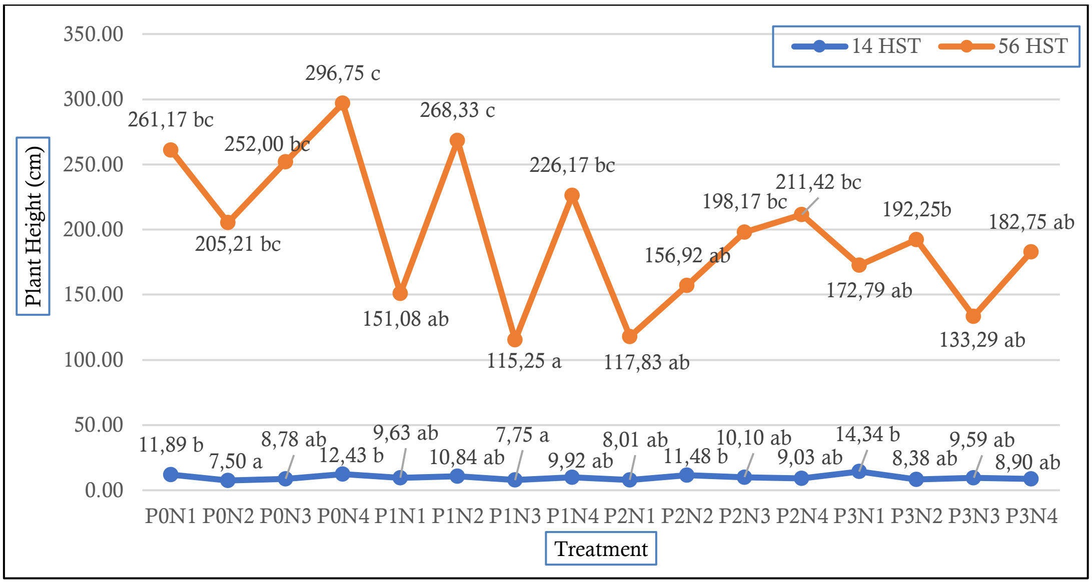

Figure 2. Graph of Average Plant Height at 14 and 56 Days After Sowing Due to the Combination of Paclobutrazol Concentration and Phonska NPK Fertilizer Dosage Treatments. **Note:** P0=0 ppm; P1= 100 ppm; P2= 150 ppm; P3=200 ppm; N1= 250 kg/ha; N2= 300 kg/ha; N3= 350 kg/ha; N4=400 kg/ha

According to Utami et al., (2018), neutral soil pH (6.7–6.8) and optimal light conditions further enhance nutrient uptake, so the combination of low-dose paclobutrazol and high-dose NPK yields the best vegetative growth, whereas high-dose paclobutrazol inhibits growth due to limited hormonal activity and nutrient uptake. However, at low to moderate doses, paclobutrazol does not completely suppress growth; rather, it stabilizes vegetative growth, making it more efficient in utilizing nutrients from NPK fertilizer.

The nitrogen (N) content in NPK fertilizer greatly aids in the formation of chlorophyll and proteins in plant tissues, which accelerates the development of productive green leaves for photosynthesis. Meanwhile, phosphorus (P) strengthens root development and enhances nutrient uptake from the soil. Sari et al., (2025) Therefore, the combination of paclobutrazol with high fertilizer doses creates stable physiological conditions in plants, where vegetative growth remains active but not excessive (Martiani, 2022).

Table 1 shows that the application of paclobutrazol had no significant effect on the plant height of long beans at 21 days after sowing (DAS), but from 28 to 49 DAS, the treatments showed significant differences. The 0 ppm treatment consistently produced taller plants compared to the 100, 150, and 200 ppm treatments. At 49 DAP, the longest plant height was achieved by the 0 ppm treatment (244.43 cm), while the 200 ppm treatment produced the shortest height (136.03 cm) and was not significantly different from the 100 and 150 ppm treatments. The decrease in plant height at higher paclobutrazol concentrations indicates that paclobutrazol effectively inhibits gibberellin biosynthesis, which plays a role in cell elongation. These results are consistent with the findings of Wahyudi et al., (2017), who reported that increasing paclobutrazol concentrations (0–250 ppm) in long beans significantly reduced stem growth due to reduced elongation activity and internode formation.

Regarding the Phonska NPK fertilizer treatment, no significant differences were observed at 21–35 days after sowing (DAS); however, at 42 DAS, the 400 kg/ha dose began to show a significant effect and resulted in greater plant height compared to the lower doses. At 49 DAP, the 400 kg/ha treatment still produced the longest plant height (210.22 cm), while the 350 kg/ha dose produced a shorter height (156.41 cm) and showed no significant difference compared to the 300 kg/ha dose. These results indicate that sufficient availability of N, P, and K nutrients supports the vegetative growth of long beans. These results are supported by research by Lestari & Wahyudi (2019), who stated that increasing the NPK fertilizer dose for long beans enhances plant height and vigor because nitrogen compounds support chlorophyll formation and phosphorus promotes cell division, while potassium strengthens tissues and facilitates the transport of photosynthates.

This study is further supported by the findings of Handayani (2020), who reported that long beans fertilized with NPK up to the optimal dose exhibited a significant increase in plant height compared to plants deficient in nutrients. In contrast to the paclobutrazol treatment, which tends to suppress growth, the addition of NPK fertilizer actually increased the rate of vegetative growth. Thus, the results of this study are generally consistent with the literature, which indicates that paclobutrazol inhibits vegetative growth, whereas NPK fertilizer accelerates the vegetative growth of long beans up to a certain dose limit.

Number of Pods per Harvesting Period and Total per Plant (fruits)

The results of the analysis of variance indicate that the combination of paclobutrazol and Phonska NPK had a significant effect on the number of pods in the second and third weeks, while each factor also had a significant effect individually. The single factor of paclobutrazol had an effect in the first week but not in the fourth week, whereas the single factor of NPK had no effect in the first week but did have an effect in the fourth week. The average number of pods for the combination of paclobutrazol and NPK Phonska fertilizer treatments is presented in Table 2. The average number of pods for the single treatments of paclobutrazol concentration and NPK Phonska fertilizer dose is presented in Table 3. The average total number of pods during the harvest period is presented in Table 4.

Table 2. Average Number of Pods on Long Bean Plants Under Combined Treatments of Paclobutrazol Concentration and Phonska NPK Fertilizer Dosage During the Second and Third Weeks

Paclobutrazol Concentration (ppm)	Number of Pods per Plant, Week 2			
	Phonska NPK Fertilizer Application Rate (kg/ha)			
	N1	N2	N3	N4
P0	15.08±1.18^{b}	15.00±2.46^{b}	11.57±2.06^{a}	19.83±1.63^{c}
P1	15.17±0.95^{b}	14.25±0.25^{ab}	15.25±1.75^{b}	14.83±1.51^{ab}
P2	13.67±2.57^{ab}	16.58±1.04^{bc}	14.08±1.01^{ab}	15.50±2.63^{b}
P3	13.25±2.78^{ab}	12.83±2.10^{ab}	13.17±2.02^{ab}	13.17±2.32^{ab}
BNJ 5%	3.41			

Paclobutrazol Concentration (ppm)	Number of Pods per Plant, Week 3			
	Phonska NPK Fertilizer Application Rate (kg/ha)			
	N1	N2	N3	N4
P0	19.83±2.27[b]	20.92±0.63[b]	20.00±2.05[b]	26.08±3.91[c]
P1	24.42±0.80[bc]	20.75±1.00[b]	17.75±4.39[ab]	20.00±0.66[b]
P2	19.17±1.81[ab]	17.17±2.45[ab]	16.58±1.38[ab]	19.83±2.52[b]
P3	23.17±1.88[bc]	21.08±1.94[b]	19.08±1.88[ab]	15.08±6.36[a]
BNJ 5%	4.66			

Note: Mean values followed by the same letter indicate no significant difference in the BNJ test at the 5% level

Table 3. Average Number of Pods on Long Bean Plants Under Single Treatments of Paclobutrazol Concentration and Phonska Plus NPK Fertilizer Dosage

Treatment	Average Number of Pods per Long Bean Plant	
Paclobutrazol Concentration (ppm)	**Week 1**	**Week 4**
0	8.50±1.75[b]	12.29±3.96
100	7.25±1.07[a]	11.27±2.38
150	7.02±1.46[a]	11.33±1.49
200	7.29±0.90[a]	11.46±1.64
BNJ 5%	0.41	tn
Fertilizer Dosage NPK Phonska (kg/ha)		
250	7.79±1.70	10.44±2.13[a]
300	7.42±0.90	11.54±2.19[b]
350	7.48±1.19	10.96±1.27[ab]
400	7.38±1.83	13.42±3.24[c]
BNJ 5%	tn	0.80

Note: Mean values followed by the same letter and corresponding to the same treatment and age group indicate no significant difference in the BNJ test at the 5% level; ns = not significant.

Table 4. Average Total Number of Pods per Long Bean Plant per Harvesting Period as a Result of Different Paclobutrazol Concentrations and Phonska Plus NPK Fertilizer Dosages

Paclobutrazol Concentration (ppm)	Total Number of Pods per Plant (fruits)			
	Phonska NPK Fertilizer Application Rate (kg/ha)			
	250	300	350	400
0	54.67±2.47[b]	54.00±2.88[b]	50.15±5.23[ab]	72.67±5.36[c]
100	56.75±0.75[b]	54.42±2.08[b]	51.00±3.97[ab]	54.33±5.06[b]
150	49.08±2.93[ab]	53.08±2.13[ab]	49.58±1.63[ab]	54.25±4.38[b]
200	56.17±1.18[b]	52.92±2.57[ab]	50.50±0.43[ab]	46.25±10.04[a]
BNJ 5%	7.14			

Note: Mean values followed by the same letter indicate no significant difference in the BNJ test at the 5% level

Based on the study, the optimal results for pod number were obtained with a combination of 0 ppm paclobutrazol and 400 kg/ha of Phonska NPK, yielding the highest pod counts: 19.83 pods in the second week and 26.08 pods in the third week, while the combination of 0 ppm paclobutrazol and 350 kg/ha NPK as well as 200 ppm paclobutrazol and 400 kg/ha NPK yielded lower results of 11.57 and 15.08 pods, respectively. These results indicate that increasing the NPK dose supports flower formation and pod filling through the availability of phosphorus (P) and potassium (K), which play a role in the plant's generative development, whereas high doses of paclobutrazol suppress gibberellin activity, which is crucial for the formation of floral and pod organs. The combination without paclobutrazol allows for natural growth without hormonal inhibition, while high NPK doses maintain the supply of energy and photosynthetic metabolites for perfect seed formation. According to Zuhrufah et al., (2015), environmental factors such as neutral soil pH (6.7–6.8) and optimal light conditions also support nutrient uptake and the photosynthetic process. Physiologically, the balance between the availability of macronutrients and hormonal activity is key to the success of this combination in enhancing pod formation, where the absence of paclobutrazol combined with high NPK levels has proven most effective in producing the maximum number of pods.

This study is also consistent with the findings of Fitriyanti & Darmawa (2020) on mung beans, where an increase in NPK dosage also increased the number of filled pods and seed weight due to the high phosphorus content, which supports energy production (ATP) and plant metabolism. Differences in results across studies may be influenced by plant type, environmental conditions, or variety, but these findings confirm that the synergy between macronutrient availability and hormonal regulation is key to successfully enhancing pod formation. As explained by Sugiharto et al., (2020), neutral soil pH and optimal light intensity also aid nutrient uptake and photosynthesis, thereby supporting maximum pod formation.

The single application of paclobutrazol in this study showed a significant effect on the number of long bean pods in the first week, where the 0 ppm treatment produced the highest number of pods (8.50 pods) because gibberellin activity was not inhibited, allowing for optimal flower initiation, whereas concentrations of 100–200 ppm reduced the number of pods due to the suppression of gibberellin biosynthesis. However, by week 4, none of the paclobutrazol concentrations had a significant effect anymore, as the pod-filling phase is more determined by the availability of photosynthates and environmental conditions. Conversely, Phonska NPK fertilizer had no effect in the first week but showed a significant effect in the fourth week, with a dose of 400 kg/ha yielding the highest number of pods (13.42 pods) because the P and K elements support energy formation and photosynthate accumulation during the pod-filling phase.

These results are consistent with the study by Putri & Kurniawan (2021) on long beans, which reported an increase in the number of pods as NPK doses increased, and are consistent with Hidayati et al., (2020), who demonstrated that higher NPK doses in mung beans increased the number of filled pods through the role of phosphorus in metabolic processes. Thus, the growth phase determines the effectiveness of paclobutrazol, while the availability of nutrients, particularly P and K, is a determining factor for pod productivity in the late generative phase.

The results of the study also showed that the combination of paclobutrazol concentration and NPK Phonska Plus fertilizer dose had a significant effect on the total number of pods per harvest period of long beans; the highest average total number of pods per long bean plant was obtained in the treatment combining 0 ppm paclobutrazol and 400 kg/ha NPK Phonska Plus, at 72.67 pods, which was significantly different from the other treatments, while the combination of 200 ppm paclobutrazol and 400 kg/ha of NPK Phonska Plus yielded a lower average of 46.25 pods, a result that was significantly different from several other treatments. Paclobutrazol at high concentrations can inhibit plant growth and reduce the rate of photosynthesis, thereby leading to a decrease in yield. When compared to the description of the Katon Tavi long bean variety, which has a yield potential of approximately 30–40 pods per plant, the results of this study indicate that the variety used can produce a higher number of pods when provided with appropriate fertilization and growth regulation, particularly at the highest fertilizer dose without paclobutrazol.

Pod Weight per Harvesting Period and Total per Plant (g)

The results of the analysis of variance indicate that the combination of paclobutrazol concentration and NPK Phonska had a significant effect on the pod weight per long bean plant at harvest in the third week. The single treatment of paclobutrazol concentration also had a significant effect on pod weight per plant in the 1st and 2nd weeks, while the NPK Phonska concentration treatment affected pod weight per plant in the 2nd and 4th weeks. The average results for pod weight per plant are presented in Figure 3 below. The average pod weight per plant for the single paclobutrazol treatment and the NPK Phonska Plus fertilizer dose are presented in Table 5. The average total pod weight during the harvest period is presented in Table 6.

Table 5. Average Pod Weight of Long Bean Plants Under Single Treatments of Paclobutrazol Concentration and Phonska NPK Fertilizer Dosage

Treatment	**Average Pod Weight per Plant (g)**		
Paclobutrazol Concentration (ppm)	**Week 1**	**Week 2**	**Week 4**
0	126.15±34.24[c]	263.83±42.70[b]	242.69±55.84
100	80.25±20.32[a]	262.02±89.31[b]	267.63±65.98
150	93.44±28.41[b]	271.65±58.62[b]	247.38±31.50
200	88.79±20.62[b]	211.35±69.72[a]	227.88±19.22
BNJ 5%	8.48	17.86	tn
Fertilizer Dosage NPK Phonska (kg/ha)			
250	94.25±22.51	297.73±78.57[c]	274.31±68.23[c]
300	96.31±29.91	228.79±55.70[a]	229.04±33.74[a]
350	89.15±25.34	233.19±61.83[ab]	245.75±34.66[b]
400	108.92±43.17	249.15±64.96[b]	236.46±37.86[ab]
BNJ 5%	tn	17.86	12.78

Note: Mean values followed by the same letter and corresponding to the same treatment and age group indicate no significant difference in the BNJ test at the 5% level; ns = not significant.

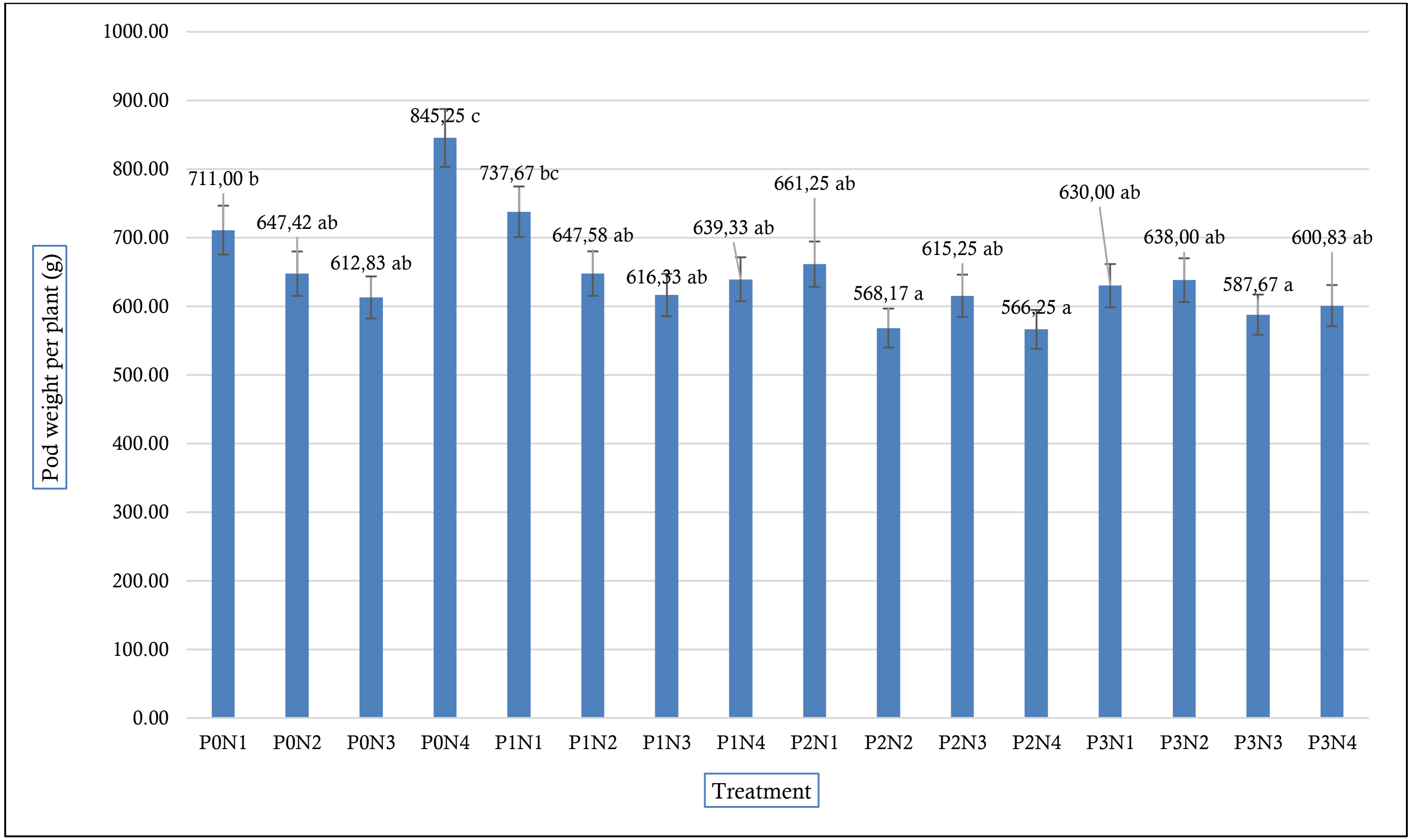

Figure 3. Average Pod Weight per Plant in the Paclobutrazol and Phonska NPK Fertilizer Combination Treatment in the Third Week. **Note:** P0: 0 ppm; P1: 100 ppm; P2: 150 ppm; P3: 200 ppm; N1: 250 kg/ha; N2: 300 kg/ha; N3: 350 kg/ha; N4: 400 kg/ha

Table 6. Average Total Pod Weight per Long Bean Plant per Harvesting Period as a Result of Different Paclobutrazol Concentrations and Phonska Plus NPK Fertilizer Dosages

Paclobutrazol Concentration (ppm)	Total Pod Weight per Plant (g)			
	Phonska NPK Fertilizer Application Rate (kg/ha)			
	250	300	350	400
0	1354.58±164.50[b]	1216.58±99.64[ab]	1236.17±46.70[ab]	1539.83±60.68[b]
100	1533.83±142.36[b]	1189.08±125.66[ab]	1186.83±122.50[ab]	1170.75±94.30[ab]
150	1338.25±101.64[b]	1154.17±84.35[ab]	1193.75±173.98[ab]	1174.58±95.52[ab]
200	1178.42±175.23[ab]	1157.92±64.36[ab]	1087.67±66.79[a]	1144.58±288.6[ab]
BNJ 5%	212.63			

Note: Mean values followed by the same letter indicate no significant difference in the BNJ test at the 5% level

The results of the study indicate significant differences in the combination of Paclobutrazol growth regulator concentrations and Phonska NPK fertilizer doses. It can be seen that the treatment combination with the lowest pod weight occurred at a Paclobutrazol concentration of 150 ppm and an NPK dose of 400 kg/ha, yielding 566.25 g, while the highest pod weight occurred in the combination of 0 ppm Paclobutrazol and 400 kg/ha NPK (Figure 3). This difference indicates that excessively high Paclobutrazol concentrations can inhibit the photosynthesis process due to a decrease in the number of functional leaves. In fact, leaves are the primary organ in the formation of carbohydrates required for pod filling. According to Rahmah et al., (2021), high doses of paclobutrazol reduce leaf growth rates and suppress chlorophyll formation, thereby decreasing photosynthetic capacity and reducing crop yield. On the other hand, increasing the NPK fertilizer dose to 400 kg/ha provides adequate nutrient availability to support pod formation and maximum seed filling. This demonstrates that Phonska NPK fertilizer plays a crucial role in improving plant physiological performance, particularly during the generative phase when energy and nutrient requirements increase.

These differences indicate that high doses of paclobutrazol inhibit the formation of functional leaves and reduce photosynthetic capacity, thereby hindering pod filling, while the availability of N, P, and K at high NPK doses supports energy production and the translocation of photosynthates during the generative phase. These results align with the study by Suganda & Permadi (2020), which reported that a combination of 0 ppm paclobutrazol and 350 kg/ha NPK on long beans yielded a pod weight of 792.14 g—lower than in this study—yet demonstrated the same response pattern: low paclobutrazol doses combined with high NPK yields the best results. When compared quantitatively, the optimal NPK dose in this study (400 kg/ha) is slightly higher than that in the previous study (350 kg/ha); however, both studies confirm that applying a low dose of paclobutrazol or no paclobutrazol at all is the most ideal condition for generative development, as it does not interfere with gibberellin synthesis—which is crucial for flower formation, fruit enlargement, and pod filling.

This finding is supported by Arifin et al., (2019), who found that 200 ppm paclobutrazol reduced the pod weight of green beans from 655.32 g to 580.44 g due to a decrease in chlorophyll content and leaf area; however, the combination with high-NPK fertilizer was still able to promote pod filling, although not as effectively as in plants without paclobutrazol. According to Faizah et al., (2025), the consistency of results from these studies indicates that the success of increasing pod weight is largely determined by the balance between hormonal regulation and nutrient sufficiency, where the combination of no paclobutrazol and high NPK proved to provide the most favorable physiological conditions for crop productivity.

Table 5 shows that the concentration of paclobutrazol had a significant effect on the weight of long bean pods in the first and second weeks, with the highest values of 126.15 g (0 ppm) in the first week and 271.65 g (150 ppm) in the second week, while the lowest values were obtained at 100 ppm (80.25 g) and 200 ppm (211.35 g), respectively. There were significant differences primarily between the 0 ppm treatment and the other treatments in the first week, as well as between the 150 ppm and 200 ppm treatments in the second week, while there were no significant differences among all treatments in the fourth week. The Phonska NPK rate also had a significant effect in the second and fourth weeks, with the highest yields consistently observed at the 250 kg/ha rate (297.73 g and 274.31 g) and the lowest at the 300 kg/ha rate (228.79 g and 229.04 g), while week 1 showed no significant differences. In both significant harvest periods, the 250 kg/ha dose generally differed significantly from several other treatments, while the 300 and 350 kg/ha doses tended not to differ from one another.

High doses of paclobutrazol can reduce the activity of invertase and amylase enzymes, which play a crucial role in the seed-filling process (Fitriana, 2024). Additionally, the inhibition of respiration caused by paclobutrazol reduces the energy supply for carbohydrate synthesis during the pod-filling phase. However, at moderate doses, paclobutrazol can extend the functional life of leaves, allowing photosynthesis to continue for a longer period and enabling the assimilation products to be used for the formation of more uniform and compact pods. This phenomenon indicates that paclobutrazol, at optimal concentrations, plays a role in enhancing the efficiency of photosynthetic product distribution without inhibiting total production.

At an NPK application rate of 250 kg/ha, the highest pod weights were recorded at 297.73 g and 274.31 g, significantly higher than those at 300 kg/ha, which were only 228.79 g and 229.04 g. The superiority of the 250 kg/ha dose is attributed to balanced nutrient supply, particularly phosphorus and potassium, which support flower formation, ATP synthesis, and the translocation of photosynthates to the pods, as well as sulfur (S) and zinc (Zn), which play a role in seed protein formation and embryo development (Wicaksono et al., 2021). Conversely, the 300–350 kg/ha dose resulted in lower pod weight because excess nitrogen promoted excessive vegetative growth, preventing photosynthates from being optimally transported to the generative organs; this finding aligns with Rahman et al., (2021), who stated that an imbalanced C/N ratio caused by excess nitrogen inhibits seed filling. Thus, a dose of 250 kg/ha is the most efficient fertilization rate for maximizing pod weight per plant.

The results of the study also showed that the combination of paclobutrazol concentration and Phonska Plus NPK fertilizer dose had a significant effect on the total pod weight per harvest period of long beans. The best results were obtained in the treatment without paclobutrazol (0 ppm) and a dose of 400 kg/ha of Phonska Plus NPK fertilizer, with an average of 1,539.83 g per plant, although this was not statistically significantly different from the other treatments. The high pod weight in this combination indicates that the plants were able to form and fill seeds optimally because vegetative growth was not inhibited by paclobutrazol, while the availability of sufficient macro nutrients (N, P, and K) enhanced photosynthesis, flower formation, pod size, and seed weight. Adequate nitrogen supply increases biomass production and protein formation, while phosphorus plays a role in energy transfer for generative development, and potassium enhances carbohydrate synthesis and cell enlargement, thereby contributing to increased yield. Conversely, the lowest yield was observed in the treatment with 200 ppm paclobutrazol and 350 kg/ha of Phonska Plus NPK fertilizer, at 1087.67 g, which was also not statistically significantly different from the other treatments. The low yield in this treatment is suspected to be due to the high concentration of paclobutrazol, which inhibits stem and leaf elongation, hinders the formation of effective photosynthetic area, and reduces the translocation of photosynthates to the pods.

Pod Yield per Hectare (tons)

The results of the analysis of variance for the combination of paclobutrazol concentration and NPK Phonska fertilizer dose treatments did not show a significant interaction on the pod weight per hectare parameter in long bean plants. For single factors, the application of paclobutrazol and NPK Phonska each had a significant effect on pod weight per hectare. The average pod weight per hectare for the single treatments of paclobutrazol concentration and NPK Phonska fertilizer dose is presented in Table 7.

Table 7. Average Pod Weight per Hectare of Long Bean Crops Under Single Treatments of Paclobutrazol Concentration and Phonska NPK Fertilizer Dosage

Treatment Paclobutrazol Concentration (ppm)	Pod Yield per Hectare (tons)
0	20.88±2.42^{d}
100	19.09±2.92^{c}
150	18.22±1.89^{b}
200	17.04±2.49^{a}
BNJ 5%	0.61
NPK Phonska Fertilizer Application Rate (kg/ha)	
250	20.23±2.94^{b}
300	17.64±1.43^{a}
350	17.70±2.05^{a}
400	19.66±3.47^{b}
BNJ 5%	0.61

Note: Mean values followed by the same letter and corresponding to the same treatment and age group show no significant difference in the BNJ test at the 5% level; ns = not significant

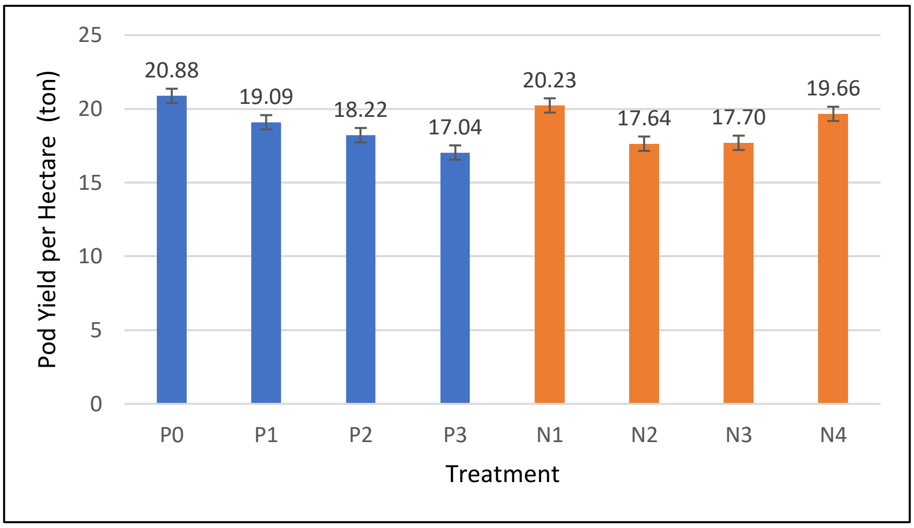

Figure 4. Graph of Pod Yield per Hectare (tons). **Note:** P0:0 ppm; P1:100 ppm; P2:150 ppm; P3:200 ppm; N1:250 kg/ha; N2:300 kg/ha; N3:350 kg/ha; N4:400 kg/ha

Based on the results of statistical analysis of the pod weight per hectare parameter, it was found that single treatments involving different concentrations of paclobutrazol and doses of Phonska NPK fertilizer yielded varying responses in terms of pod weight per hectare for long beans. In the paclobutrazol treatment, it was observed that a concentration of 0 ppm produced the highest pod weight, namely 20.88 tons/ha, while a concentration of 200 ppm actually produced the lowest figure, namely 17.04 tons/ha (Figure 4). Paclobutrazol at excessively high doses tends to suppress gibberellin production excessively, thereby inhibiting vegetative growth, reducing leaf area, and diminishing the plant's ability to produce and transport photosynthates for pod formation. These results align with the findings of Latifah et al., (2020), who noted that the use of high-dose paclobutrazol on legume crops can reduce pod numbers and lower yields due to a decrease in photosynthetic activity. In the Phonska NPK fertilizer treatment, the 250 kg/ha dose yielded the highest yield of 20.23 tons/ha, although it did not show a significant difference compared to the 400 kg/ha dose. Conversely, the 300 kg/ha dose, which yielded only 17.64 tons/ha and was not significantly different from the 350 kg/ha dose, indicates that an increase in fertilizer dose does not always result in higher yields.

This condition likely occurs because nutrient uptake is not yet optimal or due to environmental factors that limit the plants' ability to utilize nutrients. This is consistent with Maulanda et al., (2024), who stated that the effectiveness of NPK fertilizer is highly dependent on environmental conditions and the physiological capacity of the plants, and is supported by Ekawati et al., (2021), who explained that plants can only achieve optimal yields if they receive balanced nutrients that meet their specific needs. Thus, the variation in yields in this study indicates the existence of an optimal limit in the use of paclobutrazol and NPK fertilizer to maximize long bean production.

Fruit Set (%)

The results of the analysis of variance indicate that the combination of paclobutrazol concentration and Phonska NPK fertilizer dose had a significant

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interaction on the fruit set parameter in long bean plants (*Vigna sinensis* L.). The mean values from the post-hoc tests for fruit set are shown in Figure 4.

Table 8. Average Fruit Set Percentage Under Different Paclobutrazol Concentrations and Phonska NPK Fertilizer Dosages

Paclobutrazol Concentration (ppm)	**Fruit Set (%)**			
	Phonska NPK Fertilizer Application Rate (kg/ha)			
	250	**300**	**350**	**400**
0	60,79±2,07^{a}	69,00±2,19^{ab}	60,82±1,29^{a}	86,92±1,48^{b}
100	72,32±5,10^{ab}	70,89±6,26^{ab}	76,71±8,44^{b}	78,45±11,45^{b}
150	70,54±7,18^{ab}	73,21±10,10^{ab}	66,50±4,32^{ab}	61,98±6,58^{ab}
200	75,62±7,23^{b}	80,01±19,15^{b}	71,20±12,16^{ab}	67,65±5,39^{ab}
BNJ 5%	14,66			

Note: Mean values followed by the same letter and corresponding to the same treatment and age group indicate no significant difference in the BNJ test at the 5% level; ns = not significant.

The combination of paclobutrazol concentration and NPK Phonska fertilizer dose had a significant effect on the fruit set percentage of long beans, with the highest value reaching 86.92% in the treatment with 0 ppm paclobutrazol and 400 kg/ha NPK Phonska. The high fruit set in this treatment indicates that without paclobutrazol application, plant growth proceeds optimally with greater allocation of photosynthates to generative organs, thereby increasing the success of flower development into fruit. High photosynthetic output and optimal nutrient supply promote the efficiency of generative organ formation. High fertilizer doses also provide sufficient nitrogen, phosphorus, and potassium to support flowering metabolism, particularly phosphorus as an energy source for seed formation, and potassium, which strengthens reproductive organ tissues. Firmansyah et al., (2017) added that, on the other hand, the phosphorus and potassium components in Phonska NPK fertilizer play a crucial role in supporting flower formation, pollination, seedling development, and pod tissue strengthening, thereby increasing fruit set success. Sufficient P availability facilitates metabolic activity and cell division in generative organs, while K maintains cellular water balance and strengthens the walls of the fruit primordia. Additionally, research by Kusumawati & Widodo (2020) also indicates that the application of NPK fertilizer enhances flower formation and reduces flower drop in long beans, while a study by Fauzi et al., (2018) states that regulating vegetative growth using growth inhibitors must be done at the appropriate dose to avoid disrupting flower development. Thus, the combination of no paclobutrazol and high fertilizer doses appears most effective in supporting successful fruit set because it produces more stable physiological conditions in the plants and optimal nutrient supply during the generative phase.

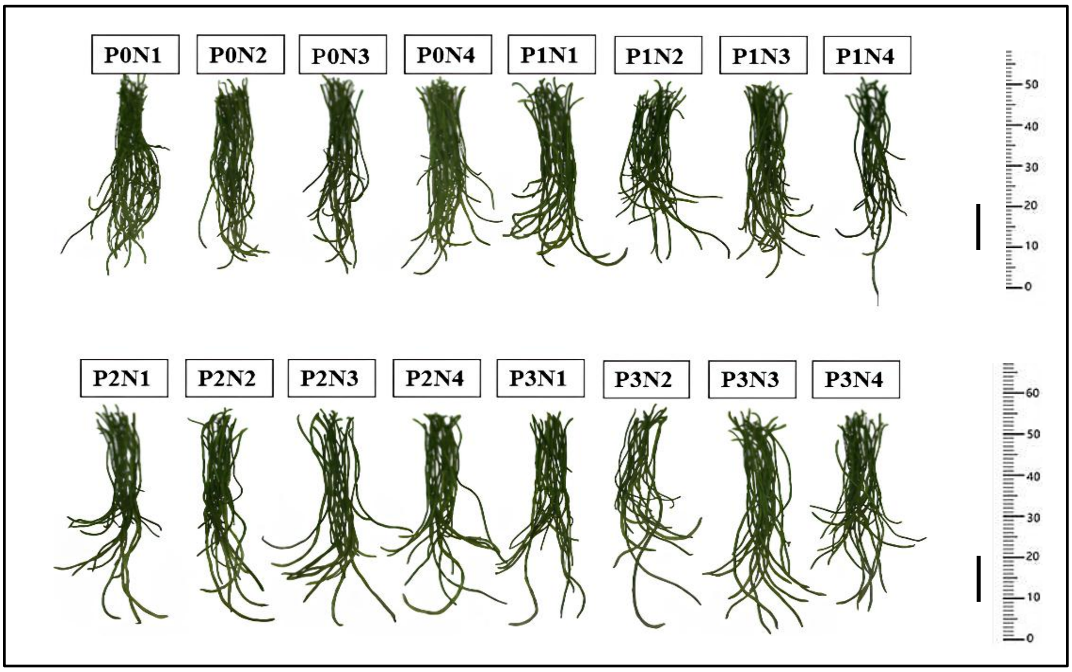

Figure 5. Long bean pods from the sample treated with a combination of paclobutrazol and NPK Phonska Plus

The combination of paclobutrazol and balanced NPK Phonska Plus fertilizer significantly increased the number of flowers that successfully developed into fruit. This indicates that fruit set in long beans is largely determined by the synergy between paclobutrazol as a growth regulator and the nutrient availability from NPK Phonska Plus fertilizer, which together support the physiological processes from flowering to fruit set. Thus, selecting the appropriate combination of paclobutrazol and NPK Phonska Plus fertilizer doses can optimize the yield and quality of long bean crops (Khatun et al., 2020). According to Nizar (2018), paclobutrazol improves flowering quality by reducing flower drop, thereby increasing the likelihood of pod formation. The range of fruit set values obtained in this study, approximately 60.79 – 86.92%, falls into the moderate to fairly good category for long beans, given the numerous environmental and physiological factors that can cause flower drop. The following images show long bean pods from samples of the Paclobutrazol and NPK Phonska treatment combinations under each treatment (Figure 5).

The results of the regression analysis in Figure 6 indicate a very strong positive linear relationship between pod weight per plant and pod weight per hectare in long bean crops. The regression equation obtained is $y = 0.0156x – 0.5436$ with an R^2 value of 0.9121 (Figure 6). This regression coefficient indicates that every 1-gram increase in pod weight per plant will increase pod weight per hectare by approximately 0.0156 tons. The coefficient of determination of 91.21% indicates that the majority of the variation in pod yield per hectare is strongly influenced by pod weight per plant, while the remaining 8.79% is influenced by other factors such as environmental conditions, the efficiency of Phonska Plus NPK fertilization, the plant's physiological response, and cultivation management. The data distribution pattern (linear relationship) following the regression line confirms that an increase in yield at the individual plant level is directly proportional to an increase in productivity at the hectare scale. This indicates that the accumulation and distribution of assimilates to the generative organs occur optimally, making pod weight per plant a very strong indicator for predicting long bean production per hectare (Andayani et al., 2024).

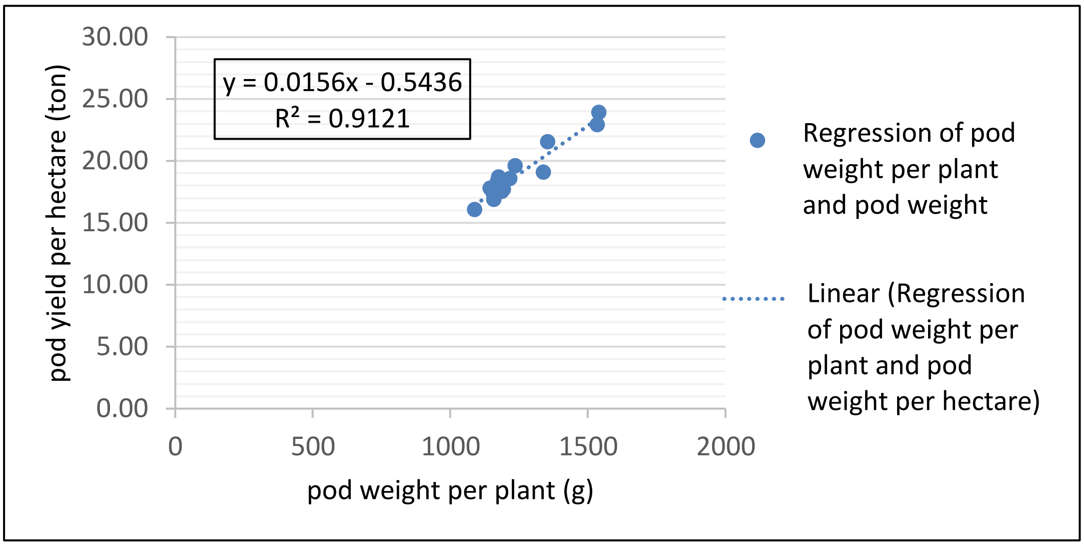

Figure 6. Regression Graph of Pod Weight per Plant and Pod Weight per Hectare

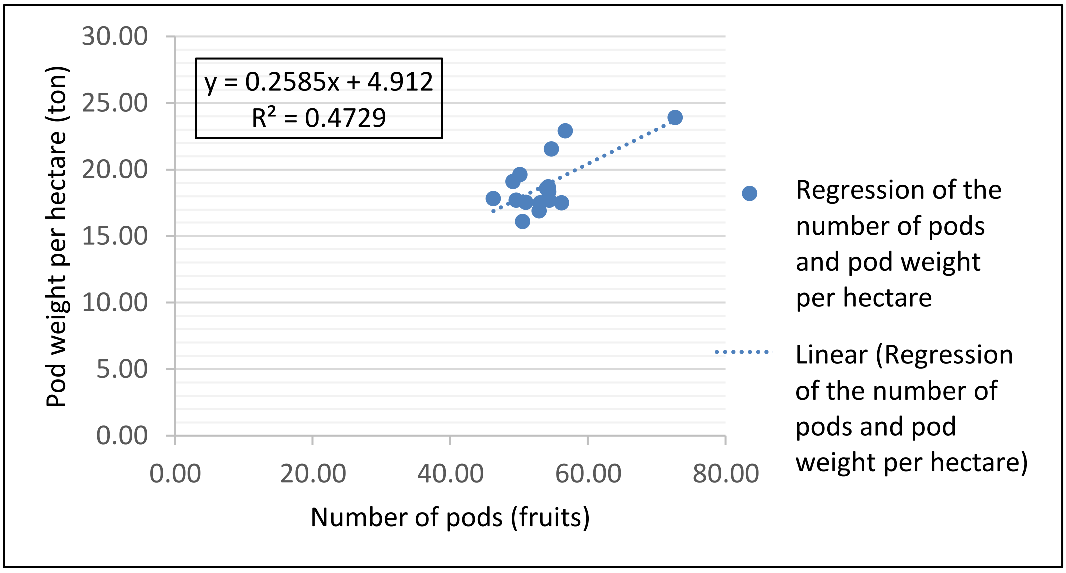

Figure 7. Regression Graph of Pods per Plant and Pod Weight per Hectare

The results of the regression analysis in Figure 7 show a positive relationship between the number of pods and pod weight per hectare in long bean crops. This relationship is represented by the regression equation y= 0.2585x + 4.912, with a coefficient of determination of R^2= 0.4729 (Figure 7). This equation indicates that every additional pod has the potential to increase pod weight per hectare by approximately 0.2585 tons. The R^2 value of 47.29% indicates that the relationship between the number of pods and pod weight per hectare falls into the moderate category, where nearly half of the variation in yield per hectare can be explained by changes in the number of pods. Meanwhile, the remaining 52.71% is influenced by other factors such as pod size and weight, the efficiency of Phonska Plus NPK fertilization, the plant's physiological response, environmental conditions, and the pod-filling process. The linear relationship pattern in the graph confirms that an increase in the number of pods still makes a significant contribution to increased yield on a per-hectare scale, although other agronomic factors also play a role in determining the final production volume (Darmawansyah & Sabli, 2023).

CONCLUSION

The application of 150 ppm paclobutrazol and 400 kg/ha of Phonska Plus NPK fertilizer yielded the most optimal results for the growth and production of long beans, with significant increases in plant height, number of flowers, number of pods, and pod weight per plant, per plot, and per hectare. The single factor of paclobutrazol yielded the best response at a concentration of 150 ppm, particularly for vegetative growth parameters and pod formation. Meanwhile, the single factor of NPK Phonska Plus fertilizer at a dose of 400 kg/ha produced the highest results for pod weight per plant and per hectare, and a dose of 250 kg/ha effectively increased pod weight per plant. This study confirms the synergy between hormonal regulation and balanced fertilization in enhancing the efficiency of photosynthate allocation to generative organs. The novelty of this study lies in the demonstration of the specific interaction between paclobutrazol and NPK Phonska Plus in long beans, which had previously been reported only to a limited extent. The results of this study provide a scientific contribution to understanding the mechanisms underlying improved generative performance in plants, as well as a practical contribution in the form of recommended dose combinations that can be applied to increase long bean productivity more efficiently.

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