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Sustainable vegetable production through pakchoi (*Brassica rapa* L.) growth response to bio-slurry liquid organic fertilizer intervals

Produksi sayuran berkelanjutan melalui respon pertumbuhan pakchoi (Brassica rapa L.) terhadap interval pemberian pupuk organik cair bio-slurry

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ABSTRACT

Pakchoi (*Brassica rapa* L.) is a fast-growing leafy vegetable with high nutritional value, making it an important crop for sustainable vegetable production. However, its cultivation often relies on chemical fertilizers, which are costly and environmentally detrimental. Bio-slurry liquid organic fertilizer (LOF), a nutrient-rich by-product of biogas production, offers a sustainable alternative. This study aimed to evaluate the growth response of pakchoi to different application intervals of bio-slurry LOF to identify the most effective schedule for improving plant performance. A non-factorial completely randomized design was employed with four treatments: P0 (control), P1 (application of 100 ml LOF every 7 days), P2 (every 9 days), and P3 (every 11 days), each replicated six times. Growth parameters, including plant height, leaf number, leaf length, leaf width, and fresh weight, were measured and analyzed using one-way ANOVA followed by DMRT at the 5% significance level. Results showed that fertilization every 9 days (P2) produced the highest plant height, leaf number, and fresh weight compared to other treatments. These findings highlight the potential of bio-slurry LOF to reduce reliance on chemical fertilizers while enhancing pakchoi growth, thereby supporting sustainable vegetable farming practices.

ABSTRAK

Pakchoi (*Brassica rapa* L.) merupakan sayuran daun cepat panen dengan nilai gizi tinggi sehingga berperan penting dalam mendukung produksi sayuran berkelanjutan. Namun, budidayanya masih bergantung pada pupuk kimia yang mahal dan berdampak negatif terhadap lingkungan. Pupuk organik cair (POC) bio-slurry, hasil samping kaya nutrisi dari proses produksi biogas, menawarkan alternatif yang ramah lingkungan. Penelitian ini bertujuan mengevaluasi respon pertumbuhan pakchoi terhadap interval pemberian POC bio-slurry yang berbeda untuk menentukan jadwal aplikasi paling efektif dalam meningkatkan performa tanaman. Penelitian menggunakan rancangan acak lengkap (RAL) nonfaktorial dengan empat perlakuan: P0 (kontrol), P1 (pemberian 100 ml POC setiap 7 hari), P2 (setiap 9 hari), dan P3 (setiap 11 hari), masing-masing diulang enam kali. Parameter yang diamati meliputi tinggi tanaman, jumlah daun, panjang daun, lebar daun, dan bobot segar, kemudian dianalisis dengan ANOVA satu arah dan uji lanjut DMRT pada taraf 5%. Hasil penelitian menunjukkan bahwa pemberian POC bio-slurry setiap 9 hari (P2) menghasilkan tinggi tanaman, jumlah daun, dan bobot segar tertinggi dibanding perlakuan lainnya. Temuan ini menegaskan potensi POC bio-slurry dalam mengurangi ketergantungan pada pupuk kimia sekaligus meningkatkan pertumbuhan pakchoi, sehingga mendukung praktik budidaya sayuran berkelanjutan.

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INTRODUCTION

Vegetables play a vital role in ensuring food and nutritional security because they supply essential vitamins, minerals, and dietary fiber. Alongside global population growth and the rising demand for healthier diets, the need for sustainable vegetable production systems has become increasingly urgent. One of the leafy vegetables widely consumed is pakchoi (*Brassica rapa* L.), which is rich in calories, protein, carbohydrates, fiber, calcium, phosphorus, iron, and vitamins A, C, B1, B2, and B3 (Murti & Nur'aini, 2023). Pakchoi has a short growth cycle of 30–45 days, allowing multiple planting cycles annually, which makes it highly suitable for smallholder farmers seeking efficiency and rapid returns (Liana et al., 2023).

Pakchoi is considered a leading vegetable commodity with significant market and export potential. However, its cultivation faces constraints, particularly the high cost of synthetic fertilizers. Long-term use of chemical fertilizers can negatively affect soil quality by disrupting nutrient balance, reducing soil organic matter, and accelerating land degradation. These environmental drawbacks, combined with high production costs, threaten the sustainability of pakchoi farming systems.

One potential alternative is bio-slurry liquid organic fertilizer (LOF), a nutrient-rich by-product of the anaerobic decomposition of organic matter during biogas production. Bio-slurry contains essential nutrients such as nitrogen, phosphorus, and potassium, is free from harmful chemicals, and can improve soil fertility while being more easily absorbed compared to solid organic fertilizers (Tanti et al., 2019; Yani et al., 2022; Erfiani et al., 2023). Previous studies have reported the benefits of bio-slurry LOF on crop growth. For example, Rusmiati et al. (2024) observed suboptimal results when applying bio-slurry by spraying on cauliflower, while Nugroho et al. (2019) showed that the drench method was more efficient for nutrient uptake. Furthermore, Mufairoh et al. (2018) found that weekly applications enhanced shallot growth. These findings suggest that application methods and timing strongly influence the effectiveness of bio-slurry LOF.

Despite the recognized benefits of bio-slurry LOF in agriculture, most previous studies have focused on application methods or dosages in crops other than pakchoi. Few studies have examined how different application intervals affect pakchoi growth, despite fertilization timing being critical for optimizing nutrient use efficiency in sustainable farming systems. To address this gap, the present study evaluates the growth response of pakchoi to varying intervals of bio-slurry LOF application under field conditions. The results are expected to provide practical recommendations for smallholder farmers, reduce reliance on chemical fertilizers, and strengthen the role of bio-slurry LOF as a renewable input in sustainable vegetable production.

MATERIALS & METHODS

Study site

The experiment was conducted at the Agribusiness Incubator of the Indonesian Center for Agricultural Training Lembang (Balai Besar Pelatihan Pertanian, BBPP), West Bandung, Indonesia (6°3.73′–7°1.031′ S and 107°1.10′–107°4.40′ E; elevation 1.312-2.084 m above sea level), as shown in Figure 1. The area is characterized by a tropical climate with an average temperature of 17-27 °C and average annual rainfall of 2000-2500 mm. Nutrient composition of the bio-slurry liquid organic fertilizer (LOF) was analyzed at the Agrochemical Laboratory, Lembang, Indonesia.

Materials and equipment

The experimental materials included Flamingo pakchoi (*Brassica rapa* L.) seeds (sourced from PT Agri Makmur Pertiwi, Surabaya, Indonesia), bio-slurry LOF obtained from local biogas digester using cattle manure, and planting media consisting of soil:husk charcoal = 1:1 and pH 6.8. Each plant was grown in a 30 × 30 cm polybag with a capacity of 4 kg soil.

The equipment used comprised digital scales (accuracy 0.1 g; Joil, model D9, Indonesia), rulers (accuracy 1 mm), and other standard field tools. The bio-slurry LOF was stored in sealed plastic containers at ambient temperature until application.

Figure 1. The study site of this research

Experimental design and treatments

The experiment was arranged in a non-factorial Completely Randomized Design (CRD) with four treatments and six replications, resulting in a total of 24 experimental units. Each experimental unit consisted of one polybag containing a single pakchoi (*Brassica rapa* L.) plant. The treatments consisted of a control without bio-slurry application (P0) and three fertilization intervals, i.e., the application of 100 mL of bio-slurry LOF applied every 7 days (P1), 9 days (P2), and 11 days (P3). Fertilizer was applied using the drench method, in which the fertilizer solution was poured directly into the planting medium at the base of each plant. The dosage and application intervals were adapted from the study of Mufairoh et al. (2018), who reported that weekly application of 100 mL bio-slurry LOF supported optimal growth in shallot plants.

Growth parameters

Growth performance of pakchoi was evaluated by measuring plant height, number of leaves, leaf length, leaf width, and fresh weight. Plant height was determined from the base of the stem to the tip of the tallest leaf using a ruler, following the procedure described by Nasamsir and Huffia (2020). The number of leaves was recorded by counting fully expanded and normally developed leaves on each plant, as suggested by Putra and Ningsi (2019). Leaf length was measured from the base of the blade to the tip of the longest leaf, while leaf width was determined at the widest part of the lamina; both measurements were taken using a ruler according to the method of Bachtiar et al. (2021). At harvest (30 days after planting, DAP), fresh weight was obtained by weighing the entire plant using a digital balance, following the approach of Paramitha et al. (2023). Observations of plant height, number of leaves, leaf length, and leaf width were conducted at 14, 21, and 28 DAP, whereas fresh weight was measured only at 30 DAP.

Statistical analysis

All data were subjected to one-way analysis of variance (ANOVA) at a 5% significance level (α = 0.05). As stated by Raudonius (2017), ANOVA is widely used in agricultural research for analyzing experimental data, particularly in assessing the effects of different treatments on response variables with continuous measurement scales. When significant differences were detected, mean separation was performed using Duncan's Multiple Range Test (DMRT) at the 5% level (Sudrajat et al., 2024). Statistical analyses were carried out using SPSS Statistics version 30 (IBM Corp., Armonk, NY, USA).

RESULTS & DISCUSSIONS

Nutrient content analysis of bio-slurry LOF

The nutrient content of the bio-slurry LOF was analyzed at the Agro Chemistry Laboratory, Lembang. The results of the nutrient content analysis, along with a comparison to the standards set by the Ministry of Agriculture Regulation (Permentan), are presented in Table 1.

Table 1. The results of nutrient content analysis of bio-slurry LOF and its comparison with the ministry of agriculture (Permentan) standards

No.	Parameter	Unit	LOF standard (Permentan)*	Bio-slurry LOF (This study)**	Method/ Instrument
1.	pH	-	4 - 9	4.67	Elektrometry
2.	C-Organic	%	min 10	0.42	IK. 1. MPMPO/ Spectrophotometry
3.	Total N (N Organic + NH_4)		min 0.5	0.04	Kjeldahl
4.	C/N	-	15 - 25	10.5	-
5.	P_2O_5	%	-	0.01	Spectrophotometry
6.	K_2O		-	0.27	AAS
7.	N + P_2O_5 + K_2O	%	2 - 6	0.32	-

Note. *The quality standard for LOF is based on the Regulation of the Minister of Agriculture (No:261/KPTS/SR.310/M/4/2019) concerning the minimum technical requirements for organic fertilizers, biofertilizers, and soil amendments. **The laboratory analysis of bio-slurry LOF sample No. 0138.PO.11.2024 was conducted at the Agrochemical Laboratory, Lembang, Indonesia.

The pH value of the bio-slurry LOF was 4.67, which falls within the acceptable range of 4 - 9 as required for LOF quality standards according to the Regulation of the Minister of Agriculture of the Republic of Indonesia No. 261/KPTS/SR.310/M/4/2019 on the minimum technical requirements for organic fertilizers, biofertilizers, and soil amendments. The C/N ratio of the bio-slurry LOF was 10.5, which does not meet the standard set by the Ministerial Regulation No. 70/Permentan/SR.140/10/2011, which specifies a range of 15 - 25. A low C/N ratio can lead to rapid nitrogen release, making it less available to plants over time. The C/N content in bio-slurry LOF can be improved by adding materials with a high carbon content, such as green vegetable waste, which has a C/N ratio ranging from approximately 11 to 27 (Setyawati et al., 2021).

The organic carbon (C-organic) content of the bio-slurry LOF was 0.42%, which is considerably below the minimum standard of 10% as stipulated by the Regulation of the Minister of Agriculture No. 261/KPTS/SR.310/M/4/2019. The low C-organic content is likely due to insufficient carbohydrate content in the fertilizer materials, as microorganisms utilize carbon as an energy source for metabolic activities and release it into the atmosphere as CO_2 (Widyabudingsih et al., 2021). During the decomposition process, C-organic plays a vital role in supporting microbial growth and the formation of new cells (Tsaniya et al., 2021). Therefore, improving C-organic levels is essential, and one effective method is by adding banana corms, which are known to have a high carbohydrate content (Prasetio & Widyastuti, 2020).

The NPK content in the bio-slurry LOF was only 0.32%, which remains below the standard range of 2 - 6% as specified in the Regulation of the Minister of Agriculture No. 261/KPTS/SR.310/M/4/2019. The nitrogen (N) element can be increased by adding lamtoro leaves, which contain approximately 2.0 - 4.3% nitrogen (Salim et al., 2023). Meanwhile, the phosphorus (P_2O_5) content in the bio-slurry LOF was the lowest among the three macronutrients, indicating the need for organic materials rich in phosphorus, such as banana plants, which contain about 34% phosphorus (Hendrawani et al., 2021).

The potassium (K_2O) content in the bio-slurry LOF was relatively higher than nitrogen and phosphorus. This is attributed to the low potassium content in the raw materials used to produce the LOF. Rahmawati et al. (2021) emphasized that the

concentration and composition of the ingredients in LOF formulation influence the low potassium levels. Moreover, sedimentation in the LOF may also hinder the accurate detection of potassium content (Rahmawati et al., 2021). Potassium levels in bio-slurry LOF can be improved by incorporating ash derived from coconut husks, wood, and empty oil palm fruit bunches (EFB), which contain potassium concentrations of 19.85%, 3 - 4%, and 30%, respectively (Prasetyo & Evizal, 2021).

*Observation results of pakchoi (*Brassica rapa *L.) plant growth parameters*

Figure 2 illustrates the comparison of pakchoi (*Brassica rapa* L.) plant growth resulting from the application of bio-slurry LOF at different application intervals. Figure 2 also illustrates the growth performance of pakchoi plants (*Brassica rapa* L.) under different application intervals of LOF derived from bio-slurry. Morphological differences among the treatments indicate that variations in the application interval of bio-slurry LOF had an influence on pakchoi growth.

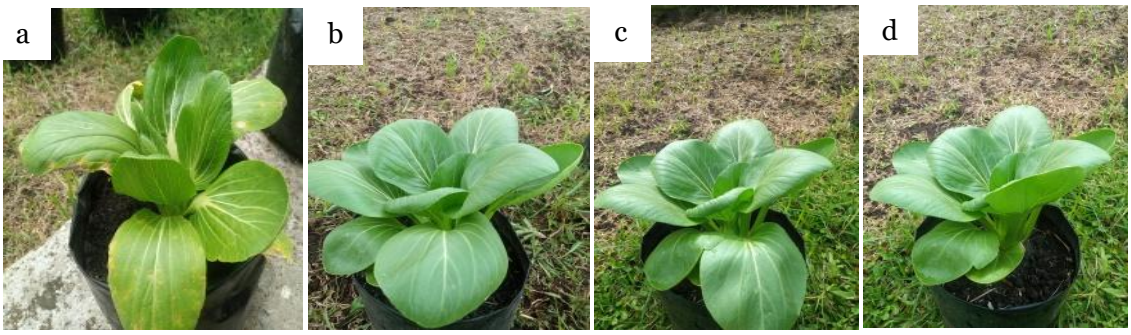

Figure 2. The comparison of research results: a=P0; b=P1; c=P2; d=P3

The observed differences suggest that bio-slurry LOF has the potential to enhance plant growth, depending on the frequency of application. A more detailed data analysis regarding the effects of bio-slurry LOF treatment on pak choi growth parameters is presented in the following section.

Plant height

The results of the analysis of variance indicate that the application of bio-slurry LOF at different time intervals significantly affected the growth rate of pakchoi plant height at 14, 21, and 28 DAP. The response of pakchoi growth in terms of plant height under different application intervals of bio-slurry LOF is presented in Table 2.

Table 2. The effect of application intervals of bio-slurry LOF on the height of pakchoi plants (*Brassica rapa* L.) (n = 6)

Treatment	Plant height (cm)		
	14 DAP	21 DAP	28 DAP
P0 (Control)	5.183 a	8.050 a	10.067 a
P1 (Bio-slurry LOF 100 ml/7 days)	6.117 ab	9.917 b	11.650 b
P2 (Bio-slurry LOF 100 ml/9 days)	6.617 b	10.283 b	16.667 d
P3 (Bio-slurry LOF 100 ml/11 days)	6.033 ab	8.117 a	13.350 c

Note. Means followed by the same letter (a, b, c, etc.) within the same column are not significantly different based on Duncan's Multiple Range Test at 5% level.

The application of bio-slurry LOF at different time intervals had a significant effect on the plant height of pakchoi. As shown in Table 2, the treatment with a 9-day application interval (P2) resulted in the highest mean plant height of 16.667 cm at 28 DAP. This interval ensured that pakchoi plants received adequate nutrients without experiencing either nutrient saturation or deficiency. In contrast, the control treatment (P0) exhibited the lowest mean plant height of 10.067 cm at 28 DAP, due to the absence of additional nutrient input. These results demonstrate that fertilization every nine days optimally meets the nutrient requirements of pakchoi and supports maximum growth. This finding is supported by Alfy and Handoyo (2022),

who stated that appropriate timing of fertilizer application helps maintain the availability of plant nutrients. Furthermore, Rismalati et al. (2024) also emphasized that proper fertilization significantly enhances plant growth and yield.

Pakchoi plants treated with bio-slurry LOF exhibited a statistically significant difference in plant height at 28 DAP, while no significant differences were observed at 14 and 21 DAP. This result can be attributed to the developmental stage of the root system in young plants, which is still immature and therefore less efficient in absorbing nutrients from the bio-slurry. As the plants mature, their root systems become more established, enhancing their ability to absorb nutrients and consequently leading to more optimal plant growth. The ability of bio-slurry LOF to increase plant height is supported by its nutrient content. According to Muliandini and Rahmayanti (2022), bio-slurry contains essential nutrients including nitrogen (0.03 to 1.15 percent), total phosphorus (0.02 to 0.04 percent), total potassium (0.07 to 0.60 percent), calcium (1.402 to 2.900 ppm), magnesium (1.200 to 1.544 ppm), and sulfur (0.50 percent). Nitrogen plays a crucial role in promoting vegetative growth and increasing plant height through cell division and elongation (Abdullah & Adjam, 2017). In addition, bio-slurry contains probiotic microorganisms that help improve soil fertility by increasing nutrient availability, supporting beneficial microbial populations, and suppressing the development of plant pathogens.

Number of leaves

The analysis of variance indicated that the application of bio-slurry LOF at different time intervals had a significant effect on the number of pakchoi leaves at 14, 21, and 28 DAP. Table 3 presents the response in the number of pakchoi leaves under different bio-slurry LOF application intervals. Fertilization using bio-slurry LOF at different time intervals significantly affected the number of pakchoi leaves at 14, 21, and 28 DAP. Based on observations, the application of bio-slurry LOF every 9 days (P_2) was the most effective interval. This treatment maintained a better availability of nutrients to support plant growth, resulting in a higher average number of leaves compared to other application intervals. These results align with the findings of Maula et al. (2023), who stated that the appropriate application interval of bio-slurry LOF positively influences leaf development and other growth parameters. In contrast, the control (P0), which received no fertilization, produced the fewest leaves due to nutrient deficiency that inhibited optimal growth.

Table 3. The effect of bio-slurry LOF application intervals on the number of pakchoi (*Brassica rapa* L.) leaves (n = 6)

Treatment	Number of leaves		
	14 DAP	21 DAP	28 DAP
P0 (Control)	4.67 a	4.67 a	9.50 a
P1 (Bio-slurry LOF 100 ml/7 days)	5.50 b	5.67 a	10.50 ab
P2 (Bio-slurry LOF 100 ml/9 days)	5.83 b	7.00 b	11.67 b
P3 (Bio-slurry LOF 100 ml/11 days)	5.17 ab	5.17 a	10.67 ab

Note. Means followed by the same letter (a, b, c, etc.) within the same column are not significantly different based on Duncan's Multiple Range Test at 5% level.

According to Mustikaningrum (2023), bio-slurry contains essential macro and micronutrients required by plants. When applied to the growing medium, these nutrients become available to the root system of pakchoi. The plant roots absorb these nutrients, which are then utilized in physiological processes such as photosynthesis, cell division, and the formation of new tissues. The application of bio-slurry LOF at appropriate intervals ensures that nutrients are available in alignment with the plant's needs at each stage of development, thereby supporting optimal growth.With a 9-day application interval, nutrient availability in the root zone remains stable, enabling the roots to efficiently absorb nutrients. This condition promotes optimal vegetative growth, as evidenced by an increase in the number of leaves.

At 14 and 28 DAP, the 9-day application interval (P_2) showed a significant difference compared to the control (P0), but not compared to the 7-day (P_1) and 11-day (P_3) intervals. In contrast, at 21 DAP, P_2 resulted in a significantly higher leaf number than all other treatments. This may be due to the ability of plants to use available nutrients effectively at 14 and 28 DAP,

while at 21 DAP plants entered a rapid growth phase requiring optimal nutrient supply. Environmental factors such as soil moisture and oxygen in the rhizosphere also affect nutrient uptake. Application of bio-slurry every 9 days ensures efficient nutrient absorption without deficiency or excess, supporting optimal growth of pakchoi.

Leaf length

The analysis of variance indicates that the application of bio-slurry LOF at different time intervals did not have a significant effect on leaf length of pakchoi at 14 DAP, but showed a significant effect at 21 and 28 DAP. The response of pakchoi leaf length to different application intervals of bio-slurry LOF is presented in Table 4.

Table 4. The effect of bio-slurry LOF application intervals on the leaf length of pakchoi (*Brassica rapa* L.) (n = 6)

Treatment	Leaf length (cm)		
	14 DAP	21 DAP	28 DAP
P0 (Control)	5.82 a	6.52 a	8.52 a
P1 (Bio-slurry LOF 100 ml/7 days)	6.40 a	8.12 bc	10.58 b
P2 (Bio-slurry LOF 100 ml/9 days)	7.08 a	8.75 c	13.18 c
P3 (Bio-slurry LOF 100 ml/11 days)	5.85 a	7.53 ab	10.23 b

Note. Means followed by the same letter (a, b, c, etc.) within the same column are not significantly different based on Duncan's Multiple Range Test at 5% level.

The application of bio-slurry LOF at different intervals had a significant effect on the leaf length of pakchoi at 21 and 28 DAP. The 9-day interval treatment (P2) consistently resulted in the highest average leaf length across all observation periods. At 14 DAP, no significant differences were observed among treatments. By 21 DAP, however, the 9-day interval resulted in significantly greater leaf length compared to the control (P0) and the 11-day interval (P3). At 28 DAP, the 9-day interval differed significantly from all other treatments. These results can be attributed to the early growth stage of the plants at 14 DAP, during which the root system is still developing, limiting the plant's ability to absorb nutrients from the bio-slurry. This may explain the absence of significant differences among treatments at that stage. As the plant matures, particularly by 21 DAP, the root system becomes more established, enhancing nutrient uptake efficiency. Applying bio-slurry LOF every 9 days ensures a consistent nutrient supply, supporting optimal leaf development. The availability of nitrogen and phosphorus in the bio-slurry plays a key role in promoting cell division and the formation of new tissues, as well as supporting the photosynthetic process. Adequate levels of nitrogen and phosphorus can enhance photosynthetic activity, thereby accelerating leaf growth and contributing to longer and healthier leaves (Pangestu et al., 2023).

The observed increase in leaf length of pakchoi at each growth stage was closely related to the nutrient content in the bio-slurry LOF. According to Table 1, the total nitrogen (N) content in the bio-slurry was 0.04%, and the P_2O_5 content was 0.01%. The relatively low nitrogen content may influence the leaf growth rate of pakchoi, as nitrogen is essential for chlorophyll synthesis. This was evident from the 14 DAP observation, where no significant differences in leaf length were found among treatments. In addition, the low P_2O_5 content in the bio-slurry may result in stunted leaf growth, smaller leaf size, or even premature leaf drop (Fatirahma & Kastono, 2020). This is supported by the control treatment (P0), which showed the shortest average leaf length due to the absence of additional nutrients from the bio-slurry. Although the nutrient content in bio-slurry is considered low, the appropriate application interval every 9 days (P2) led to better leaf length outcomes compared to other treatments. These results suggest that the effectiveness of fertilizer use is not solely determined by nutrient concentration but also by the precision of its application schedule.

Leaf width

The analysis of variance indicated that the application of LOF derived from bio-slurry at different time intervals did not have a significant effect on the leaf width of pakchoi at 21 and 28 DAP. However, a significant effect was observed at 14 DAP. The response of pakchoi growth to different bio-slurry application intervals in relation to leaf width is presented in Table 5.

Table 5. The effect of bio-slurry LOF application intervals on the leaf width of pakchoi (*Brassica rapa* L.) (n = 6)

Treatment	Leaf width (cm)		
	14 DAP	21 DAP	28 DAP
P0 (Control)	3.07 a	4.33 a	7.77 a
P1 (Bio-slurry LOF 100 ml/7 days)	3.57 a	4.82 a	8.40 a
P2 (Bio-slurry LOF 100 ml/9 days)	4.60 b	5.32 a	9.55 a
P3 (Bio-slurry LOF 100 ml/11 days)	3.48 a	4.35 a	8.55 a

Note. Means followed by the same letter (a, b, c, etc.) within the same column are not significantly different based on Duncan's Multiple Range Test at 5% level.

The observation results indicated that the application of bio-slurry LOF at nine-day intervals (P2) produced the highest average leaf width of pakchoi at all stages of observation. Fertilization at nine-day intervals resulted in optimal leaf width growth because it allowed sufficient time for nutrient absorption without causing saturation. Nutrients such as nitrogen (N), phosphorus (P), and potassium (K) in bio-slurry require time to decompose and become available to plant roots, while soil microorganisms also play a role in enhancing nutrient availability. Moreover, the nine-day interval helps maintain a balance of soil moisture and aeration, which supports healthy root development and efficient nutrient uptake.

At 14 DAP, the treatment with a nine-day fertilization interval (P2) exhibited a significant difference compared to the other treatments. This indicates that an appropriate fertilization interval supports more optimal vegetative growth than either shorter (P1) or longer (P3) intervals. At 21 and 28 DAP, no significant differences were observed among treatments, likely because the nutrient content in the growing medium was already sufficient, rendering additional bio-slurry LOF less impactful on leaf width. According to Betalia et al. (2024), the growing medium is a crucial component influencing plant growth, particularly in its role as a provider of essential nutrients required for the growth and development of pakchoi plants.

The increase in pakchoi leaf width corresponds with the optimal availability of nutrients, particularly nitrogen and other micronutrients present in the bio-slurry LOF, which supports maximal leaf growth. These results align with the findings of Hasan et al. (2024), who reported that bio-slurry contains essential nutrients for plant development. These include micronutrients such as Fe, Mn, Cu, and Zn, as well as macronutrients such as N, P, K, Ca, Mg, and S. Further research by Rahmawati et al. (2021) also emphasized that plant growth parameters, such as leaf width, are significantly influenced by the application interval of LOF.

Fresh weight

The results of the analysis of variance indicate that the application of bio-slurry LOF at different time intervals had a significant effect on increasing the fresh weight of pakchoi plants. The growth response of pakchoi treated with bio-slurry LOF at different intervals on fresh weight can be seen in Figure 3. The results of the research indicate that the application of bio-slurry LOF at different time intervals had an effect on the fresh weight of pakchoi plants. Based on Figure 3, it can be observed that applying bio-slurry LOF every 9 days (P2) resulted in a significant difference compared to the control treatment (P0), but showed no significant difference compared to applications every 7 days (P1) and 11 days (P3). This outcome may be due to the 9-day interval (P2) providing an optimal condition in which pakchoi plants received an adequate and continuous nutrient supply to support their growth.

Plants have a saturation point in nutrient absorption. If fertilizer is applied too frequently, the plants may not be able to absorb all the available nutrients, thereby reducing the effectiveness of fertilization. Conversely, overly long fertilization intervals can lead to nutrient deficiency in pakchoi, resulting in suboptimal fresh weight. Although the 7-day interval (P1) involved more frequent application, the excessive nutrient availability may have led to saturation effects in the plant. As a result, the fresh weight at the 7-day interval (P1) did not significantly increase compared to the 9-day interval (P2). These

findings are consistent with the research by Salsabila et al. (2021), which reported that applying bio-slurry LOF at excessively high concentrations can cause nutrient saturation, thereby inhibiting optimal plant growth. On the other hand, the 11-day interval (P3) may have caused nutrient shortages due to the extended time between applications, resulting in fresh weight values that were close to but not as optimal as those observed with the 9-day interval (P2).

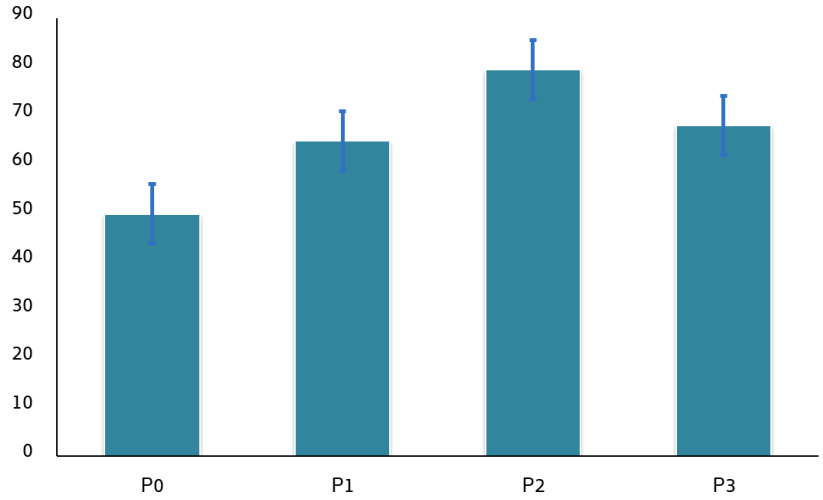

Figure 3. Fresh weight of pakchoi at 30 DAP under different bio-slurry LOF application intervals: P0 = control (no LOF), P1 = 100 mL every 7 days, P2 = 100 mL every 9 days, and P3 = 100 mL every 11 days.

Figure 3 illustrates the differences in fresh weight at harvest. Application of bio-slurry LOF at 9-day intervals (P2) resulted in the highest average fresh weight of 79.61 g. In contrast, the control treatment (P0) recorded the lowest average fresh weight at 49.83 g. This difference can be attributed to the periodic application of bio-slurry LOF, which enhances the availability of essential nutrients, thereby supporting more efficient photosynthesis and plant growth. Conversely, in the control treatment, limited nutrient availability hindered optimal plant development, leading to a lower fresh weight at harvest.

In sum, the results of the research indicate that the application of bio-slurry LOF every 9 days at a dose of 100 ml per polybag produced the best growth of pakchoi. This finding is consistent with Maula et al. (2023), who reported that a nitrogen dose of 200 kg N/ha based on bio-slurry LOF improved the growth of curly mustard. However, the present research focused more specifically on the effect of application intervals on pakchoi growth an aspect that has not been widely explored in previous research. Masitoh et al. (2018) also investigated the influence of bio-slurry liquid fertilizer dosage and plant spacing on the growth and yield of cucumbers, but did not thoroughly examine fertilization intervals. Therefore, this research provides a recommendation for the optimal bio-slurry LOF application interval to effectively support pakchoi growth.

CONCLUSIONS

This study demonstrated that the application of bio-slurry liquid organic fertilizer (LOF) every nine days at a dosage of 100 mL per polybag produced the most favorable growth response of pakchoi (*Brassica rapa* L.), significantly improving plant height, leaf number, and fresh weight. These findings emphasize the importance of optimizing fertilization intervals to maximize nutrient use efficiency, thereby supporting sustainable vegetable production and reducing reliance on chemical fertilizers. However, the research was limited to a single growing season, one location, and a fixed dosage level, which may restrict the generalization of the results across diverse environmental conditions. Further studies should therefore explore multi-season trials, different dosage levels, and long-term impacts, as well as potential synergies with other organic fertilizers, to strengthen the role of bio-slurry LOF in sustainable agriculture.

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