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COMPOSITE FERTILIZER PRODUCED FROM DECANTER CAKE AND PALM OIL MILL EFFLUENT (POME) AEROBIC SLUDGE

Nur Anis Nazihah Zuraimi[1], Hazlini Dzinun[1]*, Nur Syafiqah Mohd Zamani[1], Noraziah Ahmad[2]

[1]Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia, (UTHM), Pagoh, Malaysia
dn220134@student.uthm.edu.my https://orcid.org/0009-0005-3223-1262
[1]Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia, (UTHM), Pagoh, Malaysia
hazlini@uthm.edu.my https://orcid.org/0000-0002-8227-5168
[1]Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia, (UTHM), Pagoh, Malaysia
aa220025@student.uthm.edu.my https://orcid.org/0009-0008-1479-4127
[2]Faculty of Civil Engineering Technology, Universiti Malaysia Pahang Al-Sultan, Gambang, Malaysia
aziahahmad@ump.edu.my https://orcid.org/0000-0003-2959-866X
*Corresponding Author

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Abstract:

Composite fertilizers offer a sustainable approach to improving crop productivity while reducing reliance on chemical fertilizers. This study explores the potential of converting Palm Oil Mill Effluent (POME) aerobic sludge and decanter cake (DC) into a composite vermicompost-based fertilizer for *Capsicum annuum* cultivation. The fertilizer was produced using a 40:60 ratio of POME sludge to DC, followed by vermicomposting with *Eisenia fetida* for 60 days. Nutrient characterization revealed that the composite fertilizer (PDC) contained higher concentrations of macronutrients (N: 2.56%, P: 7.56%, K: 9.07%) and micronutrients (Fe: 16.73%, Si: 15.86%) compared to commercial fertilizer. Plant growth performance was evaluated using five fertilizer dosages (50–250 g) and compared with a control and commercial fertilizer treatment. Results showed that a 50 g application of PDC achieved 102.96% stem elongation, equivalent to the 100 g dosage of commercial fertilizer (118.53%), indicating greater nutrient use efficiency at lower input levels. The findings demonstrate that POME–DC composite fertilizer provides balanced nutrient availability, improved soil conditioning, and enhanced plant growth potential. This study highlights the feasibility of valorizing palm oil industry waste into an eco-efficient fertilizer, contributing to circular agricultural sustainability and reduced

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environmental impact.

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Keyword:

Composite Fertilizer, Palm Oil Mill Effluent Sludge, Decanter Cake

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Introduction

Fertilization plays a critical role in improving seedling vigor, nutrient uptake, and overall crop productivity. While inorganic fertilizers provide rapid nutrient availability, their prolonged use has been linked to soil compaction, nutrient leaching, and long-term degradation of soil structure (Wu et al., 2022). In response to growing environmental concerns, recent research has shifted toward developing organic and waste-based fertilizers as sustainable alternatives to conventional agrochemicals. Converting agricultural and industrial waste materials into nutrient-rich biofertilizers not only enhances soil fertility but also mitigates the negative ecological impacts associated with fertilizer runoff and waste accumulation (Badrul Hisham et al., 2020).

Among Malaysia's major agricultural industries, the palm oil sector is a leading contributor to both the national economy and organic waste generation. Malaysia remains the world's second-largest producer of palm oil, accounting for approximately 20 million tonnes annually (Ramli, 2017). However, the processing of fresh fruit bunches produces large quantities of by-products, particularly decanter cake (DC) and Palm Oil Mill Effluent (POME). These residues are typically disposed of in landfills or open ponds, contributing to pollution and greenhouse gas emissions (Duaja et al., 2021). DC is a fibrous, nutrient-containing solid residue produced during crude palm oil centrifugation, while POME is a highly organic effluent generated from the oil extraction process. Both wastes are rich in essential plant nutrients such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and iron (Fe), making them promising feedstocks for fertilizer production (Azmi et al., 2014; Rahman et al., 2023).

Recent studies have explored the use of DC and POME as soil amendments or compost materials; however, most previous works either treated them separately or required additional additives such as animal manure or microbial inoculants to achieve balanced nutrient profiles (Duaja et al., 2019; Loh et al., 2019). Limited research has focused on combining POME aerobic sludge and DC under controlled vermicomposting conditions to produce a composite fertilizer with optimized nutrient ratios and improved plant growth efficiency. The synergistic integration of these two waste streams may enhance nutrient availability, microbial activity, and soil conditioning capacity while reducing processing costs and environmental burdens.
Therefore, this study aims to develop and evaluate a composite fertilizer derived from POME aerobic sludge and decanter cake, formulated at a 40:60 ratio and processed through

vermicomposting. The objectives are to characterize the physicochemical properties and nutrient composition of the composite fertilizer; to assess its effectiveness on the growth of *Capsicum annuum* (chili plant) under different application dosages; and to compare its performance with a commercial organic fertilizer.

This research provides new insights into sustainable fertilizer formulation using palm oil industry by-products, supporting the circular economy and promoting environmentally responsible practices in tropical agriculture.

Materials And Methods

Palm Oil Mill Effluent (POME) sludge and decanter cake (DC) are two primary materials utilized in producing this composite fertilizer, which was collected from KKS Sime Darby Pagoh, Malaysia. Then, organic vermicomposting fertilizer was utilized for the commercial sample. This fertilizer was bought via online purchase. Lastly, a control sample was prepared without utilizing any fertilizer. (TNR, 12, single spacing, justify)

Preparation Of Raw Material for Composite Fertilizer

The study utilized 3.6 kg of POME sludge and alongside with 5.4 kg of DC. The arrangements of the composite fertilizer are POME and DC, followed by the upper layer by rock phosphate and soil. 100g of rock phosphate was added to the top layer in the container. This rock phosphate (Pherotools Egyptian Rock Phosphate) acts as a phosphorus element in powder form. After rock phosphate was added to the containers, it was mixed thoroughly. Adding rock phosphorus to this fertilizer stimulates root growth and fertilizes the plant by making the tree healthier. Then, 20 earthworms were utilized for the vermicomposting process to break down the organic material and produced vermicast filled with nitrogen, phosphorus, and potassium. (TNR, 12, single spacing, justify)

Composition For Composite Fertilizers

Novel Fertilizer Formulations Were Developed Through the Systematic Integration of Pome. The Experimental Matrix Comprised One Distinct Treatment, With 1:1 Ratio of Pome to Dc. The Treatment Was Designed to Evaluate Potential Synergistic Effects Between Composite Pome/Decanter Cake (Pdc) Based Substrates Fertilizer and Commercial Fertilizer on Morphological and Physiological Plant Parameters. This Novel Integration of Agricultural By-Products Represents an Innovative Approach to Sustainable Fertilizer Development, Potentially Offering Enhanced Agronomic Efficiency While Adhering to Circular Economy Principles In Agricultural Waste Management.

Methodology for composite fertilizer preparation

The primary materials for this project, POME (Palm Oil Mill Effluent) sludge and decanter cake, were combined in a 5-liter airtight plastic container at a 40:60 ratio. A layer of rock phosphate powder was added on top to enhance nutrient content in ratio of 36.36:54.55:9.09. Fig. 1 illustrates the arrangement of ingredients in container. After mixing thoroughly, the materials were allowed to compost for 15 days. On the 16th day, 20 earthworms were introduced to initiate the vermicomposting phase, which lasted for 60 days. Throughout this period, aerobic and anaerobic processes worked in tandem to decompose organic matter.

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Aerobics decomposition occurred in the oxygen-rich surface layers, where microorganisms converted waste into CO_2, water, and humus, creating an alkaline environment. In contrast, anaerobic decomposition in the lower, oxygen depleted layers produced organic acids, methane, and hydrogen sulfide, leading to a more acidic condition.

Earthworm activity enhanced this process by aerating compost through burrowing, stabilizing pH, and generating nutrient-rich castings filled with nitrogen, phosphorus, and potassium. After 60 days, the earthworms were removed, and the compost, now characterized by dark granules, was deemed ready for application and tested on Capsicum annuum (C. annuum). To analyze the nutrient content of POME sludge and decanter cake, samples were sent to the Malaysian Veterinary Institution for composition analysis, ensuring precise characterization of the primary inputs.

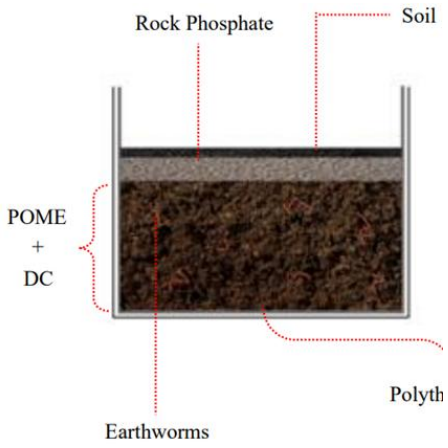


Fig. 1: Arrangement Of Ingredients in Plastic Containers

Evaluation Of the Effectiveness of Composite Fertilizer Towards C. Annuum

The plant's growth after 75 days was captured and measured. The measurement includes the average formula for the growth rate to indicate the plant's growth during the testing period. The formula for the average growth of the Capsicum annuum (C. annuum) is shown as the following:

$$(X_2\text{-}X_1) / X_1 \times 100\% \quad (1)$$

where:
X_1 = readings before being fertilized
X_2 = readings after a month being fertilized

Result And Discussion

Analysis of Nutrient Content of Raw Materials

The characteristics of two different raw materials, POME and DC, utilized in composting processes in terms of elements, moisture content, pH, and water holding capacity were measured. Regarding moisture content, DC has the highest moisture level at 79.06%, which correlates well with the reports of Abdul Razak et al. (2012) and Sahad et al. (2014). High

moisture content in decanter cake is important to overcome a lower level of moisture content in POME sludge. Huang et al. (1993) suggested maintaining compost moisture levels between 40% and 60%, as microbial activity is limited by low moisture levels, which is less than 40%. However, high moisture, on the other hand, causes anaerobic conditions because the pore spaces of solid matrices are filled with water instead of air, as referred in de Bertoldi et al. (1983) studies.

Table 1: Characteristics Of Pome and Dc

Parameter	POME	DC
Moisture	68.93	79.06
pH	7.46	5.40
Water holding capacity	60.92	70.12
Composition of elements (%)		
N	5.63	4.17
P	5.23	2.39
K	5.85	0.65
Si	12.59	13.61
Fe	16.58	6.09
Mn	0.43	0.12
Mg	1.11	1.65
Ca	0.09	8.79

As observed in Table 1, the lower moisture content of 68.93% was recorded in POME. Regarding pH levels, POME was slightly alkaline with a pH value of 7.46, while DC is acidic with a pH of 5.40. The values obtained are consistent with the previous discovery of Sahad et al. (2014), who observed a pH value of 5.03 for DC. The water holding capacity is 60.92, while DC has a notably higher capacity at 70.12. It helps maintain optimal moisture conditions of 40% to 60% for consistent microbial activity, acts as a moisture buffer, and enables gradual water release during decomposition.

Regarding elemental composition, POME is characterized by its extremely high iron (Fe) content at 16.58% while DC is rich with silicon (Si) compounds at 13.61% which only has a slightly different amount of POME value at 12.59%. This high content value of Si improved soil water retention after a month of incubation (Matichenkov et al. 2001). For macronutrients (N, P, K), POME typically contains the highest levels of N, 5.63%, P, 5.23%, and K, 5.85%, which are sufficient for the formulation of organic fertilizer to support the contents in DC. In contrast, DC has the lowest concentrations of these nutrients. Aside from that, decanter cake had the highest concentrations of calcium (Ca) at 8.79% and magnesium (Mg) at 1.65%, which can increase the efficiency of organic fertilizer composition (Hisham et al. 2019). This compositional analysis indicates that each material has specific properties ideal for making composite fertilizer.

Analysis of Nutrient Content of Composite Fertilizer

Table 2 shows the nutrient composition analysis of the composite PDC and commercial fertilizers revealing significant differences in their elemental concentrations and potential agronomic value. The composite PDC fertilizer demonstrated notably higher concentrations of all nutrients analyzed than the commercial fertilizer. The composite fertilizer (PDC) exhibits a

carefully balanced nutrient composition with a slightly alkaline at pH of 7.77, which is instrumental in neutralizing acidic soils and optimizing nutrient bioavailability.

The macronutrient content (N, P, K), including nitrogen (N), achieved a composition of 56%; this element is essential for promoting plant growth by cell division and expansion in C. annuum tissues. Nitrogen is incorporated into amino acids and proteins, forming the building blocks for new cell formation, leading to increased leaf area, stronger stems, and more extensive root systems. Next, the phosphorus (P) concentration at 7.56% helps in root development. It stimulates root development by promoting cell division and elongation in root tips. Phosphorus facilitates energy transfer throughout the plant for essential metabolic and flowering/fruiting processes by supporting the development of reproductive organs. As mentioned by Wang et al. (2019) and Petraglia et al. (2014), the consistency of C. annuum growth development depends on the enough supplement N and P composition. The abundant fertilizer supplies increased plant output by allowing for more radiation absorption during the reproductive phase (Jiang et al. 2024), notably during the flowering stage, when leaves exhibit the highest physiological activity (Blandino et al. 2022).

The potassium (K) concentration of 9.07% is significant as a macronutrient for C. annuum growth. Potassium is plants' second most important macronutrient, behind nitrogen (Bhattarai et al. 2016). According to Guntzer et al. (2012), current research has increasingly recognized its beneficial significance in stimulating plant development and protection. It greatly impacts crop yields, quality enhancement, and tolerance to adverse conditions.

This suggests composite PDC fertilizer could provide more robust nutritional support for intensive C. annuum production. Particularly noteworthy are the micronutrient levels in composite PDC fertilizer, especially silicon at 15.86% and iron at 16.73%, which are either absent or present in much lower concentrations Fe at 0.55% in the commercial fertilizer.

The high silicon content in composite PDC fertilizer could be particularly beneficial for crops known to be silicon-accumulating plants. Besides, the fertilizer's silicon content was 15.86%, contributing to better soil structure and water retention capacity. Haddad et al. (2018) found that silicon enhanced nitrogen uptake and photosynthetic activity, while also delaying leaf senescence caused by nitrogen deficiency.

The calcium content at 6.99% will strengthen cell walls, improve soil structure through enhanced aggregation, and play a crucial role in cell membrane integrity and root development. The findings suggested that integrating these materials into agricultural practices could reduce reliance on synthetic fertilizers while enhancing crop yields (Duaja et al. 2022). This comprehensive nutrient profile makes the PDC fertilizer particularly valuable for soil amendment and sustainable agriculture (Embrandiri et al. 2016), especially in nutrient-deficient or structurally poor soils, as it addresses the chemical and physical aspects of soil fertility while supporting robust plant growth and development.

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Table 2: Nutrient Contents of Composite Fertilizer Pdc and Commercial

Parameter	PDC	Commercial
pH	7.77	7.52
Composition of element (%)		Composition of elements
N	2.56	1.08
P	7.56	1.22
K	9.07	1.31
Si	15.86	-
Fe	16.73	0.55
Mn	0.44	0.018
Mg	1.18	0.46
Ca	6.99	1.75

The substantial iron concentration at 16.73% is crucial for electron transport in photosynthesis, and nitrogen fixation, helping prevent chlorosis and maintain healthy green foliage. According to Embrandiri et al. (2016), the study found that higher ratios of decanter cake in soil amendments led to increased iron availability for plant uptake. POME and DC can improve soil nutrient profiles, including iron content, crucial for chlorophyll synthesis and overall plant health.

Magnesium of 1.18% serves as the central atom in chlorophyll molecules and is essential for phosphate metabolism and enzyme activation. Magnesium regulated plant metabolic activities and reactions, such as photophosphorylation, photosynthetic carbon dioxide fixation, protein synthesis, chlorophyll production, phloem loading and photooxidation in leaf tissues (Ramli et al. 2016).

The manganese content in PDC is 0.44% which is considerably higher than in the commercial fertilizer that contains only 0.018%, potentially offering better support for photosynthetic processes and other metabolic functions. Among the micronutrients, manganese which contains 0.44% supports photosynthesis efficiency and disease resistance while activating several enzymatic processes.

The pH values of both fertilizers are relatively similar, with composite PDC fertilizers at 7.77 and commercial at 7.52, both being slightly alkaline. This pH range is generally favourable for nutrient availability and soil application. Overall, the composite PDC fertilizer appears to offer a more comprehensive nutrient package compared to the commercial alternative, potentially providing better support for plant growth and development. However, the higher nutrient concentrations in composite PDC fertilizer would require careful application management to prevent potential nutrient imbalances or excessive application rates. Further field trials would be valuable to assess the actual crop response and optimize application rates for different agricultural systems.

Effectiveness of Different Amounts of Composite Fertiliser Towards Chili Plant

The experimental data depicted in Fig. 2 demonstrates the temporal progression of stem elongation in C. annuum in response to varying concentrations of integrated PDC treatment.

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The investigation encompassed five distinct fertilizer concentrations of 50g, 100g, 150g, 200g, and 250g compared against a control treatment, 0g, with measurements recorded at 15-day intervals over 75 days. The morphometric analysis revealed that specimens treated with 150g of fertilizer exhibited maximum stem elongation, achieving a 119.56% increase in vertical growth by day 75. However, of particular significance was the growth response observed in the 50g treatment group, which demonstrated remarkable efficiency by attaining 102.96% stem elongation, representing a more than two-fold increase from initial measurements.

This growth rate indicates optimal resource utilization at lower fertilizer concentrations. In contrast, the control specimens exhibited significantly reduced growth dynamics, achieving only 64.18% increase in stem height by the conclusion of the observation period, approximately 50% lower than the 50g treatment group. While all fertilizer treatments demonstrated enhanced growth compared to the control, the specimens receiving 100g, 150g, 200g, and 250g did not exhibit proportionally enhanced growth efficiency relative to the 50g treatment. These findings suggest that 50g of composite PDC fertilizer represents the optimal concentration for maximizing stem elongation in C. annuum, achieving superior growth metrics while maintaining resource efficiency. The data supports the show that lower fertilizer concentrations can achieve optimal plant growth parameters, potentially indicating a threshold effect in nutrient utilization efficiency.

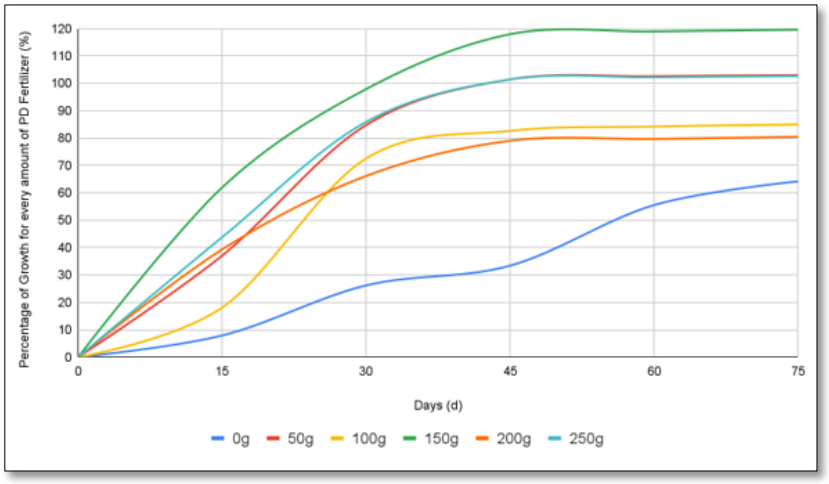


Fig 2: The Percentage of Growth Rate for Chili Plant Stems (%) Against the Amount of Composite Pdc Fertilizer

The temporal dynamics of stem elongation in C. annuum specimens subjected to varying concentrations of commercial fertilizer treatments was shown in Fig. 3. The investigation implemented a systematic approach, examining five distinct fertilizer concentrations of 50g, 100g, 150g, 200g and 250g against a control group, 0g, with morphometric measurements recorded at consistent 15-day intervals throughout a 75-day observation period. The quantitative analysis revealed that specimens receiving 250g of commercial fertilizer demonstrated superior growth performance, achieving a 121.51% increase in stem elongation by day 75.

Of particular interest was the growth response pattern observed in the 100g treatment group, which exhibited optimal growth efficiency, attaining 118.53% stem elongation which representing more than double the initial measurements. In comparative analysis, the control

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specimens displayed significantly reduced growth dynamics, achieving only 64.18% increase in stem height by the conclusion of the experimental period, approximately 54.35% lower than the 100g treatment group. While specimens receiving 150g and 200g treatments demonstrate enhanced growth compared to the control with 99.47% and 88.12% respectively, they did not exceed the growth efficiency observed in the 100g treatment. The 50g treatment group showed notably diminished growth performance of 57.48%, suggesting insufficient nutrient availability at lower concentrations. These findings indicate that 100g of commercial fertiliser represents the optimal concentration for maximising stem elongation in C. annuum.

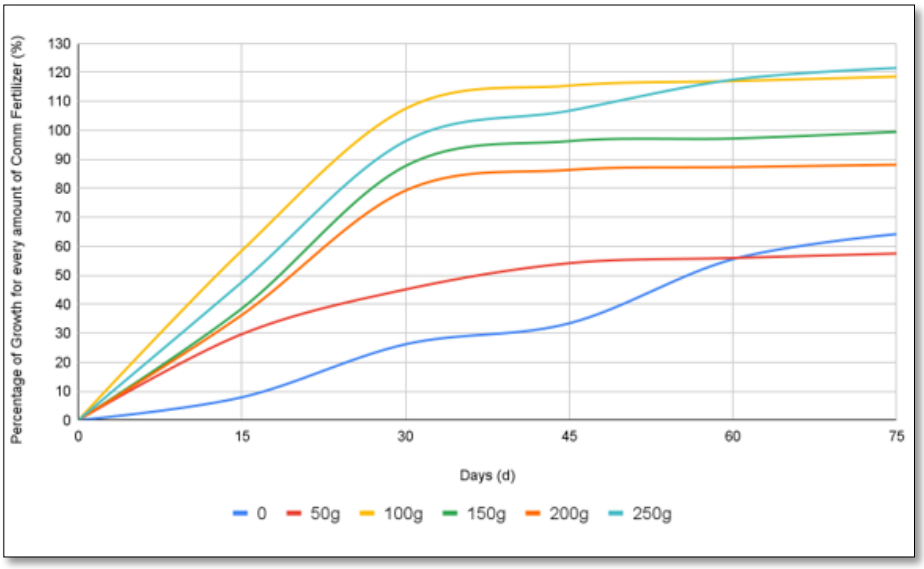


Fig. 3: The Percentage of Growth Rate for Chili Plant Stems (%) Against the Amount of Fertilizer (g) Of Commercial Fertilizer

Fig. 4 presents a comparative morphometric analysis between composite PDC fertilizer and conventional commercial fertilizer, revealing distinct nutrient utilization efficiencies and optimal concentration thresholds in C. annuum cultivation. The data demonstrates that composite PDC fertilizer exhibits exceptional physiological response at a minimal concentration of 50g, achieving approximately 100% stem elongation, a significant enhancement compared to the control specimens' 60% growth increment. This marked efficiency at 50g concentration approaches maximum growth potential observed at higher concentrations, indicating an optimal threshold for practical agronomic applications compared to the commercial fertilizer that required 100g dosage to achieve 100% growth. Thus, commercial fertilizers necessitate a substantially higher concentration (100g) to achieve comparable morphological development, suggesting reduced nutrient bioavailability and absorption efficiency. The superior performance of composite PDC fertilizer at lower concentrations has substantial implications for agricultural methodology, offering enhanced resource utilization efficiency, reduced environmental impact quotient, and optimized handling protocols. Quantitative analysis demonstrates that composite PDC fertilizer achieves superior growth metrics with minimal input requirements, as the 50g application yields equivalent morphological development to significantly higher concentrations of commercial fertilizer. This enhanced efficiency manifests in multiple operational benefits, including reduced logistics costs, minimized over-fertilization risks, and improved sustainability metrics. The differential response patterns between the two fertilizer types are characterized by composite PDC fertilizer's enhanced physiological response at lower concentrations versus commercial

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fertilizer's requirement for higher application rates and suggests superior nutrient bioavailability and enhanced rhizospheric absorption in composite PDC fertilizer applications. For agricultural practitioners and researchers, these findings provide strong empirical support for the implementation of composite PDC fertilizer at 50g concentration as an optimal methodology, effectively balancing physiological development with resource efficiency while promoting sustainable agricultural practices.

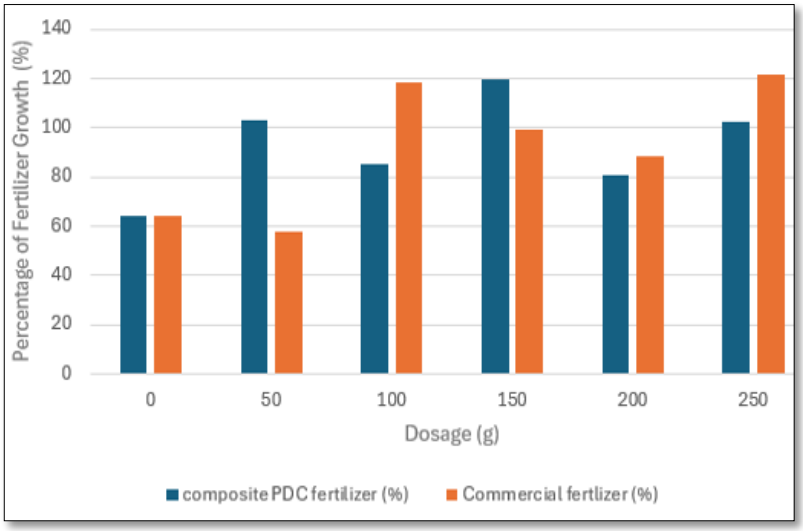


Fig. 4: Comparison of Composite Pdc Fertilizer and Commercial Fertilizer Growth Percentage

Effect Of Fertilization on Chili Plant

Fig. 5 depicts an organized experimental setup aimed at studying the effects of different fertilizer dosages on C. annuum growth after 75 days. The qualitative result shows the plants are arranged in distinct columns based on the dosage of composite PDC fertilizer applied, 3 poly bags for each dosage, ranging from 50g as seen in Fig. 5(a) to 250g in Fig. 5(e). A control group in Fig. 5(f), positioned in the middle, received no fertilizer, providing a baseline for comparison. At the back of the setup, plants treated with commercial fertilizer with the same dosage serve as a reference to evaluating the relative effectiveness of the composite PDC fertilizer. From visual observation, differences in plant size and vigor are apparent across the columns. Plants in the control group show limited growth, likely due to the absence of added nutrients. The plants in the column treated with 50g of composite PDC fertilizer achieved the optimal growth rate, displaying the healthiest and most vigorous growth compared to higher dosages. This suggests that 50g of composite PDC fertilizer provides sufficient nutrients for robust plant development without overloading the soil with excess fertilizer, which could potentially harm the plants. We could confirm that the plant can achieve the highest growth rate in 75 days by only using such as slowed growth or leaf discoloration, although this effect is not clearly visible in the image. The commercial fertilizer group at the back appears to have robust and 50g of composite PDC fertilizer which shows the better performance than 250g amount of fertilizer being used to achieve the same plant growth. Excessive fertilizer, as seen in the 250g dosage in Fig. 5(e), might lead to over-fertilization symptoms, uniform growth, suggesting its established efficiency. This serves as a benchmark to assess whether the composite PDC fertilizer can compete in terms of promoting plant development. Overall, the setup offers valuable insights into the optimal fertilizer dosage, the efficacy of the composite

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PDC formula, and its comparison with commercial alternatives. A detailed qualitative analysis of length of stem, leave condition, roots growth and chili growth will further validate this observation.

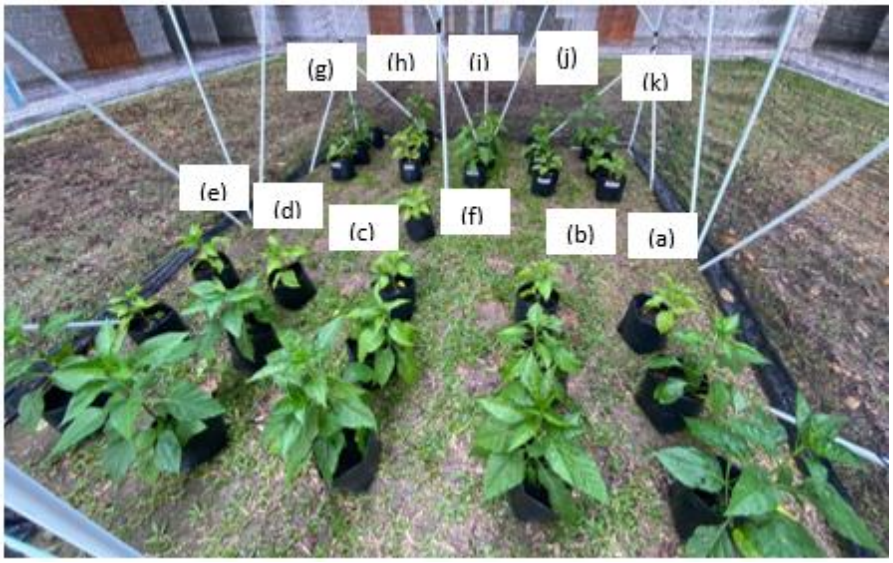


Fig. 5: C. Annuum Growth After 75days

Table 6 highlights a comparative analysis of plant growth parameters over a 75-day period under three treatments which are commercial fertilizer with 250g dosage consumed, PDC fertilizer with 50g dosage consume, and a control group with no fertilizer. The figure provides a clear comparison between the effects of composite PDC fertilizer (50g) and commercial fertilizer (250g) on plant growth, particularly focusing on their impact on C. annuum. The plants treated with composite PDC fertilizer demonstrated superior performance in several key parameters. The stem length for the PDC-treated plants reached 36.1 cm, significantly surpassing the 31.4 cm achieved.

with the commercial fertilizer, highlighting the enhanced growth-promoting properties of composite PDC fertilizer even at a lower dosage. Furthermore, the root development of PDC-treated plants was visibly more extensive and healthier, suggesting that the organic components in the composite PDC fertilizer might enhance soil structure and root uptake efficiency, providing better support for overall plant health.

The plants treated with composite PDC fertilizer exhibited larger and potentially more abundant chilies compared to those grown with commercial fertilizer. This suggests that the nutrient composition of composite PDC fertilizer is not only effective in supporting vegetative growth but also highly beneficial for reproductive development. In contrast, the commercial fertilizer, while effective, required a significantly higher dosage (250g) to achieve comparable results. This demonstrates the superior efficiency and sustainability of composite PDC fertilizer, which provides better results at a fraction of the quantity. Overall, composite PDC fertilizer proves to be a more cost-effective, eco-friendly, and efficient alternative to commercial fertilizers, offering enhanced root performance and superior fruit production for C. annuum.

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Table 6: Comparison of Growth Data Between Composite PD Fertilizer and Commercial Fertilizer Over a 75-Day Period

Growth Type Measurement	Stem Length (cm)	Roots Growth	Roots Growth	Chili Growth
Commercial Fertilizer (250g)	31.4			
	16.9			None
PD (50g)	36.1			
	15.6			None
Control	13.8			None

Comparison With Previous Study

Table 7: Types Of Fertilizer Based On The Previous Study

Type of fertilizer	Remark	Reference
Microcapsule agro-industrial waste, sodium alginate, bovine gelatin polysaccharide hydrogel beads	Approximate 50.92% increase compared to the control and has the average yield efficiency of 77.86% in releasing nutrients	(Yetilmezsoy et al. 2024)

Raw and treated POME mixed with chicken manure	Increased by over 50% compared to control	(Loh et al. 2019)
NPK fertilizer, POME, manure, and plant growth-promoting bacteria	The highest yield from integrated treatments represents approximately a 105.56% increase compared to the control yield	(Ngone et al. 2023)
Oil Palm Decanter Cake (OPDC)	Seedlings could tolerate up to a 50% OPDC mixture without BFR, showing that OPDC could substitute for inorganic fertilizers during the nursery stage	(Rahman et al. 2023)
Decanter cake 15 (15 ton/ha)	12.58% increase over control	(Duaja et al. 2019)
Composite PDC fertilizer	50 g application of PDC achieved 102.96% stem elongation, equivalent to the 100 g dosage of commercial fertilizer (118.53%)	This study

Table 7 summarizes the performance of various fertilizers, including composite PDC fertilizers, in comparison to conventional fertilizers. Microcapsule agro-industrial waste combined with sodium alginate and bovine gelatin achieved a 50.92% yield increase over the control, with an impressive nutrient release efficiency of 77.86%. Raw and treated POME mixed with chicken manure demonstrated over a 50% improvement in yield compared to the control, emphasizing its potential as a sustainable fertilizer. NPK fertilizer integrated with POME, manure, and plant growth-promoting bacteria recorded the highest yield improvement, achieving a 105.56% increase relative to the control, showcasing the benefits of combining inorganic and organic components.

Palm Oil Decanter Cake (PDC) was found to effectively replace inorganic fertilizers in the nursery stage, with seedlings tolerating up to 50% PDC mixture without adverse effects. A decanter cake application rate of 15 tons per hectare resulted in a modest yield increase of 12.58% over the control. In the current study, composite PDC fertilizer demonstrated significant potential as a sustainable alternative, contributing to superior plant growth and yield efficiency. The data collectively highlights the versatility and environmental benefits of POME-derived fertilizers, with the composite PDC fertilizer formulation emerging as a highly effective solution for enhancing crop performance while reducing dependence on traditional inorganic fertilizers.

Conclusion

This study demonstrated that a composite fertilizer derived from Palm Oil Mill Effluent (POME) sludge and decanter cake (DC) through vermicomposting exhibits strong potential as a sustainable and efficient biofertilizer. The 40:60 POME–DC formulation achieved optimal nutrient balance and superior plant growth at lower application rates compared to commercial fertilizers. The 50 g dosage produced the highest growth efficiency, reflecting improved nutrient bioavailability and reduced input requirements. The composite PDC fertilizer was rich

in essential macronutrients (N, P, K) and beneficial micronutrients (Fe, Si, Ca), enhancing soil fertility and promoting vigorous growth of *Capsicum annuum.*

The results confirm that integrating agro-industrial residues into fertilizer production can significantly reduce waste generation and dependence on synthetic fertilizers, aligning with circular economy principles. However, future studies should include replicated field trials, statistical validation, and analyses of soil microbial and physicochemical properties to verify the long-term agronomic benefits and environmental impacts. Overall, the PDC composite fertilizer represents a promising alternative for eco-friendly, resource-efficient crop production in tropical agriculturee.

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