

Development of Phosphate-Enriched Compost Blocks from Spent Coffee Grounds and Cattle Manure Using Calcium Hydroxide as a Sustainable Growing Medium for Chili Seedlings

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Abstract

The increasing generation of spent coffee grounds (SCG) from the coffee industry has created significant environmental challenges while simultaneously offering opportunities for resource recovery within a circular economy framework. This study developed phosphate-enriched compost blocks derived from SCG and cattle manure through calcium hydroxide modification and evaluated their suitability as a sustainable growing medium for chili (*Capsicum annum* L.) seedlings. Compost was produced using three cattle manure proportions (10%, 20%, and 30%), followed by enrichment with calcium hydroxide and phosphoric acid (H_3PO_4) before being formed into compost blocks. Compost quality was evaluated through pH, temperature, relative humidity, nitrogen, phosphorus, potassium, organic carbon, and C/N ratio analyses. The agronomic performance of the compost blocks was assessed by measuring seedling height, leaf number, and stem diameter. The results showed that the compost containing 30% cattle manure exhibited the highest composting temperature, the greatest phosphorus (0.15%) and potassium (0.28%) contents, and a C/N ratio within the Indonesian National Standard (SNI 19-7030-2004). Compost blocks prepared from this formulation (K30M) significantly improved chili seedling growth compared with other modified compost treatments, although their performance remained below that of commercial compost. The enhanced plant growth was associated with increased phosphorus availability following calcium hydroxide treatment, which promoted nutrient retention within the compost matrix. These findings demonstrate that phosphate-enriched compost

blocks produced from SCG represent a promising environmentally friendly alternative for reducing organic waste while partially replacing conventional nursery media.

Keywords

Spent Coffee Grounds, Compost Block, Calcium Hydroxide, Phosphate Enrichment, Chili Seedlings, Circular Bioeconomy

1. Introduction

The rapid expansion of the global coffee industry has substantially increased the generation of agro-industrial residues, particularly spent coffee grounds (SCG), which constitute one of the largest organic wastes produced during coffee beverage preparation.

Indonesia, as one of the world's leading coffee-producing countries, generates considerable quantities of SCG from household consumption, coffee shops, and coffee-processing industries. Most SCG are disposed of in landfills without further treatment, where they contribute to greenhouse gas emissions and environmental pollution through uncontrolled microbial decomposition. Nevertheless, SCG contain valuable organic matter and essential plant nutrients, including nitrogen, phosphorus, potassium, lignocellulosic compounds, and humic substances, indicating considerable potential as a renewable resource for sustainable agriculture rather than as waste (Campos-Vega et al., 2015; Ballesteros et al., 2014). The introduction of your manuscript already highlights the environmental burden associated with coffee-ground waste and its nutrient potential, providing a suitable foundation for this argument.

From the perspective of ecological engineering, the utilization of SCG represents an important strategy within the circular bioeconomy concept because it simultaneously addresses waste reduction and resource recovery. Organic waste recycling through composting minimizes landfill disposal while returning nutrients to agricultural soils. Previous studies have demonstrated that compost derived from coffee residues can improve soil organic carbon, enhance water-holding capacity, stimulate microbial activity, and increase nutrient availability for crop production (Afriliana et al., 2021). However, the direct use of fresh SCG is generally not recommended because residual caffeine, tannins, chlorogenic acids, and phenolic compounds may inhibit seed germination, suppress microbial diversity, and negatively affect plant growth (Campos-Vega et al., 2015). Consequently, biological stabilization through composting is required before SCG can be safely utilized as a soil amendment.

Composting is an effective biological process in which microorganisms transform unstable organic matter into mature humus through controlled aerobic degradation. The efficiency of composting is largely governed by substrate composi-

tion, relative humidity, aeration, pH, carbon-to-nitrogen (C/N) ratio, and microbial activity. Among various composting activators, cattle manure is widely recognized as an effective inoculum because it supplies abundant decomposer microorganisms together with readily biodegradable organic matter and balanced nutrients that accelerate the mineralization process (Bernal et al., 2009). Increasing the proportion of cattle manure generally enhances microbial respiration and raises compost temperature during the thermophilic phase, thereby accelerating organic matter degradation and compost stabilization. These mechanisms explain why cattle manure has been extensively employed for composting agricultural residues and other lignocellulosic wastes.

Although composting substantially improves SCG stability, the phosphorus availability of mature compost often remains insufficient for intensive crop production. Phosphorus is an essential macronutrient involved in energy transfer, nucleic acid synthesis, root development, membrane formation, and early seedling establishment. However, phosphorus is frequently immobilized through precipitation or adsorption, reducing its bioavailability in soil systems (Richardson et al., 2009). Therefore, increasing phosphorus availability represents an important challenge in developing high-quality compost products.

One promising strategy involves enriching compost with calcium hydroxide [$\text{Ca}(\text{OH})_2$] followed by phosphate incorporation. Calcium hydroxide not only neutralizes excessive acidity generated during composting but also modifies the physicochemical characteristics of the compost matrix. Under appropriate conditions, calcium ions interact with phosphate ions to form calcium phosphate compounds that gradually release phosphorus into the soil. Such controlled-release behavior potentially improves phosphorus use efficiency while reducing nutrient losses caused by leaching. Previous investigations have shown that calcium-based amendments can improve nutrient retention, increase compost stability, and enhance soil fertility, although studies specifically integrating calcium hydroxide treatment with phosphate-enriched SCG compost remain limited (Humayro et al., 2021).

Another important limitation in conventional compost application is its dependence on plastic polybags during seedling production. Plastic nursery containers generate persistent environmental pollution because they are rarely recycled after use. Compost blocks have therefore emerged as an environmentally friendly alternative capable of replacing plastic containers while simultaneously functioning as both growing medium and nutrient source. Unlike loose compost, compost blocks provide improved structural integrity, facilitate transplantation, reduce root disturbance, and gradually release nutrients during early plant development. Despite these advantages, research investigating phosphate-enriched SCG compost blocks for seedling production remains scarce.

Most previous studies have focused separately on SCG composting, calcium amendment, phosphorus fertilization, or compost block technology. Very limited information is available regarding the integration of these approaches into a single

sustainable cultivation system. In particular, there is insufficient understanding of how different proportions of cattle manure influence compost maturity, nutrient dynamics, phosphate enrichment, and the subsequent performance of compost blocks as nursery media. Addressing these knowledge gaps is essential for developing environmentally sustainable alternatives capable of simultaneously reducing organic waste and replacing conventional seedling substrates.

2. Materials and Methods

2.1. Composting Experiment

Composting is a process of transforming waste into beneficial and valuable agricultural products, making it reusable (Stacey et al., 2024). Composting is carried out in modified used gallon containers. The used gallon containers need to be modified by adding air ventilation to facilitate optimal air circulation aimed at enhancing the semi-aerobic process within the composting. Next, raw materials such as coffee grounds and cattle manure are collected and mixed into the modified used gallon containers with ratios of K10 (90% spent coffee grounds + 10% cattle manure), K20 (80% spent coffee grounds + 20% cattle manure), and K30 (70% spent coffee grounds + 30% cattle manure). To produce high-quality compost, several determining factors must be considered, such as oxygen, temperature, moisture, and chemical composition (Olson et al., 2024). The composting process lasts for 2 weeks, with observations of temperature, humidity, and pH parameters. This process is conducted using a soil meter and thermometer, with the materials being turned at least once a week to ensure even heat distribution and aeration. After 2 weeks, N, P, and K tests are performed to evaluate the quality of the compost using the Kjeldahl method with a spectrophotometer. Three independent composting units were prepared for each treatment (K10, K20 and K30), giving a total of nine composting units. Each composting unit was considered one experimental replicate.

2.2. Modifying Compost

Compost enrichment is carried out after the composting is terminated, after stabilization of temperature and pH. The resulting compost quality was subsequently evaluated against SNI 19-7030-2004 prior to enrichment. The finished compost is soaked in a 0.5 M calcium hydroxide solution. The compost is soaked in calcium hydroxide with a ratio of 160 mL to 2 grams of coffee grounds for 24 hours for each composition (K10, K20, K30) while slowly stirring with a flocculation machine. After soaking, the compost is oven-dried for 24 hours at 60°C. Next, the compost is soaked in a calcium hydroxide-treated compost and subsequently immersed in 0.5 M phosphoric acid (H_3PO_4) solution for 240 minutes while being slowly stirred with a flocculator, then oven-dried for 24 hours at 60°C. The results of this compost enrichment will be further processed into compost blocks.

2.3. Block the Compost

The purpose of compost blocking is to facilitate the application of compost to seeds

and reduce the use of plastic polybags that can pollute the environment. Thirty compost blocks were produced for each treatment. The compost-blocking process involves combining soil from Summersari, which has a loamy texture, with a tapioca flour adhesive mixed with water. The tool used for the blocking process is a modified balloon pump. The adhesive is prepared by dissolving 250 grams of tapioca flour in 300 mL of water, then mixing it with 700 mL of water. For compost blocks, the following combinations are used: K10M (0.3 grams of K10 compost + 100 grams of soil), K20M (0.3 grams of K20 compost + 100 grams of soil), K30M (0.3 grams of K30 compost + 100 grams of soil), with T (100% soil) and (100% commercial compost) as comparisons. Adding 0.3% of the compost to coffee grounds follows the research on coffee grounds modification by Humayro et al. (2021). Using the modified balloon pump, compost blocking can produce ready-to-use compost without the need for plastic polybags that can pollute the environment. The first step in making compost blocks is dissolving tapioca flour in hot water while continuously stirring. Next, weigh and mix the soil with the compost, then add the tapioca flour solution while stirring until evenly mixed. Finally, place the mixture into the molding tube until it forms a cylinder, then remove it. The blocked compost will have a diameter of approximately 5 cm and a height of 7 cm.

2.4. Chili Seedlings

During the early growth phase, or vegetative stage 1, observations will be made on several parameters, including stem height, number of leaves, leaf width, and leaf length from 7 days after planting until two weeks later. The seeds used are chili pepper seeds. The seeds are planted by making a small hole at the top of the compost block, placing the seed into the hole, and then covering it. Regular watering should be done, and exposure to intense sunlight should be avoided until the seeds begin to sprout.

2.5. Statistical Analysis

After the research procedures are carried out, the data obtained will include compost quality, compost enrichment, analysis of N, P, and K content in the compost, and the growth rate of chili plants. These data will then be analyzed using a one-way ANOVA method at a 5% significance level in the SPSS application. Further testing will be conducted using the Duncan Multiple Range Test (DMRT) at a 5% significance level to identify differences in the effects among treatments.

3. Result and Discussion

3.1. Compost Quality Parameters

3.1.1. pH Compost

Changes in the organic matter and pH levels occur during the composting process. Monitoring pH is crucial because the pH of composting affects the growth of decomposer microorganisms. Here are the observed pH results.

During the 14-day composting process (Figure 1) with compositions K10, K20,

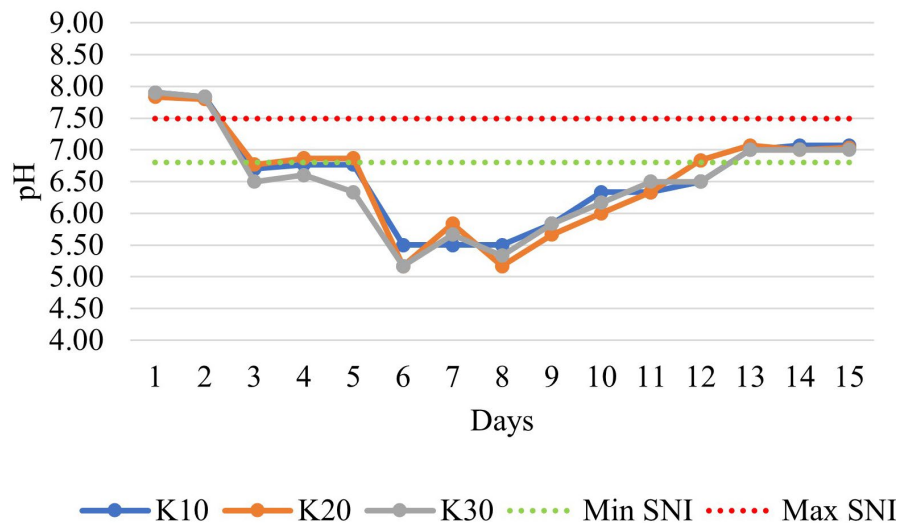


Figure 1. pH observations of coffee grounds compost over 14 days.

and K30, the most acidic pH occurred on the sixth and eighth days. These pH changes are influenced by the decomposition of cattle manure. High decomposition activity makes the compost more acidic. On the 14th day, composting can be stopped because the pH of all three compositions stabilized following SNI 19-7030-2004, with compost pH ranging between 6.80 and 7.49. At the beginning of composting, the pH is alkaline due to the release of acids but becomes more acidic due to increased bacterial activity that converts nitrogen-containing ammonia compounds, which lowers the pH. Afterward, the pH becomes alkaline again as bacterial decomposition activity decreases. The final pH of the compost is essential because extreme pH can affect compost quality. A pH that is too high can cause the release of ammonia gas, increase oxygen consumption, and harm the environment. Conversely, a pH that is too low can cause the death of essential microorganisms in the compost. However, ammonia can also be an essential factor because it can kill harmful bacteria that can infect plants and use them as hosts (Harvey et al., 2019).

3.1.2. Temperature Compost

Temperature is a crucial physical parameter for assessing compost maturity. Additionally, temperature is used to evaluate the effectiveness of the composting system and measure the ongoing decomposition rate.

Based on the data in **Figure 2**, temperature analysis over 14 days with cattle manure compositions of 10%, 20%, and 30% shows that the average highest mean composting temperature sequence is 30%, 20%, and 10%. Microbial decomposition processes in compost can generate heat, leading to temperature increases. Adding cattle manure to the composting process of coffee grounds significantly affects temperature changes due to the decomposition process. Once all components are decomposed, the temperature will decrease. According to Standard National Indonesia 19-7030-2004, compost has no minimum temperature limit, but its

maximum limit is based on groundwater temperature.

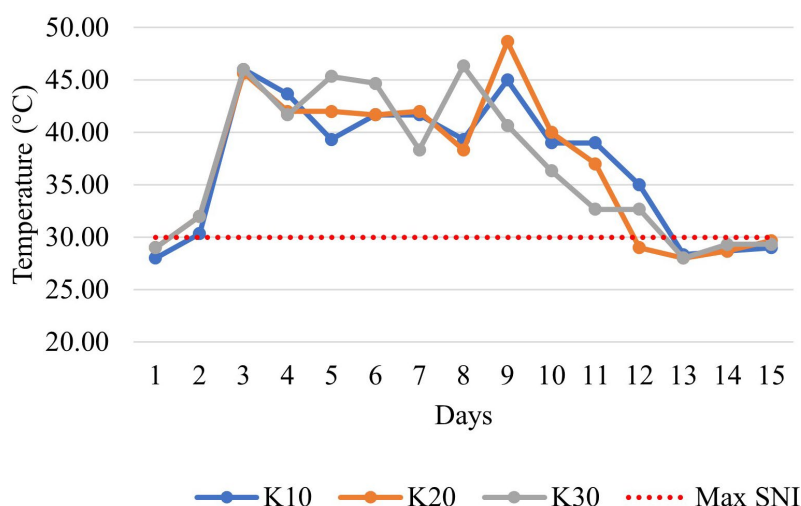


Figure 2. Temperature observations of coffee grounds compost over 14 days.

Factors influencing temperature fluctuations include microbial processes within the compost. Compost with 30% cattle manure content has the highest mean composting temperature because it contains more decomposer microorganisms. Certain bacteria can convert organic waste into simpler substances that plants easily absorb. Bacteria survive and produce CO_2 , H_2O , nutrients, humus, and energy through organic matter changes or decomposition processes. During this process, an exothermic reaction occurs, a chemical reaction that releases heat. Therefore, higher temperatures lead to increased oxygen consumption, accelerating waste decomposition. Conversely, temperatures decrease as the decomposed organic matter in the compost diminishes.

3.1.3. Humidity Compost

Moisture plays a crucial role in microbial metabolism and indirectly affects the oxygen microbes required for survival. Therefore, in the research on developing compost from modified coffee grounds using calcium hydroxide, moisture testing was conducted over a 2-week composting period. Here are the moisture results for coffee grounds and cattle manure composting (**Figure 3**).

20% and 30% show the highest to lowest relative humidity sequence as 30%, 20%, and 10%. This is influenced not only by the local climate and weather conditions around the composting site but also by microbial activity that transforms organic materials into vapor, thereby increasing the relative humidity of the compost. Additionally, insufficient or decreasing oxygen levels can increase water content and lead to excessively humid conditions. The optimal moisture range for aerobic composting is typically between 50% and 60%. If moisture is less than 50%, the composting process may slow down; if it exceeds 60%, the air volume within the compost decreases. Based on the results of the three treatments, the moisture levels still need to meet the standards set by SNI 19-7030-2004. Moisture in com-

post significantly impacts the activity of microorganisms involved in the composting process. Excessive moisture can create anaerobic conditions, lower the temperature, and reduce the quality of decomposition because it hinders the breakdown activity (Gondek et al., 2020).

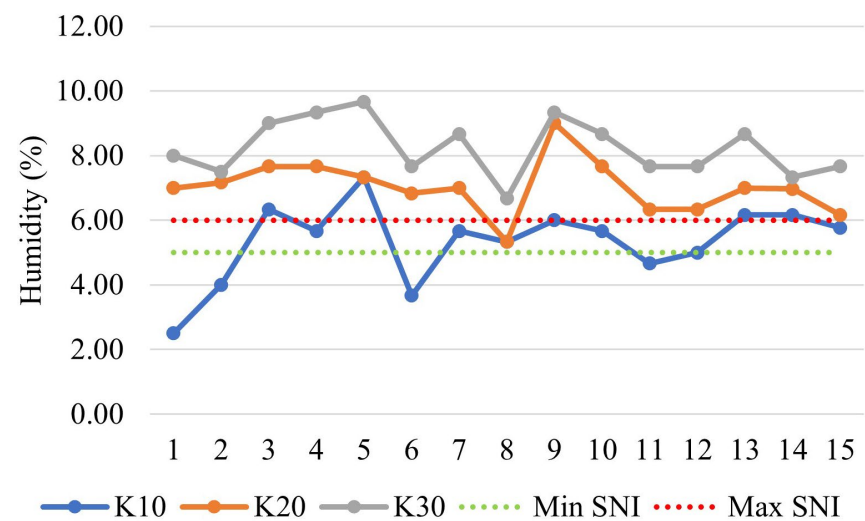


Figure 3. Humidity observations of coffee grounds compost over 14 days.

3.1.4. Nutrient Content and C/N Ratio Compost

Nitrogen (N), phosphorus (P), and potassium (K) are nutrients contained in compost, each having a specific function and serving as parameters to indicate certain symptoms when their availability in the soil is reduced or insufficient to meet plant needs. Therefore, the balance of nutrients in the compost must be maintained and observed to determine whether the compost we produce is balanced and meets the standards. Additionally, the analysis of the C/N ratio is vital in the composting process to assess the effectiveness of organic matter decomposition.

Table 1. Composting nutrients.

Sample	Nitrogen (%)	Phosphorus (%)	Potassium (%)	C-Organic (%)	C/N ratio
K10	2.00	0.12	0.17	29.00	14.50
K20	2.11	0.12	0.20	37.51	17.78
K30	1.80	0.15	0.28	35.06	19.48
SNI MAX (%)	-	-	-	32	20
SNI MIN (%)	0.40	0.10	0.20	9.8	10

Note: Description: SNI (Indonesian National Standard) 19-7030-2004 on the standard of compost from organic waste.

Based on Table 1, the highest nitrogen (N) content was found in the K20 treatment, while K30 had the highest phosphorus (P) content. The high moisture condition in K30 caused nitrogen to react with water, forming soluble nitrate, thereby

reducing the N content in the compost. Only K10 complied with the SNI requirement for organic carbon, whereas K20 and K30 exceeded the maximum allowable limit. Nitrogen concentrations in all treatments exceeded the SNI minimum requirement (0.40%). In contrast, potassium content in K10 (0.17%) remained slightly below the minimum standard of 0.20%, resulting in insufficient oxygen circulation and the potential death of decomposer bacteria. The highest mean composting temperature occurred in K20 on the eighth day, which was unstable and had the potential to damage P-decomposing microbes.

The highest potassium (K) content was in K30 and the lowest in K10. All N, P, and K contents were above the SNI standards, except P in K10, which was slightly below the standard due to the addition of cattle manure containing essential nutrients (Kaswinarni & Nugraha, 2020). The high moisture in K10 caused the potassium-containing water solution to dissolve quickly in the compost. The C/N ratio is the comparison of carbon (C) and nitrogen (N) in organic matter.

C/N analysis after 14 days of composting with 10%, 20%, and 30% cattle manure showed that the highest to lowest ratios were 30%, 20%, and 10%, with respective values of (35.06/1.80), (37.51/2.11), and (29.00/2.00). These results comply with SNI 19-7030-2004, which sets the C/N ratio between 10 and 20. A too-high C/N ratio reduces microorganisms, while a too-low ratio indicates immature compost, resulting in nitrogen loss as ammonia or through denitrification (Fatmalia & Yuliansari, 2022). Immature decomposition processes increase soil temperature around plant roots due to microbial activity generating heat, which can damage roots, especially those sensitive to temperature changes.

3.1.5. Compost Phosphate Content

Phosphate content in compost is crucial as it serves as a medium for seed germination and fulfills the phosphorus nutrient requirements essential for plant physiological processes.

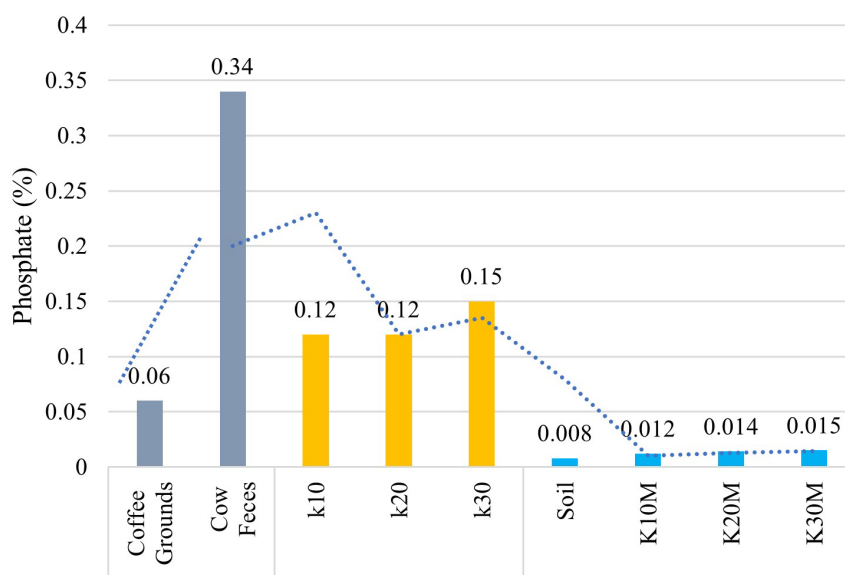


Figure 4. Compost phosphate content.

Based on **Figure 4**, the initial coffee grounds had a phosphate content of 0.06%, while the cattle manure used as an activator contained 0.34% phosphate. The composting process over two weeks using cattle manure in treatments K10, K20, and K30 showed that the highest phosphate content was in treatment K30, reaching 0.15% (Kaswinarni & Nugraha, 2020).

The modification process using calcium hydroxide ($\text{Ca}(\text{OH})_2$) and phosphoric acid (H_3PO_4) produces calcium phosphate ($\text{Ca}_3(\text{PO}_4)_2$), which has been proven to enhance soil nutrient quality. Test results indicate that adding 0.3% modified compost in treatments K10M, K20M, and K30M also increased phosphate content in the compost, although it still falls below the SNI 19-7030-2004 standard, which specifies a minimum of 0.10% phosphate. Treatment K30M had the highest phosphate content among the three treatments at 0.015%. However, all treatments still have values below commercial compost, which typically has around 2.1% phosphate content.

3.2. Chili Plant Growth

3.2.1. Chili Plant Height

Chili plant height measurement results are used as the primary indicator to evaluate growth and potential yield. Here are the Duncan Multiple Range Test (DMRT) results for the various effects of compost treatment on chili height.

Based on **Figure 5**, numbers followed by the same letter in the column indicate no significant difference in the Duncan test at the 0.05 level. The research results show differences in chili seedling height growth among different treatments. Soil and K10M compost treatment show similar effects. Meanwhile, K20M and K30M compost treatments also exhibit similar effects. Commercial compost shows no significant difference with K30M but K30M exhibited the highest numerical value among the modified compost treatments, although it was not significantly different from K20M according to the DMRT test.

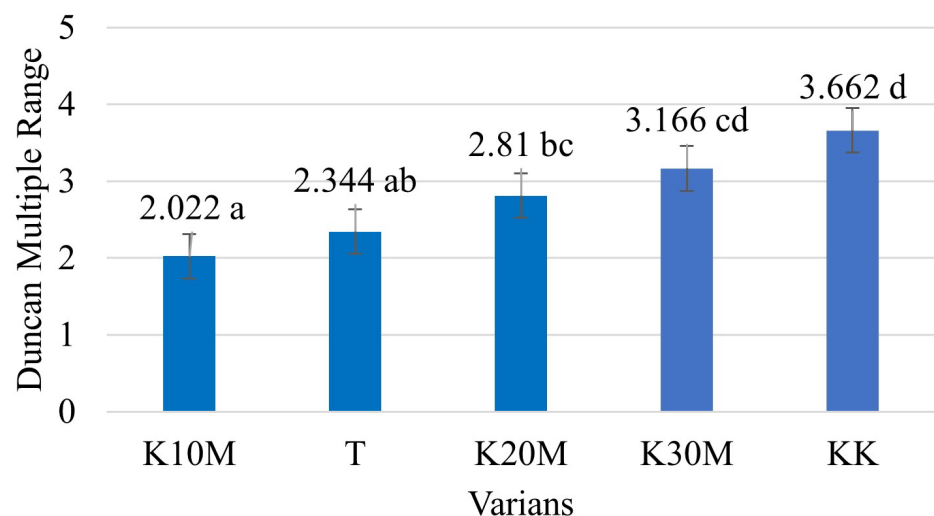


Figure 5. DMRT (Duncan Multiple Range Test) diagram for chili plant height.



Figure 6. Side view of the chili seeding.

Based on the ANOVA results and **Figure 6**, it is evident that commercial compost shows superior growth compared to all other treatments. However, the three treatments using K10M, K20M, and K30M compositions show growth improvements, with K30M recording the highest results. This factor is attributed to the high phosphorus content and the cattle manure's ability to bind aluminum and iron, making phosphorus more available to plants. Specifically, K30M composition has the highest phosphorus content after commercial compost. Phosphorus is crucial for plants as it forms phospholipids in cell membranes, contributing to better plant growth. Further ANOVA analysis was conducted to evaluate the effects of various modified coffee grounds block compost compositions using calcium hydroxide on chili plant height.

3.2.2. Average of Chili Plant Leaves

The average number of leaves on chili plants is a crucial indicator to assess the extent of chili plant development during vegetative stage 1. Here are the results.

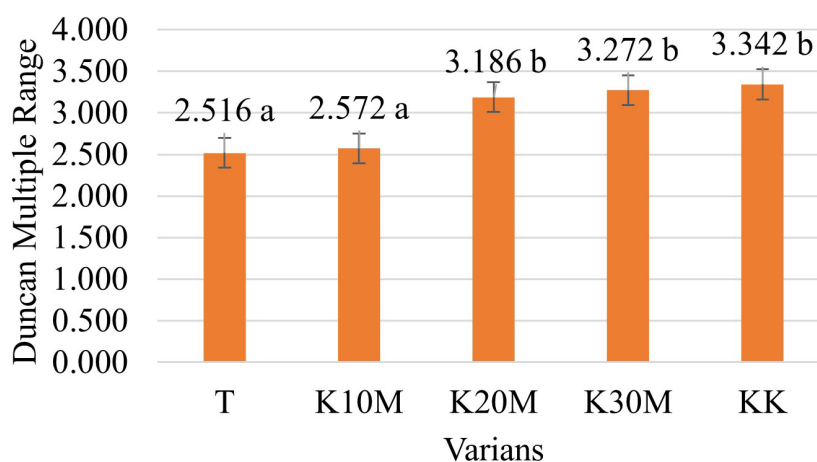


Figure 7. Chili leaf DMRT results.

Based on **Figure 7**, numbers followed by the same letter in the same column indicate no significant difference according to the Duncan test at the 0.05 significance level. The results show that the K10M compost treatment and soil do not differ significantly. On the other hand, K20M, K30M, and commercial compost provide similar results. Statistical tests indicate that commercial compost performs best, although not significantly different from K30M and K20M.

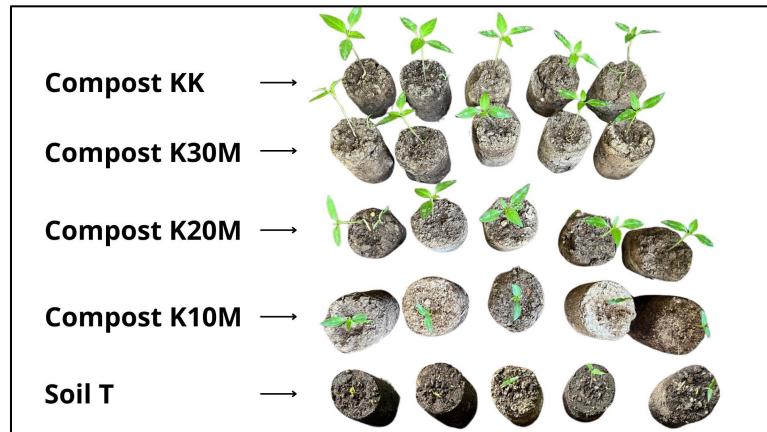


Figure 8. Top view of chili seeding.

Based on the ANOVA results and **Figure 8**, commercial compost remains the best, followed by K30M and K20M. This could be attributed to the commercial compost being enriched with complete NPK nutrients, whereas the coffee grounds compost enrichment focused solely on phosphate, using cattle manure as an activator. Nitrogen is crucial as it influences leaf formation, which can enhance carbohydrate production for vegetative growth.

3.2.3. Chili Stem Diameter

Measurement of stem diameter is essential in this study as it serves as an indicator of vegetative growth phase 1. Here are the results.

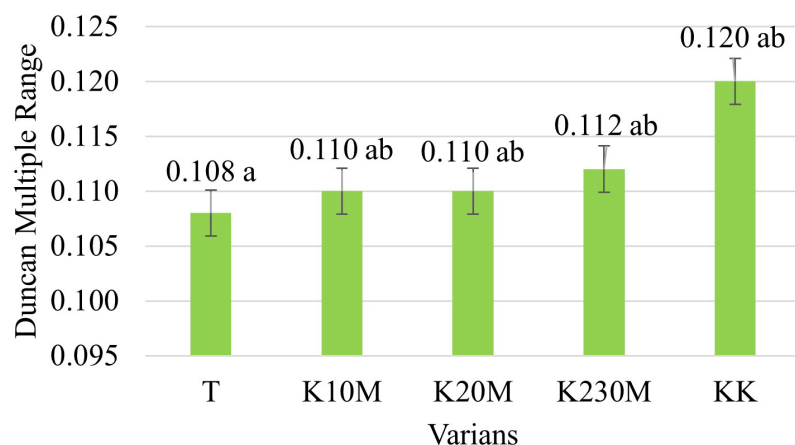


Figure 9. Duncan Multiple Range Test (DMRT) results for chili stem diameter.

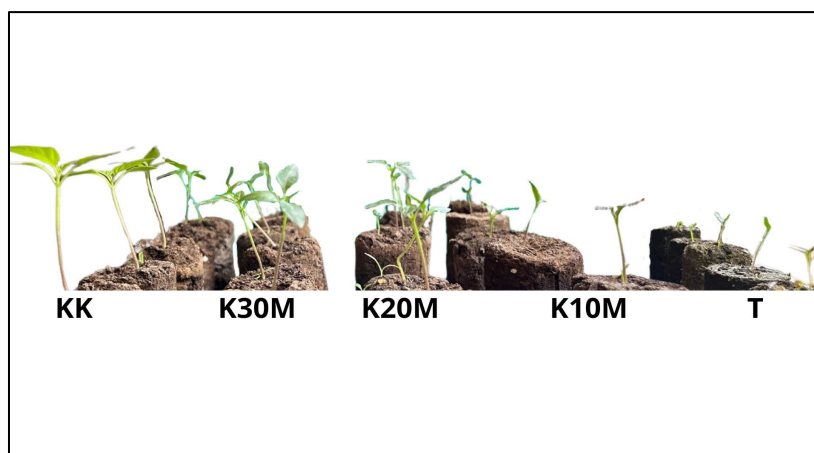


Figure 10. Appearance of the diameter of the chili seedling stem.

Based on **Figure 9**, no significant differences were observed between soil and composts K10M, K20M, and K30M in the Duncan test at a significance level of 0.05. However, there was a significant difference between soil and commercial compost. Nevertheless, no significant difference was observed between commercial compost and K30M, K20M, and K10M. The analysis of variance (ANOVA) results confirm that commercial compost consistently provided the best results among all treatments tested. On the other hand, K30M compost showed the highest values among the three types of compost evaluated, indicating the potential of using cattle manure and phosphate enrichment to improve soil quality for chili plant growth.

Based on the ANOVA results and **Figure 10**, it is evident that commercial compost consistently showed the best performance, with K30M being the treatment that closely approached the performance of commercial compost compared to other treatments. The study results revealed that the addition of phosphate and cattle manure positively influenced stem diameter across all compost treatments, particularly in K30M, which nearly matched the performance of commercial compost. Phosphate is crucial in various plant metabolic processes, including cell division and enlargement. Sufficient phosphate availability supports the synthesis of molecules that regulate these processes and facilitates the absorption of water and essential nutrients crucial for plant growth. Phosphate is also essential for developing reproductive cells and overall plant growth. The analysis of variance (ANOVA) for the growth rate of chili plant stem diameter planted in modified coffee grounds compost blocks validates this significant improvement.

4. Conclusion

Based on the research findings, compositions K10, K20, and K30 showed stable pH changes that complied with the Indonesian national standard 19-7030-2004 by the 14th day of composting. The highest mean composting temperature was recorded in composition K30, which used cattle manure, followed by K20 and K10. Although the highest humidity also occurred in composition K30, it did not

reach the recommended optimal standard (50% - 60%). The highest nitrogen (N) content was found in composition K20, while the lowest was in K10, whereas phosphorus (P) and potassium (K) were highest in composition K30. The C/N ratio in all compositions met the SNI standard, but only Organic-C in composition K10 met the standard.

Block compost with varied compositions also significantly influenced the growth of chili seedlings compared to Summersari soil, a silty clay type. Commercial compost yielded the best results compared to the three compositions of coffee grounds compost blocks. However, K30M showed better results compared to K20M and K10M. Nevertheless, the phosphate content in the compost blocks remains below the Indonesian national standard (0.10%).

Overall, commercial compost performed the best, while composition K30M showed significant improvement in chili seedling growth compared to K20M and K10M. These changes are reflected in pH, temperature, humidity, and nutrient content observations in each composition.

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Author Contributions

Conceptualization, A.A.; methodology, A.A.; formal analysis, S.A.; investigation, M.B.N.; data curation, N.P, E.N.; writing—original draft preparation, A.A., S.A.; writing—review and editing, A.A, M.B.N.; supervision, S.S.H.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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