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Quality comparison of vermicompost generated from chicken waste, rice straw, and melastoma weed using *Perionyx* and *Lumbricus* earthworms

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Abstract

Vermicompost is commonly used as a source of plant nutrients in sustainable agriculture. Several studies have shown that its quality is primarily determined by the substrate type and earthworm species involved, as both factors directly influence the nutrient composition. Therefore, this study aims to determine the yield and quality of vermicompost derived from chicken waste, rice straw, and Melastoma biomass using *Lumbricus rubellus* and *Perionyx excavatus* earthworms. Completely Randomized Design (CRD) with 2 factors was used, namely substrate type (chicken waste, rice straw, and Melastoma) and earthworm species (*Lumbricus rubellus* and *Perionyx excavatus*), with each treatment combination replicated 3 times. Vermicomposting process was carried out for 8 weeks at room temperature, with moisture maintained as needed. After incubation, vermicompost was sieved and analyzed for nutrient content and yield. The results revealed that vermicompost derived from chicken waste had the highest content of phosphorus (P), potassium (K), calcium (Ca), and copper (Cu), while Melastoma-based vermicompost exhibited the highest total nitrogen (N) and the lowest C/N ratio. However, no significant differences were observed in organic carbon (C), magnesium (Mg), and iron (Fe) across the different substrates. *Lumbricus rubellus* and *Perionyx excavatus* produced comparable vermicompost yields, pH levels, and nutrient content, suggesting similar productivity. These results emphasize that the yield and quality of vermicompost are strongly influenced by substrate type, indicating its significance in promoting sustainable agriculture.

Keywords: Agricultural residues, Nutrient, Substrate, Vermicast, Vermicomposting

1. Introduction

The use of vermicompost in sustainable agriculture has increased over the years due to its substantial benefits over other organic fertilizers. This method not only provides essential nutrients but also contains plant growth regulators that enhance the growth and development of agricultural crops [1, 2, 3]. However, the nutrient content of vermicompost can vary depending on the substrates used in vermicomposting. A previous study by [4] observed differences in vermicompost productivity when using different substrates. This indicates that selecting the appropriate substrate is crucial for producing high-quality products with optimal nutrient content and microbial activity.

According to previous studies, the substrate plays a critical role in vermicomposting for several reasons. It determines vermicompost quality by serving as the primary source of nutrients for earthworms and microorganisms [5]. In addition, it regulates microbial activity and diversity, as high-quality materials promote beneficial microbial populations that are essential for nutrient mineralization [6]. Substrate palatability, texture, and chemical properties have also been reported to influence earthworm survival, reproduction, and digestive efficiency [7,8].

Chicken waste is commonly used as a substrate for vermicomposting due to its rich nutrient content. According to [9], it contains 3.25% total nitrogen (N), 1.37% phosphorus (P), and 1.73% potassium (K). Another study by

[10] reported lower concentrations of N (2.79%), P (0.23%), and K (0.23%). However, chicken waste also has a relatively high ammonia concentration, which may interfere with earthworm activity during vermicomposting. High concentrations of ammonia can increase earthworm mortality, as suggested by [11]. Different organic wastes provide distinct advantages and challenges in vermicomposting process, influencing both its efficiency and the quality of final vermicompost.

Rice straw also holds significant potential as vermicomposting substrate due to its abundance, particularly during harvest season. However, farmers often burn the straw, causing air pollution, rather than utilizing it for composting. Rice straw has a relatively low N content, requiring a starter to accelerate decomposition. It has also been reported to contain 0.65% N, 0.095% P, 1.41% K, 1.70% Ca, and 0.75% S [12,13]. Another potential local substrate for vermicomposting is Melastoma, an invasive weed that aggressively spreads across agricultural land, noticeably reducing crop productivity. A key challenge in using Melastoma for vermicomposting is its allelopathic compounds, which may interfere with earthworm and microbial activity during the decomposition process [14]. However, this plant is rich in organic matter and can be transformed into valuable vermicompost, contributing to sustainable weed management. Melastoma biomass from agricultural land contains 39.12% organic carbon (C), 3.60% N, 0.60% P, and 0.95% K, with a C/N ratio of 10.8 [15].

Beside the substrate, vermicomposting process is highly dependent on the type of earthworms used. The characteristics and behavior of earthworms play a crucial role in determining the efficiency of vermicomposting and, ultimately, vermicompost production. Some earthworm species actively break down substrates, yielding products more quickly and in larger quantities, while others are less productive. Earthworm tolerance to environmental conditions, such as temperature, moisture, pH, and salinity, determines the stability and effectiveness of vermicomposting process [16,17]. *Lumbricus* and *Perionyx* are both epigeic earthworms with distinct behaviors. Under optimal conditions, *Perionyx* earthworms can reproduce and develop rapidly. According to [18], when using cattle waste as a substrate, this species exhibits a weight gain of 22.9 mg/worm/day and produces 0.25 cocoons/worm/day.

The combination of raw materials and earthworm species employed in this vermicomposting study represents a unique approach. While most previous studies have focused on a single organic substrate or a single earthworm species, this current study uses 3 raw materials with distinct chemical properties and C/N ratios, along with 2 earthworm species. The comparative assessment of *Perionyx excavatus* and *Lumbricus rubellus* in decomposing these substrates provides new insights into the efficiency of tropical earthworm species in converting locally available organic wastes into high-quality organic amendments. The variations in raw material types and earthworm species employed in vermicomposting process are expected to result in significant differences in the chemical composition of the resulting vermicompost. Therefore, this study aims to evaluate the yield and nutrient content of vermicompost generated from chicken waste, rice straw, and *Melastoma* biomass using *Lumbricus* and *Perionyx* earthworms. The results are expected to contribute to the advancement of sustainable organic waste management technologies through optimized vermicomposting practices.

2. Materials and methods

2.1 Vermicomposting Substrate Preparation and Earthworm Culture

This study was carried out at Vermicomposting House of the University of Bengkulu, located at an altitude of 15 meters above sea level. Chicken waste was obtained from the Animal Husbandry Experimental Station at the University of Bengkulu and incubated for 2 weeks for pre-vermicomposting to reduce methane production, which could interfere with earthworm activity. Pre-vermicomposting was conducted in a 3x3 m cement block under room temperature conditions, with watering applied as needed to maintain an appropriate moisture level. Chicken waste was selected as it represented a common type of animal waste used as a substrate in vermicomposting. Rice straw was obtained from local farms, while Melastoma was sourced from the nearby Kandang Limun Village at an altitude of 10 meters above sea level. In addition, rice straw was selected as a representative agricultural residue abundantly available in cultivated lands, while Melastoma was included as a representative weed biomass commonly occurring in plantation ecosystems in the tropical region. Both biomasses were chopped into approximately 5 cm pieces and fermented in composting bags for 2 weeks before being used as vermicomposting media. Effective microorganisms were evenly mixed to accelerate the fermentation process. The mixture was aerated weekly and maintained at optimal moisture levels through periodic watering as required.

The composition of chicken waste included 257.4 g kg^{-1} organic C, 11.3 g kg^{-1} N, 7.8 g kg^{-1} P, 10.4 g kg^{-1} K, and C/N ratio of 22.78. Meanwhile, the fermented rice straw contained 364.0 g kg^{-1} C, 16.2 g kg^{-1} N, 0.3 g kg^{-1} P, and 6.0 g kg^{-1} K, with C/N ratio of 22.5, while fermented Melastoma had 391.2 g kg^{-1} C, 36.0 g kg^{-1} N, 6.0 g kg^{-1} P, 9.5 g kg^{-1} K, and C/N ratio of 10.8 [15].

Lumbricus and Perionyx earthworms were collected from CAPS Study Station in Air Duku Village, Rejang Lebong Regency, Bengkulu Province, at an altitude of 1.054 meters above sea level. Worms underwent preconditioning in the same type of initial media, and the media was kept moist for 2 weeks to ensure worms adapted and exhibited calm behavior.

(A) (B)

Figure 1 Earthworm (A) *Lumbricus rubellus* and (B) *Perionyx excavatus* [19].

2.2 Experimental Design and Vermiculture

The experiment used Completely Randomized Design (CRD) with 2 factors, namely types of substrate sources, such as chicken waste, rice straw, and *Melastoma affine* biomass, as well as earthworm species, such as *Lumbricus rubellus* and *Peryonix excavatus.* These treatment combinations were replicated 3 times.

Vermicomposting process used a plastic bin for earthworm cultivation, and the substrate-to-earthworm weight ratio was maintained at 120:1, with 3,000 g of substrate evenly combined with 20 g of earthworms. To assist earthworms in adapting to the new medium, the initial plant biomass substrate was mixed with dairy cattle waste at a 1:1 ratio. A fine screen was used to cover the bin, preventing earthworms from escaping. Subsequently, the bin was randomly placed on a 1.5 m wooden rack and incubated for 8 weeks at room temperature. Every 2 days, 100 g of substrate was added to vermicomposting bin. Unlike the initial setup, fermented Melastoma and rice straw were not mixed with cattle waste for the remainder of the experiment. In vermicomposting process, the medium was kept moist by watering as needed, and pH levels were monitored weekly. A 5 g subsample of the substrate was collected weekly for pH determination, using a 1:5 ratio of substrate to distilled water.

At the end of the experiment, vermicompost and fresh earthworms were collected to determine vermicompost yield and earthworm weight. Vermicompost was air-dried and screened to separate it from the remaining substrate. This was then analyzed for organic C, total N, P, K, calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), and lead (Pb) using method developed by [20]. In addition, vermicompost was examined for humic acid, fulvic acid, urease activity, and phosphorylase activity.

2.3 Data Analysis

The collected data were subjected to Analysis of Variance (ANOVA) using SAS Demand for Academics at a 95% confidence level. A significant ANOVA result was followed by a DMRT test at the same confidence level.

3. Results and discussion

ANOVA results showed that the types of substrate sources (chicken manure, rice straw, and *Melastoma* biomass) and earthworm species (*Perionyx excavatus* and *Lumbricus rubellus*) had significant effects on vermicompost yield and quality ($p < 0.05$). This result indicated that variations in substrate composition and the biological capabilities of each earthworm species individually influenced vermicomposting process and the final nutrient composition of vermicompost. However, the interaction between the 2 factors was not significant ($p > 0.05$), suggesting that the effect of substrate type was independent of earthworm species, and vice versa. Therefore, both substrate variation and earthworm species played independent but important roles in determining vermicompost quality, while their combination did not exhibit a significant synergistic effect.

3.1 Effect of Substrate Sources and Types of Earthworms on Medium pH throughout the Experiment

The pH of vermicomposting media fluctuated in the experiment, increasing during the first 2 weeks of incubation and slightly decreasing from week 4 until the end of the experiment (Table 1). This increase in media pH during the first 2 weeks could be due to the release of ammonia during the ammonification process, which occurred as microorganisms decomposed organic matter. A study by [21] noted that microbial activity during aerobic metabolism released hydroxide, leading to an increase in pH. However, the subsequent decrease in pH was associated with the formation of organic acids, which became more dominant than hydroxide release [22]. This result was consistent with results reported by [23], where pH increased during the first 2 weeks and then continuously decreased until the fourth week of incubation.

In Table 1, the pH of vermicomposting medium differed significantly among substrate types. In the experiment, vermicomposting medium derived from chicken waste consistently exhibited the lowest pH compared to other sources, while those from rice straw and Melastoma were comparable. In general, substrates from plant biomass had significantly higher pH levels than those from chicken waste. At week 8, the pH of chicken waste medium was 17.8% and 16.1% lower than those of rice straw and Melastom*a*, respectively. The lower pH of chicken waste medium could be associated with the diet of this poultry. The presence of probiotics and additives in poultry feed lowered the pH of its waste. A study by [24] suggested that supplementation with a probiotic complex in broiler feed decreased fecal H_2S and NH_3 emissions, leading to a reduction in fecal pH. Meanwhile, higher content of lignin in plant biomass could lower the decomposition and the formation of organic acids, causing higher pH in vermicomposting medium. According to [25], lignin was referred to as one of the most slowly decomposing compounds, and its concentration plays a significant role in determining the rate of litter decomposition. Another study demonstrated that lignin exhibited low biodegradability during vermicomposting process with earthworm *Eudrilus eugeniae* [26]. Lignin was a heterogeneous, aromatic polymer that lacked repetitive monomeric units, in contrast to the regular, ordered structures of cellulose and hemicellulose. This structural irregularity reduced enzymatic recognition and contributed to lignin's resistance to biological degradation [27].

Using different earthworm species did not affect the pH of the medium in the 8-week incubation period (Table 1). This result suggested that vermicomposting was performed using either *Lumbricus* or *Perionyx* earthworms.

Table 1 Vermicomposting medium pH during the experiment as affected by substrate sources and types of earthworms.

Substrate Sources	Medium pH at week							
	1	2	3	4	5	6	7	8
Chicken waste	6.98 b	6.45 c	7.25 b	6.29 b	6.45 b	6.46 b	6.46 b	6.42 b
Rice Straw	7.70 a	7.15 b	8.01 a	7.71 a	7.63 a	7.69 a	7.73 a	7.56 a
Melastoma	7.50 a	7.46 a	8.18 a	7.64 a	7.54 a	7.66 a	7.68 a	7.45 a
Vermicomposting earthworm								
Lumbricus	7.40	7.09	7.76	7.19	7.19	7.30	7.34	7.06
perionyx	7.38	6.98	7.86	7.24	7.22	7.24	7.24	6.96

Note: Numbers followed by the same letter in the same column are not significantly different.

3.2 Vermicompost Yield

Types of vermicomposting substrates played a significant role in the quality and production of vermicompost. This study resulted that substrate derived from rice straw provided the highest vermicompost yield, followed by chicken waste and Melastoma (Table 2). Rice straw produced 60.9% and 14.6% higher vermicompost yield than those from Melastoma and chicken waste, respectively. However, both Lumbricus and Perionyx had comparable vermicompost yields. Lower vermicompost yield in Melastoma substrate could be related to the presence of allelochemical substances in this substrate, which were toxic to earthworms and inhibited microbial metabolism. A study by [28] revealed that an allelochemical substance from *Eucalyptus grandis* had a strong phytotoxic effect on earthworm *Eisenia fetida*, specifically during 20 to 30 days of decomposition. Melastoma also contained tannins, which were reported to influence microbial community and enzymatic activity in earthworm gut [29]. This study used 15-day fermented Melastoma, which had retained a relatively high content of allelochemicals. Table 2 also showed that vermicompost produced using Lumbricus was not significantly different from that produced by Perionyx, indicating the productivity of both earthworms was similar.

After the experiment, earthworms were separated from the remaining medium and weighed. Table 2 showed that substrate sources did not affect earthworm weight. In addition, the weight of Lumbricus (20.04 g) was not significantly different from that of Perionyx (20.39 g). These results indicated that vermicomposting was carried out using either Lumbricus or Perionyx. Both earthworms were epigeic earthworm species, but Lumbricus was commonly found in a tropical environment.

Table 2 The effects of substrate sources and the type of earthworm on vermicompost yield, earthworm weight, Organic C, total N, and C/N ratio.

Substrate Sources	Vermicompost weight (g)	Earthworm weight (g)	Organic C (g/kg^{-1})	Total N (g/kg^{-1})	C/N Ratio
Chicken waste	2051.7 [b]	20.06	212.8	16.1 [b]	13.22 [b]
Rice Straw	2352.0 [a]	22.03	247.2	12.1 [b]	20.43 [a]
Melastoma	1462.5 [c]	21.55	251.1	27.7 [a]	9.06 [b]
Vermicomposting earthworm					
Lumbricus	1920.56	20.04	236.7	19.7	12.02
Perionyx	1990.22	20.39	237.4	17.6	13.49

Note: Numbers followed by the same letter in the same column are not significantly different.

3.3 Nutrient Content of Vermicompost

Vermicomposting process released several nutrients that were beneficial for plant growth. As presented in Table 2, types of substrates and earthworm species did not prominently influence the organic C content of vermicompost. However, total N and C/N ratio varied significantly among substrates. The highest total N was observed in Melastoma substrate, while the lowest was in rice straw, with a difference of more than twofold. In addition, the higher total N in vermicompost from Melastoma was associated with N content of the substrate (36.0 g/kg^{-1}) as previously presented, while the other substrates had lower total N. The highest total N content in vermicompost from Melastoma was also accompanied by the lowest C/N ratio. Decomposition of organic matter reduced organic C content and released N to the system, resulting in a decrease in C/N ratio. A study by [30] confirmed that during vermicomposting, organic C decreased while total N increased, consequently lowering the C/N ratio.

In addition to N, vermicomposting released other essential plant macronutrients, including P, K, Ca, and Mg. The type of substrate used significantly influenced the levels of P, K, and Ca, but did not affect Mg. However, earthworm species did not impact nutrient composition (Table 3). The highest concentrations of P and Ca were found in vermicompost produced from chicken waste, while the highest K content was observed in vermicompost from Melastoma. Overall, vermicompost derived from rice straw had the lowest levels of P, K, and Ca. The nutrient composition of vermicompost highly depended on the initial nutrient composition of the substrate. In this study, vermicompost from chicken waste contained the highest P levels among the tested substrates, while K content was comparable between chicken waste and fermented Melastoma. P content in rice straw vermicompost was consistent with the results of [31] at 10.5 g/kg^{-1}, but higher than reported by [32] at 5.1 g/kg^{-1}. Similarly, K content in rice straw vermicompost was lower than the approximately 20.0 g/kg^{-1} reported by [33]. Ca and Mg content observed in this study were significantly higher than those reported by [34], at 0.56 g/kg^{-1} and 0.37 g/kg^{-1}, respectively.

Table 3 P, K, Ca, and Mg content in vermicompost from various substrates using Lumbricus and Perionyx earthworms.

Substrate Sources	P (g/kg^{-1})	K (g/kg^{-1})	Ca (g/kg^{-1})	Mg (g/kg^{-1})
Chicken waste	10.2 [a]	5.5 [b]	44.1 [a]	6.4
Rice Straw	2.0 [b]	8.0 [ab]	12.9 [b]	6.0
Melastoma	2.1 [b]	10.8 [a]	18.2 [b]	6.7
Vermicomposting earthworm				
Lumbricus	4.7	7.8	25.3	6.4
Perionyx	4.7	8.4	24.8	6.4

Note: Numbers followed by the same letter in the same column are not significantly different.

Vermicomposting also facilitated the release of micronutrients. The type of substrate used significantly influenced the content of Zn, Mn, Cu, and Pb in vermicompost, while Fe content remained unaffected. In addition, different earthworm species did not affect Fe levels. The highest concentrations of Zn, Cu, and Pb were observed in vermicompost derived from chicken waste, while the highest Mn content was found in vermicompost from Melastoma. Zn, Cu, and Pb content in vermicompost produced from rice straw and Melastoma showed no significant difference. Vermicompost generated from chicken waste contained Zn, Cu, and Pb content that were 3.51, 4.99, and 1.78 times higher, respectively, than those observed in rice straw vermicompost. Similarly, these micronutrient levels were 3.71, 4.16, and 2.03 times higher, respectively, compared to Melastoma-based vermicompost. These results were consistent with previous studies, reporting that vermicompost composition largely depended on the substrate sources [35, 36, 37]. In addition, Fe, Zn, Mn, and Cu content in chicken waste vermicompost from this study was higher than the values reported by [38]. Variations in micronutrient content among vermicomposts resulted from differences in the substrate quality, microbial activity, environmental conditions, and vermicompost maturity stage, which together controlled micronutrient transformation and availability [39,40].

Table 4 Selected plant micronutrient content of vermicompost from certain substrates using Lumricus and Perionyx earthworms.

Substrate Sources	Fe (mg/kg^{-1})	Zn (mg/kg^{-1})	Mn (mg/kg^{-1})	Cu (mg/kg^{-1})	Pb (mg/kg^{-1})
Chicken waste	12763	562.83 ^{a}	651.17 ^{c}	168.17 ^{a}	14.58 ^{a}
Rice Straw	9240	160.17 ^{b}	886.67 ^{b}	33.72 ^{b}	8.21 ^{b}
Melastoma	13043	151.67 ^{b}	1489.50 ^{a}	40.43 ^{b}	7.17 ^{b}
Vermicomposting earthworm					
Lumbricus	11508	273.78	1057.44	76.13	9.61
perionyx	11586	309.33	960.78	85.41	10.36

Note: Numbers followed by the same letter in the same column are not significantly different.

3.4 Vermicompost Biological properties

Microbial activity in earthworm gut played a major role in breaking down organic matter. During vermicomposting, these microbial processes produced stabilized compounds, including humic and fulvic acids. As presented in Table 5, the content of humic and fulvic acids in vermicompost did not differ significantly across different substrate sources or earthworm species. However, previous studies reported contrasting results, indicating significant variations in humus content among different substrates such as cow dung, kitchen waste, and garden waste [41]. These differences could be attributed to variations in substrate composition and total humus content, which includes humin, humic acid, and fulvic acid [42]. This study measured humic and fulvic acids separately, rather than as part of total humus content. Another study also reported significant differences in humic acid content across substrates, with cow dung producing the highest content, followed by grass and weeds [43]. Despite these variations, the humic acid content observed in those studies was lower than that found in this study.

Table 5 Humic and fulvic acids content of vermicompost and enzymatic activities.

Vermicomposting Source	Humic Acid (%)	Fulvic Acid (%)	Urease Activity (mg N/g/h)	Acid PMease activity (mg P/g/h)	Alkaline PMease activity (mg P/g/h)
Chicken waste	0.91	0.94	4.49	42.59	24.43
Rice Straw	1.01	1.60	2.22	33.94	17.88
Melastoma	1.14	1.57	1.58	39.99	21.09
Vermicomposting earthworm					
Lumbricus	0.99	1.50	2.59	69.44	22.74
perionyx	1.05	1.25	2.94	28.24	19.53

Note: Numbers followed by the same letter in the same column are not significantly different.

Microbial activity played a significant role in vermicomposting by converting organic matter into nutrient-rich fertilizer, as indicated by urease activity, acid phosphormonoesterase (PMease), and alkaline PMease. Urease and phosphatase contributed to N and P release during vermicomposting by catalyzing key biochemical reactions involved in nutrient mineralization [44]. Table 5 showed that the selected enzyme activities did not differ significantly across substrate sources and earthworm species. Chicken waste and fermented rice straw shared a similar C/N ratio of approximately 22.5, as previously mentioned. C/N ratio served as an indicator of organic matter decomposition, with higher values leading to slower decomposition. Despite its very low C/N ratio, vermicompost derived from Melastoma exhibited enzyme activities comparable to those of the other 2 substrates, possibly due to the presence of allelochemical compounds. [45] found that allelochemicals significantly reduced enzyme activity and affected microbial communities.

The utilization of chicken manure, rice straw, and Melastoma biomass as feedstock for vermicomposting with *Lumbricus rubellus* and *Perionyx excavates* carried substantial agronomic and ecological significance. Vermicompost produced from these substrates enhanced the availability of macro- and micronutrients, improved soil physicochemical and biological properties, and reduced reliance on synthetic fertilizers. In addition, the valorization of animal waste, crop residues, and weed biomass mitigated environmental pollution, promoted nutrient cycling, and converted invasive species such as Melastoma into value-added organic amendments. This process also fostered soil microbial diversity and was consistent with the principles of circular and sustainable agriculture.

4. Conclusions

In conclusion, vermicompost derived from chicken manure exhibits superior nutrient content compared to that produced from rice straw and Melastoma biomass. Vermicompost from chicken manure also shows the highest yield and the lowest pH in vermicomposting process, containing the highest content of P, K, Ca, and Cu. Meanwhile, vermicompost derived from Melastoma has the highest N content and the lowest C/N ratio. The contents of organic C, Mg, and Fe are comparable across all substrate types, and the concentrations of humic and fulvic acids, as well as enzyme activities, do not differ significantly among substrates. Overall, *Lumbricus rubellus* and *Perionyx excavatus* demonstrate comparable productivity, as reflected by similar vermicompost yield, nutrient composition, and microbial activity. This study is limited to evaluating the physicochemical quality of the produced vermicompost and does not assess its functional effectiveness in improving soil properties or enhancing crop performance. Further study is required to examine the agronomic potential of vermicompost in relation to soil fertility enhancement and crop productivity. These results emphasize the potential of agricultural residues as effective substrates for vermicomposting, contributing to enhanced soil quality, reducing dependence on synthetic fertilizer and promoting sustainable agricultural practices.

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6. Author contributions

The research idea, aims, and the original draft of the manuscript were developed by Zainal Muktamar. Data curation and methodology were carried out by Nanik Setyowati. Investigation and data collection were conducted by Anandyawati Anandyawati. Study materials and instruments were provided by Fahrurrozi Fahrurrozi, who also contributed to manuscript review and editing. Project administration and supervision were managed by Sigit Sudjatmiko. Validation and data analysis were performed by Mohammad Chozin, while the analysis of vermicompost variables was undertaken by Kartika Utami. All authors reviewed and approved the final version of the manuscript.

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