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Sustainable compost prepared from oyster mushroom substrate microparticles with domestic wastes as local starters

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Abstract

Oyster mushroom (*Pleurotus ostreatus*) is one of the high-demand edible mushrooms due to its high nutrition and pharmaceutical compound. However, the mushroom produce spent mushroom substrate (SMS) as a byproduct of mushroom industries, creating various environmental problems. The experiment was done by converting SMS into micrometer-sized particles. Then, the SMS particles were mixed with various domestic wastes as local starters, including Effective Microorganism-4 (EM4) , rice waste, vegetable waste, banana weevil, banana peel, chicken dung, goat dung, and cow dung. The results show that SMS mixed with domestic waste has excellent performance. Specifically, when SMS was mixed with chicken dung, it created compost with the highest performance N-Total (1.01%), P-Total (1.06%), K-Total (1.51%), Ca (1.48%), Mg (0.4%), and C/N ratio (16.97%), indicating that compost already matured. Following the Indonesian National Standard, the prepared compost from SMS mixed with chicken dung is more suitable for the standard requirement. The use of SMS microparticles brings a great impact on the enhancement of the product. The micrometer-sized particles permit a large contact area between the raw components to be contacted and interacted with easily, making them mature quickly in the bioreactor.

Keywords: *Chemical properties, Compost, Oyster mushroom waste, Waste management.*

1. Introduction

Consumption of mushrooms in Indonesia reached 47,753 tons, while mushroom production reached 37,020 tons [1]. In addition, the nutritional content of oyster mushrooms is relatively high, which has a protein of 10.5 – 30.4% per 100 grams. The efficacy of oyster mushrooms can prevent diabetes mellitus, reduce cholesterol, increase endurance, and prevent cancer. However, the high interest in mushroom consumption due to its high efficacy resulted in the high waste of mushroom growing media, which resulted in environmental pollution [2]. Moreover, the disposal of mushroom log waste could contaminate the soil, water, and air in the surrounding area [4-6]. The growing media for mushroom cultivation are sawdust, rice bran, and lime which have high benefits for nutrient availability [7]. One of the efforts to reduce mushroom-growing media waste is composting [8]. Specifically, the mushroom produce spent mushroom substrate (SMS) as a byproduct of mushroom industries, creating various environmental problems.

Compost is made up of degraded organic matter that is relatively stable due to aerobic microbial breakdown [9]. Compost is essential for enhancing soil fertility and assisting in plant productivity [10]. It is nutrient-dense and organically rich [11]. The addition of compost to the soil affects a variety of factors, including nutrient levels, as it contains several components nitrogen (N), phosphor (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S). Compost has a lot of alkaline cations; therefore, it acts as a liming agent, raising the pH of the soil [12]. The composting process is carried out by adding starters or activator materials (microorganisms or material containing microorganisms) [13]. One of the activators commonly used in Indonesia is Effective Microorganism-4 (EM4) [14]. The content of EM4 microorganisms includes photosynthetic bacteria (*Rhodopseudomonas* sp), lactic acid bacteria (*Lactobacillus* sp), Actinomycetes, Aspergillus, and Penicillium fungi [15]. The content of these microorganisms can overcome the problem of composting. However, in a developing country, especially in the rural area, commercial starters such as EM4 were limited. Therefore, due to a lot of spent mushroom substrate waste and limitations on the commercial starter, it is necessary to research the composting process of spent mushroom substrate waste using local starters from agriculture waste and household waste, which contains many microorganisms. This study aimed to determine the chemical composition of compost produced by using a local starter. Different from other studies in the preparation of compost, we introduced the use of micrometer-sized raw materials. Specifically, the experiment was done by converting SMS into micrometer-sized particles using a saw-milling process, in which detailed information for the saw-milling process is reported elsewhere [16]. The SMS particles were mixed with various domestic wastes as local starters, including EM4, rice waste, vegetable waste, banana weevil, banana peel, chicken dung, goat dung, and cow dung. The results show that SMS mixed with domestic waste has excellent performance. The use of SMS microparticles is prospective to bring a great impact on the enhancement of the product. The micrometer-sized particles permit a large contact area between the raw components to be contacted and interacted easily, making them mature quickly in the bioreactor.

2. Materials and methods

2.1. Study site and materials used

The experiment was conducted from June to September 2020 in the Oyster mushroom farmer located in Blambangan Village, Panengahan Subdistrict, and South Lampung District, Indonesia. Moreover, the chemical properties of compost were analyzed at the Soil Science Laboratory of Soil Science, Universitas Lampung. The materials used in the experiment were sawdust, rice bran, lime (raw material of spent mushroom substrate), spent mushroom substrate waste, EM4, cooked rice waste, compost, vegetable waste, banana weevil, banana peel, chicken dung, goat dung, cow dung, urea, sugar, and water. We also analyzed the component in the prepared samples, including analysis of pH, K, Ca, Mg, carbon organic component (C-Org), N, P, and carbon-to-nitrogen (C/N) ratio.

2.2. Producing spent mushroom substrate

The SMS was produced by mixing sawdust, rice bran, and lime ($CaCO_3$) with a proportion of 60, 5, and 2 kilograms, respectively. The addition of ingredients (such as rice bran) serves as a nutrient for the fungus, and lime serves to increase the pH in the growing media. All ingredients were mixed until homogeny. Once it was mixed, we added water until it was evenly distributed and moistened. Further, we placed it in the place provided for further packaging of the media into a special plastic for oyster mushroom media. In this packaging process, the material was inserted into the plastic until the plastic was tied on top. Then, we pressed it with a tool so that the media became solid. If it was insufficient, the media was added and pressed again. Lastly, the media was tied using a rope. Figure 1 shows the activity of sterilizing oyster mushroom growing media using a specially designed container for sterilization. Sterilization/steaming was carried out for about 12 hours or after the 3 kg gas cylinder and then cooled for 1-2 days. Sterilization aims to kill bacteria in the media so that fungi can grow properly. All activities were carried out manually and traditionally based on the knowledge understood by farmers. After four months (after inoculation and harvesting), spent mushroom substrate would be a waste. Furthermore, the spent mushroom substrate waste was the main material for the compost to minimize the risk of environmental problems.

Figure 1. Spent mushroom subtract after inoculation (left) and mushroom grows (right).

2.3. Compost production and experimental design

Before using, SMS were grounded using a saw-milling tool to particles of various sizes (200-1000 µm) using sieve mesh apparatus following ASTM D1921. Detailed information on the use of a saw-milling process is shown in our previous report[16].

Table 1. ***Compost fertilizer generated from various materials combinations, with a total of ten treatment combinations (C0 – C9).***

Sample	Composition of ingredients*
C0	10 kg of SMS + 100 g of Urea + 100 g of sugar
C1	10 kg of SMS + EM4 solution+ 100 g of Urea + 100 g of sugar
C2	7.5 kg of SMS + 2.5 kg of rice waste + 100 g of Urea + 100 g of sugar
C3	7.5 kg of SMS + 2.5 kg of compost + 100 g of Urea + 100 g of sugar
C4	7.5 kg of SMS + 2.5 kg of vegetable waste + 100 g of Urea + 100 g of sugar
C5	7.5 kg of SMS + 2.5 kg of banana weevil + 100 g of Urea + 100 g of sugar
C6	7.5 kg of SMS + 2.5 kg of banana peel + 100 g of Urea + 100 g of sugar
C7	7.5 kg of SMS + 2.5 kg of chicken dung + 100 g of Urea + 100 g of sugar
C8	7.5 kg of SMS + 2.5 kg of goat dung + 100 g of Urea + 100 g of sugar
C9	7.5 kg of SMS + 2.5 kg of cow dung + 100 g of Urea + 100 g of sugar

Note: *All samples were added with pure water until the total volume of the working bioreactor is 1 L.

The saw-milled SMS particles were then mixed with several materials (see Table 1). The mixing process and the combination in the 30-L bioreactor (outer diameter of 30 cm and height of 45 cm) are shown in Table 1 and Figure 2. After mixing, the materials should be put into a bioreactor and incubated for two weeks. After incubation, the lid of the bioreactor should be opened, and the material should be stirred. In addition, the top and bottom of the bioreactor are perforated to create air circulation. In every week, the bioreactor should be shaken. The composting process lasted around 85 days.

Figure 2. Spent mushroom subtract waste before mixed according to treatment combination

3. Results and Discussion

3.1. Results

Composting is transforming organic waste into a stable product under aerobic circumstances through breakdown by microorganisms [17-19]. Organic matter stabilized and turned into compounds similar to humic components in the soil is referred to as compost [20, 21]. It should also be devoid of pathogens and weed seeds, repel insects and other disease vectors, be simple to handle and store, and boost soil fertility and crop yield [20, 22, 23]. The chemical composition of compost reflects the compost's quality. Microorganisms break down organic materials creating compost that has great numbers of macro and micro nutrients required by plants [24]. Table 2 shows that C, H, O, N, P, K, S, Ca, and Mg are all macronutrients that plants require in substantial amounts. The beginning C/N ratio is critical for effective and efficient composting; the C/N ratio's end value is also critical in defining the compost's maturation duration. The C/N ratio, which reflects the compost's maturity, should be in the range of 10-20, according to the Indonesian Quality Standards of Compost. The breakdown/ decomposing process normally results in a final C/N ratio of 15-20.35 Based on Table 2, only treatment C7 (SMS + chicken dung) compost had reached maturity from all treatments. It can be seen that this treatment was highest at N-Total (1.01%), P-Total (1.06%), K-Total (1.51%), Ca (1, 48%), and Mg (0.4%) compared to other treatments. Furthermore, the C7 treatment almost met the requirements of the Indonesian Compost Quality Standard. The highest N-Total, P-Total, K-Total, Ca, and Mg values were in the C7 treatment because of the enrichment of chicken dung, where chicken dung had a high nutritional content compared to other treatments. The elements C, N, P, and K, are the primary macronutrients because they can inhibit plant development [25, 26]. The chemical content of compost fertilizer from used mushroom substrate waste was correlated as shown in Table 3. As shown in Table 3, K, Ca, and Mg components have a strong negative correlation with organic matter content because they have come from the mineralization of the organic matter; decreasing the organic matter

will increase K, Ca, and Mg amounts. P, K, Ca, and Mg components have a positive correlation due to the mineralization of organic matter with the change of shape and color in the tie of incubation as shown in Table 4.

Table 1. ***The chemical content of spent mushroom substrate compost***

Sample	Chemical content parameters							
	pH	**C-Org(%)**	**N-Total (%)**	**P-Total (%)**	**K-Total (%)**	**Ca (%)**	**Mg (%)**	**C/N Ratio**
C0	6.62	28.95*	0.86*	0.44*	0.47*	1.39	0.38	33.66
C1	7.52	26.10	0.61*	0.17*	0.31*	1.30	0.39	42.78
C2	7.48*	27.81*	0.75*	0.22*	0.38*	1.31	0.37	37.08
C3	7.26*	24.76	0.79*	0.41*	0.56*	1.35	0.39	31.34
C4	7.60	24.00	0.63*	0.29*	0.77*	1.32	0.38	38.10
C5	7.32*	24.57	0.65*	0.24*	0.88*	1.38	0.36	37.80
C6	7.54	25.72	0.53*	0.24*	1.28*	1.37	0.38	48.53
C7	7.55	17.14	1.01*	1.06*	1.51*	1.48	0.40	16.97*
C8	6.59	21.53	0.79*	0.30*	0.58*	1.24	0.38	27.25
C9	7.52	26.29	0.79*	0.19*	0.41*	1.31	0.37	33.28
Average	7.30	24.69	0.74	0.36	0.72	1.35	0.38	34.68
Min	6.59	17.14	0.53	0.17	0.31	1.24	0.36	16.97
Max	7.60	28.95	1.01	1.06	1.51	1.48	0.40	48.52
SD	0.38	3.35	0.14	0.26	0.40	0.07	0.01	8.61
SNI rate	6.8-7.49	27-58	>0.4	>0.1	>0.2	25.5	>0.6	20-Oct

Note: * the value referring to SNI standardization for compost.

Table 3. ***Correlation of chemical content of spent mushroom substrate compost***

	pH	C-Org	N-Tot	P-Tot	K-Tot	Ca	Mg	C/N
pH	1							
C-Org	-0.112	1						
N-Tot	-0.318	-0.447	1					
P-Tot	0.005	-0.731*	0.776*	1				
K-Tot	0.295	-0.678*	0.129	0.655*	1			
Ca	0.236	-0.349	0.426	0.769*	0.716*	1		
Mg	0.061	-0.519*	0.398	0.663*	0.321	0.339	1	
C/N	0.27	0.696*	-0.932*	-0.792*	-0.239	-0.337	-0.423	1

Note: * is the value was correlated with the confidence level is 95% (α = 0.05)

3.2. Discussion

According to Table 1, the highest pH is in treatment C4 with 7.6, and the lowest is C8 with 6.59, with an average of 7.3. Only C2, C3, and C5 can fit the Indonesian compost quality standards. However, in general, the pH of the compost is close to Indonesian compost quality standards, where the value is in the range of neutral to alkaline. Moreover, in this research, the pH does not have a strong correlation with other parameters (Table 3). Decomposed organic material produces OH^- ions, which can neutralize the H+ ion activity. As a result, adding compost to the soil might raise the pH. In low-pH soils, such as the Ultisol soil in Indonesia, compost with a high pH will be advantageous [27]. In addition, the highest C-organic is 28.96% shown in C0 (control), meanwhile, the lowest is 17.14% in C7 (SMS + chicken dung). The average C-organic content of compost was 24.69%. Only C0 (control) and C2 (SMS+rice waste) can match the Indonesian compost quality standards. Microorganisms use carbon as a nutrient for their growth and development, especially during the composting process; hence the C-organic concentration in other treatments is under 27% [11].

Table 4. ***Photograph images of spent mushroom substrate compost during composting***

Sample	2 Weeks Incubation	4 Weeks Incubation
C0		
C1		
C2		
C3		
C4		
C5		
C6		

Table 4. ***(continue) Photograph images of spent mushroom substrate compost during composting***

Sample	2 Weeks Incubation	4 Weeks Incubation
C7		
C8		
C9		

Composting is a bio-oxidative process in which microorganisms convert more easily biodegradable organic matter into CO_2, H_2O, and other minerals (mineralization process) or more stable organic matter over time (humification process) [28]. C-Organic was a strongly negative correlation with P, K, and Mg components (Table 3), which means the decreasing amount of C-organic through mineralization will increase the concentration of P, K, and Mg components.Nitrogen (N) is required by plants since it is a component of nucleotides and proteins. N is also one of the essential plant macronutrients, as it makes up the skeleton of chlorophyll [29]. The C7 treatment combination (SMS with chicken dung) had the highest nitrogen level (1.01%). Overall, the nitrogen concentration of all treatment combinations met the SNI 19-7030-2004 compost standard criteria, with a minimum nitrogen content of 0.50% (Table-1). This occurs as a result of the degradation of proteins found in compost. The breakdown of proteins in compost material into amino acids by microbes to produce ammonia (NH_3) and ammonium (NH_4^+) molecules causes nitrogen levels to rise [1]. Moreover, phosphorus (P) (as shown in the results) is a necessary molecule in plant cells that participates in many physiological and chemical functions such as energy transfer, protein activation, and glucose metabolism [30]. The highest P levels were detected in the treatment combination C7 (SMS + chicken dung), which had the highest phosphorus content (1.06%). Overall, all treatment combinations produce phosphorus content that met Indonesian compost quality standards, with a phosphorus content of at least 0.10%. The total Phosphorus has a strong positive correlation with the concentration of Carbon and Nitrogen and a strong negative correlation with the C/N ratio (Table 3). Microorganisms mineralize organic P by secreting phosphatase enzymes, which accelerate the hydrolysis of organic P and convert it to inorganic P, which plants can use. Phosphatase enzyme production is influenced by soil organic matter concentration, microbial nutrition requirements, and, in particular, nitrogen availability [31, 32]. As a result, N addition frequently boosts phosphatase activity [33, 34]. Both P mineralization and P solubilization likely

underlie stoichiometric constraints, because microbes need N and organic C to produce phosphatases. They also require organic substances as a source of C to create acids and exopolysaccharides that dissolve P [35]. The most abundant inorganic cation is K, Ca, and Mg, which is K required for optimal plant growth.16 In plants, K is primarily used to regulate enzyme activity, cation-anion balance, and membrane polarization. It is based on the osmotic characteristics of the substance. As a result, cell extension, stomatal movement, and turgor regulation are all dependent on it [36, 37]. Treatment C7 (SMS + chicken dung) had the highest L levels at 1.51%. The K content in all treatments met Indonesian compost quality standards, with a minimum value of 0.2%. Moreover, Ca is required for plant growth, owing to its role in the cell wall and membrane stabilization [25, 38]. Table 2 shows that the highest Ca levels were discovered in treatment combination C7 (SMS + chicken dung), which had the highest Ca content (1.48%). Compared to N, P, and K content, the Ca content in all treatment combinations did not meet the standard criteria of Indonesian compost quality standards with a minimum Ca content of 25.5%. Ca is commonly found in lime rock. In this case, the Ca does not meet the standard criteria of Indonesian compost quality because the Ca component is only from the mineralization of organic matter of raw material. Moreover, in advanced composting, usually, the farmer or factory adds lime in the composting process. Mg is an essential mineral for plant growth, as it plays a role in chlorophyll and protein production, enzyme activation, phosphorylation, photosynthesis, and carbohydrate partitioning [14,30]. Table 2 shows that the highest Mg levels were found in treatment combination C7 (SMS + chicken dung), which had the highest Mg content (0.40%). Similar to the Ca amount, the Mg content in all treatment combinations did not meet Indonesian compost quality standards, which require a minimum Ca content of 0.6%. Mg concentration was comparable to Indonesian compost quality guidelines as compared to Ca. Lastly, the application of the chicken dung treatment to plants produced the best results compared to other dung since the nutrients in chicken dung were higher than those in goat and cow dung.36 The results of the analysis showed that chicken dung contains N-total (0.72%), P_2O_5 (3.67%), and K_2O (1.87%), while goat dung contains N-total (0.78%), P_2O_5 (0.90%), K_2O (1.23%). Cow dung contains N-total (1.27%), P_2O_5 (0.81%), and K_2O (0.61%). Chicken dung has a faster rate of nutrient absorption and a higher composition of nutrients (i.e. N, P, K, and Ca) than that contained in goat and cow dung [1]. Because chicken dung decomposes more quickly, it provides the best plant response from the early to late vegetative phase. Furthermore, in producing compost, quality raw materials will determine the quality of the compost. In this study, adding chicken dung to the decomposition process of used mushroom substrates has enormous advantages, such as improving compost quality and accelerating compost maturation. Hence, based on this research, mushroom farmers are recommended to convert the used mushroom substrate into compost by adding chicken dung. In addition, the successful preparation of compost from SMS microparticles was obtained. The use of SMS microparticles brings a great impact on the enhancement of the product. The micrometer-sized particles permit a large contact area between the raw components to be contacted and interacted easily, making them mature quickly in the bioreactor. This study also gives alternative methods to reduce domestic waste problems, while many researchers are working on how to solve issues regarding environmental waste as long as in industry [39-54].

4. Conclusion

This research concludes that compost from spent mushroom substrate mixed with chicken dung gives the highest value in N-Total (1.01%), P-Total (1.06%), K-Total (1.51%), Ca (1.48%), Mg (0.4%). Furthermore, only spent

mushroom substrate mixed with chicken dung has a C/N ratio of 16.97%, which indicates that compost already matures while comparing the other treatment. Following the Indonesian National Standard, compost from spent mushroom substrate mixed with chicken dung is more suitable for the standard requirement. Converting spent mushroom substrate to compost enriched with chicken dung is recommended to be adopted by mushroom farmers. In addition, the successful preparation of compost from SMS microparticles was obtained. The use of SMS microparticles brings a great impact on the enhancement of the product. The micrometer-sized particles permit a large contact area between the raw components to be contacted and interacted easily, making them mature quickly in the bioreactor.

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