Potential of Spent *Pleurotus ostreatus* Mushroom Substrate as Compost

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Abstract – Oyster mushroom (*Pleurotus ostreatus*) cultivation produces waste in the form of mushroom substrate that has passed the production period and contaminated substrate. Non-productive spent mushroom substrates (SMS) still contain nutrients that allow them to be composted. The main goal of this study is to determine the potential of SMS as compost. The composting was done by mixing each of the old substrate waste (P1) and contaminated (P2) with a solution of EM4 and sugar. Temperature measurement and material compost stirring were done every week. The test results after 8 weeks of composting showed that the physical characteristics of compost, including the color and texture, have complied with the standards of SNI 19-7030-2004, which was brown and smooth. P1 compost has an earthy odor while P2 compost still has a slight woody. The mass of P1 and P2 composts decreased by 32% and 32.4%, respectively. Micronutrients such as Fe, Zn, and Mo were varied and according to SNI 19-7030-2004, Minister of Agriculture Regulations No.28/Permentan/SR.130/5/2009 as well as Minister of Agriculture Regulations No.70/Permentan/SR.140/10/2011. Co did not comply with the standard. The water content, pH, and macronutrients such as N-total, P₂O₅, K₂O dan C-organic in both types of compost were according to SNI 19-7030-2004, Minister of Agriculture Regulations No.28/Permentan/SR.130/5/2009 or Minister of Agriculture Regulations No.70/Permentan/SR.140/10/2011. The C/N ratio in compost was still high, compost P1 and P2 had 25,26% and 25,16%. To reduce the C/N ratio of compost, it is necessary to carry out several treatments such as increasing the decomposition time or adding other organic materials during the composting process. The addition of organic materials such as manure or bran allows the microbial activators to be optimally in decomposing compost material to shorten the composting time.

Keywords – composting, spent mushroom substrate (SMS), compost

I. INTRODUCTION

Fertilizer is one of the determining factors for the success of agricultural production or rehabilitation of critical land. The utilization of inorganic fertilizers is still the main choice for most farmers or companies that will carry out rehabilitation. The dosage of inorganic fertilizers is less and easier to decompose so that it can be absorbed and utilized directly by plants [1]. The efficiency of using inorganic fertilizers is considered to give faster results in crop production. However, using inorganic fertilizers for the long term has bad impacts on the environment, such as decreased sucrase activity, soil pH value, and microbial biomass C, although increasing the soil metabolic quotient (qCO₂) [2]. The intensive application of chemical fertilizers in excessive amounts can increase the residue of nitrates and other toxic chemicals in soil [3]. It can contribute to soil and water pollution causing a decrease in soil productivity physically, chemically, and biologically; further, increase greenhouse gas emissions [4]. Technological inputs on a land to produce greater production should pay attention to environmental and natural sustainability [5].

Environmental concerns have caught the attention of organic producers [6] and consumers [7]. The application of organic fertilizers is an alternative to increase crop productivity because of its ability to improve soil physical and biological properties, such as increasing soil macropores, about 50-500 µm [8]. In addition, organic fertilizers are also able to provide nutrients quickly to overcome nutrient deficiencies, improving soil structure, storing water, and increasing soil biological activities [9]. Compost is one of the organic fertilizers produced through the composting process of plant and animal remains with the help of living organisms [10]. The stability and quality of compost depend on raw materials, proportions, procedures, and composting time [11].

Spent oyster mushroom substrate (SMS); either old (past the production period) or contaminated substrate, is a product of mushroom cultivation that can be used as a biofertilizer or soil conditioner [12]. SMS production can reach 2,5 – 5 kg for every kilogram of mushrooms produced [13] [14]. SMS has great potential considering the national mushroom production data reached 3,32 million kg in 2020 [15]. The production of spent mushroom compost can contribute to reducing environmental pollution, especially the pungent odor from the decay of SMS and wastewater [16], as well as eliminating the opportunity for plant-destroying pests to breed in SMS [17]. SMS that is not processed properly will have a bad impact on the surrounding environment.

The composition of oyster mushroom substrate commonly used by farmers consists of sawdust, bran, lime, water and can be added decomposer microbes to accelerate substrate maturation [18]. Old or contaminated substrate waste contains macro and micronutrients that are beneficial for plants [19]. Substrate material, which is a mostly organic material, can be processed to be composted so that it has better benefits. This study aims to determine the potential of the spent oyster mushroom substrate, both old and contaminated substrate, as compost material. The utilization of SMS to be used as compost to support plant growth on the lack of nutrients land as well as a solution to overcome waste in nature.

II. METHODOLOGY

A. Research Time and Location

Spent *Pleurotus ostreatus* mushroom substrate was carried out at the locations for oyster mushroom cultivation in Makassar. Composting was carried out in April – June 2021. Tests of macronutrients (N-total, P₂O₅, K₂O, and C-organic), pH, water content, and micronutrients (Fe, Zn, and Co) were carried out in the soil, plant, fertilizer, water laboratory at the Research Center for Agricultural Technology, South Sulawesi, Maros. Analysis of Mo was carried out at the environmental biotechnology, laboratory of PT Biodiversitas Biotechnology Indonesia, Bogor.

B. Research Procedures

1) Material Preparation

SMS that will be used as the basic material for compost is separated first between the old and contaminated substrate. SMS is crushed and sifted. The substrate destruction process is carried out to get smaller material particles. Compost materials with small sizes make it easier for microorganisms to decompose the inside of substrate material particles [20]. The purpose of sifting is to separate solid SMS materials, such as clumping media, corn kernels which are carriers of oyster mushroom seeds, wood, or other impurities. SMS that has been cleaned and then weighed as much as 10 kg (each for old and contaminated SMS). In addition, other ingredients prepared are 20 ml of EM4 and 10 grams of granulated sugar which has been dissolved in water.

2) Composting

The composting of SMS was divided into 2 types of treatment, namely compost with basic materials from an old substrate (P1) and contaminated substrate (P2). SMS that has been sifted was added with EM4 and molasses [21]. The compost materials were stirred until evenly distributed. When the compost material was still dry, water was added until the water content is about 50-60% [22]. The appropriate water content is indicated by the water does not drip when the compost material is clenched and does not scatter when the fist is removed. The low water content in the compost material can cause the decomposer microbial activities to stop so that the decomposition process of the organic matter becomes imperfect [17]. On the other hand, a water content that is too high causes water to fill the space between particles of organic matter, thereby inhibiting the movement of air in the pile [23]. After the materials are evenly mixed, put into a bucket and tightly closed for the composting process.

3) Stirring

Mixing was done every week for 8 weeks by stirring the composted material in a bucket. Stirring aims so that the raw materials can be mixed evenly, decomposition process can be faster.

4) Observation

Measurements were made on the temperature formed during the composting process, physical compost, micro and macronutrients, water content, and pH. Temperature measurements were carried out every week before stirring, for 8 weeks. Physical observations of compost including color, odor, mass, and texture

were carried out after 8 weeks of the composting process. Similarly, the analysis of macronutrients (N-total, P_2O_5 , K_2O , and C-organic) and micronutrients (Fe, Zn, Co, and Mo), pH, and water content.

C. Data Analysis

The qualitative and quantitative data obtained were compared with the compost criteria according to SNI 19-7030-2004, Minister of Agriculture Regulations No.28/permentan/SR.130/5/2009 and Minister of Agriculture Regulations No.70/Permentan/SR.140/10/2011. Descriptive analysis is used to identify, describe and quantify the research results that have been obtained as they are [24].

III. RESULTS AND DISCUSSION

A. Results

SMS changes during the composting process. Changes that occur include color, odor, mass, and compost temperature. Nutrient content measurements were carried out at the end of composting.

1) Compost color

The old substrate waste before composting is light brown while the contaminated substrate waste is brown. Oyster mushroom mycelium is seen in the old substrate, but it is no longer productive. After 8 weeks of composting, compost with the basic ingredients of old substrate waste (P1) turns brown. Compost also contains more water than before composting. Compost that still contains water must be dried for 1-2 days before use [25].

Figure 1. (A) compost material before composting: (a) old substrate waste, (b) contaminated substrate waste; (B) compost after composting: (a) old substrate waste compost (P1), (b) contaminated substrate waste compost (P2) (doc. Ramdana Sari)

Color changes also occur in compost made from contaminated substrate waste (P2). The compost is dark brown at the end of composting (Figure 1).

2) Compost odor and mass

SMS has a distinctive odor. The old substrate waste smells like stale food, while contaminated substrate waste has a wood smell. In the early stages of composting, SMS that has been mixed with bio activator emits a pungent odor which indicates that the decomposer microbes were composting actively.

The compost mass has decreased from the initial mass. The amount of mass shrinkage of P1 and P2 compost was 32% and 32.4% at the end of the composting.

3) Temperature change during composting

The composting temperature for 8 weeks of observations ranged from 26°-31°C (figure 2). The highest temperature was reached in the 4th week of observations, it was 30°C for P1 compost and 31°C for P2 compost. The temperature of the compost was stable at 27°C at the end of composting. Based on SNI-19-7030-2004, a good compost temperature ranges from 26°-30°C (groundwater temperature).

Figure 2. changes in temperature formed during composting

4) Nutrient Content and Physical Properties of Compost

Tests for nutrient content, water content, and pH of compost made from SMS were carried out after 8 weeks of composting. Differences in macro, micro, pH, and water content between P1 and P2 compost can be seen in table 2. Generally, the nutrient content in P1 compost is higher than P2 compost. The old substrate waste has undergone a process of decomposition of organic matter during the growth process of oyster mushrooms. Therefore, old substrate waste which was used as the basis for compost requires a relatively short time to reach perfect maturity compared to contaminated substrate waste. Compost that still takes time for the composting process contains lower nutrients because it is absorbed and used by microbes to live and decompose material substrate [26].

Table 1. Nutrient Content and Physical Properties of Compost

No	Parameter	Old Substrate Waste Compost	Contaminated Substrate Waste Compost	SNI 19-7030-2004		Minister of Agricultural Regulations No.28/Permentan/S R.130/5/2009		Minister of Agricultural Regulations No.70/Permentan/S R.140/10/2011	
				Min.	Maks.	Min.	Maks.	Min.	Maks.
1	N-total, %	0.95	1.55	0.40	-	-	6	-	-
2	P ₂ O ₅ , %	0.18	0.07	0.10	-	-	6	-	-
3	K ₂ O, %	0.84	0.71	0.20	-	-	6	-	-
4	C-Organic, %	24	39	9.80	32	12	-	15	-
5	C/N ratio, %	25.26	25.16	10	20	15	25	15	25
6	pH	8.98	8.77	6.80	7.49	4	8	4	9
7	Water content, %	38	20	-	50	15	25	15	25
8	Fe, ppm	621	209	-	-	-	8000	-	9000
9	Zn, ppm	420	280	-	500	-	5000	-	5000
10	Co, ppm	353	168	-	34	-	20	-	-
11	Mo, ppm	1.22	1.04	-	-	-	10	-	-

B. Discussions

Composting is a decomposition of organic matter with the help of microbes [4]. The result of the decomposition process is compost which can be used to improve soil and fertilize plants. One of the organic materials that can be used as the basic materials for compost is the non-productive spent mushroom substrate (SMS). Generally, the productive period of oyster mushroom substrate ranges from 3 – 4 months. After that, the growth of mushrooms on the substrate will decrease. Farmers usually will replace the new substrate in the mushroom house. Substrate waste, both old and contaminated substrate, will be separated and disposed of. SMS

will become a waste if it is allowed without a good management process. Even though SMS still has the potential to be used as compost material.

Spent mushroom substrate (SMS), such as spent oyster substrate, still contains sufficient nutrients to be processed into compost [19]. The old substrate has lower nutritional content than the contaminated substrate. This is because oysters that are heterotrophs utilize the nutrients contained in a substrate to support their growth. Although most of the nutrients in old substrate have been utilized by the oysters, the remaining nutrients can still be processed into compost [16].

SMS can undergo a natural decomposition process, but it takes quite a long time. Composting will run faster if microorganisms are added as bio activators. The bio activators are microorganisms that play a role in activating and initiating changes in the physical and chemical properties of organic materials to produce products that are different from the previous properties [23]. Bioactivator agents that play a role in the decomposition process of cellulose during composting consist of types of bacteria and fungi [27]. EM4 is one of the bio activator products that can accelerate the decomposition process, increase soil nutrients, and improve soil structure [23].

1) *Compost Color*

An indicator of the success of the composting process is the occurrence of color changes in the compost material. Compost that is suitable for use as an organic fertilizer has a slightly dark color (blackish brown) resembling soil [16]. The color change is caused by microbial activities that remodel the compost material so that the overhauled compost material changes color [20].

2) *Compost Odor and Mass*

A pungent odor will be produced during the fermentation process, depending on the microbial activities and the compost material used [28]. After 8 weeks of observation, the smell of P1 compost changed to the smell of earth. This is an indicator that the compost was ripe and ready for use. While the P2 compost still had a slight woody odor. This indicates that P2 compost still requires a longer composting time.

Compost will decrease in mass to about 50% of its original mass [29]. The decomposition of organic matter by microbes causes the water content to decrease [30]. In addition, the evaporation due to the heat energy generated during the composting process also causes the volume of the compost material to shrink. Characteristics of compost material and the maturity level of the compost are the determining factors for the amount of shrinkage that occurs [30].

3) *Temperature Change During Composting*

Microbes that can live at a temperature of 20-35°C belong to the mesophilic group of microbes [23]. Optimal temperature and environmental conditions for microbial decomposers will support the composting. Microbes will utilize O₂ from the compost pile and release CO₂ and heat energy during the composting [27]. Microbes will utilize compost organic matter as nutrients to support their metabolic activities. Decomposer microbes will also multiply by releasing a certain amount of energy in the form of heat, thereby increasing the temperature in the compost pile [27]. After passing the maximum temperature, the decomposition process will slowly stabilize because most of the organic matter has been decomposed and the high oxygen demand has been [23].

4) *Nutrient Contents and Physical Properties of Compost*

a) *Macronutrients Content*

Macronutrients consist of Carbon (C), Nitrogen (N), Phosphorus (P), and Potassium (K). The presence of these elements is very important to support plant growth. Macronutrients are needed by plants in large amounts. The concentration of macronutrients in the dry weight of plant tissue was $\geq 0.1\%$ (1000 ppm) [30]. One of the essential nutrients that plants need in large amounts is carbon. The C-organic element is a constituent of bacterial cell walls [32] as well as a source of energy for microbial decomposers in the composting process [33].

C-organic analysis of the compost was carried out using the ashing method. The carbon content in P1 compost (C-organic 24%) complied with quality compost standards based on SNI-19-7030-2004 and Minister of Agriculture Regulations No.70/Permentan/SR.140/10/2011. P2 compost had a carbon content (C-organic 39%) exceeding the maximum standard of SNI [34] but still complied the criteria of Minister of Agriculture Regulations No.70/Permentan/SR.140/10/2011 (Table 1). Organic materials derived from wood, leaves, and

twigs become a carbon source in the composting process [32]. Wood dust and bran which are the main ingredients of oyster mushroom substrate cause high carbon content in the substrate [19]. An oyster which is a heterotrophic organism utilizes and decomposes substrate carbon sources for its metabolic needs. Therefore, the carbon content in the old substrate will decrease after passing the production period. The contaminated substrate also has a high carbon content. The contaminated substrate that has not been overgrown with oyster mushrooms still has a high carbon content. This affects the C-organic content after composting.

Nitrogen plays a role in the formation of enzymes and amino acids [33]. In the composting process, nitrogen is also utilized by decomposer microbes to support their activities. Therefore, the availability of high amounts of nitrogen in the compost material will accelerate the decomposition of organic matter [17]. Determination of nitrogen content in compost was carried out using the Kjeldahl method. The nitrogen content in P1 compost was 0.95% and P2 compost was 1.55% (Table 1). The N-total compost had complied with the quality compost requirements based on SNI 19-7030-2004 because it was above 0.40% [34]. In addition, the N-total compost was also below the maximum limit based on the Minister of Agriculture Regulations No.28/Permentan/SR.130/5/2009, which is 6% [35]. The source of nitrogen in the spent oyster mushroom substrate compost comes from the addition of bran when making substrate [19].

The ripe compost with good quality can be seen in the C/N ratio. Based on SNI 19-7030-2004 and Minister of Agriculture Regulations No.28/Permentan/SR.130/5/2009, a good C/N ratio range from 10 – 20% and 15 – 25%. The C/N ratio depends on the C-organic and N-total content in the compost. The composting process aims to reduce the C/N ratio in organic matter to the same or close to the soil C/N ratio (<20) [36]. The higher C-organic content compared to N-total causes the C/N ratio to be high, while the lower C-organic content compared to N-total causes the C/N ratio to also be low. The C/N ratio that is too high can cause the activity of microbial decomposers to be inhibited due to a lack of nitrogen, while a C/N ratio that is too low causes nitrogen to evaporate easily due to the formation of ammonia gas in the compost [36]. P1 and P2 compost still had high C/N ratios (25.26% and 25.16%, respectively). Thus, the C/N ratio of compost from SMS produced from the composting process for 8 weeks did not comply with the standards based on SNI and the Minister of Agriculture Regulations (Table 1). However, the C/N ratio of 20 - 40 is still efficient for the decomposition process [33].

Phosphorus is a nutrient that plants need in large amounts. The role of phosphorus is no less important than carbon and nitrogen. Phosphorus is an important element in the formation of proteins for macroorganisms and microorganisms [17]. The presence of P-total in the soil is less than nitrogen, potassium, and calcium [19]. To comply with the needs of plant phosphorus, it is necessary to introduce it with the addition of fertilizer. Testing of phosphorus content in compost was carried out by spectrophotometric method. Based on SNI 19-7030-2004, good quality compost has a total P content $\geq 0.10\%$. P1 Compost which has a P-total of 0.18% has complied with the standard of SNI 19-7030-2004, while P2 compost with a P-total of 0.07% did not comply with the minimum standard of SNI 19-7030-2004 but is still following under the Minister of Agriculture Regulations No.28/Permentan/ SR.130/5/2009 is ≤ 6 (Table 1).

Potassium in compost comes from fresh organic matter in the form of complex compounds that cannot be utilized directly by plants [37]. The composting process by microbes decomposes complex compounds into simple compounds and produces K^+ ions which can be absorbed by plants [38]. Free K^+ ions are also utilized by bacteria for their metabolism [17]. In addition, K^+ ions act as activators of several enzymes in plant metabolic processes [19]. The minimum standard of potassium content in quality compost based on SNI 19-7030-2004 is 0.20% [34]. P1 Compost had a K-total of 0.84% while P2 compost had 0.71% so that it complied with the standards of SNI 19-7030-2004 (Table 1).

b) Micronutrients Content

Micronutrients are nutrients needed by plants in small amounts, $\leq 0.01\%$ (100 ppm) in the dry weight of plant tissue [31]. Although it is needed in relatively small amounts, it plays an important role in plant metabolism, especially to help enzymes work [39]. The deficiency of micronutrients can interfere with enzyme performance, on the contrary, excess of micronutrients can cause poisoning in plants [31]. In addition, some micronutrients are also used by symbiotic microorganisms to infect plant roots. Micronutrients that are important for plants and soil microorganisms include iron (Fe), manganese (Mn), molybdenum (Mo) [9], and cobalt (Co) [40].

Iron (Fe) as an essential nutrient is a constituent of chlorophylls, proteins, enzymes and plays a role in the development of chloroplasts. Fe deficiency causes inhibition of chlorophyll formation so that leaves turn yellow and protein synthesis is not perfect [41]. For groups of Rhizobia bacteria that have a symbiosis with legumes, Fe is needed to compile the nitrogenase enzyme which plays a role in the nitrogen-fixing process [42]. Analysis of Fe content in compost was carried out using the Atomic Absorption Spectrophotometry (AAS) method. The total Fe content in P1 compost was 621 ppm, which was higher than P2 compost at 209 ppm. However, the total Fe content in both types of compost still complied with the quality compost standard based on the Minister of Agriculture Regulations No.70/Permentan/SR.140/10/2011, which was ≤ 9000 ppm [43]. Total Fe is the Fe content in compost, including available and unavailable Fe [44].

Zinc (Zn) content in compost was analyzed by Atomic Absorption Spectrophotometry (AAS) method. The total Zn content of P1 compost is 420 ppm, higher than P2 compost which only contains 280 ppm. Both types of compost have Zn content according to the minimum technical requirement of solid organic fertilizer of Minister of Agriculture Regulations No.70/Permentan/SR.140/10/2011, which is ≤ 5000 ppm [43]. Zn is one of the essential micronutrients which is a co-factor for more than 300 types of enzymes that play a role in protein synthesis, cell division, and nucleic acid metabolism in plants [45]. Zn minerals can also function as a catalyst to synthesize bacterial digestive enzymes, such as cellulosic enzymes [46].

Cobalt (Co) is also a micronutrient that has an important role for plants. Legume plants require more Co than non-legume plants because the presence of this element greatly affects the rhizobia bacteria that colonize their roots [47]. The element Co acts as a component of leghaemoglobin which contributes to the efficiency of nitrogen fixation of rhizobia bacteria in legume root nodules [42]. The Atomic Absorption Spectrophotometry (AAS) test method was carried out to determine the Co content in the compost. The Co content of 353 ppm in P1 compost was higher than P2 compost at 168 ppm. Co content in substrate waste compost did not comply with quality compost standards based on SNI 19-7030-2004 which must be below 34 ppm and Minister of Agriculture Regulations No.28/Permentan/SR.130/5/2009 with a maximum Co of 20 ppm. Heavy metals in compost can be toxic to plants if they are above a critical threshold. The critical threshold for metal Co in plants ranges from 30 - 40 ppm [48].

Molybdenum (Mo) content in compost was analyzed by Atomic Absorption Spectrophotometry (AAS) method. P1 compost contains 1.22 ppm and P2 compost with 1.04 ppm. Mo with Fe form Fe-Mo protein which is the center of activity for nitrogen fixation bacteria to reduce nitrogen in the air [42]. Giving Mo can cause legume root nodules to get bigger and more physiologically active. The pithy root nodules with active bacteroids in them cause the N fixation to be higher. According to the Minister of Agriculture Regulations No.28/Permentan/SR.130/5/2009, the Mo content in compost still complied with the standard because it was ≤ 10 ppm [35].

c) *Water Content of Compos*

Water content is the percentage of water contained in a material based on wet weight (wet basis) or dry weight (dry basis) [38]. Water content is an important factor affecting the composting process. The optimal water content helps decomposer microbes to decompose organic material in compost material [17]. Decomposition of organic matter in the early stages of composting produces a liquid called leachate so that it affects the moisture of the compost material. The stirring process carried out every week can create good aeration in the compost material so that the oxygen supply for microbes can be controlled. Analysis of water content in compost through the oven method. The water content of both types of compost still complied with the optimal quality compost standard based on SNI 19-7030-2004, which is $\leq 50\%$ [34]. P1 and P2 composts have a water content of 38% and 20%.

d) *Degree of Acidity (pH) Compost*

The degree of acidity is one of the physical parameters that must be considered in the composting process. Measurement of pH at the end of the composting using the electrometric method showed a fairly high pH value for both P1 and P2 compost, they were 8.98 and 8.77. Although it did not comply with the quality compost requirements according to SNI 19-7030-2004, it is still classified as good compost based on Minister of Agriculture Regulations No. 70/Permentan/SR.140/10/2011, which was in the pH range of 4 – 9 [43]. The

advantage of compost that has a high pH is that it can be applied to acidic soils [17]. The high pH of compost can increase the acid pH of agricultural soil or land that is the target of reclamation.

IV. CONCLUSIONS

A. Conclusions

- 1) The compost of old substrate waste (P1) and contaminated substrate waste (P2) have color, mass, temperature, macronutrients content (N-total, P₂O₅, K₂O, and C-organic), micronutrients content (Fe, Zn, and Mo), pH, and water content that have complied quality compost standards based on SNI 19-7030-2004, Minister of Agriculture Regulations No.28/Permentan/SR.130/5/2009 and Minister of Agriculture Regulations No.70/Permentan/SR.140/10/2011.
- 2) The old substrate waste compost (P1) generally contains higher macro and micronutrients than the contaminated substrate waste compost (P2).
- 3) Nutrient content of Co and C/N ratio in P1 and P2 composts did not comply with the criteria for quality compost, as did the odor in P2 compost.

B. Suggestion

To reduce the C/N ratio of compost, it is necessary to carry out several treatments such as increasing the composting time or adding other organic materials. The addition of organic materials such as manure or bran allows microbial activators can work optimally in decomposing compost material so that it can shorten the composting time.

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