Optimizing Compost Quality: Decomposition Of Rice Straw Agro-Waste Through Various Biological Agent Supplementations

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Abstract. Intensive agricultural activities in rice cultivation impact increasing waste, especially straw. Unfortunately, straw contains cellulose and lignin, which are difficult to decompose. This study examines the effect of adding biological agents on compost quality from rice straw waste. The study used a Randomized Block Design (RBD) with four treatments and six replications, including T0: control (without biological agents), T1: POF catalyst, T2: Bacillus sp., T3: Trichoderma sp. Observation variables for compost quality include analysis of temperature changes, pH value, water content, and chemical analysis, including the content of total macronutrients nitrogen, phosphorus, and potassium. Quantitative data were analyzed statistically using ANOVA and the LSD test $p < 0.05$. The findings indicated that incorporating biological agents in rice straw composting markedly enhanced the quality of the resulting compost. Utilizing biological agents, particularly the Trichoderma treatment, led to a notable enhancement in compost quality. The macronutrient content of nitrogen (N) increased by 3.60%, phosphorus (P) by 0.49%, and potassium (K) by 1.67%. This increase could have significant implications for the composting process. Additionally, an increase in temperature, reaching 50-60°C, significantly impacts the composting process, collectively affecting microorganisms and facilitating the decomposition of organic matter. Furthermore, the thermophilic phase in Trichoderma treatment accelerates decomposition, thus offering a potential solution for faster composting.

Keywords: Biological Agent, Compost, Decomposer, Rice Straw

INTRODUCTION

Agricultural intensification activities have significant implications for waste management, particularly regarding the volume and composition of waste generated. If not managed effectively, this increased waste generation can lead to environmental and health challenges. Waste products from agricultural activities include organic materials such as crop residues, animal manure, and other byproducts, which can be valuable resources if properly utilized [1]

Lampung Province has significant agricultural land dedicated to rice production, with a total harvest area of 489,573.23 hectares. This large-scale rice production leads to substantial rice straw waste, with a ratio of up to 60% of the total harvest. This waste can have positive environmental and economic impacts [2]. Researchers widely utilize agricultural waste as biomass due to its potential to produce sustainable fuel energy. Farmers and industries use approximately 20 percent of rice straw, employing it as in situ compost, paper, and livestock feed. It is predominantly burned or used as mulch. The utilization of rice straw is significant due to its high potential as a biomass. Rice straw is the most agricultural waste in Indonesia, with the total straw biomass produced depending on several factors such as variety, tillage, availability of nutrients, and weather. The physical properties of rice straw make it suitable for use as an energy source, while its chemical composition is appropriate for use as animal feed and organic fertilizer.

The rice straw utilization as a feedstock for bioethanol production is a significant application of plant biomass. However, the organic fertilizer production from rice straw faces challenges due to its high cellulose and lignin content. These components can hinder the enzymatic digestion of rice straw, which is a crucial step in organic fertilizer production. The cellulose and lignin in rice straw form a barrier for microbial access to cellulose, making it difficult for microorganisms to break down the straw efficiently. They lead to a lower quality of the final organic fertilizer product [3].

The conversion of organic matter into more straightforward and more accessible forms that plants can absorb can be achieved through the use of microorganisms, such as the biological agents *Trichoderma* and *Bacillus* [4]. Microorganisms play a crucial role in decomposition by breaking down complex organic matter into simpler forms that plants can utilize [5]. In composting, microorganisms such as bacteria, fungi, and protozoa work together to decompose organic matter. These microorganisms are responsible for breaking organic compounds into simpler molecules, releasing nutrients such as nitrogen, phosphorus, and potassium essential for plant growth [6], [7]. These agents can include additives such as nitrogen-rich materials, which enhance microbial activity and promote the breakdown of organic matter. The use of microorganisms in composting is particularly significant because it efficiently converts organic waste into a valuable agricultural resource [8]. This approach reduces waste disposal costs and enhances soil fertility and structure, ultimately improving crop yields and plant health. The composting process using biological agents offers several advantages beyond the primary benefits of waste reduction and soil enrichment. One significant advantage is its ability to reduce pathogenic microorganisms and weed seeds in the raw material [9]. Composters can implement biological agents cheaply, making their use beneficial. Biological agents are essential as they make the process accessible to more farmers and agricultural practitioners, especially in developing regions where resources may be limited [10].

Furthermore, the composting process using biological agents is efficient in fertilizer use. Compost produced through this method can provide a slow release of essential nutrients, reducing the need for synthetic fertilizers and promoting a more sustainable agricultural practice. Adding decomposers in the form of bacteria and fungi with cellulose activity can accelerate the decomposition process of organic matter [11]. Microbes such as *T. Pseudokoningii* and *Cytophaga sp*. are often used in composting because they can produce high lignin- and cellulose-degrading enzymes simultaneously to recycle and degrade organic matter [12]. Based on this, the research aims to investigate the effect of adding biological agents on compost quality from rice straw waste by using microbial consortium decomposers with biological agents, specifically cellulolytic and lignolytic microorganisms.

METHODS

Pre analysis of the raw materials

The rice straw was obtained from various rice varieties cultivated in Jati Agung Sub-district. Samples were collected from 5 different farms across the sub-district, representing the dominant rice varieties grown in the area. Before composting, the rice straw was first air-dried to reduce its moisture content. The rice straw was then chopped with a chopping machine and was approximately 5-10 cm in size. Furthermore, green materials were added in a ratio of 1 to 2 volumes per volume.

Composting process

This experiment was conducted at Teaching Factory Polinela Organic Farm, Department of Food Crop Cultivation, Politeknik Negeri Lampung, Indonesia, in April–September 2024. The experiment consisted of the type of biological agent for composting, namely T0 (rice straw + water), T1 (rice straw + POF catalyst), T2 (rice straw + *Bacillus sp*), and T4 (rice straw + *Trichoderma sp*). The decomposer dose used for composting was 500 ml per ton of rice straw material. Additional watering was performed using a watering can to maintain adequate moisture. The composting materials were turned regularly to ensure proper aeration [13]. The composting experiments were conducted inside the pit composting method using a randomized block design (RBD) with six replications.

Monitoring during composting process

Temperature and pH readings were taken daily throughout the composting period. Temperature was measured by inserting a thermometer into the composting materials. Four readings were taken in each composting setup: the first near the surface, the second at the center, and the third and fourth by inserting a thermometer into the compost around the first point. For pH tests, 10 g of compost was collected into a sterile plastic bag at five different points within the composting materials. Each sample was put into a 250-ml glass beaker containing 90 ml of distilled water and stirred for 20 min. It was then allowed to settle, and pH readings were taken using a digital electrode pH meter. The electrode probes were thoroughly washed and rinsed with distilled water before and after use. Water content was determined using the gravimetric method, where samples were dried until reaching a constant weight, allowing for the calculation of moisture content [14].

Chemical analysis of compost

Compost obtained from the composting experiment was analyzed for various chemical properties. Test for total nitrogen and available phosphorus was done using Kjeldahl and Bray I [15] methods, respectively. To quantify the total nitrogen, 0.1 g of compost was weighed in a glass tube, and 3 ml of concentrated H2SO4 was added to each tube in a mixture of K2SO4 and CuSO4. The samples were digested in a digester block, with a gradual elevation of the temperature to 350 °C until the extracts of the mixtures formed a greenish color. Phosphorus was measured in Type Hitachi UH5300, a digital UV-Vis Spectrophotometer at 880 nm wavelength. The potassium content in the digest was estimated using the atomic absorption spectrophotometer model AAS-GFS Thermo Scientific iCE 3000 Series. The content of organic carbon was analyzed using the Walkley–Black method [16]. The carbon-nitrogen (C: N) ratio was calculated using the carbon and Nitrogen contents. pH was measured using Digital electrode pH meters model PH-3[17].

Statistical analysis

The research used a Completely Randomized Design with four treatments and six replications. Data obtained were analyzed by one-way analysis of variance (ANOVA) and means separated by least significant difference (LSD) test ($p<0.05$). Pearson's correlation coefficient was used to determine relationships between various parameters. All statistical analyses were performed in Microsoft Excel and Statistical Tool for Agricultural Research (STAR), and the alphabet separated the means.

RESULTS AND DISCUSSION

COMPOST QUALITY IMPROVED DUE TO THE ADDITION OF BIOLOGICAL AGENTS

TABLE. 1 presents a comprehensive overview of the ANOVA analysis, which explores the diverse effects of biological agents on compost parameters derived from rice straw waste. The analysis covers several key parameters: pH value, organic carbon, C to N ratio, nitrogen, phosphorus, potassium, and compost water content. These results reveal that biological agents significantly influence changes in pH value, organic carbon, nitrogen, potassium, and water content. However, the C/N and phosphorus ratios did not show significant differences at p-values <0.05, suggesting that biological agents have a limited impact on these aspects of compost quality. This ANOVA analysis confirms the substantial effect of biological agents on the rice straw composting process, which selectively affects both the composting process and the final quality of the compost. These findings are in line with [18] which found that the C/N ratio is more influenced by the quality of the raw material content than by the addition of decomposers to composting. The quality of the raw material, including its initial C/N ratio, significantly shapes the final compost quality. For instance, a low initial C/N ratio can lead to high ammonia emissions and unstable compost, while a high initial C/N ratio can result in a slower composting process. While decomposers can influence the composting process by enhancing microbial activity and reducing odors, their impact on the C/N ratio is generally less significant compared to the initial composition of the raw materials [18], [19].

TABLE 1. ANOVA recapitulation of the impact of various biological agents on some compost parameters of rice straw waste.

Variable	*F-Test*	*P-value*	*F crit 0.05*	*CV*
pH Value	7.861 *	0.002	3.287	0.035
Organic Carbon (%)	25.01 *	4.355	3.287	0.017
Ratio C/N	0.054 ns	0.983	3.287	0.093
Nitrogen (%)	27.234 *	2.563	3.287	0.073
Phosphorus (%)	1.196 ns	0.345	3.287	0.043
Potassium (%)	37.553 *	3.253	3.287	0.122
Water content (%)	5.061 *	0.013	3.287	0.098

* = significantly different at $p < 0.05$; ns = not significant.

TEMPERATURE AND PH CHANGES

The introduction of biological agents into the rice straw composting process resulted in notable alterations in temperature across all treatment groups (**FIGURE. 1**). The findings revealed an initial elevation in temperature across all treatment groups, including the control, at the outset of the composting process. The maximum temperature was reached on the 14th day of the composting treatment, which utilized biological agents of the *Bacillus* and *Trichoderma* species, at a temperature range of 50 to 60 ºC. This phenomenon indicates the presence of an active thermophilic phase in the composting process, whereby microorganisms decompose organic matter and release heat as a by-product [20]. Following the attainment of the maximum temperature, a gradual decrease in temperature is observed, marking the transition to the cooling phase. The final stage of composting is characterized by a reduction in microbial activity, with the temperature decreasing gradually from approximately 40-45 °C until it reaches room temperature or ambient temperature.

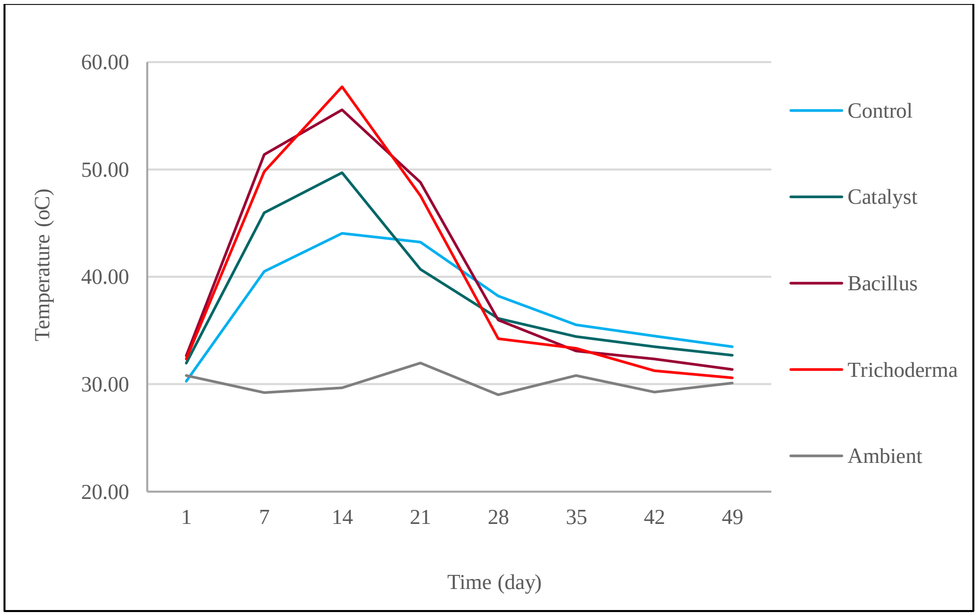

FIGURE 1. Temperature changes during the rice straw composting process using biological agents.

The temperature change pattern observed in this study is consistent with the findings of previous literature, which indicate that composting can be divided into four main phases: the mesophilic phase, the thermophilic phase, the cooling phase, and the final cooling phase. During the thermophilic phase, the temperature will increase until it reaches approximately 60-70°C due to microbial decomposition of organic matter. Subsequently, a temperature decline occurs, which is designated as the cooling phase. This evidence substantiates the assertion that using biological agents in composting, such as *Bacillus* and *Trichoderma*, has enhanced microbial activity and expedited the composting process. **FIGURE. 2** illustrates that the biological agent treatment resulted in a considerably higher temperature increase than the control. However, following the composting process, the temperature will stabilize at room temperature and reach the ambient temperature. While using a catalyst also increased the temperature, the increase was not as significant as that observed with the *Bacillus* and *Trichoderma* treatments. Catalysts, a complex mixture of several components, will generally produce insignificant effects compared to the pure biological agents *Bacillus* and *Trichoderma* when used separately.

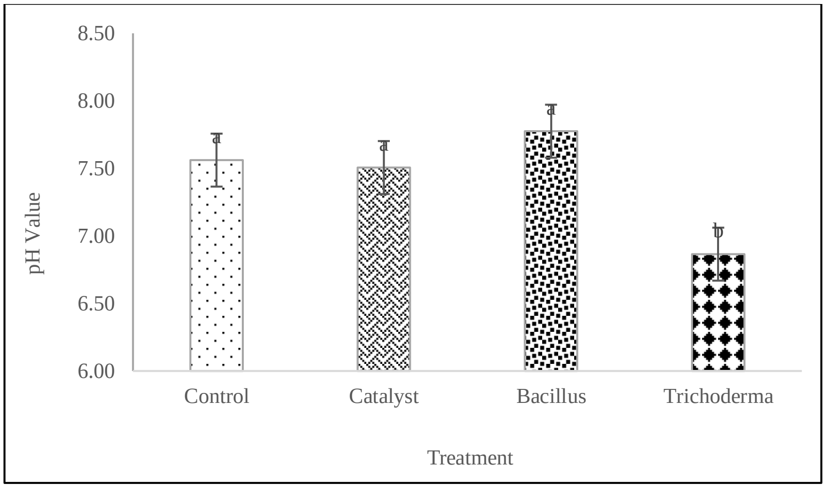

FIGURE 2. Changes in pH during the composting process of rice straw using biological agents. Note: Different letters indicate significant differences (one-way ANOVA, p< 0.05, LSD analysis)

FIGURE. 2 illustrates that incorporating *Trichoderma* as a biological agent into the rice straw composting process resulted in a notable elevation in pH relative to the control and other experimental treatments. This increase in pH facilitates microbial activity and enhances the efficiency of the composting process. **FIGURE. 2** illustrates the pH values for the control, catalyst, *Bacillus*, and *Trichoderma* treatments. The control treatment exhibited a pH value of approximately 7.5, while the catalyst and *Bacillus* treatments demonstrated slightly elevated pH levels, suggesting a probable increase in alkalinity. The *Bacillus* treatment yielded the highest pH value, indicating that this biological agent markedly elevated the alkalinity of the composting environment in comparison to the other treatments. The *Trichoderma* treatment exhibited marked differences from the control, catalyst, and *Bacillus* treatments, which did not demonstrate substantial divergences. An increase in pH can exert a significant influence on microbial activity and nutrient availability, which in turn affects the efficiency and quality of the composting process. This is also related to the characteristics of the growth environment of each biological agent. Fungal species such as *Trichoderma* prefer a more acidic environment than bacterial groups such as *Bacillus*, which like a more alkaline environment [21].

MACRONUTRIENT CONTENT

TABLE. 2 presents data on the macronutrient characteristics of the compost, namely nitrogen, phosphorus, and potassium content in various treatments (control, catalyst, *Bacillus*, and *Trichoderma*). The *Trichoderma* treatment exhibited the highest nitrogen content (3.60%) and the highest potassium content (1.67%) compared to the other treatments.

TABLE 2. Quantitative analysis of compos quality

	Macronutrient characteristics		
Treatment	**Nitrogen (%)**	**Phosphorus (%)**	**Potassium (%)**
Control	2.50 a	0.44 a	1.11 abc
Catalyst	2.86 bc	0.44 a	0.94 ab
Bacillus	2.85 b	0.49 b	0.91 a
Trichoderma	3.60 d	0.44 a	1.67 d
p-value 0.05	2.563	0.001	3.253
LSD 0.05	0.321	0.028	0.209

Mean followed by the same latter(s) are not significantly different at p <0.05 LSD test.

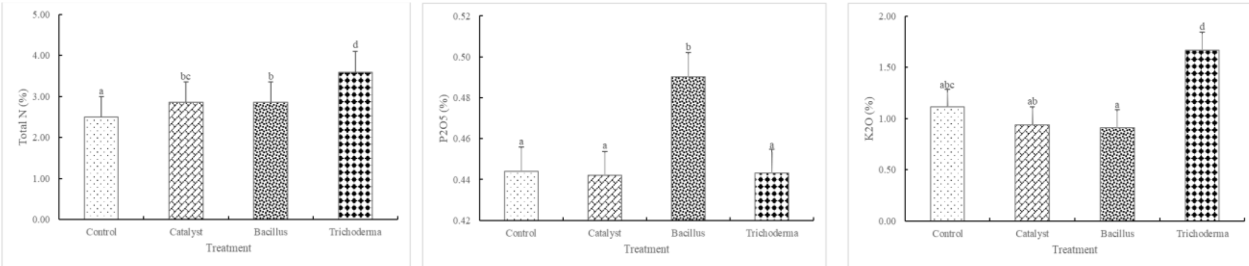

FIGURE 3. Effect of biological agents on the macronutrient content of rice straw compost. Note: Different letters indicate significant differences (one-way ANOVA, $p< 0.05$, LSD analysis)

FIGURE. 3 shows the effects of various biological agent treatments on the macronutrient content of compost, namely total nitrogen (Total N), phosphorus (P_2O_5), and potassium (K_2O). The biological agent treatment in the form of *Trichoderma* produced the highest Total N content with a value of 3.60%, higher than other treatments. The treatments of both control, *Bacillus* and Catalyst, showed similar Total N levels of less than 3%. The control treatment showed the lowest Total N content of 2.50%, but this difference was not significant compared to the *Bacillus* or Catalyst treatments. In the P_2O_5 content analysis results, *Trichoderma* also showed the highest results, at around 0.49%. At the same time, the other treatments showed the same P_2O_5 content with a value of 0.44%. The highest K_2O content analysis was demonstrated in the *Trichoderma* treatment, 1.67%. The control treatment showed an increase of 1.11% but was not different compared to the *Bacillus* and Catalyst treatments. These results indicate that adding compost using *Trichoderma* as a biological agent significantly increases its nutrient content, especially in nitrogen, phosphorus, and potassium, making this treatment very effective in improving compost quality. In line [22] *Trichoderma*-enhanced composting technology significantly altered soil properties, slightly raising pH and substantially increasing organic carbon, nitrogen, phosphorus, potassium, zinc, and boron content. Also, soil improvements offer the potential for enhanced crop production, contributing to food security and improved livelihoods.

Although the *Bacillus* treatment also showed a positive effect, especially in increasing phosphorus content, its impact on nitrogen and potassium was insignificant compared to *Trichoderma*. The catalyst treatment did not significantly increase nutrient content compared to the control; in some cases, potassium even showed lower levels. Overall, these findings indicate that *Trichoderma* is a superior biological agent for increasing nutrient content in compost. In addition, this will also provide substantial benefits for improving soil fertility in agricultural practices. The availability of higher essential nutrients such as nitrogen, phosphorus, and potassium is necessary for plant growth so that it can obtain better yields. Therefore, these results open up exciting possibilities for further research to explore the long-term effects of the influence of several types of compost enriched with biological agents to improve soil health and crop productivity.

CONCLUSIONS

This study highlights the critical role of biological agents, especially *Trichoderma*, in improving the quality of compost derived from rice straw waste. The use of biological agents, especially *Trichoderma*, contributed to the increase in macronutrients and facilitated the thermophilic phase in the composting process, leading to a faster decomposition process. In addition, biological agents play an essential role in various compost parameters such as pH, organic carbon, nitrogen, and potassium content. Still, they did not significantly affect the C/N ratio and the increase in phosphorus content. This suggests that the initial quality of the raw material also plays a more critical role in determining the compost quality, with the C/N ratio being more closely related to the raw material's inherent characteristics than the decomposers' presence. Consequently, an effective composting strategy must consider the raw material's quality to optimize the compost yield.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the financial support provided by P3M Polinela through DIPA Polinela 2024, Politeknik Negeri Lampung. This funding has been instrumental in the successful completion of this research project.

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