An Evaluation of the Effect of Takakura and Effective Microorganisms (EM) as Bio Activators on the Final Compost Quality

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Abstract. Composting is an organic waste management option, where suitable microorganisms are used to accelerate the rate and the decomposition process and improve the final compost quality. In this study, a commercial bio-activator EM4 (EM) and a traditional bio-activator prepared according to the Takakura method (Tak) were investigated. The bio-activators were mixed with a fermenting bed (fb) material consisting of rice husk and rice bran mixed in a ratio of 1:1. The inoculated fb was then used in concentrations of 0%, 20%, and 40% in a composting process of food waste. The composting process was monitored daily for 48 days, and the quality of the final compost based on its physical and chemical characteristics was measured and compared. The result revealed that all samples containing 40% fb material with both Tak and EM bio-activator contained lower moisture content in the final compost compared to samples with 20% fb material. The C/N ratio of the samples with 20% fb material for all samples decreased to 20:1, while 40% fb material increased above 20:1, compared to its initial level. Furthermore, the nitrogen level for all samples with 20% fb material increased while samples with 40% fb material decreased from the initial level. The phosphorus and potassium content also increased for all samples with both 20% and 40% fb material from the initial level. Additionally, no significant difference could be found for the final compost quality between the two bio-activators.

1. Introduction
Composting is a degradation of organic matter under a controlled environment, which is widely recognized as a mean of organic waste management today[1]. However, the process of composting in nature is slow and it is not considered an efficient process in an ever-rising organic waste in our modern society [2]. Many methods have been developed to increase efficiency and ultimately the rate of the composting process while keeping high compost quality. Numerous attempts have been done to control parameters such as temperature, pH, and moisture content, to create a pleasant environment for the composting microorganisms [3, 4]. Others have tried to add beneficial microbes to the composting pile. These microbes that aid the composting process could come from the natural environment and found often locally, in manure or from organic material such as fruit and vegetable commonly used in the Takakura composting method, which was developed at the Institute for Global Environmental Strategies.
(IGES) of Japan [5-8]. The method is based on two fermented solutions, cultured from locally available materials and inoculated with rice bran and rice husk as fermenting bed (fb) material. The inoculated fermenting bed is then used as a seed compost or starter culture for composting organic fraction of municipal solid waste [9, 10]. Usually, the exact microbial community in Takakura in the cultured solutions is unknown and can vary depending on the source of the materials used. Studies that using Takakura culture helped compost food waste into good-quality compost with a C/N ratio of 15:1, which is an indicator of compost maturity within six weeks. Abushammala et al [11] also found that the Takakura method was superior in terms of shorter composting process and produced high-quality compost, to other microorganisms produced using 60% water and 40% fruit waste only. Similarly, Saad et al [12] came to the same conclusion using Takakura culture and fruit waste cultivated microorganisms for 7 weeks. According to the study, the C/N ratio of the compost reached 20:1, which is suitable to be used for agriculture.

Lately, commercial bio-activators, containing microorganisms with specific strains known as effective microorganisms (EM) have found their way into the market. The microbial community in these products is well defined and it contains a mixture of specific species of beneficial fermentative microorganisms [13]. Husen et al [14] reported that bio-activators or commercial bio-fertilizers at the market (agricultural shops) in Bandung District, West Java, contain various strain of bacteria from genus Rhizobium, Azotobacter, Bacillus, Lactobacillus Azospirillum, Aspergillus, Actinomycetes, Lactobacillus, or Pseudomonas that has been mixed together with Actinomycetes or fungi such as Streptomyces or Aspergillus. According to a study conducted by Ihsanullah [15], the addition of commercial culture (EM1) to a mixture of cow, poultry and kitchen manure in a ratio of 2:1:1 enhanced the final compost quality. Furthermore, the study also indicated that compost C/N stabilization occurred faster (6 weeks) compared with samples without the addition of the EM (18 weeks).

Although the benefits of commercial and Takakura culture has been proven in terms of processing time and final compost quality, few studies that have investigated the difference between EM and those prepared by cultivating local material containing unknown community in a composting process [6]. Therefore, this project aims is to investigate the difference between final qualities of compost produced with commercial effective microorganism to that of using the Takakura method.

2. Materials and methods

2.1. Materials
Tempeh, oncom, and the food waste, consisting of leftover food, fruits, and vegetables, were obtained from the traditional wet market in Jakarta, Indonesia. The garden waste was gathered from around the campus area and a local flower shop. The paper waste, consisting mostly of unused office paper and tissue paper were gathered from within the campus. The rice husk and the rice bran used as fermenting bed materials were obtained from a local traditional market in Jakarta. The commercial effective microorganisms (EM4, agriculture organic fermentation bacteria) starting culture was purchased from a local shop containing proprietary microbes of fermenting bacteria, from the genus Lactobacillus, fermented mushrooms, Actinomycetes, photosynthetic bacteria, phosphate solubilizing bacteria, and yeast.

2.1.1. Takakura culture preparation
The starter culture consisted of two different fermenting solutions; a sugar solution and a salt solution that were fermented separately and then mixed. For the sugar solution, 6 L of water were mixed with 400g brown sugar (carbon source), 600 g tempeh and 600 g oncom (fermenting microorganisms). For the salt solution, 6 L of water were mixed with 120 g salt and 1200 g of shredded vegetable waste. Both fermentation solutions were loosely capped to allow better aeration and to prevent possible overpressure due to microbial activities and were incubated for two weeks inside a shaker incubator at 25 °C and 100 rpm.
2.1.2. Fermenting bed (fb) preparation
Three different fermenting beds were prepared, which were Tak (Takakura solution inoculated fermentation bed), EM (commercial EM4 inoculated fermenting bed material) and Blk (fermenting bed with no inoculation). For the Tak preparation with a moisture content of 50%, the salt and sugar solutions prepared in section 2.1.1 were mixed and 924 ml of the mixed solution was added to 2.6 kg rice bran and 210 ml solution was mixed with 0.5 kg rice husk. The inoculated rice bran and rice husk fermenting beds were then mixed in a ratio of 1:1. Similarly for EM, the rice bran and rice husk were mixed with EM4 commercial culture first and then mixed together in a ratio of 1:1 to reach a final moisture content of approximately 50%. For the Blk samples, only pure water type III was used to mix with the fermenting bed materials which were then mixed to gather in a 1:1 ratio for adjusting to a final moisture content of 50%. These inoculated fermenting beds were incubated for 1 week at 25°C before use. At the end of the incubation period, the TS (total solid content) content of each fermenting bed materials were checked and the moisture content were adjusted before setting up the experiment.

2.1.3. The organic waste mixture preparation
The food waste was sorted, and the substrate was further treated in the lab by shredding it into of 1-2 cm size. The garden waste, which was a mixture of green leaves and branches were cut down in size using a laboratory garden scissor to a size between 2-5 cm. The office paper waste was also shredded in smaller pieces. The TS of all the substrates used in this study was measured and the data is presented in Table 1. The food waste, garden waste, and paper waste were mixed based on individual C/N ratios 25:1, 30:1, and (175:1) of food scraps, garden waste, and paper, respectively described by [16]. The final waste mixture contained approximately 45% food scrap, 50% garden waste and 5% paper with a final C/N ratio of approximately 35:1.

2.2. Experimental setup
The experiment was carried out in 8 L home-made reactors with aeration holes at the sides with filter space for leachate removal at the bottom. Each experiment contained a total volume of 5 L substrate containing organic waste mixed with 20% and 40% Tak (Tak20 and Tak40), EM (EM20 and EM40) or Blk (Blk20 and Blk40). Organic waste without any fermenting bed material (FB0) was also set up as a negative control. The initial moisture content of all samples was adjusted to approximately 70 ± 7% in this study. All samples were aerated by turning the pile every day in the first two weeks in the composting house outdoors and after that only once a week for the rest of the experimental period. During the composting period, the change in temperature and pH were monitored every day. The initial and the final moisture content, C/N ratio, nitrogen, phosphorus, and potassium (NPK) content for the experiments were measured. The experiment was carried out in triplicates.

2.3. Analytical methods
The moisture content of the substrates was measured according to a protocol described by NREL procedures [17]. The solid fraction was dried at 105°C until the stable weight was recorded. Nitrogen, phosphorus, potassium, and carbon were analyzed at a service laboratory at the Bogor Agriculture Institute (IPB). The carbon analysis used ash gravimetric method [18]. The nitrogen content was analyzed using the Kjeldahl method based on block digestion and steam distillation [19]. The phosphorus analysis used spectrophotometer in the form of P2O5 molecules. The potassium analysis used F-AAS in form of K2O molecules [20].

3. Results and Discussion

3.1. Temperature and pH
The daily temperature and pH of all samples are presented in Figure 1. The temperature in all the experiments started to increase slowly in the first day after the set-up and reached the mesophilic range
at a peak between 26.5°C and 30°C after two weeks. However, the temperature never reached a thermophilic range as expected before it started to decrease for all samples at week three, which then fluctuated between 26°C and 28°C, and stayed constant at this temperature until the end of composting process. The increase in temperature in the initial stage of the composting process for all experiments is an indication of microbial activity, even though the increase was only by 2°C to 5°C at maximum. This slight temperature increase could be due to a combination of daily manual mixing for optimum aeration of the waste and small scale reactors which increases the heat loss, causing lower temperatures [21, 22].

The pH at the start of the experiments ranged between 6 and 7. The pH of all samples showed a decreasing trend during the first three weeks of the composting process. All samples reached the lowest pH (4.5 – 6) in the earlier stages of the process. This is a clear indication that the decomposition of organic waste had started due to the accumulation of organic acid [23, 24]. After week three, the pH started to slowly rise again for all samples, until the end of the process with a final pH between 6 and 7. The increase in pH was also an indication that organic acids starting to become neutralized. Moreover, no specific difference was observed between the samples inoculated with Tak culture and those of EM culture in their average pH trend during the entire process for either fb compositions used in this study and the pH of all samples was within recommended pH range (between 6 – 7) for mature compost [3, 25].

![Figure 1](image.png)

**Figure 1.** The temperature (left) and pH (right) of the experiments during 7 weeks (48 days) of composting process.

3.2. **Moisture content**

Moisture is important to support microbial activity because it increases the rate of metabolism [18]. The moisture content of the final compost is presented in Table 1. The moisture content reduced during the composting process for all samples studied. The reduction in the moisture content at the end of the composting process is a positive sign of decomposition and it is an important parameter and indicator for mature compost [26]. Furthermore, the samples with 40% fb material contained lower moisture content compared to the samples with 20% fb material at the end of the experimental period (Table 1). The moisture content of EM40, Tak40, and Blk40 were 13%, 27% and 11%, lower than EM20 and Tak20 and Blk40, respectively. This could be because samples with higher fb concentration contain proportionally lower organic matter. The fb material acts as a bulking agent causing the lower bulk density in the compost. Results of this study is in accordance with a previous study carried out by Monson and Murugappan [27], who confirmed that the decrease of bulk density will lead to higher porosity in the compost, causing moisture loss especially with frequent aeration rate at the initial stages of the composting process [28].

In general, the EM and Tak inoculated samples in both 20% and 40% fb material concentrations was lower compared to that of the Blk samples. However, no significant difference was observed in moister content between the EM and Tak (Table 1). The highest moisture content of the final compost was observed for the FB0 sample, with 66.3±1.5%. The addition of 20% fb material decreased the final moister content to 63.5±2.0 % for Blk, 45.0±1.5% for EM and 55.3±2.1% for Tak40. Increasing the fb material to 40% further decreased the final moister content to 56.9±1.8%, 45.0±1.5%, and 43.4±1.6%.
for the Blk, EM, and Tak, respectively. The higher water loss observed in all Tak and EM inoculated samples could be due to a higher concentration of microbial population causing higher microbial activity and water loss during the composting process, particularly for samples containing a higher concentration of fermenting bed material.

3.3. Carbon to Nitrogen (C/N) ratio
The results of the C/N ratio before and after the composting process were measured and the results are presented in Table 1. In general, the C/N ratio of all the samples containing 20% fb material slightly decreased after the composting process, which was stabilized at a C/N ratio between 20:1 and 21:1 at weeks 7 composting process. The decrease in C/N ratio in the final compost during the process is not uncommon, as C/N ratio decreases for the compost with increasing maturity [39] and it is caused by the release of carbon as CO$_2$ as a result of microbial activity [30]. The C/N ratio below 20:1 for Municipal solid waste (MSW) has been suggested to be an indication of whether the composts have reached maturity during the conventional composting process[12]. The decrease in C/N ratio for samples containing 20 fb was not enough for any of the samples to be considered mature compost. However, some studies argued that the C/N ratio is not an appropriate parameter for assessing compost maturity when inoculants are added [31, 32].

In contrast, the C/N ratio of all samples containing 40% fb material increased during the composting process. Increasing the fb material resulted in the samples having a somewhat higher final C/N ratio compared to their initial C/N level, which was measured to be 16:1 for the Blk and Tak samples and slightly higher around 20:1 for the EM sample. After the composting process, the C/N ratio was increased 25:1, 26:1 and 19:1 for the Blk, EM, Tak samples, respectively. The reason could be due to the low C/N ratio in the starting material (16:1-17:1) which is lower than the recommend optimum of 20:1 to 40:1 recommended for an effective composting process. A low initial C/N ratio would cause higher NH$_3$ formation and emission leading to higher nitrogen loss especially at higher bulking agent concentrations and as a result the C/N ratio of the final compost increases [33, 34]. When the C/N ratio is less than 18.1, the microorganisms transform the nitrogen in a higher degree, favoring its volatilization[35]. Furthermore, no significant difference in final C/N was observed between the EM cultures. On the other hand, the FB0 sample did not significantly change from its initial value and the C/N ratio of 25:1 which increased to 26:1 during the entire composting period which could be due to

| Samples$^a$ | Moisture Content (%) | C/N Ratio | Initial | Final | Nitrogen (%) | Initial | Final | Phosphorus (%) | Initial | Final | Potassium (%) | Initial | Final |
|-------------|----------------------|-----------|---------|-------|--------------|---------|-------|----------------|---------|-------|---------------|---------|-------|
| FB0         | 66.3±1.5             | 25:1      | 0.33±0.03 | 0.36±0.05 | 0.07±0.12 | 0.06±0.10 | 0.53±0.1 | 0.05±0.03 |
| Blk20       | 65.5±2.0             | 22:1      | 0.38±0.02 | 0.56±0.03 | 0.14±0.04 | 0.39±0.01 | 0.5±0.03  | 0.62±0.05 |
| Blk40       | 56.9±1.8             | 16:1      | 0.6±0.01  | 0.48±0.08 | 0.24±0.01 | 0.55±0.02 | 0.44±0.02 | 0.57±0.02 |
| EM20        | 52.3±2.0             | 23:1      | 0.52±0.02 | 0.57±0.02 | 0.15±0.02 | 0.31±0.04 | 0.51±0.04 | 0.68±0.02 |
| EM40        | 45.0±1.5             | 20:1      | 0.55±0.05 | 0.39±0.01 | 0.18±0.04 | 0.49±0.02 | 0.46±0.02 | 0.62±0.04 |
| Tak20       | 55.3±2.1             | 25:1      | 0.46±0.03 | 0.54±0.04 | 0.18±0.02 | 0.35±0.02 | 0.49±0.02 | 0.66±0.05 |
| Tak40       | 43.4±1.6             | 16:1      | 0.68±0.02 | 0.7±0.02  | 0.29±0.01 | 0.52±0.01 | 0.50±0.05 | 0.61±0.04 |

$^a$ FB0 (Organic waste mixture with no fermenting bed material), Blk20 and Blk40 (Organic waste mixed with 20% and 40% fermenting bed material without culture inoculation, (Blk=Blank), EM20 and EM40 (Organic waste mixed with 20% and 40% fermenting bed material inoculated with commercial EM4 culture), Tak20 and Tak40 (Organic waste mixture with 20% and 40% fermenting bed material inoculated with Takakura culture).

Table 1. The final moisture content (%), the initial and final C/N ratio, nitrogen (%), phosphorus (%) and potassium (%) content of the composting experiments with and without Tak and EM bio-activators.
low microbial community activity mostly due to limitation of microbial respiration [36] and these samples were not inoculated.

3.4. The nitrogen, phosphorus and potassium content

The nitrogen, phosphorus and potassium content of the experiments before and after the composting process were measured, and the results are presented in Table 1. An increase in the final nitrogen content was observed for all samples containing 20% fb material during the composting process as compared to that of the initial nitrogen level. The increase was almost by 17% for Blk and the Tak sample, while for EM sample the increase was 9.6%. In contrast, increasing the ratio of the fb material to 40% decreased the final nitrogen content as compared to its initial value. The Blk and EM sample decreased by almost 20% and 29%, respectively, while no difference in the initial and final nitrogen content was observed for the Tak and FB0 samples. This contradictory result in nitrogen content between samples containing 20% and 40% fb material can be explained by the difference in the ratio of organic waste to fb materials in the samples. The fb material is made up of rice husk and rice bran consisting of lignocellulose as the major component [37] with low availability and digestibility of the carbon content. Thus, having a higher ratio of fb material would affect the C/N ratio of the sample and cause higher nitrogen loss in the final compost. Some studies showed similar compost C/N ratios, a higher content of biodegradable carbon with reduced nitrogen emission, while less biodegradable carbon such as lignocellulose material would increase the nitrogen loss in the form of NH₃ emission [35]. Another reason for lower nitrogen content in the samples with higher fb material could be due to low moisture content, which affects also microbial activity. Lower moisture content in the compost samples with higher fb material could have caused limitation of the microbial activity to fix nitrogen as NH₃ emission increases at low moisture content. Furthermore, there was no difference in the initial and final nitrogen for the Tak40 and FB0 samples. For the Tak40 the low moisture content (43%) in the sample might have lowered the microbial activity at some point during the composting process where the nitrogen content neither increased nor decreased in the sample [23]. While for the control sample FB0, the lack of fermenting bed material with high moisture content causing oxygen transfer limitations in the compost, thus inhibiting the microbial activity [23, 38, 39].

The phosphorus content was also increased for all experiments during the composting process compared to their initial content. The initial phosphorous content for the experiments containing 20% fb material was 0.14±0.04%, 0.15±0.02% and 0.18±0.02% for the Blk, EM, and Tak, respectively. After the composting process, the phosphorus content of the final compost more than doubled for all samples and ranged between 0.31±0.04% to 0.39±0.01%. The same trend was also observed for the samples containing 40% fb material with the initial phosphorus content ranging from 0.18±0.04% for the EM sample to 0.29±0.01% for the Tak sample, which after the composting process more than doubled to 0.49±0.02 and 0.52±0.01%, respectively. The highest final phosphorus content was observed for the Blk sample with 0.55±0.02%. Moreover, no change in phosphorus content was observed for FB0 which remained at the same value as its initial phosphorous content of 0.07±0.12%. The final phosphorus content for Em40, Tak40, and Blk40 was 58%, and 48% and 41% higher than EM20, Tak20, and Blk20, respectively.

The potassium content also increased during the composting process for all samples containing fb material. The initial potassium content ranged from the lowest for Blk40 0.44±0.02% to the highest for EM20 with 0.51%±0.04%. After the incubation period, the final compost increased 1.3 times higher compared to the initial level for all samples studied. Moreover, the final potassium content for the EM20, Tak20, and Blk20 contained approximately 10% and 8% and 9% higher than EM40, EM20 and Blk20, respectively. The lowest potassium content in the final compost was observed for Blk40 which was about 0.57±0.02% and the highest potassium content was observed for EM20 with 0.68±0.02%. Furthermore, the final potassium content for FB0 measured to be significantly decreased from 0.53% to only 0.05±0.03% in the final compost.

The increase in the phosphorus and potassium content in the final compost in both 40% and 20% fb material could be due to the concentration effect. According to Lin [29], the concentration effect arises
from higher carbon loss rate in form CO₂ or methane during decomposition process as compared to the loss rate of phosphorus and potassium, thus leading to a higher content of phosphorus and potassium content in the compost as a result of this concentration effect. The difference in phosphorus and potassium levels in 20% and 40% fb material could be due to microbial activity and the environmental condition. Irshad et al [40] observed the potassium and phosphorus at various stages of composting and compared with the initial level. It was found that both phosphorus and potassium concentration decreased with the time of composting and concluded that the fluctuation observed in the release of P nutrient could be due to the variation in the microbial activity and C/N ratio. This indicates that the 48 days of composting time was not enough time to mature and stabilize in this study. Moreover, there was no significant difference in the final potassium content in the FB0 as compared to its initial level, which is probably due to the lack of fb material causing none or low microbial activity. The lowering of the final potassium observed in the FB0 is probably due to the loss of potassium content during the leaching process [40].

4. Conclusion
In this study, composting with 20% and 40% fermenting bed inoculated with culture fermented according to Takakura method and commercial bio-activator (EM4) mixed with organic waste was evaluated during the 48 days and compared to that of the blank sample with no inoculation. The results showed the concentration of fermenting bed material was effective in the final compost quality. On the other hand, there was no significant difference in the final compost quality between EM4 culture and Takakura culture compared to that of the blank samples based on the C/N ratio, moisture content and NPK content.

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