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Evaluation of FTIR, Macro and Micronutrients of Compost from Black Soldier Fly Residual: in Context of Its Use as Fertilizer

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ABSTRACT

The extensive use of chemical inorganic fertilizers promotes the degradation of agricultural land quality and leads to various environmental contaminations. Owing to these problems, the alternative way called "organic farming" has been developed through the use of organic fertilizers including compost. In this study, compost product obtained from composting process by using larvae as the biological agent has been prepared. Macronutrients (i.e. N, P, K, Ca, and Mg) and micronutrients (i.e. Mn, Fe, Cu, Zn, and Ni) have been determined using Inductively Coupled Plasma-Optical Emission Spectrometry, Walkey and Black method, Kjeldahl method, and P Bray-1 method, which showed sufficient content and meet the standard value. Analysis and the comparative study showed that the compost product can be used as a fertilizers substitute. The compost from residual offers more economic, great availability, and environmentally friendly fertilizers for agricultural purposes.

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1. INTRODUCTION

The increasing need for food in Indonesia is one of the main problems that the government must solve effectively. Various ways have been done to overcome this problem, including the agricultural acceleration program. This program aims to fulfill food and domestic industry needs, increase export products and farmers' income. On the other hand, this effort raises several problems, including the degradation of the quality of agricultural land due to the excessive use of inorganic chemical fertilizers. In addition, the excessive use of chemical fertilizers causes pollution, which is very dangerous for the environment and ecosystem. Inorganic chemical fertilizers generally contain phosphate, nitrate, ammonium, and potassium salts. Indonesian health insurance (known as BPJS) helps to organize health insurance for the community, which is directly supported by Community Health Centers fertilizer industry is one sector that contributes to the presence of heavy metal waste such as Hg, Cd, As, Pb, Cu, Ni, and Cu (Savci, 2012). These chemicals accumulate in the soil and are then absorbed by plants along with the nutrients contained in the soil. Over time, these harmful chemicals can enter the food chain. Furthermore, the chemicals contained in fertilizers can migrate from the soil to the aquatic environment and cause contamination (Aktar *et al*., 2009).

To handle the degradation of agricultural land quality and reduce the environmental effect caused by the extensive use of inorganic chemical fertilizers, there is a new innovative way called "organic farming". Organic farming tends to use organic fertilizers which are more easily available, low cost, and environmentally friendly. In terms of organic fertilizers, compost is one of the most promising materials that can be used to substitute inorganic chemical fertilizers for agricultural applications (Geng *et al*., 2019). Compost can be easily prepared through a composting process of organic waste. The presence of high organic content on the compost gives beneficial function to improve the agricultural land quality and enrich the soil with the essential elements that need for plant growth. However, besides its high content of organic matter, compost is suffering from a low concentration of nitrogen, phosphate, and potassium as well as macro and micronutrients compared to inorganic chemical fertilizers (Khater, 2015).

In terms of compost application for agricultural applications as inorganic chemical fertilizers substitute, the quality of the compost must be controlled and evaluated. The compost quality including chemical and physical properties is determined by the production process which promotes by the microbial activity during the composting process. The microbial activity during the composting process can adjust the rate of the composting process and increase the quality of the compost product (Jurado *et al*., 2014). However, recent research showed that the use of microorganisms as the composting agent is not efficient due to the time-consuming (Saad *et al*., 2013). Therefore, there are several alternative ways to produce compost with the short time of the composting process, including the use of larvae from Hermetia illucens or known as Black Soldier Fly (BSF). BSF larvae can grow on the organic waste, convert the organic waste to valuable biomass, and then produce the residue which can be used as compost (Diener *et al*., 2011). The use of BSF as the biological agent for compost production is expected to produce a good compost quality and rapid the composting process.

To evaluate the quality of the compost product before being applied as the fertilizers, this study focused on the evaluation of macro and micronutrient content of the compost product and comparison its value to the standard reference of compost product.

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The introduction should answer the questions of what was studied, why was it an important question, what was known about it before, and how the study will advance our knowledge.

2. METHODS

In this study, there three main materials used for the compost preparation including EM4 as a bio-activator, Black Soldier Fly (BSF) larvae, and waste of orange without the peel and ambarella fruit as the BSF feed which were obtained from Labuhan Maringgai, East Lampung regency, Indonesia.

The composting process of organic waste by using BSF larvae was conducted on a laboratory scale. This study was started by collecting organic waste including orange and ambarella fruit waste. Those organic waste then was washed and cut into small pieces. Then the organic waste was fermented by using EM4 for 4 days. After 4 days of the fermentation process, the eggs of BSF were put into the fermented organic waste. During this stage, the moisture of the fermented organic waste must be controlled to optimize the composting process. The composting process of the organic waste by using BSF larvae was conducted for 4 days until all the organic wastes were eaten by the maggot, producing compost. The obtained compost then was dried and used for further analysis. The detailed procedures can be shown in **Figure 1**.

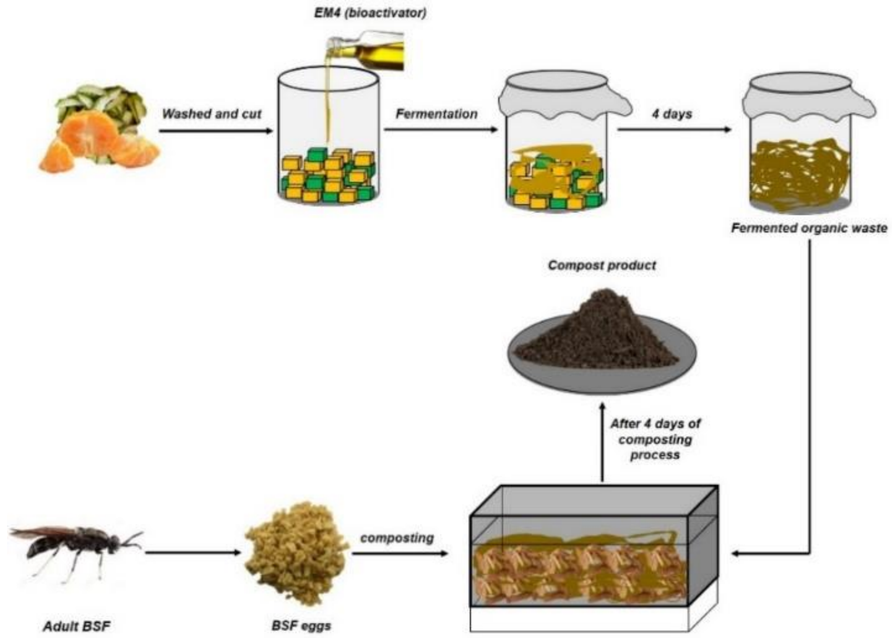

Figure 1. Composting process of organic waste by Black Soldier Fly (BSF).

2.1. Compost product analysis

Chemical properties of the compost product were analyzed by using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES 715-ES) to evaluate metal contents including K, Na, Ca, Mg, Mn, Fe, Cu, Zn, and Ni, Fourier transform infra-red (FTIR Agilent Technologies Cary 630) to determine organic functional groups, Walkey and Black method to determine the total C-organic content, Kjeldahl method to determine total N content, and P Bray-1 method to determine total P content.

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3. RESULTS AND DISCUSSION

3.1. Fourier transform infra-red (FTIR) analysis

Compost is a common fertilizer that is used by farmers to increase the quality of the soil. It can be naturally obtained from livestock manure and other waste processing products including organic and household waste. During the composting process, organic waste was decomposed and converted to be a mature and stable compost product. The maturity of the compost is one of the most important factors that affect the successful application of compost as a fertilizer in agriculture (Wu & Ma, 2002). The compost maturity can be evaluated by using various methods including Fourier transform infra-red (FTIR) analysis. The FTIR analysis result of the compost product can be shown in **Figure 2**.

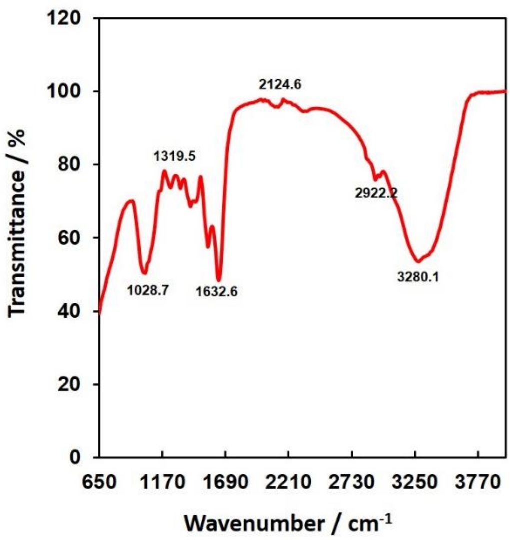

Figure 2. The FTIR analysis result of the compost product.

According to the FTIR spectrum in Figure 1, characteristic peaks of a hydroxyl group (OH) were observed by the presence of broadband at 3280.1 cm^{-1}. Stretching vibration of C-H aliphatic was also observed at 2922.2 cm^{-1}. Carbonyl vibration which corresponds to the presence of ketone, aldehyde, quinones, carboxylic acid, and esters was observed at 1632,6 cm^{-1}. The presence of polysaccharides was validated by the broad peaks at 1028.7 cm^{-1}. Small peaks around 1319.5 and 1401.5 cm^{-1} confirmed the presence of a complexation reaction between organic matter and heavy metals. This region also corresponds to the C-N stretching vibration of amine groups which acts as the organic ligand that contributed to the complexation process. N-O stretching vibration from nitrates was also observed at 1319.5 cm^{1}.

3.2. Compost Maturity

In this research, compost product was produced by the fermentation and composting process using BSF larvae. BSF larvae can convert organic waste to valuable biomass and produce the residue which can be used as compost. The compost product was expected to contain sufficient minerals and show good maturity to be applied as a fertilizer substitute. The maturity of compost is one of the most important parameters that must be monitored in terms of compost application. The use of mature compost can avoid adverse effects when applied or used to plant-growing media (Ge *et al*., 2006).

In terms of compost maturity, microbiological activity during the composting process can be used to determine compost maturity. It can be exhibited by the formation of microbial

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biomass and mesophilic and thermophilic bacteria, oxygen uptake rate, and CO2 release during the composting process (Jurado *et al*.,2014). Because degradation of organic matter in the composted organic waste is catalyzed by the specific hydrolytic enzymes, the changes of enzymatic activities during the composting process are recognized as the biological indicator of compost maturity (Vargas *et al*., 2010). The high content of intermediate biochemical degradation by-products including ammonia, sulfate, and short-chain organic acids causes phytotoxic effects as reduced seed germination, inhibited root growth, and diminished above-ground plant production (Butler *et al*., 2001). Due to its crucial factor, in this research compost maturity was determined by analyzing ammonia compared to nitrate- and sulfate-containing on the compost product. According to the compost product analysis, the content of ammonia, nitrate, and sulfate on the compost product is shown in **Table 1**.

Table 1. Ammonia, nitrate, and sulfate contents.

Nutrients	Content (mg/kg)
Ammonia (n-nh$_4$)	0.27
Nitrate (n-no$_3$)	86.46
Sulfate	2.58

According to the data shown in **Table 1**, the content of nitrate is higher than ammonia. The higher nitrate content than ammonia indicates that the compost product is mature or fully composted. During composting process, organic N is converted to NH_4 under high temperatures. This condition inhibits the conversion of NH_4 to NO_3 through the nitrification process. Moreover, when the concentration of ammonia exceeds more than 1000 ppm and the pH around 7.5, inorganic N which contains in the compost likely to be ammonia form. The presence of ammonia on the compost can harm plants when it is applied as fertilizer (Hao & Benke, 2008). On the other hand, as well as ammonia and nitrate, sulfate is also one of the most important nutrients that must be evaluated. According to various reports, they indicate that the nutrients bound by sulfate are more easily available and less harmful to the plants compared to the other salt form (Tea *et al*., 2004). In terms of its use for agricultural application, multicomponent foliar fertilizers should contain nitrogen and sulfur around 5.0 ≥ 20% of the weight and 1.5 ≥ 5.0% of the weight, respectively (Szewczuk & Sugier, 2009). Based on the ammonia, nitrate, and sulfate contents on the compost product indicates that the compost product has good maturity and fulfills the standard value to be applied as a fertilizer substitute.

3.3. Macro and Micronutrients Evaluation

In the last decade, the effort to increase agricultural production through the fertilization process by using inorganic chemical fertilizers leads several problems such as high cost, environmental contamination, and the loss of carbon contained in soil (Khan *et al*., 2007). The fertility of soil can be improved by maintaining the presence of humic acid content on the soil. The humic acid content on the soil can be increased by adding outside sources of organic matter such as compost (Susic, 2016). Moreover, the use of compost also improves the content of nutrients on the soil needed for plant growth. Six nutrients plant required in a large amount including nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S). The deficiency of these nutrients can decrease plant growth and reduce crops yield (White & Brown, 2010). However, compost has lower nutrient content compared to inorganic chemical fertilizers. In terms of compost application as the chemical fertilizers

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substitute, the content of nutrients including macro and micronutrients must be evaluated to obtain effective compost for fertilizer applications.

In this study, compost product was obtained from composting process by using BSF larvae which are expected to increase not only the rating process but also its quality. The content of micro and macronutrient content has been evaluated. The content of macronutrients can be shown in **Figure 3**.

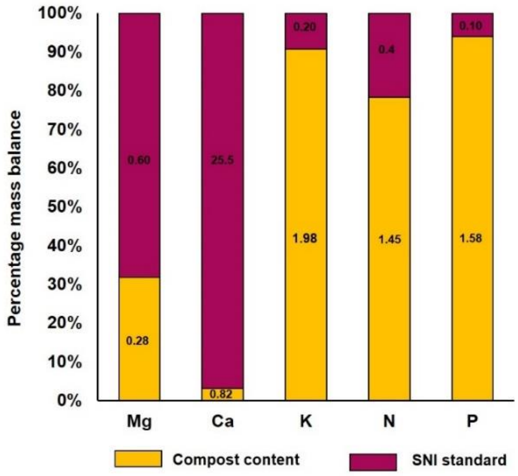

Figure 3. Macronutrients content of compost product.

According to the data shown in **Figure 3**, five macronutrients are contained in the compost product of BSF larvae. To evaluate the quality of the compost product, Indonesian National Standard (SNI) 19-7030-2004 about compost specification from organic domestic waste is used as the standard value. According to the SNI 19-7030-2004, the maximum content of magnesium and calcium-containing in compost must be 0.6 and 25.5%, respectively. Magnesium is one of the essential elements which plays an important role in the carbohydrate partitioning process and photosynthesis on crops (Farhat *et al.*, 2016). The low concentration of magnesium on the soil can promote magnesium deficiency especially for the crops grown on the acidic soil. When the soil suffers from magnesium deficiency, the crops will give responses that indicate a serious problem in their metabolism process. The most obvious response is known as Chlorosis. It causes a significant reduction of corps yields as the result of sugar transport decreases from the source to the vital organs. The content of magnesium on the soil considerably varied between 0.05-0.5% due to the high variation of magnesium on the source material and weathering process (Gransee & Führs, 2013). According to the analysis, the amount of magnesium contained on the compost product from BSF larvae residual is around 0.28% which indicates enough amount for fertilizer application and fulfills the need for magnesium ions on the soil.

As well as magnesium, calcium is the vital element responsible to hold the cell wall of the plant together. Calcium also contributes to enzyme activation and cell elongation. Naturally, the content of calcium ions in the soil is influenced by the parent materials and weathering process. It ranged from 0.1-0.3% in leached humic tropic and ranged from <1%-25% in calcareous soils (Prasad & Shivay, 2016). Based on the SNI, the maximum calcium contained in the compost product must be less than 25.5%, while the amount of calcium on the BSF residual compost is 0.82%. This value is enough to supply calcium ions for fertilization purposes compared to the calcium content on the soil for both leached humic tropic and calcareous soils**.** The need for calcium ions must be fulfilled to avoid calcium deficiency which promotes bad effects for crops including dead spots, brown spots, and stunted growth.

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On the other hand, in the context of fertilizer application, the presence of N, P, and K elements on the compost product is one of the most important aspects that must be concerned. These three essential elements are required for the growth and development process of plants. Therefore, these elements must be presented on the soil in a proper form and balance. N elements are presented on the soil in various forms including organic N, N as nitrate, N as ammonia, nitrite, dinitrogen oxide, nitrogen monoxide, and ammonia gas. However, in terms of fertilizer application, N as nitrate and ammonia must get more attention. Nitrogen as nitrate can be easily dissolved in water. It promotes the leaching process of this element into the soil. While ammonium nitrogen is more stable from the leaching and denitrification process. Analog to nitrogen, the P element can be presented in various forms in the soil including total P, organic P, and inorganic P. Orthophosphate ($H_2PO_4^-$ or HPO_4^{2-}) in the form of P element absorbed by the plant. In the long term of fertilizer containing phosphate application, environmental problems may appear due to the presence of excess P levels in the soil (DeLaune *et al.*, 2006). According to the analysis result of compost product, the nitrogen, phosphorus, and potassium contents are 1.45, 1.58, and 1.98%, respectively. Those values are higher than the minimum value of the SNI standard which indicates that the compost product contains enough macronutrients and meet meets the standard.

The quality of the compost is not only influenced by the presence of macronutrients but also micronutrients. Although found in a small amount in the soil, micronutrients play important roles in plant growth and development. In this study, the micronutrients content including Mn, Fe, Zn, Cu, and Ni elements are determined and the result can be shown in **Figure 4**.

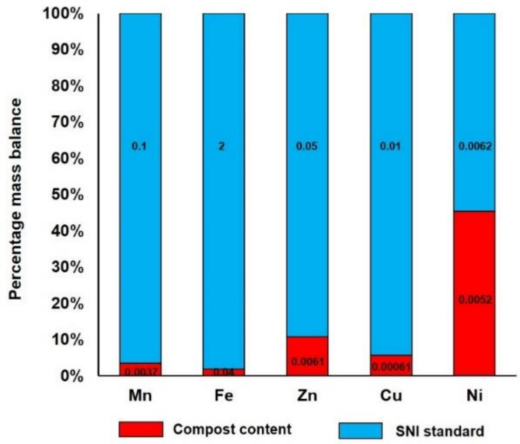

Figure 4. Macronutrients content of compost product.

According to the data shown in **Figure 4**, the micronutrients content of manganese (Mn), iron (Fe), zinc (Zn), copper (Cu), and nickel (Ni) are 0.0037, 0.04, 0.061, 0.00061, and 0.0052%, respectively. Those values are lower compared to the maximum value of the SNI standard. It indicates that the micronutrients content of the compost product meets the criteria of the standard value. Mn, Zn, Cu, and Ni are needed in a very small quantity. Those elements play important roles in the respiration, photosynthesis, and nitrogen assimilation process. While Fe is one of the most vital elements for almost metabolism process of plants. However, the presence of an excessive level of those elements can cause strong toxic effects for humans (Khan *et al*., 2016). Therefore, the micronutrients content on the compost product must be controlled to minimize soil contamination. Based on the analysis and comparative study, compost product from BSF larvae residual shows good quality both macro and micronutrients. The use of BSF larvae as the biological agent for compost production not only provides compost product that meets the standard value but also provides environmentally friendly products to be applied as fertilizers.

3.4. Soluble Salt Evaluation

According to its content, compost offers many beneficial plant nutrients. However, it is not considered a fertilizer due to the high variability of nutrients. One of the main focuses of this problem is the high salt concentration on compost products. The high concentration of soluble salt can lead to the reduction of soil quality and plant growth especially in the field with high salinity and sodicity due to the phytotoxicity associated with particular soluble salts such as sodium (Na^+) and chlorine (Cl^-) (Mahmoodabadi *et al.,* 2013). Moreover, the presence of high salt concentration in the soil can reduce the uptake of nutrient molecules into plants which causes limited vegetative growth and yield. The usual method to quantify the soluble salts concentration in compost is to measure the electrical conductivity (EC) of either the compost solution or a compost-water extract**.** To evaluate the concentration of soluble salt on the compost product, both Na^+ concentration and EC value are determined as shown in **Table 2**.

Table 2. Soluble salt parameters.

Parameter	Content
Sodium ion (na^+) (%)	0.97
Ec (ds/m^{-1})	10.71

Based on **Table 2**, it can be seen that the concentration of sodium ions is higher than Ca^{2+} and Mg^{2+} ions as explained in the previous chapter. The compost product has a high value of EC according to the soil salinity standard as shown in **Table 3** (Grattan & Grieve, 1998). In general, the use of high EC compost on the soil can promote the phytotoxicity effect for the plants. However, various researches have been developed to evaluate the effect of high salinity soil and the ability of the plants to tolerate this condition for examples strawberry and lettuce are sensitive crops that would be killed in the soil with EC values from 2 to 4 dS m^{-1}. On the other hand, salt-tolerant crops such as rye and wheat can tolerate and survive in the soil with EC values as high as 7 dS m^{-1} (Mass & Grattan, 1998). In terms of compost application, the use of compost with a high EC value might increase the electrical conductivity and change the soil characteristics. However, it can be overcome by determining the ideal compost which can be applied to the suitable type of crop being grown and soil. Moreover, high EC compost can also be mixed with other media to reduce the phytotoxic effects on plants (Gondek *et al.,* 2020).

Table 3. General degrees of salinization in soils.

Degree of salinity	Range of ec (ds m^{-1}) values
Light	2–4
Moderate	4–8
Heavy	8–16
Severe	>16

4. CONCLUSION

In this study, Black Soldier Fly (BSF) larvae have been successfully applied as the biological agent for composting organic waste. The obtained compost product contains macronutrients (N, P, K, Ca, and Mg) and micronutrients (Mn, Fe, Zn, Cu, and Ni). Both macro and

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micronutrients level of the compost product is suitable to the SNI standard. FTIR analysis and ammonia analysis also indicated that the compost has good maturity. According to these qualities, the compost product can be used as one of the excellent candidates to use as the fertilizer.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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