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# Composting of boiler-ash and biogas-sludge from the palm oil industry for using as plantlet growing media

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**Abstract** Agricultural organic waste is increasing yearly. In Thailand, the palm oil industry generates high amounts of waste 13.71 million ton/year, mainly as boiler-ash and biogas-sludge. This study focused on the basic properties of boiler-ash and biogas-sludge from the palm oil industry after composting and their possible use as growing media for lettuce. Boiler-ash and biogas-sludge from the palm oil industry were pre-treated (composting) and after that evaluated as growing media in comparison with peatmoss under pot experiment conditions. Under the pre-treatment experiment, the results showed that the type of materials affected the pH, EC, OM, total N and the C:N ratio ($P<0.05$). The pre-treatment method was affected the pH and EC ($P<0.05$). The type of growing media and porous materials affected germination percentage, germination index, shoot length, and shoot fresh and dry weight ($P<0.01$). Interaction between the type of treated materials and porous materials affected germination percentage, germination index, shoot length, root length, and shoot fresh and dry weight ($P<0.05$). The best material was boiler-ash compost with perlite as the porous material which gave 92.6% germination, 23.05 germination index, 39.10 mm in shoot length, 28.67 mm in root length, 0.2 g shoot fw/plant, and 0.0397 g shoot dw/plant but these results were not statistically different from undisturbed boiler-ash with perlite as the porous material. Therefore, boiler-ash compost and boiler-ash left for 90 days were recommended to use as growing media.

**Keywords:** Boiler-ash, Biogas-sludge, Oil palm industry, Growing media

## Introduction

A variety of waste is generated through different agricultural processes and other activities in our daily life. The agricultural organic waste includes crop residues, weeds, animal wastes, and by-products, while human habitation waste includes garbage, sewage, sludge, etc. Agricultural waste is an organic material that can be beneficial and has potential for recycling in many ways (Gomah *et al.*, 2020). Surat Thani province is the largest area of palm oil production in Thailand. The palm oil production process emits two kinds of waste which are boiler-ash (500 tons/year) and biogas-sludge (200 tons/year).

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Boiler-ash comes from the burning of palm shell for the steam boiler process. The ash has a high surface area and comprises potassium, calcium, and magnesium in the structure (Charoensri *et al.*, 2017), however, it has an alkaline pH. Another kind of waste is biogas-sludge that is generated from biogas production using decanter waste after the palm oil extraction process. The sludge contains beneficial microorganisms and nutrients such as nitrogen and phosphorus. However, the sludge might be contaminated with heavy metals and other chemicals that affect seed germination. The problems of using these materials are due to the alkaline pH, salinity, and toxic chemicals that will affect seedling quality. Therefore, both types of materials must be pre-treated before being used as growing media.

Lettuce (*Lactuca sativa*) is an annual plant of the daisy family, Asteraceae, which is nutritious and rich in vitamin C, minerals, and fiber. It has been used as a medicine for different ailments including stomach problems, inflammation, pain, and urinary tract infections since ancient times due to the presence of secondary metabolites such as terpenoids, flavonoids, and phenols (Sapkota *et al.*, 2019). Lettuce has a relatively short life cycle (65-120 days to mature) and requires high content of nitrogen and potassium. Therefore, it is suitable to be used in assessing the suitability of the growing media. The objective was to study the basic properties of boiler-ash and biogas-sludge from the palm oil industry after composting to evaluate their possible use as growing media for lettuce.

## Materials and methods

### *Boiler-ash and biogas-sludge*

The boiler-ash and biogas-sludge from the palm oil industry used in this study are provided by Kanjanadit Palm Oil Company, Surat Thani, Thailand. Boiler-ash came from oil palm fronds and empty fruit bunch fibers which were burned at 400 ˚C for 6-7 hours. Biogas-sludge came from the production of biogas from palm oil decanter cake. The characteristics of boiler-ash and biogas-sludge are shown in Table 1.

**Table 1**. Chemical and physical characteristics of the materials

| Materials | Characteristics | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pH | EC (1:10) | Available P | Extractable K | Extractable Ca | Extractable Mg | $NH_4^+$ | $NO_3^-$ | Bulk density | Porosity | Macropore | Micropore |
| | | mS/cm | (%) | (%) | (%) | (%) | mgN $kg^{-1}$ | mgN $kg^{-1}$ | g $cm^{-3}$ | % | % | % |
| Boiler-ash | 8.36 | 0.67 | 0.49 | 0.55 | 1.22 | 0.50 | 52.47 | 231.5 | 0.52 | 80.12 | 10.43 | 69.70 |
| Biogas-sludge | 6.12 | 1.09 | 0.28 | 0.23 | 0.90 | 0.35 | 265.88 | 1,005.90 | 0.82 | 90.12 | 17.55 | 85.70 |

### *Decomposition study*

Boiler-ash and biogas-sludge were pre-treated using 2x3 factorial under completely randomized design (CRD). The first factor was the type of materials (boiler-ash or biogas-sludge) and the second factor was the pre-treatment method (undisturbed, composting, and composting with microbial addition). The treatments were set as follows: T1: undisturbed boiler-ash, T2: boiler-ash compost, T3: boiler-ash compost with microbial addition, T4: undisturbed biogas-sludge, T5: biogas-sludge compost, T6: biogas-sludge compost with microbial addition. Compost under treatments T2, T3, T5 and T6 were kept at 60% moisture content and turned every 7 days. Microbial addition used in the study was LDD.1 (commercial product) provided by the Land Development Department, Thailand. The experiment was conducted in 20-liter plastic containers with 15 kg of materials. The experiment was run for 90 days in a greenhouse and the temperature was measured every 7 days. The samples were collected after 30, 60, and 90 days of composting for analysis of pH and EC. The materials were measured for total nitrogen, organic matter, and C:N ratio at the beginning and the end of experiment using the Kjeldahl method and the wet oxidation method (Keawmorakot, 2013).

### *Plant growth experiment*

The effect of the growing media combination with the porous material on plant performance was evaluated under greenhouse conditions. The experiment was designed as 7×2 factorial under CRD with three replications. The first factor was the type of growing medias from the compost with peatmoss as a control. The second factor was the type of porous materials (perlite or rice hulk). The growing media were mixed with porous material in the ratio of 70:30 (v/v). Lettuce (*Lactuca sativa*), the royal variety, was planted in seedling trays with 1 seed per hole and watering every day with distilled water. The experiment was done for 14 days in a greenhouse under natural light conditions.

#### **Seed germination percentage and germination index**

The germination percentage of the seeds was counted after planting on the $4^{th}$ and $7^{th}$ days, then evaluated according to the ISTA (2013).

Germination percentage = (seeds germinated/total seeds) x 100

Germination index (GI) was recorded daily from the $4^{th}$ day (first count) to the $7^{th}$ day (last count) and calculated as described by the Association of Official Seed Analysis (AOSA, 1983) by the following equation:

$$\text{Germination index} = \frac{\text{No. of germinated seeds}}{\text{days of first count}} + \cdots + \frac{\text{No. of germinated seeds}}{\text{days of last count}}$$

**Seedling growth**

The length of shoot, length of root, fresh weight, and dry weight (after oven-drying at 60 ˚C for 72 hr.) of seedlings were measured after 14 days of plantation using 5 seedlings per replication, 15 seedlings per treatment (Kangsopa and Siri, 2017).

### *Statistical analysis*

Statistical analysis was performed using analysis of variance (ANOVA). The honestly significant difference (HSD) test was used to establish whether the differences in the treatments were significant at the 95% confidence level.

## Results

### *Temperature of composts*

The change of temperature was occurred in composting piles during composting as shown in Figure 1. The initial temperature of the compost piles after piling ranged from 28–30 ℃ while the ambient temperature was 24 ℃. The statistical difference in temperature was observed on day 7 to day 63. During that time, the temperature of the compost pile rose slowly. The highest temperature of 60 ℃ was recorded for biogas-sludge compost and the lowest temperature of 54 ℃ was recorded for undisturbed boiler-ash on day 42. However, as composting proceeded, the temperature of the compost piles began to drop after day 42 and was stable at 24 ℃ on day 91.

### *pH of composts*

During the composting study, the clearly effect of materials on pH was observed. The pH of boiler-ash changed from alkaline (pH 8.28) in day 0 to neutral (pH 6.94) in day 90, while the pH of biogas-sludge changed from slightly alkaline (pH 7.72) in day 0 to medium acidic (pH 5.59) in day 90 (Table 2). The pre-treatment processes affected pH only in the end of experiment. Undisturbed material for 90 days reduced the pH closely to neutral, while the addition of moisture and microorganisms reduced the pH to become acidic.

**Table 2.** Changes in the pH of boiler-ash and biogas-sludge during the time of study

| **Factors** | | **pH** | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | **Composting times** | | | | | | |
| | | **0 days** | **15 days** | **30 days** | **45 days** | **60 days** | **75 days** | **90 days** |
| Type of material | Boiler-ash | 8.28 | 7.52 B | 6.90 A | 6.93 A | 7.11 A | 6.90 A | 6.94 A |
| | Biogas-sludge | 7.72 | 8.02 A | 6.07 B | 5.88 B | 6.21 B | 5.90 B | 5.59 B |
| Type of management | Undisturbed | 8.20 | 7.93 | 6.59 | 6.60 | 6.82 | 6.49 | 6.76 A |
| | Compost | 8.05 | 7.81 | 6.48 | 6.32 | 6.33 | 6.37 | 6.27 AB |
| | Compost with microbial addition | 7.75 | 7.56 | 6.38 | 6.30 | 6.54 | 6.33 | 5.76 B |
| T1: Undisturbed boiler-ash | | 8.70 | 7.91 | 7.05 | 6.88 AB | 7.29 | 6.87 | 7.20 |
| T2: Boiler-ash compost | | 7.65 | 7.64 | 6.81 | 6.89 AB | 6.99 | 6.74 | 7.11 |
| T3: Boiler-ash compost with microbial addition | | 8.49 | 7.02 | 6.83 | 7.03 A | 7.07 | 7.08 | 6.50 |
| T4: Undisturbed biogas-sludge | | 7.71 | 7.96 | 6.13 | 6.31 BC | 6.34 | 6.11 | 6.31 |
| T5: Biogas-sludge compost | | 7.86 | 7.99 | 5.96 | 5.71 CD | 6.28 | 5.92 | 5.43 |
| T6: Biogas-sludge compost with microbial addition | | 7.62 | 8.12 | 6.12 | 5.61 D | 6.03 | 5.66 | 5.02 |
| Type of material | | ns | * | ** | ** | ** | ** | ** |
| Type of management | | ns | ns | ns | ns | ns | ns | * |
| Type of material × Type of management | | ns | ns | ns | * | ns | ns | ns |
| % CV | | 8.26 | 4.47 | 4.33 | 3.65 | 5.46 | 4.42 | 9.61 |

**Table 3**. Changes in EC of boiler-ash and biogas-sludge during the time of study

| Factors | | EC (mS/cm) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Composting times | | | | | | |
| | | **0 days** | **15 days** | **30 days** | **45 days** | **60 days** | **75 days** | **90 days** |
| Type of material | Boiler-ash | 0.51 B | 0.50 B | 0.69 B | 0.64 B | 0.64 B | 0.66 B | 0.66 B |
| | Biogas-sludge | 1.46 A | 1.55 A | 2.20 A | 2.44 A | 2.17 A | 2.73 A | 2.79 A |
| Type of management | Undisturbed | 1.10 | 1.27 A | 1.33 B | 1.32 | 1.23 B | 1.36 B | 1.24 B |
| | Compost | 0.97 | 0.89 B | 1.67 A | 1.76 | 1.74 A | 1.88 A | 1.99 A |
| | Compost with microbial addition | 0.89 | 0.93 B | 1.33 B | 1.55 | 1.24 B | 1.85 A | 1.94 A |
| T1: Undisturbed boiler-ash | | 0.62 | 0.64 | 0.73 C | 0.71 A | 0.67 C | 0.71 C | 0.68 C |
| T2: Boiler-ash compost | | 0.46 | 0.42 | 0.67 C | 0.52 C | 0.64 C | 0.65 C | 0.65 C |
| T3: Boiler-ash compost with microbial addition | | 0.47 | 0.45 | 0.66 C | 0.70 C | 0.61 C | 0.61 C | 0.66 C |
| T4: Undisturbed biogas-sludge | | 1.58 | 1.89 | 1.94 B | 1.92 B | 1.78 B | 2.02 B | 1.80 B |
| T5: Biogas-sludge compost | | 1.49 | 1.35 | 2.67 A | 3.00 A | 2.84 A | 3.04 A | 3.32 A |
| T6: Biogas-sludge compost with microbial addition | | 1.33 | 1.41 | 2.00 B | 2.40 AB | 1.88 B | 3.14 A | 3.23 A |
| Type of material | | ** | * | ** | ** | ** | ** | ** |
| Type of management | | ns | ** | * | ns | * | ** | ** |
| Type of material × Type of management | | ns | ns | ** | * | * | ** | ** |
| % CV | | 14.18 | 14.79 | 12.94 | 23.13 | 21.61 | 9.74 | 12.13 |

### *Electrical conductivity (EC) of composts*

When examining the EC of materials, the results showed that both materials and pre-treatment methods affected EC of the compost (Table 3). Biogas-sludge had a higher EC than boiler-ash along the time of study. Composting with or without microbial addition had a higher EC than undisturbed materials. After 90 days of the experiment, the lowest EC was found under boiler-ash compost with 0.65 mS/cm, although it was not statistically different from the same material with different management approaches. The highest EC was found under biogas-sludge compost with 3.32 mS/cm although it was not statistically different from biogas-sludge compost with microbial addition.

### *Organic matter, total nitrogen, C:N ratio of composts*

When examining the organic matter, total nitrogen, and C:N ratio of composts, the results showed that the type of materials had a significant effect on these parameters but not for the pre-treatment method (Table 4). Biogas-sludge had higher organic nitrogen and total nitrogen but a lower C:N ratio. Interaction between materials and management showed a statistical difference ($P<0.05$) in organic matter and C:N ratio. The biogas-sludge had higher organic matter with 39.54-43.80 % but boiler-ash had a higher C:N ratio with 13.88-17.05.

### *Germination percentage and germination index*

When examining the growth of lettuce under greenhouse conditions, the results showed that the type of growing media, type of porous materials, and interaction between media and porous material had significantly affected the germination percentage and germination index at $P<0.05$ (Table 5). The highest germination percentage was found under undisturbed boiler-ash with 95.20% although this was not statistically different from boiler-ash compost (92.6%). However, the lowest germination was found under undisturbed biogas-sludge with 71.20%. The germination index showed the same trend as the germination percentage with the highest value found under boiler-ash compost (23.46) and the lowest under undisturbed biogas-sludge (17.02). Perlite is a more suitable porous material than rice husk and gave a better germination percentage (83.94 %) and germination index (21.13).

**Table 4**. Organic matter, total nitrogen, C:N ratio of boiler-ash and biogas-sludge on 0 and 90 days of the experiment

| Factors | | Organic matter (%) 0 days | Organic matter (%) 90 days | Total nitrogen (%) 0 days | Total nitrogen (%) 90 days | C:N ratio 0 days | C:N ratio 90 days |
|---|---|---|---|---|---|---|---|
| Type of material | Boiler-ash | 10.53 B | 10.55 B | 0.48 B | 0.39 B | 12.82 A | 15.87 A |
| | Biogas-sludge | 41.50 A | 41.31 A | 3.95 A | 3.92 A | 6.11 B | 6.13 B |
| Type of management | Undisturbed | 26.41 | 26.35 | 2.16 | 2.14 | 8.53 | 10.22 |
| | Compost | 25.61 | 26.28 | 2.27 | 2.17 | 10.29 | 11.51 |
| | Compost with microbial addition | 26.02 | 25.15 | 2.22 | 2.15 | 9.60 | 11.27 |
| T1: Undisturbed boiler-ash | | 9.27 | 8.90 C | 0.52 B | 0.38 | 10.39 B | 13.88 A |
| T2: Boiler-ash compost | | 11.78 | 11.98 C | 0.45 B | 0.41 | 14.97 A | 17.05 A |
| T3: Boiler-ash compost with microbial addition | | 10.52 | 10.75 C | 0.46 B | 0.38 | 13.11 AB | 16.70 A |
| T4: Undisturbed biogas-sludge | | 43.55 | 43.80 A | 3.80 A | 3.90 | 6.68 C | 6.56 B |
| T5: Biogas-sludge compost | | 39.43 | 40.59 AB | 4.08 A | 3.94 | 5.60 C | 5.98 B |
| T6: Biogas-sludge compost with microbial addition | | 41.51 | 39.54 B | 3.97 A | 3.93 | 6.07 C | 5.85 B |
| Type of material | | ** | ** | ** | ** | ** | ** |
| Type of management | | ns | ns | ns | ns | ns | ns |
| Type of material × Type of management | | ns | ** | * | ns | ** | * |
| % CV | | 11.52 | 4.67 | 4.58 | 7.32 | 12.73 | 11.38 |

(Composting times: 0 days, 90 days)

**Table 5.** Germination percentage and germination index of lettuce seedlings during the experiment under greenhouse conditions

| Factors | | Germination (%) | Germination index |
|---|---|---|---|
| Type of growing media | T1[1/] | 86.10 B | 22.19 C |
| | T2 | 95.20 A | 23.46 A |
| | T3 | 92.60 A | 23.05 AB |
| | T4 | 88.60 B | 22.64 BC |
| | T5 | 71.20 C | 17.02 E |
| | T6 | 71.80 C | 18.03 D |
| | T7 | 71.80 C | 18.26 D |
| Type of porous material | perlite | 83.94 A | 21.13 A |
| | rice husk | 81.00 B | 20.19 B |
| growing media | | ** | ** |
| porous material | | ** | ** |
| growing media × porous material | | ** | ** |
| % CV | | 2.61 | 2.48 |

[1/] T1 = Peatmoss (control), T2: Undisturbed boiler-ash, T3: Boiler-ash compost, T4: Boiler-ash compost with microbial addition, T5: Undisturbed biogas-sludge, T6: Biogas-sludge compost, T7: Biogas-sludge compost with microbial addition.

### *Seedling growth*

When examining shoot and root lengths of lettuce seedlings under greenhouse conditions, the results showed that the type of growing media significantly affected shoot length, root length, shoot fresh weight, and shoot dry weight (P<0.05). The highest shoot length, root length, shoot fresh weight, and shoot dry weight were found under boiler-ash compost with 39.10 mm, 28.67 mm, 0.2000 g/plant, and 0.0397 g/plant, respectively. However, this was not statistically different from undisturbed boiler-ash (Table 6). Perlite was a good growing porous material compared to rice husk, and provided higher shoot length, and shoot fresh and dry weight with a statistically significant difference (P<0.05) but no effect on root length was found. Interactions between the type of growing media significantly affected shoot length, root length, and shoot fresh and dry weight (P<0.05) (Table 6).

**Table 6**. The length of shoot, length of root, fresh weight and dry weight of lettuce seedlings after the experiment under greenhouse conditions

| Factors | | Shoot length (mm) | Root length (mm) | Shoot fresh weight (g/plant) | Shoot dry weight (g/plant) |
|---|---|---|---|---|---|
| Type of growing media | T1[1/] | 36.67 ABC | 19.58 BC | 0.1326 B | 0.0278 B |
| | T2 | 38.46 AB | 25.70 AB | 0.2219 A | 0.0368 A |
| | T3 | 39.10 A | 28.67 A | 0.2000 A | 0.0397 A |
| | T4 | 32.25 BCD | 18.80 B | 0.1549 B | 0.0273 B |
| | T5 | 22.90 E | 17.10 B | 0.0709 C | 0.0116 C |
| | T6 | 28.29 DE | 17.67 B | 0.0655 C | 0.0082 C |
| | T7 | 30.47 CD | 17.17 B | 0.0646 C | 0.0139 C |
| Type of porous material | perlite | 34.91 A | 22.00 | 0.1386 A | 0.0290 A |
| | rice husk | 30.27 B | 20.20 | 0.1215 B | 0.0182 B |
| growing media | | ** | ** | ** | ** |
| porous material | | ** | ns | ** | ** |
| growing media × porous material | | ** | * | ** | ** |
| % CV | | 14.26 | 31.77 | 12.65 | 20.22 |

[1/] T1 = Peatmoss (control), T2: Undisturbed boiler-ash, T3: Boiler-ash compost, T4: Boiler-ash compost with microbial addition, T5: Undisturbed biogas-sludge, T6: Biogas-sludge compost, T7: Biogas-sludge compost with microbial addition.

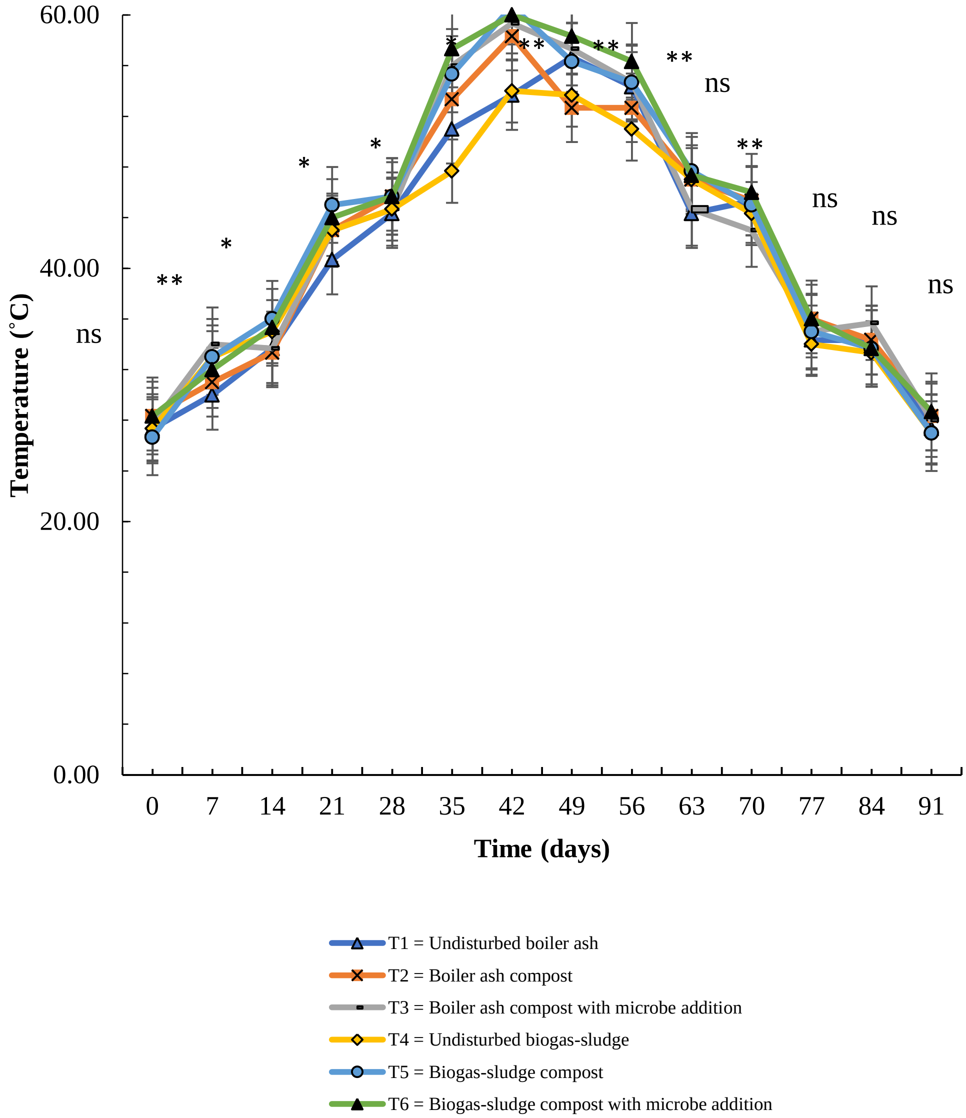


**Figure 1**. Changes in the temperature of boiler-ash and biogas-sludge with various pre-treatment methods

## Discussion

The increased temperature resulted from microbial activity (Chinakwe *et al.*, 2019). The temperature changes in the compost piles indicated that the organic materials passed through different phases which are mesophilic, thermophilic, cooling, and maturation (Chinakwe *et al.*, 2019). The increase of temperature helps in pathogen and toxic compound degradation. Under the undisturbed treatments, although water and microbes were not added to the pile, the temperature continued to rise, possibly because of moisture that remained in the materials. The decrease of pH might be caused by the perfect process of enzymatic oxidation and mineralization of basic cations (Khan *et al.*, 2009), and the formation of carbon dioxide gas and organic acid during organic matter decomposition (Zakarya *et al.*, 2019), as well as volatilization of ammoniacal nitrogen and hydrogen ions ($H^+$) through the nitrification activities of nitrifying bacteria (Roca-Pérez *et al.*, 2009). The pre-treatment of boiler-ash before use decreased its pH making it more appropriate as growing media. However, in the case of biogas-sludge, the composting of material before use made the pH more acidic, which might reduce plant germination and growth. The EC value reflected the degree of salinity in the composting material, indicating its possible phytotoxic effects on the growth of plants (Singh *et al.*, 2012). Moreover, the EC of material is related to nutrients released. The increase of EC during the time of fermentation is caused by the release of minerals such as ammonium (Singh *et al.*, 2012) and phosphate, which did not bind to the stable organic complex or which went out of the system via leachate (Francou *et al.*, 2005). The higher nitrogen and lower carbon level caused a decrease in the C:N ratio of compost treatments (Gayasinghe *et al.*, 2010). Carbon is mainly used as an energy source for building microbial cells, while nitrogen is required for microbial development and reproduction because of its role in protein synthesis (Zhou, 2016). Digestate derived from sewage sludge demonstrated not only a high rate of nitrification but also mineralization of organic matter (Tambone and Adani, 2017). However, nitrogen can be lost from the system due to ammonia volatilization (Sommer, 2001).

The lower germination percentage and germination index of plantlets growing in biogas-sludge that had higher nutrients might have been the result of nitrogen in the material. Nesse *et al.* (2018) reported that ammonium concentrations above 0.1 g/100 g DM and total N content above 3% in growth media are phytotoxic. Seed germination can be affected by inorganic and organic chemicals present in the material. Moreover, salinity often inhibits seeds by influencing the water uptake crucial for germination (Marchiol, 2002). The good germination index indicated earlier germination because the media provided good moisture and aeration as well as sufficient porosity which permits gaseous exchange between the media and the seeds (Gawankar, 2019). Rice husk had a high C:N ratio that might have affected seedling quality. However, the two materials both gave germination percentages greater than 80% which means they can be used as porous materials. Perlite is a better porous material than rice husk, but rice husk is a low-cost by-product material. Ideal growing media are expected to continuously supply plant roots with nutrients throughout the period of seedling development (Adediran, 2005). The recommended conditions for lettuce growth are 5.6-6.0 in pH (Brechner *et al.*, 2013), 1.8 mS/cm in EC (Samarakoon *et al.*, 2019) and 19-24 ˚C in temperature (Samarakoon *et al.*, 2020).

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