Rapid production of organic fertilizer using subcritical water treatment on waste biomass

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Abstract. Waste biomass are highly valuable and have potential to be converted to organic fertilizers or compost. This is a great alternative to replace the uses of commercial chemical fertilizers towards sustainable agriculture. However, due to its complex molecular structure and high lignin content, it hinders full decomposition of these wastes into mature compost. Therefore, subcritical water (SCW) pre-treatment was studied to enhance the hydrolytic degradation of biomass waste such as rice straw, banana peel, and chicken feathers to be converted into mature compost within a shorter time. Validation on the maturity of the treated substrates and measurements of the level of phytotoxicity in the compost were studied based on the germination index (GI) of Japanese mustard seeds. Results showed that all treated substrates provided high GI of more than 60% at its optimum concentration which indicates the significant contribution of SCW pre-treatment to produce effective mature compost.

1. Introduction

In Malaysia, our agro-industry contributes to one of the most generated waste whereby 1.2 million tonnes are disposed to the landfill per year [1]. Generation of agricultural waste reaching 0.122 kg/cap/day in 2009 and expected to reach 0.210 kg/cap/day by 2025 [2]. Traditional composting is a general approach to convert these wastes due to its low cost techniques and simplicity. However, this conventional method consumes large carbon footprint and time to complete its degradation which often produces immature compost [3]. Hence, advanced technologies and strategies are required to overcome these problems.

One such technology is the subcritical water (SCW) treatment. The term subcritical water denotes to liquid water at temperature higher than the normal boiling point (100ºC) and below the critical temperature (374ºC) with pressure higher than vapour saturation up to 22.1 MPa to maintain the water in its liquid state [4]. The characteristics of SCW technology include fast decomposition of a variety of organic waste at low temperatures and pressures without generating harmful gases, complete disinfection of bad bacteria and virus, as well as removal of odor. Furthermore, the water acts as a green solvent and catalyst which contributes to rapid hydrolysis of recalcitrant biomass waste into smaller molecules which in turn speeds up the composting process. Traditional composting requires 2-3 months to complete compared to SCW pre-treated waste which degrade easier into mature compost within 7 days.

Therefore, the purpose of this study is to accelerate the degradation of a few selected waste with different textures i.e. rice straw, banana waste and chicken feather and further studied for its potential production as an organic fertilizer by using the SCW treatment. These wastes were selected due to the availability of this material, high content of natural nutrients and potential conversion to value-added products. In agricultural practice, rice straw generally goes through slow decomposition where it takes around 90 days to produce mature compost [5]. This is due to its lignocellulosic content whereby rice straw consists of 35% cellulose, 18% hemicellulose and 15% lignin [6]. Presence of hemicellulose and lignin form a barrier for microbial access to cellulose, thus hinder the enzymatic digestion of rice straw [7].

The compost produced were subjected to germination index which is as an important bioassay to measure level of phytotoxicity in the compost [8]. There has been limited research on the effect of subcritical water treatment of biomass for its rapid conversion into compost. Therefore, this study investigates and evaluates the performance of agro-industry waste treated with subcritical water treatment for its potential as organic fertilizer to promote sustainable agriculture.

2. Materials and methods

2.1 Collection of organic waste

Organic waste used in this study were rice straw, chicken feather and banana waste. Rice straw was collected from nearby paddy field while chicken feather and banana waste were collected from a wet market in Muar, Johor.

2.2 Subcritical water treatment

Two hydrolysis experiments were conducted using a $2m^3$ subcritical water (SCW) system available at laboratory in UTM Pagoh, Muar, Johor. In this study, one experiment was performed by using rice straw and another experiment using a mixture of chicken feather and banana waste. Rice straw of 250 kg were loaded in the reactor and run at 1.2 MPa pressure for 30 minutes. The next batch was 550 kg mixture of chicken feather and banana waste and run at 1.5 MPa pressure for 15 minutes. Favourable reaction conditions were selected based on previous trials for nutrient recovery.

2.3 Analysis of nutrient

The product produced were further analysed for its nutritional content which were total nitrogen (N), phosphorus (P) and potassium (K). These nutritional content was compared with commercialized organic fertilizer (COF) bought off-shelf. The N component was measured using a protein analysis method by following Malaysian Standard (MS 417: Part 3: 1994) while P and K were determined using inductively coupled plasma-optical emission spectrometry (ICP-OES). The pH and conductivity of all samples were measured using pH meter (HI 98107) and EC portable meter (HI 98304).

2.4 Germination index (GI)

Assessment of maturity and stability of organic fertilizer produced were done using germination index (GI) test. A comparative study between the SCW organic fertilizers (SCW-RS and SCW-BC) and a COF (bought as solid) were subjected to phytotoxicity bioassays where the Japanese mustard seed was grown in fertilizers diluted with distilled water to various concentrations (non-dilution, dilution 1:100 and dilution 1:1000). Five seeds were sown in each Petri dish lined with filter paper. Distilled water was used as a control and all test were conducted in triplicate. All the samples were placed in the dark for 5 days. Phytotoxicity was determined by GI test which require observation on numbers of germinated seed and measurement of root length. After 5 days, all the germinated seeds was counted and the root length produced from the seeds were measured to the nearest millimeter with a ruler. The GI was calculated according to the formula proposed by Zucconi et al. [9]:

$$\textbf{\% Germination} = \frac{\text{Average number of germinated seeds in test sample}}{\text{Average number of germinated seeds in control sample}} \text{ x } 100 \quad (1)$$

$$\textbf{\% Root elongation} = \frac{\text{Average length of root in test sample}}{\text{Average length of root in control sample}} \text{ x } 100 \quad (2)$$

$$\textbf{Germination Index (GI)} = \frac{(\text{\% Germination}) \text{ x } (\text{\% Root elongation})}{100} \quad (3)$$

3. Results and discussion

3.1 Organic fertilizer production by SCW treatment

In this study, two types of organic fertilizers were successfully produced. Treated rice straw (SCW-RS) remained as >90% solid, and treated banana and chicken waste (SCW-BC) turned into almost 99% liquid. The concentration of nitrogen (N), phosphorus (P) and potassium (K) were determined and compared with COF; benchmarked to the Malaysian Standard (MS1517:2012) as shown in Table 1.

Table 1. Nutrient composition of organic fertilizers.

Nutrient content	SCW-RS	SCW-BC	COF	MS 1517:2012 Standard
Nitrogen, N (%)	0.32	2.80	1.30	> 1.5
Phosphorus, P (%)	0.07	0.03	0.70	NA
Potassium, K (%)	1.18	0.23	0.70	NA

Based on the NPK analysis, rapid hydrolysis of the rice straw produced highest amount of K compared to SCW-BC and COF. However, N content itself did not meet the standard requirement of an organic fertilizer which is natural for high carbon waste.

Conversely, SCW-BC contained the highest amount of N of 28 000 mg/kg (2.80%) compared to others due to the use of chicken feathers which are rich in protein [10]. Comparatively, it is reported that composting of raw chicken feather with *Bacillus subtilis* for 30 days produced only 0.72 mg/kg of nitrogen [11]. Due to this, utilization of chicken feathers as a source of nitrogen in organic fertilizer previously was limited due to the recalcitrant structure of keratin protein in its feathers. Meanwhile, in this study, rapid hydrolysis of chicken feathers to organic fertilizer could be achieved within a week. Moreover, banana waste increased the P content which suggests mixtures of waste to formulate effective organic fertilizer can be done effectively to improve crop productivity. Therefore, SCW treatment was proven to recover variety of nutrients from waste biomass to produce organic fertilizer with essential nutrients needed for proper growth of plant.

3.2 pH and electrical conductivity (EC)

In the beginning of composting process, the initial pH value for SCW-RS and SCW-BC were 4.0 and 6.8, respectively. The average pH and EC values observed for 7-days of SCW-RS and SCW-BC compared to COF are shown in Table 2.

Table 2. pH and EC results of mature organic fertilizers.

Materials	Average pH	Average EC (µs/cm)
SCW- RS	5.43	1989
SCW-BC	7.73	3468
COF	9.7	1372

At the end of the composting, average pH values for SCW-RS and SCW-BC increased due to the degradation of organic matter whereby most of the organic nitrogen was converted into ammonia by microbial activities [12]. From previous studies, optimum pH value for mature compost varies between pH 6.0 to 8.0 depending on the type of waste used [13,14]. Electrical conductivity (EC) refers to the total soluble salt content in the compost whereby increase in EC denotes to the formation of minerals salts including ammonium ions and phosphates during decomposition of organic matter [15]. It is reported that EC value greater than 4000 µS/cm are phytotoxic to the plant growth and value less than 4000 µS/cm are recommended as bio-fertilizers [16]. In this study, the EC values are within the preferred range at 1989 µS/cm for SCW-RS and 3468 µS/cm for SCW-BC, respectively.

3.3 Germination index (GI)

The germination index (GI) test is necessary to be done prior to the application of organic fertilizer on agricultural soils to reduce risk to the crops. The GI value lower than 60% is perceived as immature compost and may inhibit plant growth due to the presence of ammonia or heavy metals whereas GI higher than 80% is phytotoxic-free and used as a benchmark for mature compost [17]. For this study, phytotoxicity test were done using various concentrations which is non-dilution, dilution 1:100 (1%) and dilution 1:1000 (0.1%). This dilution is important to determine the nutrients concentration needed by plants for its germination.

Table 3 shows the results for germination rate and average root length of Japanese mustard seed using SCW-RS and SCW-BC compared to COF.

Table 3. Comparative studies on plant bioassay

Results	Non-diluted	0.1%	1%	Distilled water (Control)
SCW-RS				
Germination rate (%)	0	80	80	100
Average root length (mm)	0	37.73	46.03	46.23
SCW-BC				
Germination rate (%)	0	93.4	20	100
Average root length (mm)	0	30.27	4.5	46.23
COF				
Germination rate (%)	0	100	93.4	100
Average root length (mm)	0	58	41.7	46.23

When all organic fertilizers were undiluted, the GI value was 0 indicating high concentrations can negatively affect germination of seed [18]. This was also observed in 1% SCW-BC with the GI value of only 1.95% indicating strong phytotoxic effect on plant. This is possible due to its concentrated nutrients and high level of salts resulting in the inhibition of seed germination and radicle growth. Hence, further dilution is necessary to reduce the concentrated nutrients down to the level required by the plants. All other GI values exceeded 60% which indicates acceptable range for mature fertilizer.

Throughout the study, it was observed that solid SCW-RS required less dilution compared to liquid SCW-BC. Meanwhile, further dilution of COF contributes to high GI indicating no phytotoxicity effect on the plant. Thus, acceptable dilutions for SCW-RS, SCW-BC and COF were 1%, 0.1% and 0.1%, respectively. The GI values can be improved further by adding supplemental nutrients in the formulation. Any added nutrients in COF is not reported by the manufacturer. Figure 1 summarizes the germination index of organic fertilizer using 0.1% and 1% dilutions.

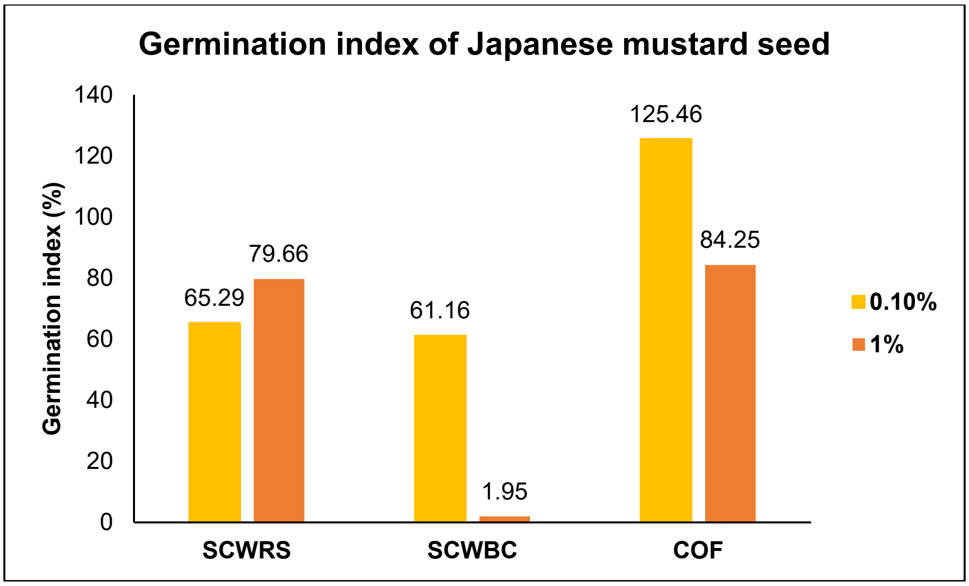

Figure 1. Germination index using organic fertilizer at different dilutions.

4. Conclusion

In conclusion, SCW pre-treated rice straw and mixture of banana waste with chicken feather could be formulated further as organic fertilizer based on the nutrient content analysis and positive result of germination index. Thus, SCW hydrolysis is a feasible treatment that could rapidly hydrolyze organic waste and enhance composting. This is a sustainable solution which could effectively convert organic waste into rich nutrient source for the plants.

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