

## Recycling of Sago (*Metroxylon sago*) Bagasse with Chicken Manure Slurry through Co-composting

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### ABSTRACT

Mass generation of bagasse wastes from every 100 kg of sago starch pith being processed are likely to pollute the water when they are discarded into rivers. The increase of livestock production increases manure production and improper management of these manures will pollute the soil and environment, and causing diseases outbreak. Co-composting of sago bagasse and chicken manure could serve as a viable alternative of managing these wastes. In order to reduce pollution, the objective of this study was to co-compost sago bagasse and chicken manure slurry to obtain a high quality organic fertilizer. The sago bagasse was thoroughly mixed with chicken manure slurry, chicken feed, and molasses in polystyrene boxes. Co-compost temperature readings were taken 3 times daily. Nitrogen and P concentrations increased (1.46 and 0.12%, respectively), whereas C content decreased (48.6%) throughout the co-composting. The CEC increased from 45.7 to 68.3 cmol kg<sup>-1</sup> indicating humified organic material. By the end of co-composting, humic acid and ash contents also increased from 7.3 to 10.0% and 7.1 to 11.6%, respectively. The pH of the co-compost increased from 4.78 to 7.21. The final co-compost had no foul odour, but it had low heavy metals content, and a desired amount of nutrients. Seed germination indices of phytotoxicity test were above 80% of final co-compost. Co-compost product with balanced nutrients content can be produced by co-composting sago bagasse and chicken manure slurry.

**Keywords:** Agricultural waste management, Humic acid, Organic fertilizer, Phytotoxicity test.

### INTRODUCTION

The sago palm is indigenous to South East Asia. It grows well mainly on peat soil and it has been the best option as starch source for the world (Chew *et al.*, 1998). Production of sago and the Malaysian export value has been increasing by 15 to 20% every year. It is reported as the fifth agricultural income to the country after pepper, palm oil, cocoa, and rubber (Abd-Aziz, 2002; Awg-Adeni *et al.*, 2009). At present, Sarawak, a state of Malaysia, is the world's biggest exporter of sago starch, exporting about 45,000 tons per annum (Apun *et al.*, 2009). Sago waste is a

copious fibrous residue and it is usually disposed of after the extraction of starch from the sago trunk. According to Cecil (2002), for every 100 kg of sago starch in pith, approximately 10 kg of sago bagasse (or commonly known as 'hampas') is generated, and these sago bagasse are likely to be discarded into rivers because most of the sago processing factories are built near the rivers without any facilities for wastewater treatment. This practice may cause water pollution. In addition, extraction of starch in an inefficient way will contribute to large amounts of waste (Oates and Hicks, 2002). Even when the concentration of this

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waste does not exceed the standard limits, there is still a potential for long-term contamination (Quek *et al.*, 1998). The quantity of sago bagasse being generated may be higher if there is inefficient extraction process as sugars, proteins, and starches can lead to high BOD and COD levels in rivers (Cecil, 2002; Vikineswary *et al.*, 1994).

In recent times, wastes generated from chicken farms are increasing as a result of rapid growth of the chicken farm industry (Arifin *et al.*, 2006). Thus, the application of chicken farm wastes as sources of nutrients for the agricultural sector has become popular. Currently, chicken manure is usually applied directly as organic fertilizer in agriculture. However, direct application of chicken manure in agriculture causes environmental pollution and diseases outbreak. Turning chicken manure into slurry has the potential to be used in co-composting.

In order to reduce environmental pollution, sago bagasse and chicken manure slurry can be co-composted to obtain high quality organic fertilizers. This hypothesis was adopted in the present study as sago bagasse has a high C/N ratio and slow to decompose on its own. If it is co-composted with a low C/N material such as chicken manure slurry which is also serves as source of microorganisms, a more favorable ratio can be achieved for rapid decomposition of sago bagasse. This may lead to production of a co-compost that is rich in plant nutrients (Abdulla, 2007).

Apart from producing organic fertilizers from sago bagasse and chicken manure, this alternative way of managing these wastes may contribute to reduction of environmental pollution. Co-composting is an interesting example of integrated waste management. It is the most suitable approach for recycling solid and liquid wastes into high organic matter content materials that can be used for environmental preservation and restoration. Co-composting can be defined as biological decomposition and stabilization of two different types of

wastes (Ahring *et al.*, 1992; Angelidaki and Ahring, 1997), by producing thermophilic temperatures to produce a co-compost product that is free from pathogens, heavy metals, and weed seeds (Gopinathan and Thirumurthy, 2012). In addition, co-composting allows resource recovery with many advantages. For example, it costs less than separate treatment systems, better handling and digestibility of the solid waste, as well as being able to produce a better nutrient balance output (Angelidaki and Ahring, 1997).

Generation of co-compost has the potential to reduce environmental pollution caused by agricultural wastes such as sago bagasse and chemical fertilizers. According to Smidt *et al.* (2007), co-composting can be considered as a humification technology that enables a large part of original organic matter to be mineralized and transform residual organic matter into new organic materials called humic substances, which are known to be one of the greatest carbon reservoirs on earth (Campitelli *et al.*, 2006; Pena-Mendez *et al.*, 2005).

The essential factor that affects the successful use of agricultural manure compost such as chicken manure is its stability and maturity. This leads to generation of differences in the chemical composition and other characteristics in the finished composts. Application of unstable or immature compost generates an anaerobic condition that releases phytotoxic compounds during co-composting (Mathur *et al.*, 1993; Hue and Liu, 1995). The most important feature that determines whether the finished compost is safe to be used is its phytotoxicity. Compost stability is determined by the microbial biomass activity level (Iannotti *et al.*, 1994), while compost maturity is defined as degree of decomposition of toxic organic substances being produced during the active co-composting stage (Wu *et al.*, 2000).

Developing a new technique to manage agricultural wastes in Malaysia and elsewhere is a challenge. In order to reduce environmental pollution, sago bagasse and

chicken manure slurry were co-composted to obtain a high quality organic fertilizer. This study also investigated the effect of water extract from the organic fertilizer on the germination of maize seeds (*Zea mays*) so as to determine its phytotoxicity.

## MATERIALS AND METHODS

### Co-composting Site

The co-composting process was conducted at the Research Complex of Universiti Putra Malaysia Bintulu Sarawak Campus, Malaysia. Three polystyrene boxes with length of 38 cm, width of 36 cm, and height of 32 cm were used for the co-composting. A total of 8 holes with 2 cm-diameter were drilled on the sides of the boxes to allow good aeration during the co-composting process. Although a relatively small reactor was used due to financial constraints, we hope for a scale-up of it in future for commercial utilization.

### Raw Materials and Co-composting Process

The sago bagasse was obtained from a company in Mukah, Sarawak, Malaysia. Sago bagasse was collected from the heap of the sago waste produced by a sago processing plant, 10 bags of sago bagasse were randomly sampled. The samples were bulked, after which they were divided into 3 portions, air-dried, and composted as 3 replications. Chicken manure was obtained from a chicken farm at Universiti Putra Malaysia Bintulu Sarawak Campus, Malaysia. The sago bagasse was shredded and air-dried before the co-composting process. The compost was produced by mixing 4.5 kg of shredded sago bagasse+450 g of chicken feed+3.5 L of chicken manure slurry+225 g of molasses. Chicken manure slurry was obtained by dissolving 225 g of chicken manure in 3.5 L of water and filtered. The sago bagasse served as

substrate (bulking material) and the chicken manure slurry was used as source of moisture, microbes, and nutrients. The chicken feed was included as source of energy for the microbes. Molasses was added to provide carbohydrate for the microbes. Mixing of the co-compost was done manually prior to co-composting. The chicken feed and molasses were added gradually while mixing the sago bagasse and chicken manure slurry so as to obtain a uniform mixture. The co-composting material was turned when necessary. The co-composting process was carried out in three replications so as to ascertain repeatability (precision) in minimizing error (Tables 1 and 2), and completed within 57 days. The ambient temperature and compost temperature were monitored daily (7 am, 1 pm, and 7 pm) using a digital thermometer with accuracy of  $\pm 1^{\circ}\text{C}$  (Cen-Tech, Pittsburgh).

### Physical, Chemical, and Biological Analyses

The sago bagasse was analysed for pH (Peech, 1965), total organic matter (OM), and total carbon (C) using the combustion method (Chefetz *et al.*, 1996); total N using micro-Kjeldahl method (Bremner and Lees, 1949); total P extracted using the method described by Tan (2003) and development of blue colour using Murphy and Riley (1962) method. Afterwards, C/N and C/P ratios were calculated. The leaching method described by Schollenberger and Dreiselbis (1945) was used to determine the cation exchange capacity (CEC) of the sago bagasse. Total potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), zinc (Zn), copper (Cu), iron (Fe) and lead (Pb) of sago bagasse were also determined. Humic acid (HA) content was determined using standard procedures (Stevenson, 1994; Ahmed *et al.*, 2004). The sago bagasse was also analyzed for ash content, ammonium ( $\text{NH}_4\text{-N}$ ), and nitrate ( $\text{NO}_3\text{-N}$ ) (Keeney and Nelson, 1982). Chicken manure, chicken feed, and molasses

**Table 1.** Selected chemical properties of shredded sago bagasse, chicken feed, molasses and chicken manure slurry.<sup>a</sup>

Property	Sago bagasse	Chicken feed	Molasses	Chicken manure slurry
pH	3.42±0.02	6.66±0.03	5.63±0.05	7.52±0.09
Total organic matter (%)	95.3±0.55	97.3±0.79	96.7±0.40	80.7±0.51
Total carbon (%)	52.4±0.61	56.4±0.43	56.1±0.56	46.8±0.52
Total nitrogen (%)	0.56±0.04	4.10±0.23	0.51±0.07	4.65±0.10
Total phosphorus (ppm)	62.1±0.55	1745.0±1.04	Trace	2960.0±1.05
C/N ratio	93.6±5.65	13.76±0.47	110.0±3.63	10.0±0.19
C/P ratio	8438.0±2.91	323.2±2.10	nd	158.1±1.61
Cation exchange capacity (cmol kg <sup>-1</sup> )	44.3±0.85	nd	nd	nd
Total K <sup>+</sup> (mg kg <sup>-1</sup> )	411.7±4.47	2710.0±1.02	76.7±0.75	127600.0±1.13
Total Ca <sup>2+</sup> (mg kg <sup>-1</sup> )	3636.0±7.21	382.7±1.35	111.1±1.05	44033.0±4.94
Total Mg <sup>2+</sup> (mg kg <sup>-1</sup> )	616.7±3.53	723.3±1.30	7.9±0.30	2800.0±8.31
Total Na <sup>+</sup> (mg kg <sup>-1</sup> )	49.0±1.00	24.0±0.50	87.3±0.60	5002.0±1.50
Total Zn <sup>2+</sup> (mg kg <sup>-1</sup> )	16.8±0.35	9.7±0.66	Trace	545.0±1.00
Total Cu <sup>2+</sup> (mg kg <sup>-1</sup> )	Trace	Trace	Trace	309.0±1.00
Total Fe <sup>2+</sup> (mg kg <sup>-1</sup> )	85.6±0.45	330.0±1.01	Trace	1579.0±2.84
Total Mn <sup>2+</sup> (mg kg <sup>-1</sup> )	230.7±0.73	Trace	Trace	450.0±1.32
NH <sub>4</sub> -N (mg kg <sup>-1</sup> )	53.6±0.72	28.0±0.62	14.0±0.64	1288.0±2.02
NO <sub>3</sub> -N (mg kg <sup>-1</sup> )	14.0±0.80	16.3±0.55	11.6±7.5	91.6±0.95
Humic acid (%)	2.0±0.40	nd	nd	nd
Ash content (%)	4.6±0.50	nd	nd	nd
Bacterial count (CFU mL <sup>-1</sup> )	nd	nd	nd	1.13×10 <sup>7</sup> ±0.30

<sup>a</sup>To convert mg L<sup>-1</sup> to percentage (%), divide by 10,000, nd= Not determined.

**Table 2.** Selected chemical properties of before and after co-composting of sago bagasse.

Property	Before co-composting	After co-composting
pH	4.78±0.03	7.21±0.02
Electrical conductivity (dS m <sup>-1</sup> )	5.2±0.10	7.1±0.05
Moisture content (%)	64.0±0.57	50.0±1.15
Total organic matter (%)	92.9±0.60	88.4±0.90
Total carbon (%)	51.1±0.70	48.6±0.30
Total nitrogen (%)	0.84±0.02	1.46±0.02
Total phosphorus (ppm)	850±6.02	1260±6.42
C/N ratio	60.8±5.00	33.3±2.00
C/P ratio	601.2±6.00	385.3±5.00
Cation exchange capacity (cmol kg <sup>-1</sup> )	45.7±0.40	68.3±0.36
Total K <sup>+</sup> (mg kg <sup>-1</sup> )	1810.0±4.66	4157.2±4.80
Total Ca <sup>2+</sup> (mg kg <sup>-1</sup> )	7780.0±5.50	10810.0±7.63
Total Mg <sup>2+</sup> (mg kg <sup>-1</sup> )	913.0±3.60	1663.3±1.19
Total Na <sup>+</sup> (mg kg <sup>-1</sup> )	425.0±5.00	651.0±7.20
Total Zn <sup>2+</sup> (mg kg <sup>-1</sup> )	38.6±0.73	61.7±0.40
Total Cu <sup>2+</sup> (mg kg <sup>-1</sup> )	19.8±0.15	5.7±0.40
Total Fe <sup>2+</sup> (mg kg <sup>-1</sup> )	106.0±0.51	57.2±0.60
Total Mn <sup>2+</sup> (mg kg <sup>-1</sup> )	226.0±2.08	427.5±0.76
Humic acid (%)	7.3±0.10	10.0±0.30
Ash content (%)	7.1±0.10	11.6±0.70
NH <sub>4</sub> -N (mg kg <sup>-1</sup> )	32.6±0.30	28.0±0.75
NO <sub>3</sub> -N (mg kg <sup>-1</sup> )	28.0±0.51	32.0±0.92
Bacterial count (CFU g <sup>-1</sup> )	2.45 x 10 <sup>8</sup> ±0.20	2.47 x 10 <sup>7</sup> ±0.15

were also analyzed for pH, total OM, total C, total N, total P, C/N and C/P ratio, total cations (K, Ca, Mg, Na, Zn, Cu, Fe, and Mn), ash content, ammonium (NH<sub>4</sub>-N), and nitrate (NO<sub>3</sub>-N) using the methods that were previously cited.

The mixture of the sago bagasse, chicken manure slurry, chicken feed, and molasses were analysed for pH, total OM, total C, total N, total P, C/N and C/P ratio, CEC, total cations (K, Ca, Mg, Na, Zn, Cu, Fe and Mn), HA content, ash content, ammonium (NH<sub>4</sub>-N), nitrate (NO<sub>3</sub>-N), and electrical conductivity (EC) before and after co-composting. All analyses were done in triplicate. Changes in the co-compost colour, texture, particle size, and odour were recorded through physical observation. Spread plate count method was carried out to quantify viable bacterial count on the first and final co-composting days, and chicken manure slurry (Brock and Madigan, 1991). One gram of co-compost was weighed into a 9 mL sterile distilled water tube. Serial dilutions were carried out by shaking the

solution for 15 minutes, and then filtering, using a sterile cheese cloth. Next, 1 mL of the solution was pipetted into the next tube containing 9 mL of sterile distilled water to produce 1:100 dilution factor. Serial dilution was repeated to produce 10<sup>-3</sup>, 10<sup>-4</sup>, 10<sup>-5</sup>, 10<sup>-6</sup> and 10<sup>-7</sup> dilution factors. Afterwards, 0.1 mL of the solution from each tube was pipetted into a Nutrient Agar and spread by hockey stick. Samples were then incubated at 28°C for 48 hours. Bacterial colony was counted by using colony counter under optical microscope (40x). The value of CFU was calculated as:

$$\text{CFU (mL}^{-1}\text{)} = \frac{\text{Number of colony counted/Amount of solution spread on plate}}{\text{Dilution factor}}$$

### Phytotoxicity Test

A phytotoxicity test based on germination bioassay was carried out using the method described by Zucconi *et al.* (1981). Ten gram of co-compost was weighed and mixed



with 100 mL of distilled water, and was shaken for 24 hours. The samples were centrifuged for 20 minutes at 10,000 g and the supernatants were filtered through Whatman No. 42 filter paper. The extract was diluted five times and another one with distilled water only served as the control. The pH and EC of these extract were determined. Ten FI HY Thai Super Sweet Corn maize seeds (*Zea mays*) were placed in 9 cm diameter petri dishes lined with a filter paper (Whatman No. 42). Five mL of extract was pipetted into each petri dish, while petri dishes with 5 mL distilled water only served as the control. Parafilm was used to seal each petri dish to prevent water loss while allowing air penetration. The petri dishes were placed in a dark area for seeds germination. Each replicate consisted of 10 seeds. Results were reported as means of the 10 replicates. Seed germination and measurement of length of roots and shoots were done after 72 hours for all of the extracts and the control. The germination index (GI) was obtained by multiplying germination (G) and relative root growth (RRG), both expressed as percentage (%) of the control values. The formula was as follows:

$$\text{Germination index} = (\text{G}\% \times \text{RRG}\%) \times 100$$

Where,  $\text{G}\% = (\text{Number of seeds germinated in a sample} / \text{Number of seeds germinated in the control}) \times 100$ ;  $\text{RRG}\% = (\text{Mean root length in a sample} / \text{Mean root length in the control}) \times 100$ ;

$\text{Vigor Index} = \text{Germination}\% \times (\text{Mean root length} + \text{Mean shoot length})$ .

### Data Analysis

Data obtained from the phytotoxicity test were analysed using the Statistical Analysis System (SAS) Version 9.2. Analysis of Variance (ANOVA) was used to detect significant difference between seed germination indices. Tukey test ( $P \leq 0.05$ ) was used to separate the means of the indices.

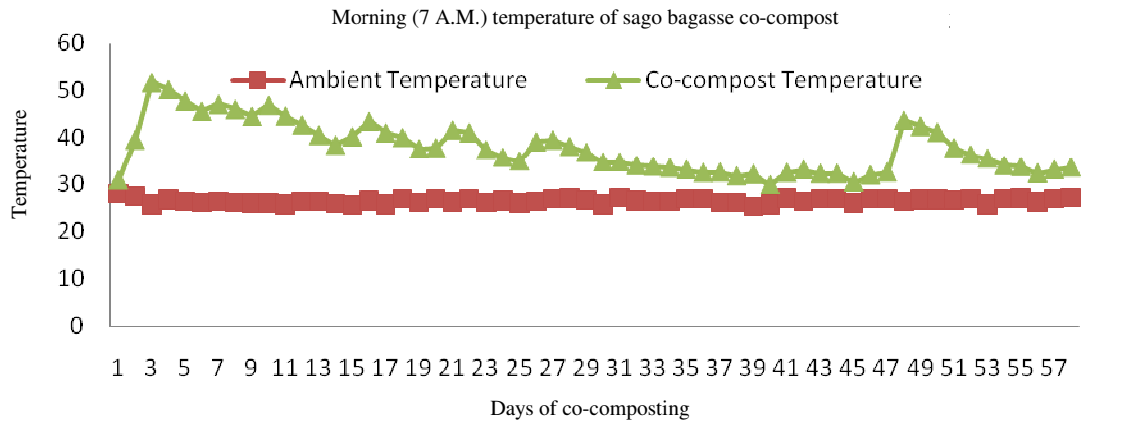
## RESULTS

### Selected Nutrients Composition of the Raw Materials Used in Co-composting

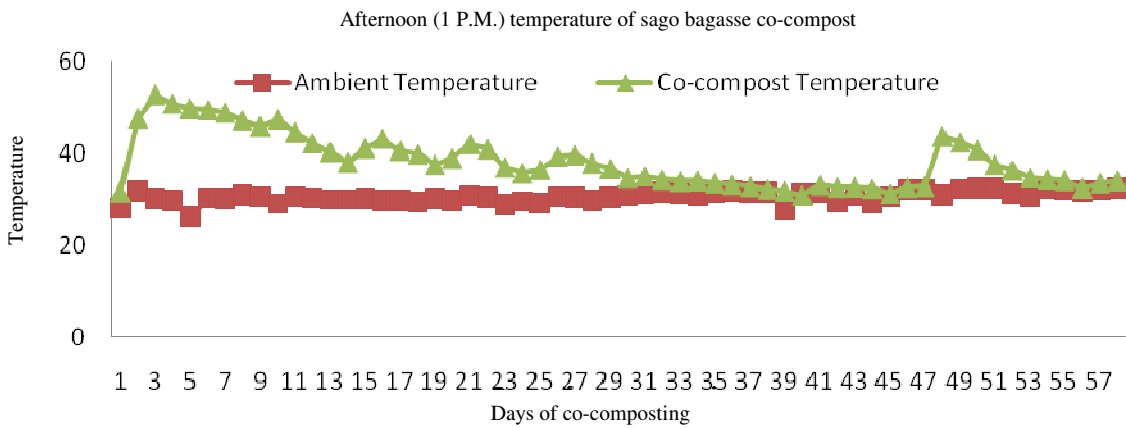
Table 1 shows that the K, Mg, Ca, and Na in the sago bagasse were high in the order of  $\text{Ca} > \text{Mg} > \text{K} > \text{Na}$  with values of 3636, 616.7, 411.7, and 49.0  $\text{mg kg}^{-1}$ , respectively. The pH of the sago bagasse was acidic (3.42). The sago bagasse had very low concentrations of Zn (16.8  $\text{mg kg}^{-1}$ ), Cu (trace), Fe (85.6  $\text{mg kg}^{-1}$ ) and Mn (230.7  $\text{mg kg}^{-1}$ ). These values were consistent with those reported by Woods End Research Laboratory (2005). The chicken manure slurry had a lower C/N ratio (10.0) but it had higher concentrations of P (2,960  $\text{mg kg}^{-1}$ ), K (127,600  $\text{mg kg}^{-1}$ ), Ca (44,033  $\text{mg kg}^{-1}$ ), Na (5,002  $\text{mg kg}^{-1}$ ) and Mg (2,800  $\text{mg kg}^{-1}$ ) (Table 1). The chicken feed used also had a lower C/N ratio (13.76) compared to the sago bagasse (93.6). It also had higher concentrations of N (4.10%) and other nutrients. The molasses had a lower N concentration (0.51%).

### Co-composting Process and Temperature Profile

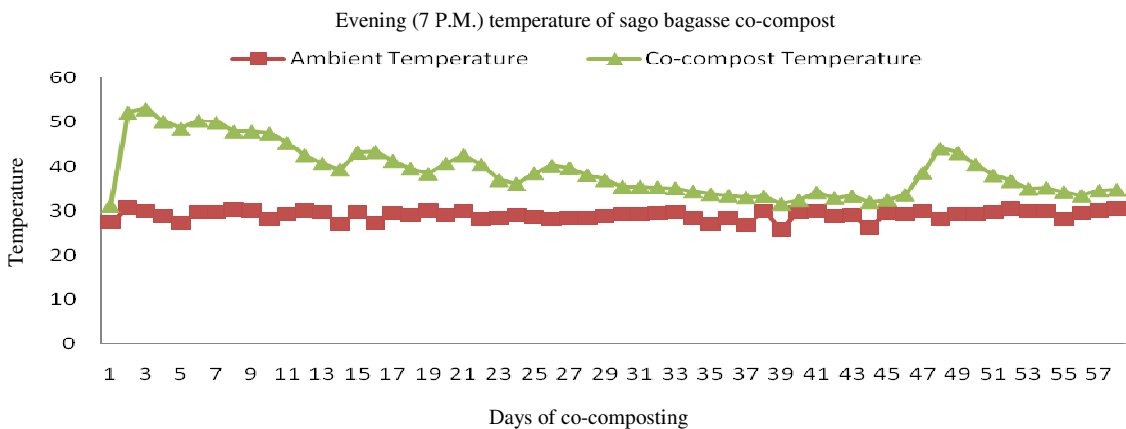
Three typical co-composting phases were observed (Figure 1; a, b and c) during the co-composting process. The ambient temperature was between 25 to 32.5°C throughout the co-composting period. The temperature of the co-compost was at mesophilic stage in the morning (7 am) and afternoon (1 pm) on the first day of co-composting. The temperature increased sharply to thermophilic (52.1°C) on the second day and it was maintained between 45.3 to 52.1°C from day 2 until day 10 of co-composting (Figure 2). Turning was done to obtain uniform temperature. The thermophilic phase was continued until day 10. The thermophilic temperature obtained in this study was higher compared to the previous work by Aldry *et al.* (2009) who



(a)



(b)



(c)

Figure 1. Co-compost temperature readings in (a) Morning (7 am); (b) Afternoon (1 pm), and (c) Evening (7 pm).



**Figure 2.** (a) Colour and texture of raw sago bagasse, and (b) Colour and texture of finished matured sago waste co-compost.

also used sago bagasse as feedstock but failed to achieve thermophilic stage during composting.

After day 10, the temperature gradually decreased to below 45°C to second mesophilic stage as the food sources available to thermophilic organisms started to deplete. Temperature range of 32 and 44.1°C was maintained from day 11 till day 57 (period when the compost temperature was equal to ambient temperature). At day 40, fungus started to grow throughout the co-composting materials. This process followed gradual depletion of bacteria. This could be observed whereby the bacterial count decreased after the co-composting process (Table 3). At the end of co-composting, the average temperature inside the box was 34.8°C. The temperature slightly increased on day 46 because last turning of the compost was carried out to allow the compost to further stabilize.

Selected Physico-chemical and Biochemical Changes during Co-composting

The matured co-compost in the present study was brownish-black in color, soft, coarse with friable texture. It also had an earthy smell compared to the grayish-brown color of the raw sago bagasse. The sago bagasse was initially hard and rigid in texture (Figure 2). The co-compost became softer and coarser at the end of co-composting, and the moisture content of the final matured co-compost was 50% lower as compared to the initial value of 64.0% (Table 2).

Cation exchange capacity increased from 45.7 to 68.3 cmol kg<sup>-1</sup> (Table 2). The HA and ash contents at 57 days of co-composting increased from the initial amount of 7.3 to 10.0% and 7.1 to 11.6%, respectively. The C/N ratio of the sago bagasse was 93.6 with C and N values of 52.4 and 0.56%, respectively, while the C/P

**Table 3.** Bacterial counts for before and after co-composting of sago bagasse and chicken manure slurry.<sup>a</sup>

Sample	CFU mL <sup>-1</sup> of sample
First day mixed co-compost (10 <sup>-5</sup> dilution)	2.45 x 10 <sup>8</sup>
Final matured co-compost (10 <sup>-4</sup> dilution)	2.47 x 10 <sup>7</sup>
Chicken manure slurry (10 <sup>-4</sup> dilution)	1.13 x 10 <sup>7</sup>

<sup>a</sup> CFU mL<sup>-1</sup> = (Number of colony counted/Amount of spread on plate, mL)/Dilution factor.



ratio was 8438 with a P content of 62.1 mg kg<sup>-1</sup> (0.00621%). Nitrogen and P concentrations increased whereas C content decreased after co-composting (Table 2). The initial C/N ratio of co-compost was approximately 60.8, which decreased to 33.3 at the end of co-composting. Chicken manure slurry and chicken feed had lower C/N ratio (10.0 and 13.76, respectively) compared to the sago bagasse (93.6). Chicken manure slurry had a high moisture and N content (4.10%) while biodegradable sago bagasse was high in organic carbon and it also had good bulking properties. However, the C/N value of the finished co-compost (33.3) exceeded the range of 10-15.1 reported by Trautmann and Krasney (1997). The C/P ratio also decreased from 601.2 to 385.3.

The pH of the co-compost increased from 4.78 to 7.21 and its EC also increased from 5.2 to 7.1 dS m<sup>-1</sup> (Table 2). The final co-compost did not only have the desired nutrients but it also had very low heavy metals, hence suggesting that it was safe for use without causing toxicity to plants (Table 2). Nitrogen, P, K, Ca, Mg and Na contents increased after co-composting. The N, P, K, Ca, Mg, and Na contents in the matured co-

compost were 1.46, 0.126, 0.41, 1.08, 0.16, and 0.06%, respectively. The micronutrients also increased (Table 2). The ammonium (NH<sub>4</sub>-N) decreased from 32.6 to 28.0 mg L<sup>-1</sup> whereas nitrate (NO<sub>3</sub>-N) content increased from 28.0 to 32.0 mg L<sup>-1</sup>.

### Bacterial Count and Phytotoxicity Test

The initial total bacterial count was about 2.45×10<sup>8</sup> CFU mL<sup>-1</sup> when the chicken manure slurry was added and mixed together with the shredded sago bagasse. The bacterial count decreased to 2.47×10<sup>7</sup> CFU mL<sup>-1</sup> when the compost matured at day 57 (Table 3). The maize seeds germination indices in the co-composted sago bagasse were greater than 80% regardless of dilution factor (10, 100, and 1,000X) (Table 4). The heavy metal contents of the co-composted sago bagasse (Table 2) were lower than the thresholds provided by USEPA (1993).

## DISCUSSION

At the mesophilic stage of co-composting (first day), the co-compost was predominated by mesophilic bacteria consuming readily

**Table 4.** Summary of phytotoxicity test (seed germination) for co-composted sago bagasse.<sup>a</sup>

Co-compost	Mean root length (cm)	Mean shoot length (cm)	Mean seed germination (%)	Relative seed germination (%)	Relative root growth (%)	Germination index (%)	Vigour Index
Sago bagasse (Original)	3.63	1.17	90.0a	92.9b	96.5a	89.6a	432.0b
Sago bagasse (10 X)	3.43	1.42	93.3a	100a	81.1b	81.1b	452.5b
Sago bagasse (100X)	3.77	1.47	86.7b	90.b	89.1b	80.2b	454.3b
Sago bagasse (1000X)	4.18	1.60	86.7b	92.9b	98.8a	91.8a	501.1a
Sago bagasse (10000X)	4.10	1.67	86.7b	90.0b	96.9a	87.2a	500.3a
Control	4.23	1.55	93.3a	100a	100a	100a	539.3a

<sup>a</sup> Means within column with different letter(s) indicate significant difference by Tukey test at  $P \leq 0.05$ .



available and digestible substrate (mainly sugars and protein compounds), leading to generation of substantial amount of metabolic heat that caused the temperature to increase sharply to thermophilic stage (Day and Shaw, 2000). During thermophilic stage, the high temperature was less favorable for mesophilic bacteria and was dominated by mostly *Bacillus* species (thermophilic bacteria) that are responsible for protein and carbohydrate compounds decomposition (Strom, 1985). Lignin, which is the more stable material, was oxidized along the prolonged thermophilic phase (Baffi *et al.*, 2006). Bacteria and actinomycetes degrade sugars and proteins, whereas fungi are the major microorganisms present when cellulose, hemicelluloses, and lignin are available (Ayed *et al.*, 2007). Temperature determines the efficiency of co-composting as it affects the population dynamics and biological characteristics of microbes, and also the physicochemical properties of co-compost (Luo *et al.*, 2008). Moisture also plays an important role in regulating enzymes activities and microbial respiration during co-composting process (Hu *et al.*, 2008). In general, 50% of moisture is the minimum requirement for maintaining high microbial activity (Liang and Das McClendon, 2003). A maximum temperature of 52.1°C was able to destroy pathogens and to perform the sanitation of the co-compost. A study by Wiley and Westerberg (1969) found that compost temperature between 47 and 55°C maintained for three days was able to kill all the pathogens in composted sewage sludge which had been inoculated with polio virus, *Salmonella*, roundworm eggs, and *Candida albicans*. Temperature range of 32 and 44.1°C was maintained from day 11 till day 57 (period when the compost temperature was equal to ambient temperature). This suggests that the co-compost was mature. During this curing stage, microbial activity was low. Curing is defined as lower level of microbial activity and it is responsible for stabilizing the products resulting from active composting period. Fungus is the dominant microorganisms found in the curing stage when cellulose, hemicelluloses, and lignin

are available. (Ayed *et al.*, 2007). When the co-composting process was about to approach maturity, not all compounds were well decomposed. Microbes in the co-compost were able to construct long polymers by linking all those degraded materials. The polymers produced were restricted from further decomposition and became a humic compound). An evidence of this is presented in Table 2 where HA content was higher after co-composting compared to the first day of co-composting (Graves and Hattemer, 2000).

The co-compost became softer and coarser at the end of co-composting. This was mainly due to alteration of the structure of shredded sago bagasse during co-composting indicating cellulose and hemicellulose linkages were disrupted due to actions of cellulolytic and lignolytic microbes present during co-composting (Baharuddin *et al.*, 2010). The decrease in moisture content of the final matured co-compost (Table 2) was due to factors such as high thermophilic temperature and aeration caused evaporation thereby reducing the moisture content of the compost during co-composting. The high CEC of the final co-compost suggested that the organic material of the compost had been humified (Sullivan and Miller, 2000) and this could be observed in the increase of HA and ash contents at 57 days of co-composting (Table 2).

By co-composting sago bagasse (high C/N ratio) and chicken manure slurry (low C/N ratio), the benefits of each material can be used to optimize the co-composting process and the product by balancing and compensating the C/N ratio of the co-composting materials. The slightly high C/N value of the finished co-compost (33.3) was mainly due to combination of hemicellulose and lignin which protects cellulose (Kuhad *et al.*, 1997). Wong *et al.* (2001) also reported that enzymes produced from microbes have difficulties in degrading lignin and it shields the cellulose from further degradation. There was a reduction of C content at the end of co-composting and this was due to rapid degradation of cellulolytic and proliferation by

the microbes in co-compost which immobilize N (Satisha and Devarajan, 2007).

The release of mineral salts such as ammonium and phosphate during decomposition and mineralization of organic substances increased the EC during co-composting (Wong *et al.*, 2001). In the early stages of co-composting, organic acids accumulate as organic matter during decomposition by bacteria and fungi. The resulting increase in pH due to breakdown of organic acids facilitates the growth of fungi, which are responsible in decomposing lignin and cellulose. The organic acids usually break down further during co-composting, and hence increase co-compost pH (Trautmann and Krasney, 1997). The increase in pH during the co-composting was mainly due to protein degradation, a process that leads to ammonia release and rapid metabolic degradation of organic acids (Satisha and Devarajan, 2007). The ammonium ( $\text{NH}_4\text{-N}$ ) decreased from 32.6 to 28.0  $\text{mg kg}^{-1}$  whereas nitrate ( $\text{NO}_3\text{-N}$ ) content increased from 28.0 to 32.0  $\text{mg kg}^{-1}$  suggesting that part of  $\text{NH}_4$  was mineralized to  $\text{NO}_3$ . This explains the increase in the pH of the co-compost through evolution of ammonia (Baharuddin *et al.*, 2010).

The chicken manure slurry used in this study served as microbial seeding, thus, the application of effective microbes (EM) can be excluded to reduce the cost of a co-compost. The maize seeds germination indices were greater than 80% regardless of dilution factor (10x, 100x, and 1000x), indicating that the co-compost was phytotoxic-free and mature (Zuconi *et al.*, 1981; Tiquia and Tam, 1998). According to Tiquia and Tam (1998), seed germination index has proven to be the most sensitive test capable of detecting low levels of toxicity affecting root growth and high toxicity levels affecting seed germination. Compost stability based on temperature and  $\text{CO}_2$  evolution and its maturity based on seed germination are indeed two different characteristics of compost quality (Wu *et al.*, 2000). Generally, the degree of stability and maturity of co-compost are closely linked to each other as more stable compost tends to

be more mature. However, due to variation in compost materials and co-composting process, some stable co-compost require longer period to decompose and degrade phytotoxic substances. As a result, both variables need to be assessed to ensure high quality compost is produced. Wu and Ma (2001) showed that heavy metals caused phytotoxicity and they could delay the maturation of compost if heavy metals concentrations are higher than the standard threshold. In this work, the heavy metal contents of the co-composted sago bagasse (Table 2) were lower than the threshold provided by USEPA (1993).

## CONCLUSIONS

The co-compost produced had no foul odor, low heavy metals content, and the desired amount of nutrients. Seed germination indices of phytotoxicity test were above 80% for the final co-compost. The initial C/N ratio of co-compost was approximately 60.8 and it decreased to 33.3 at the end of co-composting. Chicken manure slurry and chicken feed had lower C/N ratio, high moisture and N content. However, the biodegradable sago bagasse was high in organic carbon and it also had good bulking properties. Co-compost with balanced nutrients can be produced by co-composting sago bagasse and chicken manure slurry. Testing of the co-compost product in the greenhouse and field is ongoing. Although the findings of the present study are limited composting using a relatively small reactor, the findings provided insight for co-composting sago bagasse. However, to make out findings commercially useable, we are at the moment soliciting for funds to achieve this aspect.

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## باز چرخانی باگاس نخل ساگو (*Metroxylon sagu*) با دوغاب کود مرغی به روش کمپوست سازی همزمان

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### چکیده

تولید انبوه باگاس ضایعات فرآوری هر ۱۰۰ کیلوگرم نشاسته مغز ساقه ساگو که به رودخانه ریخته می شود می تواند آب را آلوده کند. با بیشتر شدن تولیدات دامی، تولید کود دامی نیز افزایش می یابد و مدیریت نادرست این کودها منجر به آلودگی خاک و محیط زیست شده و به بروز امراض می انجامد. کمپوست سازی همزمان باگاس نخل ساگو (*Metroxylon sagu*) با کود مرغی می تواند به عنوان روش مدیریتی جایگزین و مطمئن به کار رود. بر این اساس، برای کاهش آلودگی، هدف پژوهش حاضر کمپوست سازی همزمان باگاس نخل ساگو (*Metroxylon sagu*) با دوغاب کود مرغی برای تهیه کود آلی با کیفیت بالا بود. به این منظور، باگاس ساگو کاملاً با دوغاب کود مرغی، خوراک طیور، و مولاس در جعبه های پلی استرین مخلوط شد. درجه حرارت در طی فرایند کمپوست سازی همزمان، روزانه سه نوبت اندازه گیری و ثبت شد. اندازه گیری نیتروژن و فسفر نشان داد که در طی این فرایند غلظت آنها افزایش یافت (به ترتیب ۱/۴۶٪ و ۰/۱۲٪) در حالیکه مقدار کربن کم شد (۴۸/۶٪). ظرفیت تبادل کاتیونی هم از ۴۵/۷ به ۶۸/۳ سانتی مول در کیلو گرم افزایش یافت که این نشانگر هموسی شدن مواد آلی بود. در انتهای فرایند کمپوست سازی، محتوی هومیک اسید و خاکستر نیز به ترتیب از مقدار ۷/۳٪ به ۱۰/۰٪ و از ۷/۱٪ به ۱۱/۶٪ رسید. اسیدیته هم-کمپوست هم از ۴/۷۸ به ۷/۲۱ افزایش یافت. در آخر فرایند، کمپوست به دست آمده بوی نامطلوبی نداشت ولی مقدار کمی فلزات سنگین و مقدار مناسبی عناصر غذایی (برای گیاه) داشت. شاخص های جوانه زنی بذر کمپوست نهایی در آزمون سمیت گیاهی (*phytotoxicity*) در حد ۸۰٪ بود. بنا بر این، با کمپوست سازی همزمان باگاس ساگو و دوغاب کود مرغی می توان کمپوستی دارای عناصر غذایی متعادل تولید کرد.