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Pilot-scale vermicomposting of pineapple wastes with earthworms native to Accra, Ghana

Nana O.K. Mainoo [a], Suzelle Barrington [a,*], Joann K. Whalen [a], Luis Sampedro [b]

[a] Faculty of Agricultural and Environmental Sciences, Macdonald Campus of McGill University, 21 111 Lakeshore, Ste Anne de Bellevue, Québec, Canada H9X 3V9
[b] Centro de Investigacións Forestais e Ambientais de Lourizán, Departamento de Ecoloxía, Apartado 127, 36080 Pontevedra, Galicia, Spain

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ABSTRACT

Pineapple wastes, an abundant organic waste in Accra, Ghana, were vermicomposted using native earthworms (*Eudrilus eugeniae* Kinberg) collected from the banks of streams and around bath houses of this city. Triplicate pilot-scale vermidigesters containing about 90 earthworms and three other control boxes with no earthworms were fed pineapple pulp or peels, and the loss of wet mass was monitored over 20 weeks. In a second experiment, a 1:1 mixture of pineapple peels and pulp (w/w) was fed to triplicate pilot-scale vermicomposters and control boxes during a 20 week period. One month after feeding ended, the vermicompost and composted (control) waste was air dried and analyzed. During the first experiment, the vermicomposted pineapple pulp and peels lost 99% and 87% of their wet mass, respectively, indicating the potential for vermicomposting. Fresh pineapple waste exhibited an initial pH of 4.4, but after 24 weeks, the vermicompost and compost had acquired a neutral to alkaline pH of 7.2–9.2. The vermicompost contained as much as 0.4% total N, 0.4% total P and 0.9% total K, and had a C:N ratio of 9–10. A reduction of 31–70% in the *Escherichia coli* plus *Salmonella* loads and 78–88% in the *Aspergillus* load was observed during vermicomposting. The rapid breakdown of pineapple wastes by *E. eugeniae* demonstrated the viability of vermicomposting as a simple and low cost technology recycling this waste into a soil amendment that could be used by the 2500 vegetable producers of Accra and its surrounding areas.

1. Introduction

Accra's rapid urbanization, coupled with Ghana's national debt, has left the metropolitan authority with insufficient resources for waste collection (Boadi and Kuitunen, 2003). This is especially evident in low-income areas where many residents dispose of wastes improperly, at informal dumpsites and in canals, water bodies and surface drains (Boadi and Kuitunen, 2003). One strategy to reduce indiscriminate dumping is to divert organic materials from the waste stream and convert them into organic mulch. Approximately 85% of Accra's solid waste includes food leftovers, rotting fruits, vegetables, leaves, crop residues, animal excreta and bones, which could be recycled (Asomani-Boateng and Haight, 1999; Boadi and Kuitunen, 2003). Pineapple wastes are particularly plentiful and local fruit juicing companies produce an estimated 1.25 tonnes of pineapple wastes per 1000 L of juice extracted. A medium-sized enterprise in Accra produces some 20 m^3 of pineapple juice per year solely for local consumption (Mainoo, 2006).

Small-scale waste recycling by vermicomposting is the accelerated breakdown of organic wastes by the combined action of microorganisms and earthworms in a mesophillic environment (Dominguez, 2004), and this process holds some promise as a waste management technology. The simplicity and low cost of vermicomposting could make it an attractive venture for resource-poor informal waste collectors in the city. Another compelling argument for vermiculture is that the organic mulch could be used by urban and peri-urban farmers. In 2000, there were approximately 2400 individuals involved in small scale commercial vegetable farming in Accra (Armar Klemensu and Maxwell, 2000). A waste recycling approach that includes vermicomposting could bring the communities involved closer to achieving the United Nation's Millennium Development goals for sanitation, health and employment (United Nations, 2006).

Mainoo et al. (2008) reported *Eudrilus eugeniae* (Kinberg), an appropriate vermicomposting earthworm, living around stream banks and bath houses in Accra, Ghana. As far as we know, *E. eugeniae*'s ability to decompose pineapple waste has not been reported previously, nor are the characteristics of vermicompost from pineapple waste known. The decomposition rate of pineapple wastes, due to the activities of earthworms and soil foodweb organisms, and the characteristics of the vermicompost remain to be determined. Vermicompost contains plant-available nutrients and organic matter, making it a valuable potting media, organic amendment and soil conditioner. The general range of nutrients offered by vermicomposts ranges from 0.36% to 4% total N, 0.13% to

* Corresponding author. Tel.: +1 514 398 7776; fax: +1 514 398 8387.
E-mail address: suzelle.barrington@mcgill.ca (S. Barrington).

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4.37% total P, and 0.22% to 3.74% total K (Aranda et al., 1999; Kaviraj and Sharma, 2003). Since pineapple wastes contain 0.5–1.2% total N (Adediran et al., 2003; Rani and Nand, 2004), its vermicomposting may produce an organic mulch as rich in nutrients as other organic fertilizers.

Another issue is that there is no thermophilic stage during vermicomposting, compared to composting, and the presence of pathogens and parasites could pose a health hazard to vermicompost producers and end-users. Equal amounts of *Aspergillus fumigatus* and *Aspergillus flavus* in the *Scedosporium* state were found in mature compost and vermicompost (Anastasi et al., 2005), suggesting that vermicomposting was as effective as composting at reducing the pathogen load. Whether this is the case for vermicompost from pineapple waste remains to be determined.

The objective of this study was to determine the suitability of vermicomposting with *E. eugeniae* for pineapple waste management in Accra, Ghana. Specifically, the decomposition rate of pineapple waste was investigated along with the nutrient content and microbial pathogen loads of the resulting vermicompost.

2. Methods

2.1. Earthworm culture and pineapple waste

Earthworms, namely *E. eugeniae*, were collected from the soil litter and root layers of stream banks and around bath houses at several sites around the city of Accra (Mainoo et al., 2008). Pineapple peels, approximately 5 cm long and 1.5 cm wide, were obtained from a community dump in Aladzo (Accra, Ghana). The Milani Food Processing Company in Abelenkpe (Accra, Ghana) supplied the pineapple pulp consisting of long particles less than 2 mm in diameter. Experiments were conducted in a greenhouse at the University of Ghana, Accra, Ghana between January and April, 2006.

2.2. Experiment 1: mass loss from pineapple waste during vermicomposting

Pilot-scale vermidigesters were used to monitor the decomposition of pineapple waste, measured as the loss of wet mass during 20 weeks. The vermidigesters were wooden boxes measuring 0.6 m by 0.6 m and 0.1 m in depth, with plywood sides and open at the top, which contained about 15 kg of the culture medium (soil, leaf litter and pineapple waste) and approximately 90 clitellate earthworms (adults). Wooden boxes with 15 kg of earthworm-free soil were also tested as a control. Two treatments, pineapple peels and pineapple pulp, were applied to the vermidigesters ($n = 12$ for each treatment) and control boxes ($n = 12$) during the experiment. Each vermibed or soil layer was evenly topped with 3 kg of pineapple peel or 6 kg of pineapple pulp. On the 5th, 10th, 15th and 20th week after feeding with pineapple peel, the surface waste was collected after gently brushing earthworm casts from the waste. After weighing on a Camry 20 kg spring scale, the pineapple peel waste was returned to the correct vermidigester or control box. All boxes were irrigated to maintain the moisture at about 80% water content. The same procedure was used to evaluate the decomposition of pineapple pulp, although sampling dates were the 5th, 10th and 15th day after feeding.

2.3. Experiment 2: vermicompost quality of pineapple waste

Three vermidigesters and one earthworm-free control (described in the previous section) were each fed 4 kg of mixed pineapple peels and pulp (1:1 w/w) every 3 weeks between January and April, 2006. The vermidigesters and control boxes were irrigated regularly to maintain the soil water content at 80% during the feeding period and for one more month after the last pineapple waste application. The earthworm casting at the top of the vermibed, representing a 5 cm layer, was subsequently removed from each vermidigester and dried in the sun for 2 days in preparation for analysis. The top 5 cm of the composted pineapple waste from the earthworm-free control was also removed and dried for 2 days before being analyzed.

2.4. Chemical and microbiological analyses

Vermicompost characterization was conducted with the waste decomposed during the second experiment using a 1:1 mixture of pineapple peels and pulp. Air-dried samples of fresh pineapple waste, vermicompost from three vermidigesters and composted pineapple waste from one control box, all representing a 1:1 mixture of pineapple peels and pulp (w/w), were ground to less than 2 mm in preparation for analysis. All chemical analyses were conducted in triplicate. The pH was determined in a 1:1 (w/v) vermicompost:water suspension. Total nitrogen was measured with the total Kjeldahl nitrogen method (Bremner, 1996) and total organic carbon with the Walkley–Black method (Nelson and Sommers, 1996). Total phosphorous was determined in perchloric acid digests and plant-available phosphorous was evaluated with the Bray-1 method after colorimetric analysis with the molybdate blue method at 712 nm (Kuo, 1996). Potassium was extracted with ammonium acetate and measured with a flame photometer (Helmke and Sparks, 1996). Since there was very little mineral soil associated with the materials studied, ammonium acetate-extractable K was assumed to be equivalent to total K.

The microbial load was evaluated for the fresh pineapple waste, vermicompost and composted pineapple waste from the control boxes, respectively. Microbiological analyses were performed in quadruplicates, using standard aseptic methods. MacConkey Agar and Sabouraud's Malt Agar were used as media for *Escherichia coli* plus *Salmonella* and *Aspergillus*, respectively. A 10 g homogenous sample of each organic substrate was placed into a sterilized medicinal flat bottle containing 90 ml Ringer's solution. After dilution (10^{-3} and 10^{-4}), the media were inoculated with the pour plate method, incubated for 48 h in Gallenkamp Pius 2 incubators set at 37 °C for *E. coli* and 25 °C for *Aspergillus*, and the number of colonies was counted.

2.5. Statistical analysis

The loss of wet mass from the pineapple waste was evaluated using exponential decay curves and the decay coefficients, k, were compared statistically with a t-test at the 95% confidence level (Montgomery and Runger, 2007). The chemical and microbiological characteristics of fresh pineapple waste, vermicompost and composted pineapple waste were evaluated by one-way analysis of variance, followed by contrast analysis (vermicompost vs. fresh pineapple waste) at the 95% confidence level.

3. Results and discussion

3.1. Pineapple waste decomposition rates

During the first 20 week experiment, the vermicomposted pineapple pulp (Fvc) lost 98.9% (±0.8%) of its wet mass while the composted pulp (Fc) in the control boxes lost 77.5% (±4.4%) of its wet mass. Pineapple peels suffered a less dramatic wet mass loss, with 86.9% (±3.2%) in the vermidigesters (Pvc) and 70.7% (±4.5%) in the controls (Pc). Waste in the vermidigesters (Fvc and Pvc) was transformed into a homogeneous mass, but in the earthworm-free controls, pineapple waste (Fc and Pc) remained in distinct clumps on the soil surface, indicating a lack of microbial degradation likely because of drying. Accordingly, vermicomposting did decompose

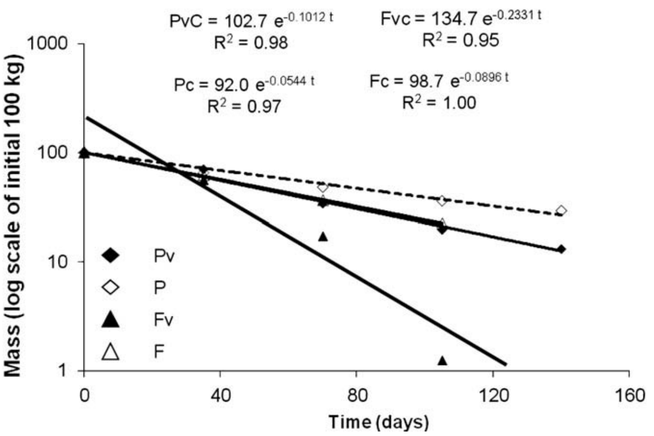

Fig. 1. Breakdown rates shown as the wet mass of pineapple peels and pulp remaining during a 20 week period. The coefficient of variation associated with the data ranges between 3% and 5% ($n = 12$ for each treatment). Trend lines and slopes of the lines were generated with Microsoft Excel 2002 software. Pvc and Fvc: vermicomposted peels and pulp, respectively; Pc and Fc: composted peels and pulp in earthworm-free controls, respectively; and t is time in days.

the pineapple waste, and especially the pulp, whereas the control treatments exposed to microbial decomposition seem to have suffered from a lower level of activity, likely because of the substrate dried out between watering events.

The loss of wet mass as a function of time is illustrated using a natural log scale in Fig. 1. The decay coefficients, k, for the pineapple waste were found to fit a first order equation:

$$M_t = M_i e^{kt} \quad (1)$$

where M_t and M_i are the wet mass at time t and 0, respectively, in kg; t is time in days; and k is the decay coefficient in days^{-1}.

With typically 80–85% water content, pineapple waste is subjected to high moisture losses, besides the organic matter loss that is a result of microbial decomposition during the vermicomposting and composting processes. The decomposition and drying of pineapple waste followed the order Fvc > Pvc $\geqslant$ Fc > Pc. The pineapple pulp decomposition and drying was significantly accelerated by earthworm activity (Fvc), compared to the control (Fc) which was simply composted ($P < 0.05$, t-test). The rate of mass loss was accelerated as of the 5th week, following the observation of earthworm activity beginning in the 3rd week, likely because the pineapple pulp became less acidic by this time. The rate of mass loss for the vermicomposted pulp accelerated after the initiation of earthworm activity. The vermicomposted pineapple peels dried faster than those simply composted ($P < 0.05$, t-test), but the difference in mass loss rate compared to the composted control was not as large as for the pulp. This slower decomposition and drying rate of the pineapple peels compared to the pulp can be attributed to their larger particle size, slower natural drying and higher lignin content of about 12% lignin (Rani and Nand, 2004) as compared to 4% for the pineapple pulp (Adediran et al., 2003). Thus, vermicomposting did accelerate the decomposition and mass loss of the pineapple waste compared to composting, which was limited by the drying of the waste between watering events.

3.2. Chemical composition of vermicompost

Initially, the fresh pineapple waste was moderately acidic with a pH of 4.4, but after vermicomposting or decomposition in earthworm-free soil, the pH ranged from 7.2 to 9.2 (Table 1). Since the change in pH was similar in vermidigesters as the earthworm-free control (Table 1), earthworms probably did not affect the pH of the vermicompost. The pH of vermicompost is substrate dependent (Ndegwa et al., 2000) and earthworms do not affect the pH of organic substrates, although they do exert physiological control, such as secreting intestinal Ca and excreting NH_4–N, to maintain neutral pH in their digestive tract (Dominguez, 2004). The initial acidity of the pineapple waste was problematic for earthworms and a few individuals perished in the first 2 days after adding the waste to the vermidigesters. Colonization of the pineapple waste usually proceeded on the 3rd week. Edwards and Bohlen (1996) reported that earthworms avoid substrates with a pH less than 4.5 and prolonged exposure can be lethal. Composting acidic fruit wastes for 2 weeks resulted in an increase in pH to neutrality, namely a pH of 6–7, because microorganisms readily degrade organic acids (Van Heerden et al., 2002). Accordingly, pre-composting pineapple waste before adding it to vermidigesters could be an option to reduce earthworm mortality.

During vermicomposting, the total N concentration of pineapple waste declined by as much as 53% (Table 1). This differs from vermicomposting studies where the N concentration remained stable or increased (Elvira et al., 1998; Atiyeh et al., 2000; Nogales et al., 2005). The increase in pH observed during pineapple waste decomposition could have led to NH_3 volatilisation because this process occurs in alkaline conditions. Also, NH_4^+ is soluble and tends to volatilize in the form of NH_3 as the waste loses moisture. In addition, frequent watering of the vermidigesters could stimulate leaching of NO_3–N or gaseous N loss via denitrification. The total organic C content of pineapple waste declined by 74–81% during vermicomposting (Table 1), which is consistent with the 19–67% loss of organic C from substrates during vermicomposting (Elvira et al., 1998; Nogales et al., 2005; Garg et al., 2006). Fresh pineapple wastes had a C/N ratio of about 21, but vermicompost had a C:N ratio less than 12, similar to a mature compost (Bernal et al., 1998).

The extractable K declined during pineapple waste decomposition in vermidigesters and the earthworm-free control (Table 1), probably a consequence of frequent watering and subsequent

Table 1
Chemical properties and microbial pathogen loads in fresh pineapple waste, vermicomposted pineapple waste from three vermicomposters (V1, V2, V3) and composted pineapple waste from one earthworm-free control. The starting material in all cases consisted of a 1:1 mixture of peels and pulp (w/w) that was air-dried prior to analysis. Values are the mean ± standard errors of 3–4 analytical replicates.

	PW	V1	V2	V3	C	V vs. PW
pH	4.4 ± 0.4	7.2 ± 0.2	9.2 ± 0.2	7.9 ± 0.3	8.7 ± 0.3	$P < 0.001$
Total nitrogen (%)	0.78 ± 0.05	0.29 ± 0.03	0.43 ± 0.08	0.38 ± 0.02	0.21 ± 0.02	$P < 0.001$
Total organic carbon (%)	40.5 ± 1.3	20.3 ± 3.2	28.0 ± 1.7	24.3 ± 1.4	13.3 ± 3	$P < 0.001$
Total potassium (%)	1.43 ± 0.09	0.46 ± 0.12	0.92 ± 0.13	0.52 ± 0.12	0.31 ± 0.09	$P < 0.001$
Total phosphorous (%)	0.20 ± 0.04	0.38 ± 0.08	0.38 ± 0.06	0.31 ± 0.03	0.12 ± 0.03	$P = 0.001$
Bray-1 phosphorous (mg/kg)	191 ± 13	344 ± 28	349 ± 25	304 ± 23	50.6 ± 9	$P < 0.001$
E. coli + *Salmonella* ($\times 10^4$ CFU/g)	13.7 ± 0.6	4.58 ± 1.7	9.45 ± 3.5	4.15 ± 1.7	3.83 ± 1.4	$P = 0.014$
Total *Aspergillus* ($\times 10^4$ CFU/g)	24.4 ± 1.0	3.00 ± 1.2	4.00 ± 1.5	5.30 ± 2.1	20.4 ± 7.9	$P = 0.003$

PW: pineapple waste, V: vermicompost, C: earthworm-free control. All values are expressed on a dry weight basis. The P values are the probability of a significant difference between pineapple waste and vermicompost.

leaching of this soluble element. Total P and available P concentrations were greater in vermicompost than in the composted pineapple waste (control) and fresh pineapple waste (Table 1). Since P is not volatile and sparingly soluble, it tends to become concentrated as the mass of waste decreases through earthworm- and microbial-mediated decomposition.

3.3. Microbial loads

Fresh pineapple wastes contained appreciable *E. coli* plus *Salmonella* (both can grow in MacConkey agar) and *Aspergillus* loads, but there was a 31–70% reduction in *E. coli* plus *Salmonella* loads and a 78–88% reduction in *Aspergillus* load during vermicomposting (Table 1). In the earthworm-free control, there was a decline of 75% in *E. coli* plus *Salmonella* during the same period, as well as a 16% decline in *Aspergillus* (Table 1). Further investigation with more replicate earthworm-free controls is required to understand the abiotic and biotic factors that control pathogen populations in vermicomposters and earthworm-free decomposition systems. The low pathogen load in vermicompost, compared to the fresh pineapple waste, suggests that it is a safer material to handle, store and transport, although appropriate sanitation practices are recommended such as wearing gloves during handling and hand-washing after handling.

4. Conclusions

Pineapple waste is acidic and fiberous but it can be decomposed in vermicomposters by *E. eugeniae*, a native earthworm to Accra, Ghana. After 5 months, earthworms produced homogenous humus-like material containing as much as 0.4% total N, 0.4% total P and 0.9% total K. This vermicompost could therefore be used as a soil conditioner. Its nutrient value could be boosted by controlling the pH and water regime during vermicomposting to conserve more N and K, but this remains to be confirmed. The effect of mixing pineapple waste with other organic substrates, such as food processing residues, palm fiber, cocoa and mineral supplements such as rock phosphate, could affect the decomposition rate and nutrient value of the final vermicompost. Further research is required to investigate cost effective strategies for vermicomposting pineapple waste.

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