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

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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 vermicomposters 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 pathogen load was demonstrated.

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 m³ 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 mesophilic 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...
litter and root layers of stream banks and around bath houses at
Accra, Ghana. Specifically, the decomposition rate of pineapple
peel waste was returned to the correct vermidigester or
control box. All boxes were irrigated to maintain the moisture at
80% during the feeding period and for one more month after the last pineapple
feeding.

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 Adadzo (Accra, Ghana). The Milani Food
Processing Company in Abelenkpe (Accra, Ghana) supplied the
pineapple pulp consisting of long particles less than 2 mm in diam-
eter. Experiments were conducted in a greenhouse at the Univer-
sity 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 decomposi-
tion 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 citel-
late 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 vermicompost 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 evalu-
ate 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 (de-
scribed in the previous section) were each fed 4 kg of mixed pine-
apple peels and pulp (1:1 w/w) every 3 weeks between January and
April, 2006. The vermidigesters and control boxes were irri-
gated 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 vermi-
bed, 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 mix-
ture of pineapple peels and pulp (w/w), were ground to less than
2 mm in preparation for analysis. All chemical analyses were con-
ducted in triplicate. The pH was determined in a 1:1 (w/v) vermi-
compost: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 di-
gests 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
ammoniumacetateandmeasuredwithaflamephotometer(Helm-
ke and Sparks, 1996). Since there was very little mineral soil asso-
ciated 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 dilu-
tion (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 microbiologi-
cal 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 pine-
apple pulp (Fvc) lost 98.9% (±0.8%) of its wet mass while the com-
posted pulp (Fc) in the control boxes lost 77.5% (±4.4%) of its wet
mass. Pineapple peas 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 trans-
formed into a homogeneous mass, but in the earthworm-free con-
trols, 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
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:

\[
M_t = M_0 e^{kt}
\]

where \( M_0 \) and \( M_t \) are the wet mass at time \( t = 0 \) and \( t \), 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 \( Fvc > Pvc > Fc > Pc \). 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 (Ndewa 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; Ateyeh 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

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**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.

<table>
<thead>
<tr>
<th></th>
<th>PW</th>
<th>V1</th>
<th>V2</th>
<th>V3</th>
<th>C</th>
<th>V vs. PW</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>4.4 ± 0.4</td>
<td>7.2 ± 0.2</td>
<td>9.2 ± 0.2</td>
<td>7.9 ± 0.3</td>
<td>8.7 ± 0.3</td>
<td>( P &lt; 0.001 )</td>
</tr>
<tr>
<td>Total nitrogen (%)</td>
<td>0.78 ± 0.05</td>
<td>0.29 ± 0.03</td>
<td>0.43 ± 0.08</td>
<td>0.38 ± 0.02</td>
<td>0.21 ± 0.02</td>
<td>( P &lt; 0.001 )</td>
</tr>
<tr>
<td>Total organic carbon (%)</td>
<td>40.5 ± 1.3</td>
<td>20.3 ± 3.2</td>
<td>28.0 ± 1.7</td>
<td>24.3 ± 1.4</td>
<td>13.3 ± 3</td>
<td>( P &lt; 0.001 )</td>
</tr>
<tr>
<td>Total potassium (%)</td>
<td>1.43 ± 0.09</td>
<td>0.46 ± 0.12</td>
<td>0.52 ± 0.13</td>
<td>0.52 ± 0.12</td>
<td>0.31 ± 0.09</td>
<td>( P &lt; 0.001 )</td>
</tr>
<tr>
<td>Total phosphorus (%)</td>
<td>0.20 ± 0.04</td>
<td>0.38 ± 0.08</td>
<td>0.38 ± 0.06</td>
<td>0.31 ± 0.03</td>
<td>0.12 ± 0.03</td>
<td>( P = 0.001 )</td>
</tr>
<tr>
<td>Bray-1 phosphorous (mg/kg)</td>
<td>191 ± 13</td>
<td>344 ± 28</td>
<td>349 ± 25</td>
<td>304 ± 23</td>
<td>50.6 ± 9</td>
<td>( P &lt; 0.001 )</td>
</tr>
<tr>
<td>E. coli + Salmonella (( \times 10^6 ) CFU/g)</td>
<td>13.7 ± 0.6</td>
<td>4.58 ± 1.7</td>
<td>9.45 ± 1.5</td>
<td>4.15 ± 1.7</td>
<td>3.83 ± 1.4</td>
<td>( P = 0.014 )</td>
</tr>
<tr>
<td>Total Aspergillus (( \times 10^5 ) CFU/g)</td>
<td>24.4 ± 1.0</td>
<td>3.00 ± 1.2</td>
<td>4.00 ± 1.5</td>
<td>5.30 ± 2.1</td>
<td>20.4 ± 7.9</td>
<td>( P = 0.003 )</td>
</tr>
</tbody>
</table>

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 microbe-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 handwashing after handling.

4. Conclusions

Pineapple waste is acidic and fibrous 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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