Bioresource Technology 126 (2012) 437–443

Contents lists available at SciVerse ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Management of food industry waste employing vermicomposting technology

V.K. Garg [a,*], S. Suthar [b], Anoop Yadav [a]

[a] *Department of Environmental Science and Engineering, Guru Jambheshwar University of Science and Technology, Hisar 125001, Haryana, India*
[b] *School of Environment and Natural Resources, Doon University, Dehradoon, India*

ARTICLE INFO

Article history:
Available online 3 December 2011

Keywords:
Food industry sludge
Vermicomposting
Poultry droppings
Eisenia fetida
Cocoons

ABSTRACT

This paper reports the vermicomposting of food industry sludges (FIS) mixed with different organic wastes employing *Eisenia fetida*. A total of 10 vermicomposting units containing different wastes combinations were established. After 15 weeks significant increase in total nitrogen (N_{total}) (60–214%), total available phosphorous (P_{avail}) (35.8–69.6%), total sodium (Na_{total}) (39–95%), and total potassium (K_{total}) (43.7–74.1%), while decrease in pH (8.45–19.7%), total organic carbon (OC_{total}) (28.4–36.1%) and C:N ratio (61.2–77.8%) was recorded. The results indicated that FIS may be converted into good quality manure by vermicomposting if spiked with other organic wastes in appropriate quantities.

1. Introduction

Food processing industries, livestock and poultry farms generate huge quantities of liquid and semi-solid wastes. Treatment, disposal and management of these wastes is a scientific challenge for industries, urban local bodies, scientists and engineers. Conventionally these wastes are disposed by non-scientific methods which invite public attention due to health and civic reasons. These organic wastes contain valuable plant nutrients and organic matter which are essential for soil fertility and crop production. So land application may be a recycling option for these wastes. But their direct land application may be harmful due to heavy metals, toxic organic compounds, pathogenic microorganisms, etc. Zucconi et al. (1981) have reported that application of immature organic materials in agricultural fields inhabit plant growth due to nitrogen starvation and production of toxic metabolites. Whereas Mishra et al. (1989) have reported that application of stabilized organics can supply essential nutrients to plants and improve soil fertility.

In vermicomposting process worms convert and stabilize organic wastes into nutrient rich humus-like material called vermicompost. In this process the action of earthworms on organic wastes is physical as well as biochemical. The physical action includes the aeration, mixing and grinding of organic waste, while the microbes are responsible for biochemical degradation of organic waste (Aira et al., 2008). During the transit of material through worms' gut, some important plant metabolites like NPK present in the organic waste are converted into such chemical forms which are more available to plants. Several studies have been made on the use of epigeic earthworms in vermicomposting processes using various organic materials (Elvira et al., 1998; Benítez et al., 2000; Gajalakshmi et al., 2002; Khwairakpam and Bhargava, 2009). The ability of *E. fetida* for agricultural, animal, poultry and wastes management has reported by several researchers (Loh et al., 2005; Garg and Kaushik, 2005; Yadav and Garg, 2011; Suthar, 2008). But utilization of heterogeneous wastes combinations in vermicomposting process is yet to be proven. Keeping this in view experiments were conducted on the vermicomposting of wastewater treatment plant sludge of a food industry mixed with cow dung, biogas plant slurry and poultry droppings in different combinations employing epigeic earthworm, *E. fetida*.

2. Methods

2.1. Waste materials and earthworms (Eisenia fetida)

Cow dung (CD) was collected from a livestock farm located at Hisar, India. The main physico-chemical parameters of CD were: pH: 8.0 ± 0.2; total organic carbon (OC_{total}): 495 ± 23 g/kg; total nitrogen (N_{total}): 8.2 ± 0.4 g/kg, total available phosphorous (P_{avail}): 5.7 ± 0.3 g/kg; total potassium (K_{total}): 7.8 ± 1.1 g/kg; total sodium (Na_{total}): 4.0 ± 0.25 g/kg total C:N ratio: 60.3 ± 5.5. Fresh anaerobically digested biogas plant slurry (BPS) was collected from post-methanation storage tank of an on-farm biogas plant situated at Hisar. The raw material used in the biogas plant was cow dung. The main physico-chemical parameters of BPS were: pH: 7.8 ± 0.2, OC_{total}: 471 ± 31 g/kg; N_{total}: 6.2 ± 0.3 g/kg, P_{avail}: 5.6 ± 0.15 g/kg; K_{total}: 4.2 ± 0.1 g/kg; Na_{total} 1.9 ± 0.05 g/kg; C:N ratio: 75.9 ± 4.5. The poultry droppings (PD) were collected from a poultry farm located near Hisar, India. The main physico-chemical parameters of

---

* Corresponding author. Tel.: +91 1662 275375; fax: +91 1662 276240.
E-mail address: vinodkgarg@yahoo.com (V.K. Garg).

0960-8524/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biortech.2011.11.116

PD were: pH: 7.7 ± 0.4, OC_{total}: 390 ± 12 g/kg; N_{total}: 14.5 ± 1.1 g/kg, P_{avail}: 9.2 ± 0.5 g/kg; K_{total}: 3.1 ± 0.1 g/kg; Na_{total}: 4.3 ± 0.1 g/kg; Total C:N ratio: 26.9 ± 1.7. Food industry sludge (FIS) was procured from wastewater treatment plant of a food industry located at Bahadurgarh, Haryana, India. The main physico-chemical parameters of FIS were: pH: 6.3 ± 0.2, OC_{total}: 360 ± 12 g/kg; N_{total}: 11.6 ± 0.5 g/kg, P_{avail}: 8.8 ± 0.4 g/kg; K_{total}: 1.8 ± 0.1 g/kg; Na_{total}: 8.0 ± 0.1 g/kg; C:N ratio: 31.0 ± 3. Then CD, BPS, FIS and PD were allowed to dry under shade with periodic turnings. Then FIS was mixed with CD, BPS and PD in different proportions. Unclitellated hatchlings of *E. fetida* weighing 100–200 mg (live weight) were used for the experiment.

A total of 10 vermicomposting units containing different waste mixture compositions were established. Each unit contained 2.5 kg waste mixtures on dry weight basis. Circular plastic containers of appropriate size were used for experiment. All the used waste mixtures were decomposed for 4 weeks, for semi-decomposition and thermal stabilization to have optimum action of earthworms and microorganisms. After 4 weeks, 100 unclitellated hatchlings of *E. fetida*, randomly picked from stock culture, introduced in each unit. Triplicates were prepared for each unit. All the containers were kept in dark at a laboratory temperature of 22 ± 3 °C. The moisture content was maintained at 60–80% by during the study period.

The composition of waste mixtures in vermicomposting units is given below:

Vermicomposting unit 1: 100% CD
Vermicomposting unit 2: 100% BPS
Vermicomposting unit 3: 75% CD + 25% FIS
Vermicomposting unit 4: 50% CD + 50% FIS
Vermicomposting unit 5: 75% BPS + 25% FIS
Vermicomposting unit 6: 50% BPS + 50% FIS
Vermicomposting unit 7: 25% CD + 25% BPS + 50% FIS
Vermicomposting unit 8: 25% CD + 25% PD + 50% FIS
Vermicomposting unit 9: 25% BPS + 25% PD + 50% FIS
Vermicomposting unit 10: 25% CD + 25% BPS + 25% PD + 25% FIS

Samples were drawn at zero day and after 15 weeks physicochemical analysis. The zero days refers to the day of inoculation of earthworms after pre-composting of 4 weeks. The physicochemical analysis was done on dry weight basis as reported by Yadav and Garg (2009).

2.2. Biomass gain and reproduction

Biomass gain and cocoon production by the earthworms in each vermicomposting units was recorded weekly. The waste in the container was turned out, then earthworms and cocoons were separated from the waste by hand sorting, counted and weighed after washing with water. Then all earthworms and the feed waste (but not cocoons) were returned to their respective container. On the basis of obtained data of biomass and cocoon numbers, other growth parameters of earthworms such as maximum biomass achieved, net biomass gain, maximum growth rate (mg biomass/worm/day) and reproduction rate (cocoon produced/worm/week) were calculated, for different vermicomposting units.

2.3. Statistical analysis

All the results reported in the text are the mean of three replicates. One-way ANOVA was used to analyze the significant differences among different vermicomposting units for studied parameters. Tukey's *t*-test as a post hoc was also performed to identify the homogeneous type of vermicomposting unit for the various parameters. All statistical tests were evaluated at the 95% confidence level. Statistical analysis of the data was carried out with the SPSS 12.0 software program.

3. Results and discussion

3.1. Manurial quality of vermicomposts produced from vermicomposting units

The pH of waste materials significantly influences the vermicomposting process. There were slight changes in pH of vermicomposts as compared to initial values (Table 1). The pH of waste mixtures was neutral at the beginning but slightly acidic of the vermicomposts. Initially pH values in different waste mixtures were ranged from 7.0 ± 0.11–8.1 ± 0.10 and in final vermicomposts ranged from 5.9 ± 0.11 to 6.7 ± 0.22. Maximum decrease in pH (19.7%) was reported in vermicomposting unit 1 and minimum was in vermicomposting unit 8 (8.45%). Several studies have reported similar results during vermicomposting of different wastes (Elvira et al., 1998; Garg and Gupta, 2011). The decrease in pH has been related to the decomposition of organic materials and formation of intermediate chemical products like ammonium ions and humic acids during the vermicomposting process (Yadav and Garg, 2011). Decrease in pH in vermicomposting unit 2, 3, 5 & 9 and in vermicomposting unit 4, 6 & 7 was not significantly different from each other ($P < 0.05$).

Electrical conductivity (EC) of all the vermicomposts was higher than initial waste mixtures (Table 1). After vermicomposting 14.5–78.5% increase in EC was recorded in different vermicomposting units. Increase in EC may be due to the release of minerals during decomposition of organic matter in the form of cations in the vermicomposts (Tognetti et al., 2005). The OC_{total} content decreased from initial levels and highest decrease was observed in vermicompost obtained from vermicomposting unit 1 (36.1%) and least decrease was in vermicomposting unit 9 (28.4%). Elvira et al. (1996) have reported that earthworms modify the substrate conditions, which subsequently enhance the carbon losses from the substrates through microbial respiration in the form of CO_2. There were no significant differences in the OC_{total} between vermicomposting unit 2, 3, 4, 5, 6, 7 and 10 ($P < 0.05$).

N_{total} content in waste mixtures and vermicomposts is given in Table 1. An increase in the N_{total} content after vermicomposting was observed in all the units. The N_{total} content of the waste mixtures ranged from 6.2 ± 0.21 to 11.5 ± 0.41 g/kg and in vermicomposts it ranged from 17.5 ± 0.50 to 23.7 ± 0.20 g/kg (Table 1). The N_{total} content showed about 1.6 (vermicomposting unit 9) to 3.14 (vermicomposting unit 2) fold increase as compared to initial waste mixtures. Fernández-Gómez et al. (2010) have reported 96% increased in nitrogen content after vermicomposting of wastes. It might be due to the concentration effect caused by the degradation of the labile organic compounds, which could have reduced the volume of the composting mass due to release of CO_2 and the mineralization of nitrogen during decomposition of organic matter resulting in increased N_{total} in the vermicompost (Elvira et al., 1998; Garg and Kaushik, 2005). However, earthworm activity during vermicomposting may also have played a role because ammonia is one of the worm excretory products (Lee, 1985). Plaza et al. (2008) have reported that the nitrogen content of vermicomposts may be higher due to mineralization of C-rich materials and, possibly, due to the action of N-fixing bacteria present in the waste material.

Total available phosphorus (P_{avail}) content of vermicomposts increased from 35.8% to 66.7% in different vermicomposting units (Table 1). The P_{avail} content of initial waste mixtures was in the range of 5.6 ± 0.30–8.1 ± 0.53 g/kg, while, P_{avail} in vermicomposts was in the range of 9.5 ± 0.3–11.1 ± 0.1 g/kg. Lee (1992) has

Table 1
Physico-chemical characteristics of initial waste mixtures and vermicomposts (mean ± SD, $n = 3$).

Vermicomposting unit	pH	EC (dS/m)	OC_{total} (g/kg)	N_{total} (g/kg)	P_{aval} (g/kg)
Physico-chemical characteristics of initial waste mixtures					
1	8.1 ± 0.10b	1.2 ± 0.05a	495 ± 15d	8.2 ± 0.10c	5.7 ± 0.80a
2	7.8 ± 0.60b	1.4 ± 0.07b	470 ± 5cd	6.2 ± 0.21a	5.6 ± 0.30a
3	7.6 ± 0.05ab	1.4 ± 0.02b	454 ± 16bcd	9.0 ± 0.15de	6.5 ± 0.31ab
4	7.2 ± 0.10a	1.7 ± 0.05cd	422 ± 13ab	9.9 ± 0.20f	7.2 ± 0.52bc
5	7.4 ± 0.21a	1.6 ± 0.10c	440 ± 12abc	7.5 ± 0.12b	6.4 ± 0.50ab
6	7.0 ± 0.11a	1.8 ± 0.10d	410 ± 8ab	8.9 ± 0.06d	7.2 ± 0.70bc
7	7.1 ± 0.0a	1.7 ± 0.05cd	421 ± 8ab	9.4 ± 0.08e	7.3 ± 0.30bc
8	7.1 ± 0.14a	2.2 ± 0.10f	398 ± 10a	11.5 ± 0.41h	8.1 ± 0.53c
9	7.0 ± 0.21a	2.8 ± 0.0g	390 ± 7a	10.9 ± 0.30g	8.1 ± 0.70c
10	7.5 ± 0.14a	2.0 ± 0.10e	425 ± 46a	10.1 ± 0.10f	7.3 ± 0.30bc
Physico-chemical characteristics of vermicomposts					
1	6.5 ± 0.12bc	2.1 ± 0.12a	316 ± 7b	23.7 ± 0.20d	9.5 ± 0.30a
2	6.3 ± 0.10ab	2.5 ± 0.2abc	305 ± 9ab	19.5 ± 0.70abc	9.5 ± 0.20a
3	6.1 ± 0.23ab	2.1 ± 0.10a	308 ± 7ab	20.9 ± 0.20c	10.1 ± 0.10abc
4	6.0 ± 0.11a	2.4 ± 0.10abc	282 ± 9ab	19.7 ± 0.31bc	10.6 ± 0.30cd
5	6.1 ± 0.21ab	2.2 ± 0.21ab	303 ± 13ab	18.0 ± 0.60ab	9.8 ± 0.20ab
6	5.9 ± 0.21a	2.4 ± 0.10abc	287 ± 12ab	18.7 ± 0.40ab	10.4 ± 0.15bcd
7	5.9 ± 0.11a	2.6 ± 0.15bc	289 ± 9ab	28.1 ± 0.62e	10.6 ± 0.40cd
8	6.5 ± 0.20bc	2.7 ± 0.20c	276 ± 20a	18.4 ± 0.65abc	11.0 ± 0.35cd
9	6.1 ± 0.13ab	3.2 ± 0.20d	279 ± 9a	17.5 ± 0.50a	11.1 ± 0.10d
10	6.7 ± 0.22c	2.6 ± 0.22bc	298 ± 22ab	19.1 ± 0.90abc	10.4 ± 0.30bcd

Mean value followed by different letters is statistically different (ANOVA; Tukey's test, $P < 0.05$).

reported that if organic matter passes through the gut of earthworm, it then a fraction of P is converted to more plant available forms. Pramanik et al. (2007) have reported that acid production during organic matter decomposition by the microorganisms is the major mechanism for solubilization of insoluble phosphorus, which subsequently results in increase in phosphorus content in vermicomposts. The P_{avail} content in vermicomposting unit 1 & 2; 4, 7 & 8, and 6 & 10 was not significantly different ($P < 0.05$).

Initial K_{total} content in the waste mixtures was in the range of 2.7 ± 0.3–7.8 ± 0.3 g/kg while it was in the range of 4.5 ± 0.2–11.3 ± 0.4 g/kg in vermicomposts (Table 2). Pramanik (2010) has reported that K content may increase 59–77% during vermicomposting of wastes (bagasse and coir) depending on initial physico-chemical characteristics of wastes. The K_{total} content in all the vermicomposting units was significantly different from each other ($P < 0.05$). The activity of earthworms led to an increase in the Na_{total}, which ranged from 3.7 ± 0.2 to 9.0 ± 0.21 g/kg, whereas it was 1.9 ± 0.1–6.1 ± 0.1 g/kg in initial waste mixtures (Table 2). Maximum increase in Na_{total} content was recorded in vermicomposting unit 1 and minimum was in vermicomposting unit 7. Singh et al. (2010) have too reported that higher Na concentration (30.53–92.80%) in the vermicomposts prepared from beverage industry sludge. C:N ratio decreased in all vermicomposting units due to increased N_{total} and decrease in OC_{total}. C:N ratios decreased from (34.6 ± 0.3–75.8 ± 3.3) to: 13.4 ± 0.4 to 16.8 ± 1.25 (Fig. 1). Several authors have reported a decrease in C:N ratio after vermicomposting, in different wastes (Table 3).

Some heavy metals are essential nutrient for plants growth, though their concentrations and exposure periods above a certain level can be toxic to soil organisms affecting their abundance, diversity and distribution (Malley et al., 2006). Vermicomposting caused significant changes in the metal concentration. The Fe

Table 2
Elemental characteristics of initial waste mixtures and vermicomposts (mean ± SD, $n = 3$).

Vermicomposting unit	K_{total} (g/kg)	Na_{total} (g/kg)	Fe (mg/kg)	Zn (mg/kg)	Cu (mg/kg)
Elemental characteristics of initial waste mixtures					
1	7.8 ± 0.3f	4.0 ± 0.2c	1125 ± 24ab	130 ± 7b	44.2 ± 2.4c
2	4.2 ± 0.2cd	1.9 ± 0.1a	1070 ± 42a	34 ± 2a	23.5 ± 2.5a
3	6.3 ± 0.3e	4.9 ± 0.1de	1268 ± 19bc	312 ± 10d	50 ± 4.0cd
4	4.8 ± 0.3d	6.1 ± 0.1f	1409 ± 60c	496 ± 10f	56.2 ± 2.8de
5	3.6 ± 0.3bc	3.4 ± 0.4b	1218 ± 46b	241 ± 15c	35 ± 2.2b
6	3.1 ± 0.6ab	5.0 ± 0.3de	1380 ± 82c	448 ± 27e	46.2 ± 2.8c
7	3.9 ± 0.1bc	5.5 ± 0.4ef	1401 ± 82c	478 ± 19ef	50.5 ± 3.5cd
8	3.6 ± 0.4bc	6.1 ± 0.0f	1226 ± 47b	511 ± 11f	61.2 ± 3.8e
9	2.7 ± 0.3a	5.5 ± 0.3ef	1212 ± 34b	491 ± 12f	55.9 ± 4.1de
10	4.2 ± 0.2cd	4.6 ± 0.3cd	1068 ± 69	308 ± 24d	50.1 ± 2.9cd
Elemental characteristics of vermicomposts					
1	11.3 ± 0.4h	7.8 ± 0.4d	1350 ± 26bc	179 ± 15b	58.4 ± 1.6cd
2	6.6 ± 0.1ef	3.7 ± 0.2a	1289 ± 11ab	41 ± 8a	30.7 ± 2.3a
3	9.4 ± 0.3g	8.4 ± 0.1def	1395 ± 22cd	343 ± 18d	61.2 ± 3.3cde
4	6.9 ± 0.1f	9.0 ± 0.2f	1549 ± 20g	545 ± 16f	67.5 ± 1.5e
5	6.0 ± 0.1cd	6.2 ± 0.3b	1461 ± 28ef	290 ± 5c	46.1 ± 2.9b
6	5.4 ± 0.3b	8.0 ± 0.1de	1518 ± 16fg	497 ± 18e	54.5 ± 2.5c
7	6.5 ± 0.1def	8.6 ± 0.3ef	1685 ± 16h	573 ± 6f	56.8 ± 3.8c
8	5.5 ± 0.1bc	8.2 ± 0.05de	1348 ± 26bc	562 ± 14f	68.4 ± 4.4e
9	4.5 ± 0.2a	7.8 ± 0.2d	1445 ± 14de	541 ± 9f	67.5 ± 2.5e
10	6.3 ± 0.3de	6.9 ± 0.44c	1281 ± 50a	369 ± 8d	64.8 ± 1.8de

Mean value followed by different letters is statistically different (ANOVA; Tukey's test, $P < 0.05$).

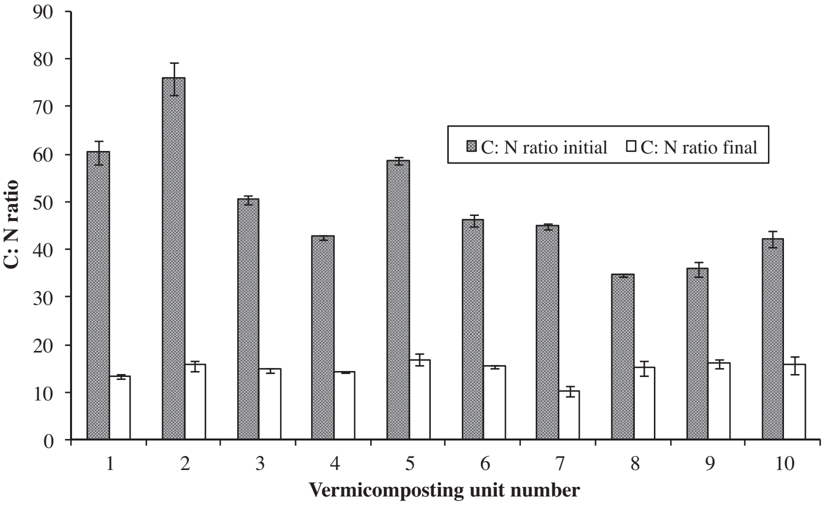

Fig. 1. C:N ratio in initial feed mixtures and final vermicomposts obtained from different vermicomposting units.

Table 3
Change in C:N ratio after vermicomposting wastes mixtures.

Substrates	Earthworm species	Vermicomposting period (days)	Initial C:N ratio	Final C:N ratio	Reference
Sugar mill filter cake + horse dung (1:1)	*E. fetida*	84	22.5	16.5	Sangwan et al. (2008)
Press mud + cow dung (1:1)	*E. fetida*	91	21.9	16.3	Sangwan et al. (2010)
Filter cake + saw dust	*E. fetida, E. eugeniae and P. excavatus*	45	17.5	9.1	Khwairakpam and Bhargava (2009)
Press mud + cow dung (1:1)	*P. ceqlanensis*	100	26.6	7.8	Prakash and Karmegam (2010)
Sugar industry sludge + cow dung (40% + 60%)	*E. fetida*	90	26.6	7.8	Suthar (2010)
Food industry sludge + cow dung (30% + 70%)	*E. fetida*	84	45	26	Yadav and Garg (2009)
Food industry sludge + poultry droppings + cow dung (25% + 25% + 50%)	*E. fetida*	91	31.2	20.9	Yadav and Garg (2011)
Paper mill sludge + sewage sludge (3:1)	*E. andrei*	70	40	6.4	Elvira et al. (1996)
Paper mill sludge + cattle manure (1:4)	*E. andrei*	70	23	16	Elvira et al. (1998)
Solid textile mill sludge + cow dung (30% + 70%)	*E. fetida*	90	131	26.4	Kaushik and Garg (2003)
Solid textile mill sludge + poultry droppings (70% + 30%)	*E. fetida*	77	76.3	14.9	Garg and Kaushik (2005)
Solid textile mill sludge + Biogas plant slurry (20% + 80%)	*E. fetida*	105	80.1	34.5	Garg et al. (2006)
Distillery sludge + cow dung (40% + 60%)	*E. fetida*	90	40.9	12.9	Suthar (2008)
Winery industry waste (Spent Grape marc)	*E. andrei*	240	35	29	Nogales et al. (2005)
Beverage industry waste + cow dung (1:1)	*E. fetida*	120	27.3	19.9	Singh et al. (2010)
Fly ash + cow dung (1:3)	*E. eugeniae*	60	41.7	7.6	Venkatesh and Eevera (2008)
Olive cake + biosolids (8:1)	*E. andrei*	180	43	24	Melgar et al. (2009)
Spent mushroom waste	*E. fetida and E. anderi*	84	15.4	6.67	Tajbakhsh et al. (2008)
Paper mill sludge + cattle dung (1:1)	*E. fetida*	150	28.11	10.37	Kaur et al. (2010)

content over the initial content was highest in vermicomposting unit 2 (20.4%) and lowest in vermicomposting unit 8 (9.9%) after vermicomposting (Table 2). The Fe content in all the vermicomposting units was significantly different from each other ($P < 0.05$). The Zn content was maximum in vermicomposting unit 1 (20.4%) and minimum in vermicomposting unit 4 (9.93%). The Zn concentrations in vermicomposting unit no. 4, 6, 7 and 9; 3 and 10 were not significantly different from each other, but the variation was significant with other vermicomposting units ($P < 0.05$). Cu content was 11.7–32.1% more in vermicomposts than initial waste mixtures. The Cu concentrations in vermicomposting unit 6 & 7 and in 8 & 9 were not significantly different from each other, but different with other vermicomposting units ($P < 0.05$). This increase in heavy metal contents in final vermicomposts may be due to the concentration effect caused by the weight and volume loss associated with mineralization of the organic matter during the process. Increased levels of heavy metals in vermicomposts have been reported by several researchers (Table 4). Although vermicomposts produced in this study having higher metals concentration as compared to initial waste mixtures, but it was much lesser than the international permissible levels of metals for compost, which indicates that these vermicompost can be used in the agriculture fields as manure and potting media in horticulture.

3.2. Earthworm growth and fecundity

The earthworm's biomass in different vermicomposting units is given in Table 5. The worm biomass was significantly ($P < 0.05$) affected by the waste composition. During the experimental period, worms grew well in all the vermicomposting units and no mortality was observed in any vermicomposting unit. The growth pattern of *E. fetida* in different vermicomposting units with time is given in

Table 4
Heavy metal content (mg/kg) in the vermicompost produced from different waste mixtures.

Waste mixture	Fe		Zn		Cu		Mn		Ni		Pb		Reference
	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	
Sugar mill filter cake + horse dung (1:1)	22270	24849	1199	1536	421	661	1877	2296	223	467	–	–	Sangwan et al., 2008
Cow dung	1859	1902	110	111.4	234	267	561	589.6	–	–	–	–	Yadav and Garg, 2009
Food industry sludge + poultry droppings + cow dung (25% + 25% + 50%)	1280	1400	475	805	59.8	77.8	–	–	–	–	–	–	Yadav and Garg, 2011
Dairy sludge + cattle manure (1:4)	7.4	9.3	198	198	39	43	298	218	25	37	13	18	Elvira et al., 1998
Paper mill sludge + cattle manure (1:4)	6.9	7.5	110	108	31	34	180	190	25	29	15	13	Elvira et al., 1998
Fly ash + cow dung (1:3)	27.5	64.9	8.6	14	1.2	11.8	12.9	29.6	–	–	–	–	Venkatesh and Eevera, 2008
Winery industry waste (Spent Grape marc)	623	2497	22	62	22	30	8	53	–	–	–	–	Nogales et al., 2005
Cow dung	–	–	35.9	44.3	221.1	280.5	_	_	_	_	_	_	Malley et al., 2006
Press mud + cow dung (1:1)	162.5	214.5	30.5	44.6	8	15.6	–	–	–	–	–	–	Prakash and Karmegam, 2010
Paper mill sludge + cattle dung (1:1)	4252	4632	171.5	218.5	32.5	38.5	96	101.5	–	–	–	–	Kaur et al., 2010
Cow dung + vegetable waste (80% + 20%)	1721	3665	189	324	82	172	96	212	–	–	2	3.2	Garg and Gupta, 2011

Fig. 2. Initial increase in worm biomass in all the vermicomposting units was followed by a decline at the later stages of vermicomposting. The maximum earthworm biomass was observed in vermicomposting units 1 (1165 ± 42 mg), while the minimum worm biomass was recorded in vermicomposting unit 9 (714 ± 21 mg). Maximum worm biomass was attained in 8th week in vermicomposting unit 1, 2, 3 and 5; in 9th week in vermicomposting unit 4, 6 and 7 whereas the same was attained in 10th week in other vermicomposting units (Table 5). Maximum worm biomass gain 1020 ± 25 mg per worm was recorded in vermicomposting unit 1 and minimum worm biomass gain was 563 ± 26 mg per worm in the vermicomposting unit 8. The net biomass gain in different vermicomposting unit was significantly different from each other ($P < 0.05$).

The growth rate (mg biomass gained/day/worm) has been considered a good indicator of earthworm's growth in different wastes (Edwards et al., 1998). The highest worm growth rate was observed in vermicomposting unit 1 (18.21 ± 0.21 mg biomass gained/worm/day), whereas the vermicomposting unit 8 had least worm growth rate (9.38 ± 0.18 mg biomass gained/worm/day). The growth rate in vermicomposting unit 7 & 10; and vermicomposting unit 8 & 9 were not significantly different from each other ($P < 0.05$) but differ from others. Highest worm biomass gain per unit of the waste was in vermicomposting unit 1 (9.1 ± 0.08 mg/g) and lowest worm biomass gained per unit waste was observed in vermicomposting unit 8 (5.1 ± 0.10 mg/g) (Table 5). Table 6 encapsulates the reproductive potential of *E. fetida* in different vermicomposting units. Clitellum development by worms was

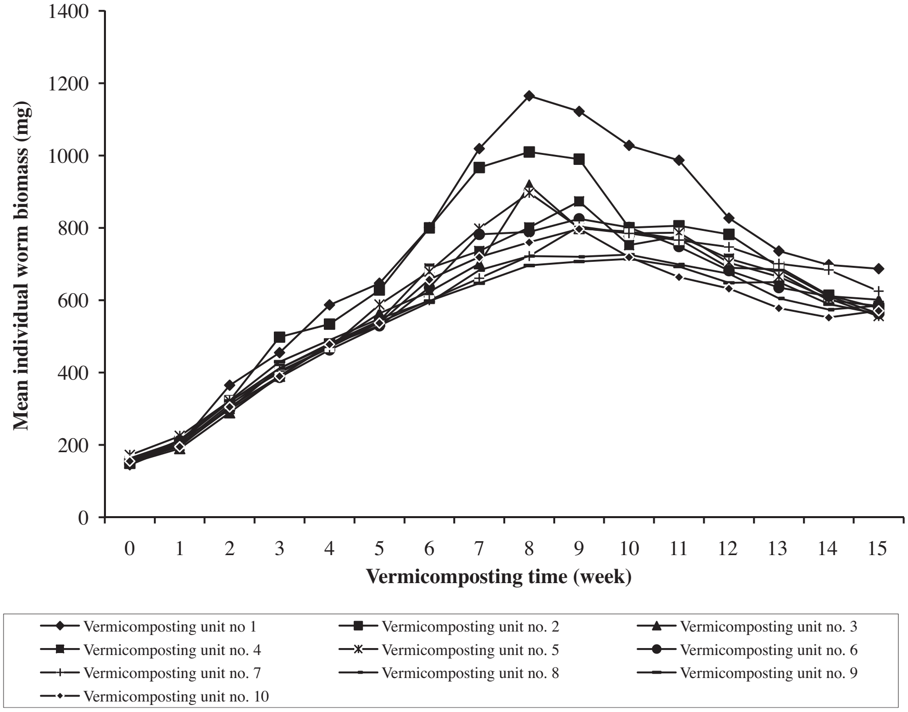

Fig. 2. Growth curves of *E. fetida* in different vermicomposting units.

Table 5
Biomass production by *E. fetida* in different vermicomposting units (mean ± SD, $n = 3$).

Vermicomposting unit	Mean initial biomass/worm (mg)	Maximum biomass gained/worm (mg)	Net biomass gained/worm (mg)	Maximum biomass achieved in (week)	Growth rate/ worm/day (mg)	Worm biomass gained per unit waste (mg/g)
1	145 ± 22a	1165 ± 42g	1020 ± 25f	8th	18.21 ± 0.21g	9.1 ± 0.08f
2	149 ± 7a	1010 ± 23f	861 ± 19e	8th	15.37 ± 0.37f	7.6 ± 0.10e
3	150 ± 9a	918 ± 20e	768 ± 21d	8th	13.71 ± 0.51e	6.8 ± 0.12d
4	156 ± 9a	873 ± 15cde	717 ± 17cd	9th	11.38 ± 0.28cd	6.4 ± 0.10c
5	172 ± 11a	897 ± 36de	725 ± 29cd	8th	11.91 ± 0.09d	6.5 ± 0.12cd
6	158 ± 7a	825 ± 17cd	667 ± 13bc	9th	10.58 ± 0.42bc	5.9 ± 0.10b
7	160 ± 5a	804 ± 18c	644 ± 9b	9th	10.22 ± 0.13ab	5.7 ± 0.14b
8	163 ± 5a	726 ± 32ab	563 ± 26a	10th	9.38 ± 0.18a	5.1 ± 0.10a
9	150 ± 9a	714 ± 21a	564 ± 39a	10th	9.40 ± 0.25a	5.1 ± 0.05a
10	163 ± 7a	797 ± 28bc	642 ± 27b	9th	10.19 ± 0.19ab	5.7 ± 0.13b

Mean value followed by different letters is statistically different (ANOVA; Tukey's test, $P < 0.05$).

Table 6
Reproduction by *E. fetida* in different vermicomposting unit (mean ± SD, $n = 3$).

Vermicomposting unit	Clitellum development started in (week)	Cocoon production started in (week)	Number of cocoons after 15 weeks	Reproduction rate (cocoons/earthworm)	No. of cocoons produced/ earthworm/week
1	4th	5th	1498 ± 39e	14.89 ± 0.39e	1.50 ± 0.05d
2	4th	5th	1197 ± 85d	11.97 ± 0.85d	1.19 ± 0.08b
3	4th	5th	1026 ± 39cd	10.26 ± 0.39cd	1.02 ± 0.04b
4	5th	6th	961 ± 15bc	9.61 ± 0.15bc	1.06 ± 0.06bc
5	4th	5th	1012 ± 141c	10.12 ± 1.41c	1.01 ± 0.08b
6	5th	6th	860 ± 43bc	8.60 ± 0.43bc	0.96 ± 0.04b
7	5th	6th	893 ± 40bc	8.93 ± 0.40bc	0.99 ± 0.06b
8	5th	7th	610 ± 21a	6.10 ± 0.21a	0.76 ± 0.05a
9	6th	7th	580 ± 55a	5.80 ± 0.55a	0.72 ± ± 0.02a
10	6th	7th	826 ± 35b	8.26 ± 0.35b	1.03 ± 0.03a

Mean value followed by different letters is statistically different (ANOVA; Tukey's test, $P < 0.05$).

started in 4th week (vermicomposting unit 1, 2, 3 and 5); in 5th week (vermicomposting unit 4, 6, 7 and 8) and in 6th week in other vermicomposting units. Cocoon production by earthworms was started in 5th week (vermicomposting unit 1, 2, 3 and 5); in 6th week (vermicomposting unit 4, 6 and 7) and in 7th week in other vermicomposting units. The earthworms exhibited different patterns of cocoon production in different vermicomposting units. The maximum cocoons were produced in vermicomposting unit 1 (1498 ± 39) and minimum cocoons were produced in vermicomposting unit 9 (580 ± 55). Cocoons produced in vermicomposting unit 4, 6 and 7; 8 and 9 were not significantly different from each other ($P < 0.05$). Mean number of cocoons produced by each worm was in the range of 14.98 ± 0.39 (vermicomposting unit 1) to 5.8 ± 0.55 (vermicomposting unit 9). The addition of FIS in other organic wastes affected the cocoon production efficiency of *E. fetida*. The differences in cocoon production in different vermicomposting units may be due to variable waste characteristics, which significantly influence the sexual maturation and onset of reproduction by worms (Edwards et al., 1998).

4. Conclusion

This study concludes that if food industry sludge is mixed with other organic wastes in appropriate quantities then it can be vermicomposted by *E. fetida*. Vermicomposts obtained in the study were rich in the micro and macronutrients, which are essential for plant growth, and had low conductivity, low C:N ratio, optimal stability and maturity. A considerable amount of earthworm biomass and cocoons was also produced in the different vermicomposting units. Finally, it is conclude that vermicomposting can be applied for food industry sludge management.

References

Aira, M., Sampedro, L., Monroy, F., Domínguez, J., 2008. Detritivorous earthworms directly modify the structure, thus altering the functioning of a micro decomposer food web. Soil Biol. Biochem. 40, 2511–2516.

Benítez, E., Nogales, R., Masciandaro, G., Ceccanti, B., 2000. Isolation by isoelectric focusing of humic urease complexes from earthworm (*Eisenia foetida*)-processed sewage sludges. Biol. Fertil. Soils 31, 489–493.

Edwards, C.A., Dominguez, J., Neuhauser, E.F., 1998. Growth and reproduction of *Parionyx excavatus* (Perr.) (Megascolecidae) as factors in organic waste management. Biol. Fertil. Soils 27, 155–161.

Elvira, C., Goicoechea, M., Sampdro, L., Mato, S., Nogales, R., 1996. Bioconversion of solid paper-pulp mill sludge by earthworms. Bioresour. Technol. 75, 173–177.

Elvira, C., Sampedro, L., Benitez, E., Nogales, R., 1998. Vermicomposting of sludges from paper mill and dairy industries with *Eisenia andrei*: a pilot scale study. Bioresour. Technol. 63, 205–211.

Fernández-Gómez, M.J., Nogales, R., Insam, H., Romero, E., Goberna, M., 2010. Continuous-feeding vermicomposting as a recycling management method to revalue tomato-fruit wastes from greenhouse crops. Waste Manage. 30, 2461–2468.

Gajalakshmi, S., Ramasamy, E.V., Abbasi, S.A., 2002. Vermicomposting of paper waste with the anecic earthworm *Lampito mauritii* Kinberg. Indian J. Chem. Technol. 9, 306–311.

Garg, V.K., Kaushik, P., 2005. Vermistabilization of textile mill sludge spiked with poultry droppings by an epigeic earthworm *Eisenia foetida*. Bioresour. Technol. 96, 1063–1071.

Garg, V.K., Kaushik, P., Dilbaghi, N., 2006. Vermiconversion of wastewater sludge from textile mill spiked with anaerobically digested biogas plant slurry employing *Eisenia foetida*. Ecotoxicol. Environ. Saf. 65 (3), 412–419.

Garg, V.K., Gupta, R., 2011. Optimization of cow dung spiked pre-consumer processing vegetable waste for vermicomposting using *Eisenia fetida*. Ecotox. Environ. Safe. 74, 19–24.

Kaushik, P., Garg, V.K., 2003. Vermicomposting of mixed solid textile mill sludge and cow dung with epigeic earthworm *Eisenia foetida*. Bioresour. Technol. 90, 311–316.

Kaur, A., Singh, J., Vig, A.P., Dhaliwal, S.S., Rup, P.J., 2010. Cocomposting with and without *Eisenia fetida* for conversion of toxic paper mill sludge to a soil conditioner. Bioresour. Technol. 101, 8192–8198.

Khwairakpam, M., Bhargava, R., 2009. Vermitechnology for sewage sludge recycling. J. Hazard. Mater. 161, 948–954.

Lee, K.E., 1985. Earthworms: *Their Ecology and Relationships with Soil and Land Use*. Academic Press, London.

Lee, K.E., 1992. Some trends opportunities in earthworm research or: darwin's children. The future of our discipline. Soil Biol. Biochem. 24, 1765–1771.

Loh, T.C., Lee, Y.C., Liang, J.B., Tan, D., 2005. Vermicomposting of cattle and goat manures by *Eisenia foetida* and their growth and reproduction performance. Bioresour. Technol. 96, 111–114.

Malley, C., Nair, J., Ho, G., 2006. Impact of heavy metals on enzymatic activity of substrate and on composting worms *Eisenia fetida*. Bioresour. Technol. 97, 1498–1502.

Melgar, R., Benitez, E., Nogales, R., 2009. Bioconversion of wastes from olive oil industries by vermicomposting process using the epigeic earthworm *Eisenia andrei*. J. Environ. Sci. Health 44, 488–495.

Mishra, M.M., Kukreja, K., Kapoor, K.K., Bangar, K.C., 1989. Organic recycling for plant nutrients. In: Somani, L.L., Bhandari, C.S. (Eds.), Soil Microorganisms and Crop Growth. Divyajyoti Parkashan, Jodhpur, pp. 195–232.

Nogales, R., Cifuentes, C., Benitez, E., 2005. Vermicomposting of winery wastes: a laboratory study. J. Environ. Sci. Health Part B 40, 659–673.

Plaza, C., Nogales, R., Senesi, N., Benitez, E., Polo, A., 2008. Organic matter humification by vermicomposting of cattle manure alone and mixed with two-phase olive pomace. Bioresour. Technol. 99, 5085–5089.

Prakash, M., Karmegam, N., 2010. Vermistabilization of pressmud using *Perionyx ceylanensis* Mich. Bioresour Technol. 101, 8464–8468.

Pramanik, P., 2010. Changes in microbial properties and nutrient dynamics in bagasse and coir during vermicomposting: Quantification of fungal biomass through ergosterol estimation in vermicompost. Waste Manage. 30, 787–791.

Pramanik, P., Ghosh, G.K., Ghosal, P.K., Banik, P., 2007. Changes in organic-C, N, P and K and enzyme activities in vermicomposts of biodegradable organic wastes under liming and microbial inoculants. Bioresour. Technol. 98, 2485–2494.

Sangwan, P., Kaushik, C.P., Garg, V.K., 2008. Feasibility of utilization of horse dung spiked filter cake in vermicomposters using exotic earthworm *Eisenia foetida*. Bioresour. Technol. 99, 2442–2448.

Sangwan, P., Kaushik, C.P., Garg, V.K., 2010. Vermicomposting of sugar industry waste (pressmud) mixed with cow dung employing an epigeic earthworm *Eisenia foetida*. Waste Manage. Res. 28, 71–75.

Singh, J., Kaur, A., Vig, A.P., Rup, P.J., 2010. Role of *Eisenia fetida* in rapid recycling of nutrients from bio sludge of beverage industry. Ecotox. Environ. Safe. 73, 430–435.

Suthar, S., 2008. Bioconversion of post harvest residues and cattle shed manure into value added products using earthworm *Eudrilus eugeniae* Kinburg. Ecol. Eng. 32, 206–214.

Suthar, S., 2010. Pilot-scale vermireactors for sewage sludge stabilization and metal remediation process: comparison with small-scale vermireactors. Ecol. Eng. 36, 703–712.

Tajbakhsh, J., Abdoli, M.A., Mohammadi Goltapeh, E., Alahdadi, I., Malakouti, M.J., 2008. Trend of physico-chemical properties change in recycling spent mushroom compost through vermicomposting by epigeic earthworms *Eisenia foetida* and *E. Andrei*. J. Agri. Technol. 4, 185–198.

Tognetti, C., Laos, F., Mazzarino, M.J., Hernandez, M.T., 2005. Composting vs. vermicomposting: a comparison of end product quality. Compost Sc. Utili. 13, 6–13.

Venkatesh, R.M., Eevera, T., 2008. Mass reduction and recovery of nutrients through vermicomposting of fly ash. Appl. Ecol. Environ. Res. 6 (1), 77–84.

Yadav, A., Garg, V.K., 2009. Feasibility of nutrient recovery from industrial sludge by vermicomposting technology. J. Hazard. Mater. 168, 262–268.

Yadav, A., Garg, V.K., 2011. Recycling of organic wastes by employing *Eisenia fetida*. Bioresour. Technol. 102, 2874–2880.

Zucconi, F., Pera, V., Forte, M., De Bertoldi, V., 1981. Evaluating toxicity of immature compost. Biocycle 22, 54–57.