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Recycling of organic wastes by employing *Eisenia fetida*

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ABSTRACT

This paper reports the recycling of nutrients by vermicomposting of cow dung (CD), poultry droppings (PD) and food industry sludge (FIS) employing earthworms (*Eisenia fetida*). A total of six vermicomposting units were established and dynamics of chemical and biological parameters has been studied for 13 weeks. The waste mixture containing 50% CD + 25% PD + 25% FIS had better fertilizer value among studied waste combinations. At the end of experiment, vermicomposts showed decrease in pH and organic C, but increase in EC, total Kjeldhal N, total available P and total K contents. The C:N ratio of final vermicomposts also reduced to 10.7–12.7 from 22.8 to 56 in different waste combinations. The earthworms have good biomass gain and cocoon production in all vermicomposting units but CD alone and 50% CD + 25% PD + 25% FIS were better than other studied combinations.

1. Introduction

Large scale industrialization, urbanization and population growth have affected the healthy relationship between man and nature. Various human activities generate huge quantities of solid wastes throughout the world and their management has become a technical and ecological challenge for all. Most of the wastes are disposed in ecologically unsustainable manner by open dumping or burning. These environmentally unhealthy waste disposal methods may lead to loss of nutrients present in the waste and economic loss (Elvira et al., 1995). The conversion of a waste into beneficial materials is an important component of resource recovery and recycling principles. Scientific utilization of organic solid wastes can provide nutrients for plant growth as well as improve soil health.

In India food industries, intensive livestock farming and poultry farms generate huge quantities of organic solid wastes, which have the potential for being recycled on agricultural land. These wastes are among the major under-utilized resources and their disposal is the major concerns for municipalities and industries in all countries. Fresh organic waste materials cannot be applied to soil until they have been sufficiently biostabilized, because application of immature organic materials to soil may effect plant growth due to nitrogen starvation and production of toxic metabolites (Zucconi et al., 1981).

These wastes have not been fully exploited due to non-availability of a viable technology for their economical recycling. Under these circumstances, vermicomposting may be an eco-friendly and economically viable technology for converting these wastes into organic manure. Vermicomposting is a biological waste management technology by which organic fraction of the waste stream is decomposed by microorganisms and earthworms in controlled environmental conditions to a level in which it can be handled, stored, and applied in the agricultural fields without adverse impacts on the environment (Aira et al., 2002). It is a simple biotechnological process in which earthworms are employed to convert the organic waste material into vermicompost, excellent organic manure (Benítez et al., 2000). In vermicomposting process microbes are responsible for biochemical degradation of organic matter and earthworm acts as mechanical blenders, by comminuting the organic matter; they modify its biological, physical and chemical state, gradually reducing its C:N ratio and increasing the surface area exposed to microorganisms. Most of the non-toxic, salinity-free, compostable agricultural residues, animal dungs, urban and industrial organic wastes can be used for vermicomposting. Vermicompost is an excellent soil conditioner that has higher nutrient availability for plant growth, since it is homogenous, has desirable aesthetics, has reduced levels of contaminations and tend to hold more nutrients over a longer period (Ndegwa and Thompson, 2000). Vermicompost contains important plant nutrients (N, P & K) present in forms that are much more soluble and available to plants than parent organic waste substrate (Ndegwa and Thompson, 2001).

The ability of epigeic earthworms to consume and breakdown a wide range of organic wastes such as sewage sludge (Sinha et al., 2008; Gupta and Garg, 2008; Khwairakpam and Bhargava, 2009), cattle wastes (Loh et al., 2005; Plaza et al., 2007), poultry waste

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(Ghosh et al., 1999; Garg and Kaushik, 2005), crop residues (Suthar, 2009), bagasse (Pramanik, 2010; Kumar et al., 2010), industrial sludge/waste (Sen and Chandra, 2006; Sangwan et al., 2008; Yadav and Garg, 2009; Subramanian et al., 2010) and human faeces (Yadav et al., 2010) has been reported. Although, literature is available on utilization of earthworms for agriculture, animal, poultry, sewage and industrial wastes recycling, but utilization of heterogeneous wastes combinations is yet to be proven for vermicomposting process. This paper reports the feasibility of vermicomposting for the management of wastewater treatment plant sludge of a food industry and poultry droppings with cow dung. The objective of the present paper is to produce nutrient-rich vermicompost and earthworm biomass from cow dung spiked with food industry sludge and poultry waste using earthworm *Eisenia fetida*.

2. Methods

Three different types of organic wastes e.g. food industry sludge, cow dung and poultry dropping have been used in this study. Dewatered food industry sludge (FIS) was procured from aerobic wastewater treatment plant of a food industry located at Bahadurgarh, Haryana, India. Fresh cow dung (CD) was procured from a live-stocked farm at Hisar, India. The poultry droppings (PD) were collected from a poultry farm located near Hisar, India. CD, FIS and PD were allowed to dry under shade in large size plastic containers in laboratory with periodic turnings at room temperature. Then FIS was mixed with CD and PD in different proportions. The physico-chemical characteristics of CD, FIS and PD are given in Table 1. *E. fetida* a composting worm was used in the experiments due to its well established potential for vermicomposting of compostable organic materials such as agricultural wastes and animal manures (Edwards et al., 1998). Unclitellated hatchlings weighing 100–150 mg (live weight) were used for the experiment.

A total of six 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. Triplicates were prepared for each unit. All the used waste mixtures were pre-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* were randomly picked from stock culture and introduced in 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 periodic sprinkling of water throughout the study period. Vermicomposting units were covered with moist jute clothes to prevent moisture loss and to keep away the pests.

Table 1
Initial physico-chemical characteristics of cow dung (CD), poultry dropping (PD) and food industry sludge (FIS).

S. no.	Parameter	CD	PD	FIS
1	pH	8.1 ± 0.30	7.7 ± 0.35	6.3 ± 0.20
2	EC (dS m^{-1})	2.24 ± 0.1	3.35 ± 0.32	1.7 ± 0.1
3	TOC (g/kg)	486 ± 22	405 ± 12	371 ± 20
4	TKN (g/kg)	8.6 ± 0.4	14.5 ± 0.8	23.2 ± 1.5
5	TAP (g/kg)	8.7 ± 0.1	9.2 ± 0.6	8.8 ± 0.3
6	TK (g/kg)	5.5 ± 0.4	3.1 ± 0.1	3.9 ± 0.2
7	C:N ratio	56.5 ± 5.5	27.9 ± 1.8	15.9 ± 1.3
8	C:P ratio	55.8 ± 5.0	44 ± 2.8	42.1 ± 1.3
9	TNa (g/kg)	1.38 ± 0.1	4.37 ± 0.3	6.9 ± 0.2
10	TCa (g/kg)	2.0 ± 0.1	10.4 ± 0.6	3.0 ± 0.3
11	Fe (mg/kg)	1884 ± 110	373.5 ± 20	1414 ± 80
12	Cu (mg/kg)	35 ± 3.5	69 ± 6.0	67.7 ± 18
13	Cr (mg/kg)	80 ± 4	184 ± 10	212 ± 12
14	Zn (mg/kg)	141 ± 5.0	201 ± 15	838 ± 18
15	Cd (mg/kg)	4.5 ± 0.25	4.1 ± 0.2	3.1 ± 0.2

The composition of feeds in different vermicomposting units is given below:

Vermicomposting unit no. 1: – 100% CD (without FIS and PD).
Vermicomposting unit no. 2: – 75% CD + 25% PD.
Vermicomposting unit no. 3: – 50% CD + 50% PD.
Vermicomposting unit no. 4: – 25% CD + 25% PD + 50% FIS.
Vermicomposting unit no. 5: – 25% CD + 50% PD + 25% FIS.
Vermicomposting unit no. 6: – 50% CD + 25% PD + 25% FIS.

From vermicomposting units samples were drawn at 0 day (experiment initiation) and after 91 days (experiment termination) for the analysis of total organic carbon, total Kjeldhal N, total available P, total K, total Ca, heavy metals (Cu, Cr, Cd, Fe and Zn) content. C:N ratios was calculated from the measured value of C, and N. The 0 days refers to the day of inoculation of earthworms after pre-composting of 4 weeks. The physico-chemical analysis was done on dry weight basis. Double distilled water was used for analytical work. All the samples were analyzed in triplicate and results were averaged. The pH and electrical conductivity (EC) were determined using a double distilled water suspension of each sample in the ratio of 1:10 (w/v). Total organic carbon was measured by using the method provided by Nelson and Sommers (1982). Micro-Kjeldhal method of Bremner and Mulvaney (1982) was used for measuring nitrogen. Total potassium and total sodium were determined by flame photometer (Elico, CL 22 D) after digesting the samples in diacid mixture. Total available phosphate was analyzed by using the spectrophotometric method with molybdenum in sulphuric acid. Total heavy metals were determined by atomic absorption spectrophotometer (AAS 6300 Shimadzu, Japan) after digesting the samples with conc. HNO_3 and conc. $HClO_4$ (9:1, v/v).

Biomass gain, clitellum development and cocoon production by the earthworms in each vermicomposting units was recorded weekly for 91 days. The feed in the container was turned out, then earthworms, hatchlings and cocoons were separated from the feed by hand sorting, after which they were counted and weighed after washing with water and drying them by tissue papers. Then all earthworms, hatchlings and cocoons were returned to their respective units. The worms were weighed with full gut. At the end of vermicomposting period the earthworms, hatchlings and cocoons were separated and the final vermicompost from each container was air-dried at room temperature and packed in airtight plastic vials for further physico-chemical 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 vermicomposters for studied parameters. Tukey's *t*-test as a post hoc was also performed to identify the homogeneous type of vermicomposters for the various parameters. The probability levels used for statistical significance were $P < 0.05$ for the tests.

3. Results and discussion

3.1. Nutrient quality of vermicomposts

The earthworms in composting process modify the physical, biological and chemical properties of the waste materials. The final vermicomposts were odour free, granular, darker and homogeneous than initial waste mixtures. The manurial value of vermicompost depends on several factors viz., nature of feed substrate, aeration, moisture, temperature and earthworm species used in the process. Hence it is essential to specify various physico-chemical characteristics, such as pH, electrical conductivity, total

Table 2
Comparison of physico-chemical characteristics of initial feed mixtures and vermicomposts obtained from different CD, PD and FIS feed mixtures (mean ± SD, $n = 3$).

Vermicomposting unit number	pH	EC	TCa	TNa	TK	TAP	TKN
Physico-chemical characteristics of initial feed mixtures							
1	8.1 ± 0.18d	2.26 ± 0.04a	2.1 ± 0.12a	1.48 ± 0.17d	5.5 ± 0.17d	8.7 ± 0.15a	8.7 ± 0.3a
2	8.0 ± 0.14cd	2.54 ± 0.2abc	4 ± 0.42b	2.2 ± 0.13c	4.8 ± 0.13c	8.8 ± 0.14a	10.4 ± 0.6ab
3	7.8 ± 0.17bcd	2.85 ± 0.03c	6.4 ± 0.27d	3.0 ± 0.31ab	4.3 ± 0.31ab	9.0 ± 0.40a	11.9 ± 0.9b
4	7.2 ± 0.16a	2.25 ± 0.19a	4.6 ± 0.15c	4.8 ± 0.12a	4.0 ± 0.21a	8.9 ± 0.20a	18.0 ± 0.8d
5	7.4 ± 0.37ab	2.72 ± 0.15bc	6.5 ± 0.26d	4.35 ± 0.18a	4.0 ± 0.18a	9.1 ± 0.14a	15.5 ± 0.4c
6	7.5 ± 0.12abc	2.48 ± 0.07ab	4.8 ± 0.15c	3.5 ± 0.17bc	4.6 ± 0.17bc	8.8 ± 0.38a	14.0 ± 0.6c
Physico-chemical characteristics of final vermicomposts							
1	6.5 ± 0.14a	4.50 ± 0.30d	7.5 ± 0.27a	2.99 ± 0.32a	7.8 ± 0.2c	13.4 ± 0.40b	31.4 ± 0.4c
2	6.4 ± 0.19a	4.24 ± 0.16 cd	9.5 ± 0.10c	3.68 ± 0.19b	6.7 ± 0.3b	12.9 ± 0.60ab	26.6 ± 0.5a
3	6.7 ± 0.23a	3.81 ± 0.22bc	9.2 ± 0.28c	5.29 ± 0.35d	6.1 ± 0.1a	12.9 ± 0.40ab	28.5 ± 0.3ab
4	6.8 ± 0.17a	3.16 ± 0.06a	6.9 ± 0.21a	5.45 ± 0.34d	5.5 ± 0.25a	11.9 ± 0.55a	29.4 ± 0.3b
5	6.7 ± 0.25a	3.50 ± 0.06ab	7.5 ± 0.38a	4.62 ± 0.17c	5.6 ± 0.05a	13.0 ± 0.80ab	29.2 ± 1.2b
6	6.5 ± 0.2a	3.65 ± 0.02ab	8.3 ± 0.15b	4.14 ± 0.32bc	6.9 ± 0.2b	12.8 ± 0.40ab	26.6 ± 1.0a

Units of all the parameters except pH and EC are in g kg^{-1}. The EC values are in dS m^{-1}.

organic carbon, total Kjeldhal nitrogen, total available phosphorus, total potassium, metal content etc. to quantify the dynamics of vermicomposting process. Physico-chemical characteristics of the initial feed mixtures and vermicomposts are given in Table 2.

pH of vermicomposts was significantly different than initial pH. The pH of all the feed combinations decreased from alkaline (7.2–8.1) to slightly acidic (6.4–6.8). Similar observations have been reported by other scientists for vermicomposting process. Khwairakpam and Bhargava (2009) reported a decrease in pH during the vermicomposting of sewage sludge. The difference in pH of different waste mixtures can be attributed to difference in physico-chemical characteristics of wastes used in the process. Ndegwa and Thompson (2000) have reported that shift in pH values may be due to N and P mineralization and conversion of the organic material into intermediate of organic acids. Pramanik et al. (2007) have postulated that decomposition of organic matter leads to the formation of ammonium (NH_4^+) and humic acids. The combined effect of these two oppositely charged groups actually regulates the pH of vermicompost leading to a shift of pH towards neutrality or acidity. Mean pH of vermicomposts produced from different vermicomposting units was 6.4 ± 0.2, which is within the optimal range for plant growth (Goh and Haynes, 1977). The pH for all the vermicomposting units was not different significantly ($P < 0.05$).

Electrical conductivity (EC) of vermicomposts was higher than initial wastes. The EC reflects the salinity of any material and it is a good indicator of the applicability and utility of a compost or vermicompost for agricultural purposes. The EC was in the range of 3.16–4.50 dS m^{-1} for different vermicomposts (Table 2). This increase in EC might have been due to release of different mineral ions, such as phosphate, ammonium, potassium etc. (Kaviraj and Sharma, 2003). There was significant variation ($P < 0.05$) in EC for all the vermicomposts.

Calcium (Ca) content was higher in the vermicompost than their parent material. Increase in Ca was 1.15–3.57-folds in different vermicomposts. The final calcium content of vermicomposts was in range of 6.9–9.5 g kg^{-1} in vermicomposts. Maximum increment was observed in 100% CD vermicompost and minimum increment in 50% CD + 50% PD vermicompost (Table 2). Garg and Kaushik (2005) have also reported a significant increase in calcium content during the vermicomposting of industrial wastes spiked with other organic waste. They have reported that earthworms drive the mineralization process and convert a proportion of calcium from binding form to free forms, resulting in its enrichment in worm casts.

There was slight increase in sodium content (Na) in all the vermicomposts as compared to initial values (Table 2). Initial Na content in the initial feed mixtures was in the range of 1.48–4.8 g kg^{-1}. Where as final Na content was in range of 2.99–5.45 g kg^{-1}.The increase in Na content was 1.06–2.05-fold in the final vermicomposts as compared with Na content in respective waste combination. Variation in the Na content may be due to the difference in initial feed substrate characteristics in different vermicomposts. The Na content was statistically different in all the vermicomposters except in 50% CD + 50% PD and 25% CD + 25% PD + 50% FIS waste combinations ($P < 0.05$).

The potassium (K) content was also greater in all the vermicomposts than initial waste combinations (Table 2). The increase in potassium content was 39.5–50% in the vermicomposts as compared with K content in initial waste mixtures. The differences in the results can be attributed to the differences in the chemical nature of the initial raw materials. Suthar (2008) has reported 104–160% increase in potassium content during vermicomposting. Sangwan et al. (2010) have also reported an increase in K in vermicomposts after bioconversion of sugar industry waste. Kaviraj and Sharma (2003) have reported that enhanced number of micro-flora present in the gut of earthworms might have played an important role in the process and increased potassium content during vermicomposting process. There was about 33.7–54% increase in total available phosphorus in vermicomposts compared with phosphorus content in initial waste mixtures. After vermicomposting phosphorus content was highest in 100% CD (13.4 g kg^{-1}), and minimum in 25% CD + 25% PD + 50% FIS waste mixture (11.9 g kg^{-1}) (Table 2). Sangwan et al. (2010) have also reported a 1.3–1.5-fold increase in phosphorus content in the vermicomposting of press mud. Le Bayon and Binet (2006) have reported that some amount of phosphorus is converted to more available forms partly by earthworm gut enzymes, i.e., acid phosphatases and alkaline phosphatases. Actions of phosphorus-solubilizing microorganisms present in earthworm's casts may also be responsible for the release of phosphorus in vermicomposting (Prakash and Karmegam, 2010).

Total organic carbon (TOC) content was lesser in all the vermicomposts than initial TOC (Fig. 1). Maximum decrease in TOC was recorded in 75% CD + 25% PD (38%) followed by 100% CD (31%), 50% CD + 25% PD + 25% FIS (24%), 50% CD + 50% PD (18%), 25% CD + 25% PD + 50% FIS (18%) and 25% CD + 50% PD + 25% FIS (16%). The combined action of earthworms and microorganisms may be responsible for TOC loss from the initial feed waste in the form of CO_2. Similar observations have been reported by Prakash and Karmegam (2010) during vermicomposting of sugar industry waste. Kaviraj and Sharma (2003) have reported 20–45% reduction of TOC as CO_2 during vermicomposting of municipal or industrial wastes. Inoculation of earthworms in decomposing organic waste

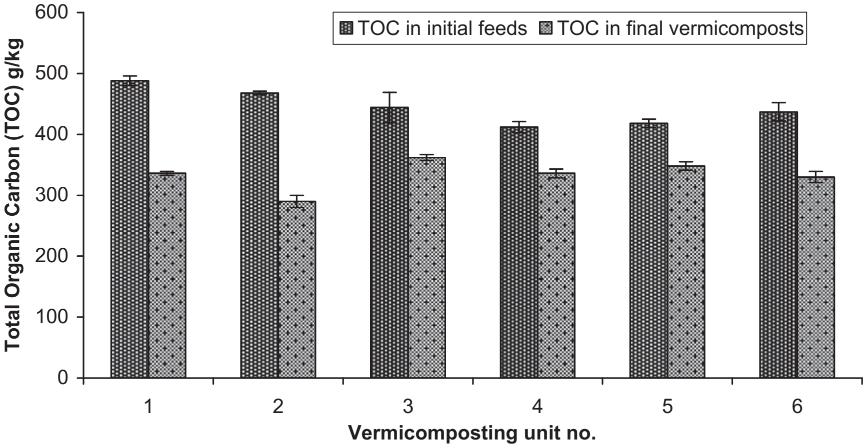

Fig. 1. TOC content of initial feed mixtures and final vermicomposts obtained from different vermicomposting units.

material promotes biochemical degradation, and their activity also promoted the colonization of decomposer communities of waste system, this is due to stable biological as well as chemical environmental conditions. Dominguez and Edwards (2004) has reported that earthworm fragments and homogenizes the ingested material through muscular action of their foregut and also adds mucus and enzymes to ingested material and thereby increases the surface area for microbial action, while microorganisms perform the biochemical degradation of waste material providing some extra-cellular enzymes within the worm's gut. Thus combined action earthworms and microorganisms bring about C loss from the substrates in the form of CO_2.

Total Kjeldhal nitrogen (TKN) content in the vermicomposts was higher than initial waste mixture. The initial TKN content of the waste mixtures was in the range of 8.7–18 g kg^{-1} (Fig. 2). Whereas, TKN content of vermicomposts was in the range of 26.6–31.4 g kg^{-1} after vermicomposting. There was 1.6–3.6-fold increase observed in TKN at the end of experiment. Kaushik and Garg (2004) have reported 2.0–3.2-fold increase in TKN during vermicomposting of textile mill sludge mixed with cow dung and wheat straw. Plaza et al. (2007) have reported that the nitrogen content of vermicomposts increase due to mineralization of C-rich materials and, possibly, due to the action of N-fixing bacteria. Decreases in pH may be another important factor in nitrogen retention by vermicompost which otherwise may be lost as ammonia at higher pH values. The difference in TKN content of vermicomposts was significantly different from each other ($P < 0.05$).

Initial C:N ratio was in range of 22.8–56 (at 0 day), but after 91 days there was a significant decrease in the C:N ratio in all the vermicomposting units. Final C:N ratio was in the range of 10.7–12.7. The lowest C:N ratio was in vermicomposting unit no. 1 material containing cow dung (10.7) while vermicomposting unit no. 3 material had highest C:N ratio (12.7). The reduction in C:N ratio was 2.0–5.2-fold in final vermicomposts during vermicomposting process. The C:N ratio indicates the degree of stabilization of a waste, as carbon is lost as CO_2 during vermicomposting whereas nitrogen content is enhanced during this process and these factors contributes to the lowering of C:N ratio. The decrease in C:N ratio and relative increase in the TKN of vermicomposts may also be due to the loss of dry mass in terms of CO_2 as well as moisture loss by evaporation during vermicomposting (Viel et al., 1987). So, a high degree of organic matter stabilization of waste material was achieved in all the vermicomposters which prove that *E. fetida* can promote decomposition and mineralization of organic matter.

3.2. Heavy metal content in vermicomposts

Heavy metal content in initial waste mixtures and vermicomposts are given in Table 3. When a heavy metal element is introduced into the soil through compost or vermicompost, it will either be dissolved in water of drainage, enter in the plants or adsorbed on soil. The major portion of heavy metals is accumulated in the soil, generally in complex forms with humic or fulvic

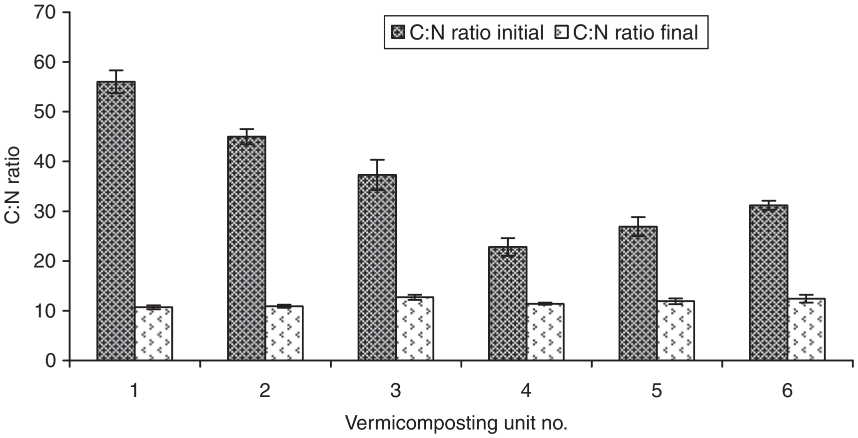

Fig. 2. C:N ratio in initial feed mixtures and final vermicomposts obtained from different vermicomposting units.

Table 3
Heavy metal content (mg kg^{-1}) in initial feed mixtures and vermicomposts obtained from different CD, PD and FIS feed mixtures *(Mean SD, n = 3)*.

Vermicomposting unit number	Total-Fe	Total-Cu	Total-Zn	Total-Cd	Total-Cr
Heavy metal content in initial feed mixtures					
1	1810 ± 182d	32.4 ± 1.3a	145 ± 4^{a}	4.29 ± 0.31^{a}	82 ± 7a
2	1560 ± 209cd	42.5 ± 1.5b	151 ± 11^{a}	4.51 ± 0.21a	106 ± 5a
3	1138 ± 74ab	50.5 ± 4.5c	179 ± 8^{a}	4.44 ± 0.04a	138 ± 26b
4	1280 ± 120abc	59.8 ± 2.2d	475 ± 7c	3.92 ± 0.28a	180 ± 9c
5	1024 ± 34a	62.3 ± 3.7d	510 ± 33c	4.07 ± .023a	168 ± 13bc
6	1390 ± 175bc	51.2 ± 4.8c	351 ± 5b	4.18 ± 0.18a	144 ± 12b
Heavy metal content in final vermicomposts					
1	2280 ± 185c	52.6 ± 3.6a	193 ± 19a	5.84 ± 0.24a	194 ± 12a
2	1908 ± 95b	59.9 ± 4.9ab	262 ± 29^{a}	5.52 ± .022cd	211 ± 22a
3	1398 ± 131a	74.1 ± 7.1b	291 ± 14a	5.28 ± 0.22bcd	191 ± 16a
4	1400 ± 90a	77.8 ± 9.2b	805 ± 90b	4.51 ± 0.21a	210 ± 33a
5	1215 ± 60a	96 ± 7.0c	858 ± 36b	4.61 ± 0.39ab	187 ± 8a
6	1710 ± 78b	76.8 ± 9.0b	886 ± 29b	4.98 ± 0.2abc	228 ± 26a

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

acids. The metal toxicity is not caused by the mere presence of metals, but it depends on metal concentration, toxicity, mobility in free form, the route of uptake mechanism and bioavailability if it is accumulated in plants (Alloway and Ayers, 1994).

So, before organic manure including vermicompost application to agricultural fields, heavy metals should be quantified in them. While comparing the metal concentration of the vermicomposts with initial waste mixtures, it was observed that the concentration of all the metals was higher in vermicomposts. Total Fe content of vermicomposts was 1215–2280 mg kg^{-1} in different vermicomposting units. Total Cu content was also higher after vermicomposting. Minimum Cu content was observed in vermicomposting unit no. 1 (52.6 mg kg^{-1}) and maximum was recorded in vermicomposting unit no. 5 (96 mg kg^{-1}). Zinc (Zn) content was 33–152% higher in final vermicomposts in than initial concentration.

The cadmium content (Cd) was slightly higher in vermicomposts (4.51–5.84 mg kg^{-1}) as compared to initial values (3.92–4.29 mg kg^{-1}). Similarly chromium (Cr) content was higher in all vermicomposts than parent materials, it was in range of 187–288 mg kg^{-1} in vermicomposts and in range of 82 ± 7–180 ± 9 mg kg^{-1} in initial waste mixtures (Table 2). The vermicomposts collected from different vermicomposting units showed a statistical significant difference (ANOVA; $P < 0.05$) for heavy metals.

The results indicate that metal content in vermicomposted material was closely related to the metal concentration in initial wastes. Gupta and Garg (2008) have reported an increase in heavy metals concentration in final vermicomposts of sewage sludge. Suthar et al. (2008) have also reported higher concentration of metals in earthworm casts collected from sewage soils and cultivated lands. The weight and volume reduction due to mineralization and decomposition of organic matter during vermicomposting may be the reasons for increase in heavy metal concentrations in vermicomposts (Deolalikar et al., 2005).

3.3. Growth and reproduction of *E. fetida* in different waste mixtures

During vermicomposting worm growth rate was recorded in terms of biomass. The earthworms reared in different waste mixtures had significant difference in growth rate and fecundity parameters. The biomass growth rate in different waste mixtures with time has been depicted in Fig. 3. Initially growth rate was rapid in all waste mixtures followed by a stabilized growth rate and finally a decrease in growth was recorded. Growth rate reduction during later phase of vermicomposting in *E. fetida* has also been reported by other workers (Sangwan et al., 2008). The reduction in growth rate in last phase of vermicomposting may be due to exhaustion of feed substrate. The biomass and fecundity of worms in different wastes has been encapsulated in Table 4. In this study maximum mean worm biomass was observed in 50% CD + 25% PD + 25% FIS (1172 mg earthworm^{-1}) and lowest in 25% CD + 25% PD + 50% FIS (1015 mg earthworm^{-1}). There was no statistical significant difference among different waste mixtures for biomass gained per worm ($P < 0.05$). The maximum mean worm biomass was attained in 6th week (in 100% CD), in 7th week (in 50% CD + 50% PD), in 8th week (in 75% CD + 25% PD, 25% CD + 25% PD + 50% FIS & 50% CD + 25% PD + 25% FIS) and in 9th week (in 25% CD + 50% PD + 25% FIS waste mixture). Highest growth rate was observed in 100% CD (24.4 ± 2.1 mg worm^{-1} day^{-1}) where as 25% CD + 50% PD + 25% FIS (8.14 ± 0.32 mg worm^{-1} day^{-1}) supported the minimum growth rate, but the values of growth rate were not significantly different from other waste mixtures (Table 4).

Food availability and population size determine the time to reach sexual maturity for earthworms (Neuhauser et al., 1980). The time needed for clitellum development in earthworms varies directly with nutrient availability. Sexual maturity was attained after 2nd week in 100% CD, after 3rd week in 75% CD + 25% PD, 50% CD + 50% PD, 25% CD + 25% PD + 50% FIS & 50% CD + 25% PD + 25% FIS and after 4th week in 25% CD + 50% PD + 25% FIS waste mixture which is determined with clitellum development (Table 4). The cocoon production started in 4th week (in 100% CD & 50% CD + 25% PD + 25% FIS), in 5th week (in 75% CD + 25% PD & 50% CD + 50% PD) and in 6th week (in 25% CD + 25% PD + 50% FIS & 25% CD + 50% PD + 25% FIS) during the experiment (Table 4). The residual (at termination of experiment) cocoon number of in different waste mixtures was in range of 528 ± 120 (in 25% CD + 50% PD + 25% FIS) to 1826 ± 140 cocoons (in 50% CD + 25% PD + 25% FIS). The earthworm reproduction rate was different among the waste mixtures, depending upon the quality of the feed substrate. Number of cocoons produced by per worm in different waste mixtures were in the order; 50% CD + 25% PD + 25% FIS > 100% CD & 75% CD + 25% PD > 50% CD + 50% PD > 25% CD + 25% PD + 50% FIS > 25% CD + 50% PD + 25% FIS.

Maximum numbers of hatchlings were produced in 100% CD (885 ± 71) and minimum in 25% CD + 25% PD + 50% FIS (341 ± 50) (Table 4). The number of hatchlings in 100% CD, 75% CD + 25% PD and 50% CD + 25% PD + 25% FIS were not statistically different from each other. In similar manner, number of hatchlings in 25% CD + 25% PD + 50% FIS and 25% CD + 50% PD + 25% FIS did not show significant difference ($P < 0.05$).

Some worm mortalities were observed during the vermicomposting experiment. The mortalities were in the range of 3.3–10% of the total number of the worms present in different waste mixtures. Mortality was higher in those waste mixtures which had higher PD and FIS concentrations. The dead worms were

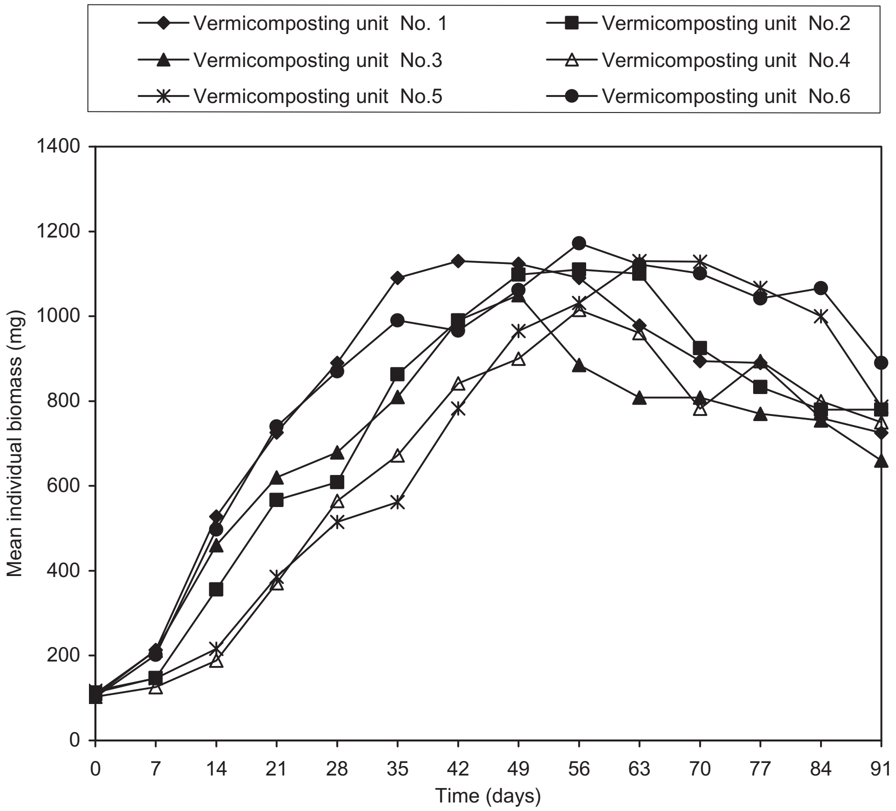

Fig. 3. Growth curves of *E. fetida* in different vermicomposting units.

Table 4
Biomass production and reproduction by *E. fetida* in different vermicomposting units.

Vermicomposting unit number	Mean initial biomass worm^{-1} (mg)	Max. biomass gained worm^{-1} (mg)	Max. biomass achieved in (week)	Growth rate worm^{-1} day^{-1}	Total no. of cocoon after 91 days	Total no. of hatchlings after 91 days
1	105 ± 4a	1130 ± 80ab	6th	24.4 ± 2.1ab	1704 ± 90cd	885 ± 71c
2	113 ± 6a	1110 ± 47ab	8th	17.8 ± 1.2a	1547 ± 80bc	809 ± 69c
3	110 ± 3a	1050 ± 60ab	7th	19.18 ± 1.1a	1156 ± 160bc	643 ± 20b
4	103 ± 4a	1015 ± 35a	8th	16.28 ± 0.72a	783 ± 110ab	341 ± 50a
5	117 ± 7a	1130 ± 40ab	9th	16.07 ± 0.43a	528 ± 120a	387 ± 42a
6	102 ± 5a	1172 ± 47b	8th	19.10 ± 1.88a	1826 ± 140d	806 ± 49c

All values are reported as mean ± standard deviation between three replicates; values in the same column with different letters are significantly different (ANOVA; Tukey's test, $P < 0.05$). The experiment was terminated on 91 day.

replaced with equal number of new worms (of almost same biomass) from the stock culture. Maximum mortality was observed in 50% CD + 50% PD (10%) followed by 25% CD + 25% PD + 50% FIS (6.67%), 75% CD + 25% PD & 25% CD + 50% PD + 25% FIS (3.34%) and no mortality was observed in 100% CD & 50% CD + 25% PD + 25% FIS. Suthar (2010) has also reported some earthworms mortality during the vermicomposting of biogas plant slurry mixed with crop residues. The different mortality rates may be due to the difference in the quality and chemical composition of waste mixtures used for vermicomposting. The survival rate of earthworms also depends upon the rate of food consumption during acclimatization of worms in the waste mixtures. Changes in chemical composition of feed, changes in pH of substrate, higher C:N ratio of initial substrate and production of toxics or foul smelling gases (ammonia, carbon dioxide, nitrogen oxides, etc.) may be some of the factors responsible earthworms mortality (Flegel and Schreder, 2000).

4. Conclusions

This work was undertaken to explore the use of vermicomposting technology in food industry waste management. Various combinations of CD with PD and FIS were vermicomposted using an epigeic earthworm (*E. fetida*) and the vermicompost quality and growth & fecundity were estimated in different waste mixtures. The final vermicomposts was rich in important plant nutrients (nitrogen, phosphorus and potassium) and their C:N ratio was below 20 which indicate their agronomic importance. The quality of initial feed substrates determined the physico-chemical characteristics of vermicomposts prepared after vermicomposting. The results suggest that vermicompost can be introduced as one of the technologies for converting industrial wastes into value added products.

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