Bioresource Technology 274 (2019) 512–517

Contents lists available at ScienceDirect

Bioresource Technology

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

Biotransformation of bakery industry sludge into valuable product using vermicomposting

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ARTICLE INFO

Keywords:
Bakery industry sludge
Vermicompost
Eisenia fetida
Heavy metal
C:N ratio

ABSTRACT

The aim of present work was to evaluate periodic changes in bakery industry sludge during vermicomposting. Six different blends of cow dung (CD) and bakery industry sludge (BIS) containing 10 to 50% of BIS were assessed in this study. Changes in physico-chemical parameters were evaluated at 21 days interval up to 105 days. Earthworms significantly increased NPK content and EC, while decreased pH, TOC and C: N ratio of BIS. After vermicomposting, TKN, TAP and TK contents increased 2.0–3.5, 1.2–1.9 and 1.2–1.4 times, respectively as compared to initial blends. A significant reduction (65.4–83.5%) in C: N ratio was observed in all blends. The concentrations of metals were found to be higher in the vermicomposts as compared initial blends. It was inferred that bakery industry sludge spiked with cow dung can be biotransformed into valuable manure employing earthworms.

1. Introduction

In the present era, population explosion, haphazard industrialization and unplanned urbanization have caused an enormous upsurge in solid waste generation. Waste production is directly proportional to the technological advancement, population, urbanization and industrialization. Disposal of solid waste is a foremost environmental issue all over the world. Developing nations facing this problem in a serious manner due to gap in the availability and requirement of appropriate disposal technologies. In India, about 1,88,500 tonnes of municipal solid waste are produced per day (Arumugam et al., 2018) from various human, industrial and domestic activities. Furthermore, industrialization at its pace and day by day increasing number of industries generate millions of tons of industrial waste every day (Bhat et al., 2018). Industrial sludges are produced in large quantities during efflunet treatment by various industries. This is a solid/semi-solid stuff that sometimes contain noxious compounds and heterogeneous in nature (Lee et al., 2018). Therefore, management and disposal of sludges is a challenging task. Various industries such as pulp and paper, sugar, cement, tanneries, pharmaceutical and food processing produce sludge and sometimes dispose it in irrational manner.

Effluent treatment plants at Bakery industries produce non-toxic and biodegradable sludge (Yadav et al., 2015). Improper and poor management of bakery industry sludge may have adverse environmental impacts, including wind-blown litter, attraction to vermins, generation of liquid leachate, soil pollution, water pollution and health hazards. Therefore, safe technologies to manage industrial sludge are desired that are ecologically sound, economically viable and acceptable to community.

Now-a-days biological processes are suggested to process, and treat non-toxic wastes with a paradigm to convert them into energy and organic manure (Sharma and Garg, 2018). Vermicomposting is one such biological technology that can be used for the biotransformation of the bakery industry sludge into manure (Yadav et al., 2015). It is a sustainable and economical process, by which worms convert organic waste materials into a nutrient rich, well stabilized and aesthetically pleasent material, i.e., vermicompost. Vermicompost is a peat-like material with excellent structure, porosity, aeration, drainage and enhanced moisture holding capacity with the capability of enhancing plant growth (Sharma and Garg, 2017a). Several studies have been conducted in the past to investigate the potential of vermicomposting to stabilize various industrial wastes including Paper-pulp mill sludge (Elvira et al., 1998; Kaur et al., 2010), Tannery industry wastes (Ravindran et al., 2016), Textile industry sludge (Garg and Kaushik, 2005), Distillery industry sludge (Mahaly et al., 2018), Sago industry waste (Subramanian et al., 2010), Food industry waste (Yadav and Garg, 2013), Dairy industry sludge (Desai et al., 2016; Singh et al., 2017); Petrochemical industry sludge (Banu et al., 2005) and

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https://doi.org/10.1016/j.biortech.2018.12.023
Received 28 October 2018; Received in revised form 7 December 2018; Accepted 8 December 2018

Aquaculture sludge (Kouba et al., 2018). Although attempts have been made to vermicompost various industrial wastes but modest attention has been given to bakery industry sludge as a raw material for vermicomposting in India.

Bakery industry waste contains significant proportion of organic matter, organic carbon, sugars, proteins, enzymes, micro and macronutrients. However, the direct use of industrial waste in soil as fertilizer might inhibit plant growth due to nitrogen starvation and the production of toxic metabolites (Lee et al., 2018). Industrial organic wastes have promiing potential for restoring the soil organic matter (Yadav and Garg, 2015). Based on available literature it is hypothesized that vermicomposting technology can be a ueful technology to handle BIS. The manure so produced can be used as a input in cultivable fields. Keeping this in view, the objective of this study was to evaluate the dynamics of physico-chemical parameters and heavy metals' content during vermicomposting of bakery industry sludge (BIS) and cow dung (CD) blends.

2. Material and methods

2.1. Raw substrates and earthworm

Fresh sludge was collected from wastewater treatment plant of a bakery industry. The dewatered sludge (mixture of primary and secondary sludge) was collected from the sludge drying beds in plastic containers with the help of plastic scoops. It was dried in direct sunlight for a week with periodic turnings before use, as a feedstock in the waste mixture used for vermicomposting.

Fresh urine free cow dung was collected from a livestock farm located at Hisar, India. CD was stored in plastic containers at room temperature. The CD was mixed with sludge in different compositions. The physico-chemical characteristics of BIS and CD are given in Table 1. The earthworm species *Eisenia fetida* was used for the biotranformation of waste mixtures due to its better survival potential in sludges laden feed (Yadav and Garg 2009, 2013, 2016a).

2.2. Experimental design

10 kg (dry weight) of each waste blend (V_1-V_6) was fed in a circular plastic bin. The ratio of CD and BIS in each blend is given in Table 2. Each bin was established in triplicate. Waste in all bins was allowed to decompose for three weeks to reduce C: N ratio and to liberate heat produced during initial decomposition. Then 200 *Eisenia fetida* hatchlings, each having ≈200 mg biomass, were introduced in each bin. The day of earthworm inoculation was considered 0 day.

All the vermicomposting bins were kept in dark at a temperature of 22 ± 3 °C. The moisture content was maintained at 60–70%. Vermicompost samples were collected at 21 days interval from each bin to evaluate the dynamics of biotransformation of wastes. These samples dried in shade, powdered, sieved and stored in plastic vials for physico-chemical analysis. All the analysis was done on dry weight basis.

Table 1
Initial physico-chemical characteristics of CD and BIS used in the experiment (Mean ± SD, n = 3).

S. No.	Parameter	CD	BIS
1	pH	8.3 ± 0.50	6.5 ± 0.30
2	EC (dS/m)	1.2 ± 0.1	2.2 ± 0.2
3	TOC (g/kg)	495 ± 23	370 ± 12
4	TKN (g/kg)	8.2 ± 0.45	11.8 ± 0.7
5	TP (g/kg)	5.72 ± 0.15	8.81 ± 0.5
6	TK (g/kg)	7.8 ± 0.2	1.81 ± 0.09
7	C: N ratio	60.3 ± 2.2	31.3 ± 1.8
8	TNa (g/kg)	4.2 ± 0.22	8.8 ± 0.23
9	TCa (g/kg)	1.9 ± 0.09	3.85 ± 0.3
10	Zn (mg/kg)	137 ± 11.0	900 ± 56.0
11	Fe (mg/kg)	1134 ± 25	1670 ± 51
12	Cu (mg/kg)	49 ± 2.4	67 ± 3.1

Table 2
Composition of wastes (CD and BIS) in vermicomposting bins.

Vermicomposting bin code	Description of waste in vermicomposting bin	Composition of vermicomposting bin
V_1	100% CD + 0% BIS	10 Kg CD + 0 Kg BIS
V_2	90% CD + 10% BIS	9 Kg CD + 1 Kg BIS
V_3	80% CD + 20% BIS	8 Kg CD + 2 Kg BIS
V_4	70% CD + 30% BIS	7 Kg CD + 3 Kg BIS
V_5	60% CD + 40% BIS	6 Kg CD + 4 Kg BIS
V_6	50% CD + 50% BIS	5 Kg CD + 5 Kg BIS

2.3. Physico-chemical and metal analysis

The pH and electrical conductivity (EC) of the waste/vermicompost were determined using their 1:10 (w/v) aqueous suspension. Total organic carbon (TOC) and Total Kjeldahl nitrogen (TKN) were determined as reported by Nelson and Sommers (1982) and Bremner and Mulvaney (1982) respectively. Total available phosphorous (TAP) was determined spectrophotometrically and Total potassium (TK) was determined using flame photometer. Heavy metals were determined by atomic absorption spectrophotometer (AAS). All samples were digested in appropriate digestion mixture prior to analysis. The digestion of samples was done as reported by Yadav and Garg (2009). C: N ratio was calculated from TOC and TKN content.

2.4. Statistical analysis

All the samples were analyzed in triplicate and the results were averaged. All statistical analyses were done using the SPSS 16.0 software. One-way analysis of variance (ANOVA) was considered to analyze the significant differences among different samples for studied parameters. Tukey's *t*-test as a post hoc was also evaluated to categorize the homogeneous type of samples for the various parameters. A *P* value of less 0.05 was considered to indicate a significant difference between the values compared.

3. Results and discussion

The finished end product of the process, i.e. vermicompost was uniform textured, dark coloured than initial blend. Physico-chemical properties and heavy metals' content of the waste mixtures were significantly transformed after vermicomposting.

3.1. Change in physico-chemical properties

A reduction in pH was found during vermicomposting process (Table 3). pH of vermicomposts harvested on 105th day was in acidic or near neutral range (6.5–6.9). This decline in pH may be due to the bioconversion of various organics present in waste mixture into organic acids (Ndegwa et al., 2000; Yadav and Garg, 2016b). Production of humic acids and fulvic acids by microbes from organic matter may also be a reason for lowering of pH during vermicomposting process (Swarnam et al., 2016). Decrease in pH in different vermicomposting bins was insignificant with each other (Table 3). The dissimilarity in pH of different bins may be due to production of different quantities of organic acids.

The results showed that electrical conductivity (EC) increased during vermicomposting process in all the bins. EC of vermicomposts were in the range of 1.6–2.2 $\mathrm{dS\,m^{-1}}$ (Table 3). Increase in EC may be due to the release of soluble salts in the vermicomposting bins owing to combined action of earthworms and microflora during the degradation of organics. Ascend in mineral salt content with a corresponding loss of

Table 3
Physico-chemical characteristics in initial feed mixtures and vermicompost obtained from the mixtures of CD and BIS.

Vermicomposting bin	pH	EC (dS/m)	TCa (g/kg)	OM (%)
V_1	8.3 ± 0.15c	1.2 ± 0.12a	1.9 ± 0.27a	85.3 ± 4.2ab
V_2	8.1 ± 0.2bc	1.3 ± 0.13a	2.1 ± 0.44ab	83.1 ± 7.4b
V_3	7.9 ± 0.23abc	1.4 ± 0.1a	2.3 ± 0.3ab	81.3 ± 5.2ab
V_4	7.8 ± 0.11ab	1.5 ± 0.26a	2.4 ± 0.26ab	78.9 ± 6.9ab
V_5	7.5 ± 0.21a	1.6 ± 0.18a	2.6 ± 0.27ab	76.3 ± 1.3ab
V_6	7.5 ± 0.15a	1.7 ± 0.27a	2.8 ± 0.19b	74.5 ± 2.3a
Physico-chemical characteristics of vermicomposts				
V_1	6.9 ± 0.29a	1.6 ± 0.16a	3.18 ± 0.29a	48.2 ± 1.9a
V_2	6.7 ± 0.1a	1.8 ± 0.23a	3.24 ± 0.35a	50.8 ± 2.1ab
V_3	6.6 ± 0.14a	1.7 ± 0.12a	3.46 ± 0.25a	52 ± 2.3ab
V_4	6.6 ± 0.18a	1.8 ± 0.10a	3.49 ± 0.30a	53.4 ± 2.4b
V_5	6.5 ± 0.21a	2.0 ± 0.10ab	3.58 ± 0.30a	53.7 ± 1.3b
V_6	6.5 ± 0.12a	2.2 ± 0.15b	3.75 ± 0.05a	54.9 ± 1.3b

Mean values (mean ± SD, n = 3), followed by different letters is statistically different (ANOVA; Tukey's test, $P < 0.05$).

organic matter may be another reason for the increase in EC (Khawairakpam and Bhargava, 2009; He et al., 2016). Soumare et al. (2002) have suggested that threshold value of EC for a material is 3.0 dS m^{-1} for its safe application to the agricultural soils. The data revealed that EC of vermicomposts obtained from different bins were not significantly different from each other ($P > 0.05$).

After vermicomposting, organic matter (OM) content decreased significantly in all the vermicomposting bins (Table 3). Loss in OM content was in the range of 43.5–26.3% in different vermicomposting bins. Maximum OM loss was in V_1 bin after 105 days. The earthworm mediated microbial propagation further activates the degradation of organic waste, and directly affects the OM budget of the wastes (Suthar, 2008). Loss of organic matter is directly related to earthworm activity and mineralization of organic matter during the vermicomposting process (Yadav and Garg, 2009).

Total organic carbon (TOC) also reduced in all bins as compared to initial blends (Table 4). There was 26.1–42.8% loss of TOC in different vermicomposting bins by the end of the experimental period. The result suggests that the easily biodegradable pool of organic carbon was gradually exhausted during the process which was responsible for the reduction in TOC. The maximum TOC loss was found in V_1 (100% CD). In other bins TOC loss was goverened by sludge content in the bin. The TOC loss was found to be inversely related to the sludge content in the vermicomposting bins. Several other researchers have also reported similar observations for TOC loss during vermicomposting of different wastes. Kaushik and Garg (2003) have reprted 20–45% TOC loss during vermicomposting of textile mill sludge. Yadav and Garg (2013) have reported 22–44% TOC loss while bioremediating the industrial solid watses and Sharma and Garg (2017a) have also reported 39.9–48.2% reduction in TOC during vermicomposting process. The TOC loss may be due to the utilization of carbon as a source of energy by earthworms and microorganisms and the loss of carbon in the form of CO_2 through microbial respiration during the process (Yadav and Garg, 2016a; Hanc and Dreslova, 2016; Sharma and Garg, 2017a,b). Further, the increase in earthworms' biomass, which is due to the conversion of some part of organic fraction of the substrate, can also cause a decrease in carbon from the substrate and the stabilization of OM by earthworms (Suthar, 2008; Hanc and Dreslova, 2016). According to Goswami et al. (2016) lower TOC content also indicates the richness of humic substances, stability and maturity of compost.

Total Kjeldahl Nitrogen (TKN) content increased after vermiprocessing of the waste mixture. TKN content was 2.0–3.5 folds higher in different vermicomposting bins, probably due to mineralization of organic matter present in waste blends. It is evident from Table 4 that there was slight increase in TKN content up to day 21; thereafter, it increased rapidly and the increase was inversely proportional to the increasing concentrations of BIS in the vermicomposting bins. Sharma and Garg (2018) have also reported higher TKN during vermiprocessing of ruminant excreta. Nitrogen mineralization, addition of nitrogenous excretory substances and mucus by earthworms, secretion of polysaccharides, hormones and enzymes by earthworms, loss of organic carbon and reduction in pH, reduction in dry mass, could be the major causes for nitrogen addition during the vermiprocessing of waste (Suleiman et al., 2017; Sahariah et al., 2015).

TAP in vermicomposts was higher than the initial waste mixtures and increased gradually with vermicomposting period (Table 5). Increase in TAP content in different bins was in the range 1.85–5.70 g/kg. It was 1.25–1.99 folds higher than the initial levels. Similar results on

Table 4
Change in TOC and TKN (g/kg) in vermicomposts during the experimental period.

Vermicomposting bin	0 day	21 day	42 day	63 day	84 day	105 day
TOC content (g/kg)						
V_1	490 ± 12c	450 ± 21a	401 ± 8a	356 ± 2a	315 ± 7a	280 ± 9a
V_2	482 ± 5bc	444 ± 26a	399 ± 8a	350 ± 6a	310 ± 14a	295 ± 26a
V_3	472 ± 5bc	438 ± 16a	394 ± 29a	349 ± 16a	309 ± 3a	302 ± 18a
V_4	458 ± 8ab	428 ± 17a	388 ± 17a	342 ± 15a	312 ± 15a	310 ± 7a
V_5	443 ± 8a	414 ± 23a	384 ± 21a	368 ± 15a	335 ± 12a	312 ± 16a
V_6	432 ± 15a	400 ± 11a	371 ± 18a	348 ± 22a	332 ± 13a	319 ± 20a
TKN content (g/kg)						
V_1	8.2 ± 0.40a	12 ± 0.03ab	18.6 ± 0.4c	22.6 ± 0.9c	25.0 ± 1.4bc	28.2 ± 1.3bc
V_2	8.5 ± 0.11ab	10.9 ± 0.74a	15.8 ± 0.4a	22 ± 0.89c	26.4 ± 0.5c	30.5 ± 1.1c
V_3	8.9 ± 0.06bc	11.0 ± 0.50a	15.8 ± 0.1a	21.8 ± 0.17c	25.5 ± 2.5bc	28.2 ± 0.4bc
V_4	9.3 ± 0.08cd	12.1 ± 0.75b	17.0 ± 0.6ab	21.2 ± 0.1bc	24.4 ± 0.4abc	26.6 ± 0.4b
V_5	9.6 ± 0.05d	12.7 ± 0.07b	16.8 ± 0.7ab	20 ± 0.46ab	22.1 ± 0.21ab	23.6 ± 0.85a
V_6	10.1 ± 0.09e	12.7 ± 0.01b	17.1 ± 0.4b	19.2 ± 0.24a	21.0 ± 1.6a	21.2 ± 1.1a

Mean values (mean ± SD, n = 3), followed by different letters is statistically different (ANOVA; Tukey's test, $P < 0.05$).

Table 5
Change in TAP and TK (g/kg) content in vermicomposts during the experimental period.

Vermicomposting bin	0 day	21 day	42 day	63 day	84 day	105 day
TAP content (g/kg)						
V_1	5.74 ± 0.09a	6.99 ± 0.1a	8.8 ± 0.3a	9.64 ± 0.32b	10.94 ± 0.38c	11.44 ± 0.74c
V_2	6.08 ± 0.18ab	6.84 ± 0.17a	8.44 ± 0.27a	9.6 ± 0.01b	10.15 ± 0.34bc	11.0 ± 0.67bc
V_3	6.37 ± 0.17bc	6.88 ± 0.08a	8.1 ± 0.11a	9.65 ± 0.2b	10.42 ± 0.29bc	10.85 ± 0.64bc
V_4	6.63 ± 0.16 cd	7.14 ± 0.12ab	8.2 ± 0.13a	9.1 ± 0.12b	9.7 ± 0.25ab	9.74 ± 0.21ab
V_5	6.95 ± 0.04de	7.48 ± 0.2bc	8.1 ± 0.27a	8.5 ± 0.26a	9.0 ± 0.35a	9.1 ± 0.02a
V_6	7.25 ± 0.13e	7.58 ± 0.15c	8.1 ± 0.6a	8.45 ± 0.22a	9.1 ± 0.5a	9.1 ± 0.13a
TK content (g/kg)						
V_1	7.8 ± 0.53e	7.9 ± 0.23d	8.8 ± 0.3d	9.4 ± 0.19e	9.9 ± 0.22e	10.2 ± 0.41e
V_2	7.2 ± 0.3de	7.5 ± 0.39 cd	8.1 ± 0.35cd	8.5 ± 0.39de	8.8 ± 0.36d	9.3 ± 0.06d
V_3	6.6 ± 0.24cd	6.9 ± 0.45bcd	7.6 ± 0.29c	8.1 ± 0.55 cd	8.4 ± 0.36cd	8.5 ± 0.15c
V_4	6 ± 0.47bc	6.2 ± 0.61abc	6.8 ± 0.34b	7.3 ± 0.08bc	7.7 ± 0.16bc	7.7 ± 0.11b
V_5	5.5 ± 0.39ab	5.8 ± 0.59ab	6.5 ± 0.17b	6.7 ± 0.29ab	7.2 ± 0.22ab	7.4 ± 0.27ab
V_6	4.8 ± 0.36ab	5.1 ± 0.76a	5.7 ± 0.4a	6.2 ± 0.36a	6.5 ± 0.36a	6.8 ± 0.28a

Mean values (mean ± SD, n = 3), followed by different letters is statistically different (ANOVA; Tukey's test, $P < 0.05$).

vermicomposting of different wastes have been reported by Yadav and Garg (2016b). They have reported 29.5–75% higher TAP in vermicompost than initial waste mixtures. It is clearly evident from Table 5 that there was slight increase in TAP content up to day 42; thereafter, it increased rapidly till the termination of the experiment. This increase in phosphorus may probably be due to mineralization and mobilization of organic matter by the combined effect of microorganisms and faecal phosphatase activity of earthworms. Vermicomposting is an effective process for the bio-transformation of unavailable forms of phosphorus to easily available forms for plants (Ghosh et al., 1999; Bhat et al., 2016). Phosphate solubilizing bacteria in gut of earthworms play a key role in increasing the phosphorus content in vermicompost (Suthar, 2009).

Total potassium (TK) content was also higher (1.28–1.41 times) in the vermicomposts obtained from different bins (Table 5). TK content increased gradually with time in all vermicomposting bins. TK content of vermicomposting bins were significantly different from each other ($P < 0.05$). Swarnam et al. (2016) have reported an increase (38%) in the TK content in vermicompost after bioconversion of coconut husk by *Eudrilus eugeniae*. Increase in TK content during vermicomposting may be attributed to reduction in mass and volume of waste during vermicomposting. Increased microbial activity during the vermicomposting also result into higher potassium content (Thomas et al., 2018).

It is evident from Fig. 1 that C: N ratios decreased with time in all the vermicomposting bins. C: N ratios of vermicompost were in the range of 9.6–15.04, depicting the overall reduction of 65.4–83.5% after 105 days of worms' activity. C: N ratio was lesser in those waste mixtures that had higher sludge content due to higher TKN content and lower TOC content. Alidadi et al (2016) have reported that the decline in the C: N ratio may be attributed to the greater loss of carbon through microbial respiration in the form of CO_2. Similar observation regarding the reduction of C: N ratio after vermicomposting have been reported by other authors (Sharma and Garg, 2018; Arumugam et al., 2018).

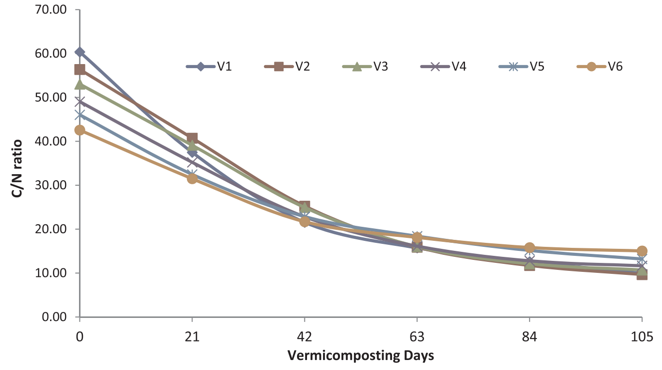

Fig. 1. C: N ratio in different vermicomposting bins with time.

Total calcium (TCa) content increased in the final vermicomposts in comparison to initial values (Table 3). TCa was in the range of 1.9–2.8 g/kg and 3.18–3.75 g/kg in initial blends and vermicomposts, respectively. Increase in TCa content, during vermicomposting, has been reported by several authors (Raphael and Velmourougane, 2011; Sharma and Garg, 2017a). Raphael and Velmourougane (2011) have reported 85.7% increment in calcium content after vermicomposting of coffee pulp.

3.2. *Dynamics of heavy metals during vermicomposting process*

Metals' content in vermicomposts is usually variable depending on physico-chemical properties of the raw waste, metals' concentration in raw waste, earthworm species employed for the purpose of vermicomposting, environmental conditions etc. During vermicomposting process metals' concentration could be influenced by two different processes. First process is reduction in mass and volume of raw waste due to the decomposition and mineralization of organics, and second process is accumulation of heavy metals in earthworms' body during the vermicomposting process (Zhu et al., 2014; Lv et al., 2016).

Heavy metals' content in different vermicomposting bins was affected by their composition during vermicomposting. Experimental data revealed that Nickel (Ni) content was 8.1–20% higher in vermicomposts as compared to the initial blends. Maximum increase in Ni was in V_1 and the minimum in V_6 (Fig. 2a). Iron (Fe) content was 27.3 to 31% higher than initial blends. The rate of Fe change was comparatively higher in the initial phase of vermicomposting. Copper (Cu) content in different vermicomposting bins decreased by 1.7–40.8% (Fig. 2c). This loss or reduction of Cu in the vermicompost may be attributed to its use and bioaccumulation in the earthworm body. The decrease in heavy metal content in the vermicompost indicates the capability of *E. fetida* in accumulating some heavy metals in their body. Similar observations have been reported by Leonard and Dolfing (2001).

Chromium (Cr) content of vermicompost was 28–80% higher. Maximum incrase in Cr content was observed in vermicomposting bin V_1 (100% CD) (Fig. 2d). During vermicomposting, periodical estimation of the total Zinc (Zn) content of different vermicomposting bins, revealed a specific pattern of Zn dynamics (Fig. 2e). Different vermicomposting bins had a variable increase in Zn content during vermicomposting. Zn content increased 7.5 to 32.8% in vermicompost over the initial. At the end of the experiment the Zn content in different vermicomposting bins were significantly different from each other ($P < 0.05$). There was a steady increase in Manganese (Mn) content during vermicomposting (Fig. 2f). Increase in Mn content in

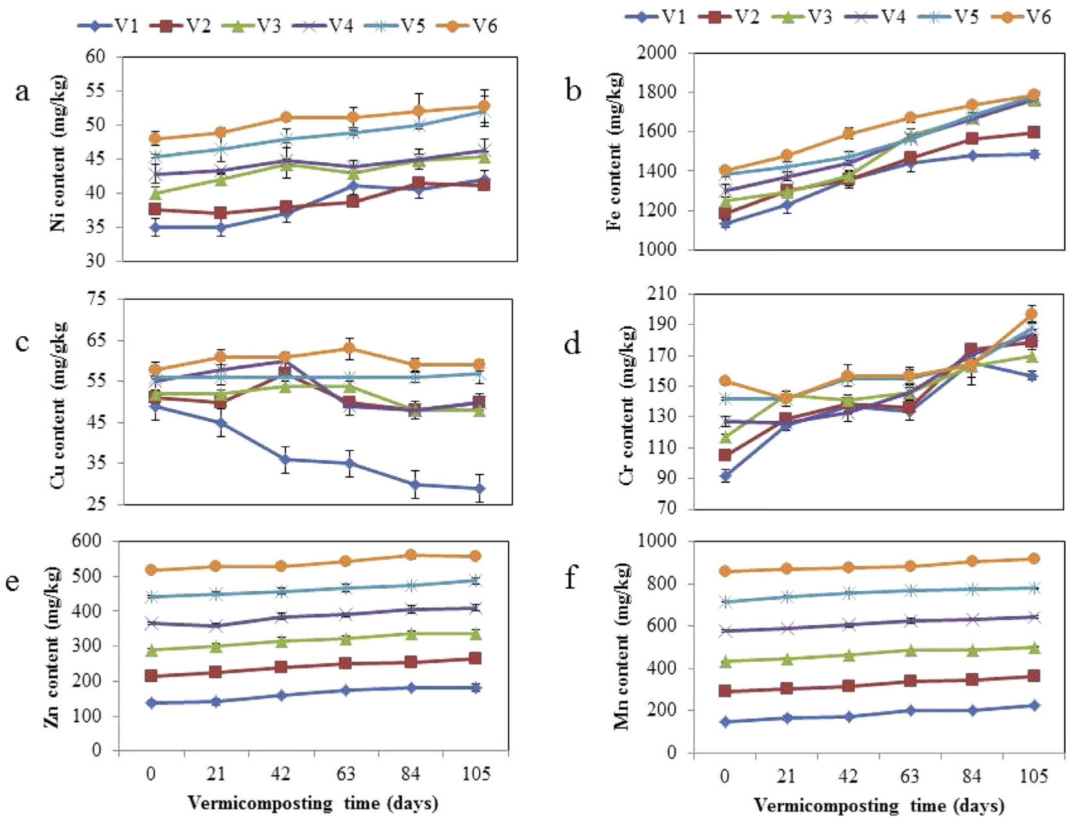

Fig. 2. Change in heavy metal concentration in different vermicomposting bins during vermicomposting.

vermicomposts was 7.1–51.6%. Lv et al. (2016) reported that the augmented amount of heavy metal in vermicompost indicates the concentration effect caused by organic matter stabilization. Suthar (2009) has also reported that the concentration of metals was greater in casts of both epigeic and endogeic earthworms collected from different habitats.

Heavy metal, when in higher concentrations, has the potential to be both phytotoxic and zootoxic (Haroun et al., 2007). It is widely known that the bioavailability of heavy metals in soil is strongly influenced by the amount and the quality of organic matter that can react with the heavy metals, forming complexes and chelates of varying stability (Leita et al., 1998). Presence of high total metal concentrations in manures alone is not responsible for causing potential environmental impacts, since it may indicate the overall level of metals in the material, but metal toxicity depends on several factors such as the chemical nature, reactivity and potential mobility of a particular metal. High concentration of metals in soil does not necessarily imply their release or their availability to plants (Sánchez-Martín et al., 2007). This study indicated that vermicomposting of CD and BIS before soil application may have mixed effects on the metal contents by increasing or decreasing some fractions, depending on waste composition and concentration of metals in raw wastes.

4. Conclusion

Based on the results of this study it an be inferred that an industrial sludge can be suceessfully coverted in manure. After vermicomposting, various physico-chemical properties (pH, EC, C: N ratio) and overall nutrient status (NPK) of the wastes were better than initial raw wastes. This improvement in physico-chemical properties make these vermicomposts an ideal manure for field applications to improve soil health.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biortech.2018.12.023.

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