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RESEARCH ARTICLE

Management of food and vegetable processing waste spiked with buffalo waste using earthworms (*Eisenia fetida*)

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Abstract The present investigation was focused on the vermicomposting of food and vegetable processing waste (VW) mixed with buffalo dung (BW) under laboratory condition employing *Eisenia fetida* earthworm species. Four different proportions of VW and BW were prepared and subjected to vermicomposting after 3 weeks of pre-composting. After vermicomposting, nitrogen (7.82–20.73 g/kg), total available phosphate (4.80–11.74 g/kg) and total potassium (7.43–12.75 g/kg) content increased significantly as compared to initial feed stocks. Significant reduction was observed in pH (7.56 to 6.55), total organic carbon (48.25–23.54%) and organic matter (83.18–40.68%). Metal content (Fe, Cu, Zn and Ni) was higher in all the vermicomposts than feedstocks. Data on growth and reproduction of earthworm revealed that the highest biomass gain and fecundity of worms were attained in 100% BW followed by [BW75% + VW25%] > [BW50% + VW50%] > [BW25% + VW75%] feedstocks. Results evidenced the suitability of VW (up to 50%) spiked with BW for increasing earthworm population and in providing potent organic manure for agricultural applications.

Keywords Organic waste · Vermicomposting · Organic matter · NPK · Heavy metals · *Eisenia fetida*

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Introduction

The planet has undergone rapid urbanization and economic development over the past few decades. As the world continues to grow, millions of tonnes of food waste are generated continuously in rural and urban areas of both developed and developing countries. At global level, out of the total food produced for human consumption, about 1.3 billion metric tonnes food is wasted every year which is one third of the total food production (Hanc and Pliva 2013). Food and vegetable processing wastes are generally contributed by restaurants, food plazas, canteens, household kitchens and food processing industries (Bharadwaj 2010). Peeling and cutting of raw fruits and vegetable prior to processing, eating and cooking also produce significant quantities of waste. According to FAO, more than 50% of fruits and vegetables are wasted during production, distribution and consumption (FAO 2011). CIPHET (2013) has reported that in India, the percentage of waste residue from total production (221.4 million metric tonnes) of fruit and vegetable is 5.8 to 18%.

Different methods preferred for the disposal of food wastes include open dumps, landfills or common garbage dumps. Improper disposal of these wastes causes air pollution, foul odour and creates health hazards and also act as a source of green house gases emission (Eleazer et al. 1997). Furthermore, it may induce climate change and biological diversity alterations. This problem is more severe when regulations are not followed in stringent manner (Garg and Gupta 2011; Kumar et al. 2014). Therefore to tackle all these issues, waste residues should be collected and processed to some valuable product by applying a cost-effective waste conversion technology (Soobhany et al. 2015; Das et al. 2015; Senapati and Julka 1993). Vermicomposting is an eco-friendly, cost-effective, zero waste technology which can be used to convert non-toxic organic waste residues into valuable product (vermicompost). Vermicompost is an environmentfriendly organic manure having high quantities of humic acids, plant growth hormones, enzymes and antimicrobial substances (Tajbakhsh et al. 2011).

Increased attention towards organic farming has accepted vermicomposting technology as a potential tool to stabilize a wide array of natural and anthropogenic non-toxic wastes from different sources. Various studies have reported the vermiprocessing of organic wastes including human faeces (Yadav et al. 2010), mushroom residues (Song et al. 2014), tomato wastes (Fernández-Gómez et al. 2010, 2013), leaf litter (Suthar and Gairola 2014), municipal solid waste (Sahariah et al. 2015), paper waste (Arumugam et al. 2015), grape marc (Gomez-Brandon et al. 2011), tanning sludge (Malafaiaa et al. 2015), jute mill waste (Das et al. 2016a) and paddy straw (Das et al. 2016b). However, limited data is available on the vermicomposting of food and vegetable processing waste (Garg and Gupta 2011; Huang et al. 2014; Wani et al. 2013). High organic matter and non-toxic nature of food processing wastes make them attractive feedstock for earthworms (Garg and Gupta 2011).

Recently, Abbasi et al. (2015) have reported that most of the studies in the past used cow dung as supplementary substrate and no study is available in which buffalo dung has been used as a spiking substrate or a bulking agent, whereas buffalo excreta is available in huge quantity in Asian nations. Therefore, the present study was designed to evaluate vermicomposting potential of food and vegetable processing waste spiked with buffalo dung as a bulking agent. Vermicomposting of both these wastes could be an effective solution to reduce the antagonistic impacts of improper disposal of food and vegetable processing waste as well as buffalo excreta.

Materials and methods

Collection of wastes and culturing of earthworms

Food and vegetable processing waste was collected from a fruit and vegetable processing industry, and buffalo dung was collected from a dairy farm, Hisar, India. *Eisenia fetida* species of earthworms was employed for vermicomposting purposes. *E. fetida* worms were picked from the stock cultures maintained in the laboratory.

Experimental set-up and vermibin preparation

The experimental set-up was established with three different combinations of VW spiked with BW to explore their bioconversion and stabilization by earthworms (*E. fetida*). A vermibin with 100% BW was used as a control. Composition of VW and BW was as follows:

Vermibin no. 1. (VB 1): BW 100% (control)
Vermibin no. 2. (VB 2): BW 75% + VW 25%
Vermibin no. 3. (VB 3): BW 50% + VW 50%
Vermibin no. 4. (VB 4): BW 25% + VW 75%

Experiments were conducted in plastic vermibins (diameter 40 cm, depth 12 cm), and each treatment was established in triplicate. Waste mixtures were pre-composted for 3 weeks in order to remove volatile toxic gases, if any (Garg et al. 2006; Garg and Gupta 2011). During pre-composting, readily decomposable compounds are degraded and the potential toxic substances are eliminated, which may be otherwise lethal to earthworms. So, pre-composting of various organic wastes prior to vermicomposting is necessary to make feedstock palatable to the worms.

Twenty healthy clitellate worms were picked from stock cultures, weighed and released in each vermibin, after 3 weeks of pre-composting (Garg et al. 2006; Yadav and Garg 2010). Earthworms are aerobic fauna and sensitive to anaerobic conditions, and their feeding activities reduced under anaerobic conditions which may cause mortality in the vermibins. So, in order to provide suitable aeration to the earthworms, the feedstocks were turned manually and fortnightly. All the vermibins were kept in the dark at a room temperature of 25 ± 3 °C. The moisture was maintained at 60–80%, and further, to prevent moisture loss, the vermibins were covered with jute covers (Yadav and Garg 2010). The experiment was conducted for 90 days and biomass gained was studied at the end of the experiment. After termination, earthworms were sorted and counted separately as adult and hatchlings as suggested by Garg et al. (2006).

Physico-chemical analysis of raw wastes and vermicompost

Different feedstocks and final product (vermicomposts) were analysed as per standard protocols. Physico-chemical characteristic of the raw wastes used in the present study is given in Table 1.

The vermicompost was air-dried at room temperature, homogenized and packed in the airtight plastic bags for physico-chemical analysis. Raw wastes and vermicomposts were analysed for different parameters like pH, electrical conductivity (EC), total organic carbon (TOC), total Kjeldahl nitrogen (TKN), total available phosphorus (TAP), total potassium (TK), total calcium (TCa), total sodium (TNa) and heavy metals (Fe, Cu, Zn and Ni). The pH and EC were determined by a digital pH and EC meter using double-distilled water suspension of each sample in the ratio of 1:10 (*w*/*v*). TOC was determined by a dry combustion method as reported by Nelson and Sommers (1982). Nitrogen was determined after digesting the sample with concentrated sulphuric acid and perchloric acid (9:1, *v*/*v*). Phosphorus was determined

Table 1 Initial physico-chemical characteristics of vegetable and food processing (VW) and buffalo dung (BW)

Parameter	Buffalo dung	Food and vegetable processing waste
pH	7.56 ± 0.06	7.31 ± 0.03
EC (mS/cm)	2.87 ± 0.11	7.58 ± 0.09
Total organic carbon (%)	39.91 ± 0.45	51.79 ± 0.25
Organic matter (%)	68.81 ± 0.77	89.29 ± 0.43
Ash content (%)	31.19 ± 0.77	10.71 ± 0.43
Potassium (g/kg)	7.77 ± 0.22	4.48 ± 0.38
Sodium (g/kg)	3.34 ± 0.07	4.74 ± 0.45
Calcium (g/kg)	2.55 ± 0.09	3.54 ± 0.39
TAP (g/kg)	7.67 ± 0.34	3.68 ± 0.24
TKN (g/kg)	7.82 ± 0.28	12.00 ± 0.23
Fe (mg/kg)	3568 ± 120	2645 ± 129
Ni (mg/kg)	8.39 ± 0.25	9.64 ± 0.45

spectrophotometrically with molybdenum in sulphuric acid. Potassium content was determined after digesting the sample in a diacid mixture of concentrated nitric acid and concentrated perchloric acid (9 : 1, *v/v*) using a flame photometer. Heavy metals were determined using an atomic absorption spectrophotometer (GBC, Australia) after digestion of the sample with a diacid mixture of concentrated HNO_3 and concentrated $HClO_4$ (9:1, *v/v*).

Statistical analysis

The reported results are the mean of three replicates with standard deviation (mean ± SD). The probability levels used for statistical significance were $P < 0.05$ for the tests. Statistical analysis of the data was carried out with the SPSS 16.0 software program.

Results and discussion

During the vermicomposting process, earthworms mineralized the feedstocks and converted them into odourless, homogenous and nutrient-rich vermicompost. Physico-chemical properties of the wastes were significantly altered after 90 days of vermicomposting (Table 2). The pH of vermicomposts, obtained from different vermibins, was in the range of 6.55–7.29. Pramanik et al. (2007) have reported that during vermicomposting, secretion of intestinal Ca and NH_4–N by earthworms neutralizes carboxylic and phenolic groups of humic acids which maintain the pH of vermicompost in a neutral range. Slight reduction in pH was observed in all the treatments which may be due to mineralization of nitrogen and phosphorus into nitrites (Nath and Singh 2015). Decreases in pH were significantly ($P < 0.05$) different between different vermibins.

EC increased at the end of experiment. Initial values were in the range 2.40–2.95 mS/cm and finally increased to 3.38–3.94 mS/cm. Electrical conductivity of the vermicompost depends on the feedstock used for vermicomposting and is a function of available minerals and ions produced by earthworm activities (Atiyeh et al. 2002; Garg et al. 2005, 2006; Yadav and Garg 2010; Lim et al. 2011).

The TOC content of the initial waste mixtures was in the range 39.91–48.25%, and in the vermicompost, it was 23.54–34.03%. This loss in TOC may probably be associated with enhanced carbon mineralization and respiratory activity of earthworms (Deka et al. 2011; Khwairakpam and Bhargava 2009). Maximum TOC reduction (16.37%) was observed in BW (100%) followed by BW (75%) + VW (25%) [15.98%] mixture. Suthar (2009) and Garg and Gupta (2011) have also reported significant reduction in TOC of cattle dung as compared to vegetable waste and cattle dung waste mixtures during their vermicomposting. Reduction in TOC may be due to mineralization of feedstocks, loss of carbon as CO_2 and assimilation of carbon into earthworm biomass aided by combined action of earthworms and microbes. Low TOC also indicates richness of humic substances, compost stability and maturity (Goswami et al. 2016). This reduction may probably be due to the fact that mineralization of animal dung is faster than that of other organic wastes as it contains higher population of decomposing communities (Edwards and Fletcher 1988). Busato et al. (2016) have reported that higher microbial activity, organic acid and enzyme levels in the alimentary canal of the animals favour the breakdown of lignocellulosic content of the feed, allowing the release of complex forms of carbon. Hence, TOC reduced more efficiently and faster in 100% BW. Further, percentage of organic carbon reduction decreases with increasing concentration of VW as it was not passed through any animal gut (Busato et al. 2016).

Organic matter also followed a reductional trend from initial waste mixtures to processing into vermicompost. Organic

Table 2 Physico-chemical characteristics of the feedstocks and vermicomposts (mean ± SD)

	pH		EC (mS/cm)		TOC (%)		OM (%)	
	Feedstock	Vermicompost	Feedstock	Vermicompost	Feedstock	Vermicompost	Feedstock	Vermicompost
VB 1	7.56 ± 0.06	6.79 ± 0.14	2.87 ± 0.11	3.38 ± 0.05	39.91 ± 0.45	23.54 ± 0.35	68.81 ± 0.77	40.59 ± 0.61
VB 2	7.42 ± 0.04	7.07 ± 0.12	2.60 ± 0.05	3.83 ± 0.06	42.99 ± 0.17	27.02 ± 0.73	74.12 ± 0.29	46.57 ± 1.08
VB 3	7.57 ± 0.04	6.55 ± 0.09	2.95 ± 0.10	3.76 ± 0.05	45.63 ± 0.33	30.44 ± 0.27	78.67 ± 0.57	52.47 ± 0.47
VB 4	7.38 ± 0.05	7.29 ± 0.06	2.40 ± 0.04	3.94 ± 0.08	48.25 ± 0.20	34.03 ± 0.57	83.18 ± 0.34	58.66 ± 0.98

matter content in the initial waste mixtures ranged from 68.81 to 83.18%, but after vermicomposting, it was decreased in the range of 40–60% in different vermibins. This decrease in organic matter during vermicomposting showed that earthworms were consuming the wastes at a faster rate along with enhancing a decomposition process (Huang et al. 2016; Lim and Wu 2016).

In contrast to TOC and OM, nitrogen content (TKN) increased after vermiprocessing (Fig. 1). Data revealed that TKN content was significantly higher ($P > 0.05$) in the vermicompost (15.46–20.43 g/kg) as compared to initial waste mixtures (7.82–10.46 g/kg). Due to vermicomposting, TKN content increased 1.58–3.21-fold with highest TKN increment in vermibin no. 1 (from 7.82 to 20.73 g/kg) followed by vermibin no. 2 (from 8.54 to 18.70 g/kg) and minimum increment in TKN content was recorded in vermibin no. 4 (from 10.46 to 15.46 g/kg) (Fig. 1). An increase in TKN after vermicomposting process may be due to various earthworm activities such as addition of nitrogenous excreta and mucus, secretion of polysaccharides, growth-stimulating hormones and enzymes (Edwards et al. 1998; Sahariah et al. 2015). A decrease in pH and total organic carbon and fixing of atmospheric nitrogen by microorganisms may also be responsible for increase in TKN content (Hartenstein and Hartenstein 1981; Viel et al. 1987; Kumar et al. 2010; Huang et al. 2016).

As demonstrated in Fig. 2, phosphorus (TAP) content increased from 4.80 to 11.74 g/kg in different vermibins after vermicomposting. The highest phosphorus content (11.74 ± 0.36 g/kg) was observed in vermibin no.1; however, maximum increment of 4.24-fold was recorded in vermibin no. 3. Similar observations regarding TAP after vermicomposting have been reported by several authors (Suthar 2008, 2009; Garg and Gupta 2011; Yadav and Garg 2011). This increase in TAP may be due to mineralization and mobilization of phosphorus by bacterial and faecal phosphatase activity of earthworms further supplemented by the phosphorus-solubilizing microorganisms of the worm castings (Lee 1992; Tripathi and Bhardwaj 2004; Suthar 2008).

Carbon:nitrogen (C:N) ratio and carbon:phosphorus (C:P) ratio are the most widely studied indices regarding maturation and stabilization of waste. A C:N ratio of 20:1 and C:P ratio of 15:1 are considered important from agronomical point of view as plants are able to assimilate nitrogen and phosphorus at these ratios (Senesi 1989; Garg and Gupta 2011). During this study, a significant decrease in a C:N ratio was observed in all the vermibins compared to the initial one (Fig. 3). Comparatively, reduction in C:N ratio was maximum in 100% BW feedstock (39.74%) followed by BW75% + VW25% feedstock (35.90%) and BW50% + VW50% feedstock (28.85%) and minimum reduction in C:N ratio was in BW25% + VW75% feedstock (24.11%). These findings corroborate with the results obtained by different authors in earlier studies (Wani et al. 2013; Huang et al. 2014). Lowering of C:N ratio is attributed to mineralization and decomposition of organic matter and loss of carbon as CO_2 during the process of respiration (Garg and Kaushik 2005). Another possible reason for reduction in C:N ratio during vermiprocessing may be acceleration of humification by the earthworms (Suthar 2006; Vig et al. 2011; Malafaiaa et al. 2015); degradation of hemicellulose, cellulose and other organic substances (Das et al. 2016a; Huang et al. 2016). Combined action of microbial population and earthworms makes the process of decomposition faster.

C:P ratio also registered a decreasing trend in all the vermibins (Fig. 4). Initial C:P ratio was in the range of 52.1–100.5, and in the vermicomposts it ranged from 20.1 to 44.1. Results further revealed that final C:P ratio was significantly different in all the treatments which suggest higher degree of stabilization of the feedstocks by earthworm. Garg and Gupta (2011) have also reported a similar C:P ratio in the vegetable

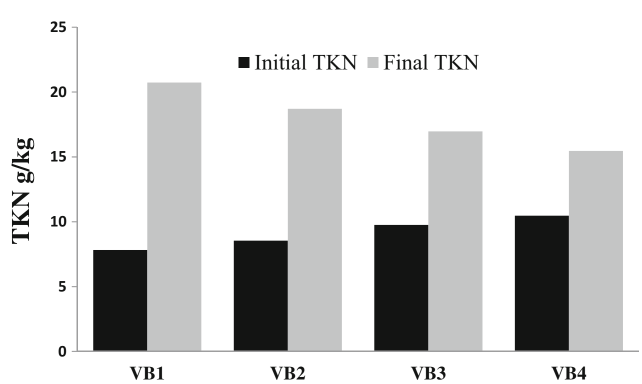

Fig. 1 Changes in the TKN in the initial waste and vermicompost

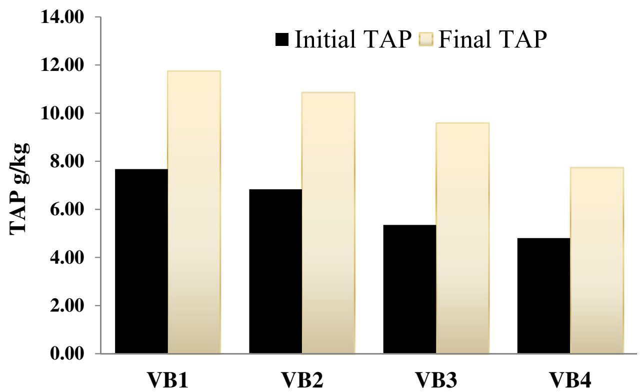

Fig. 2 TAP in the initial waste mixtures and vermicompost

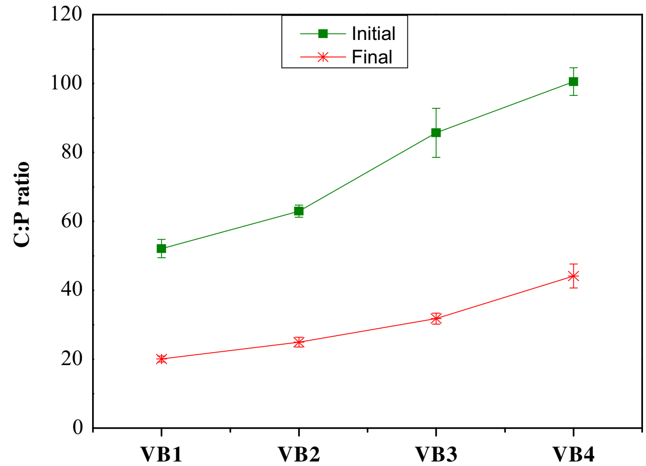

Fig. 4 C:P ratio in the initial waste mixtures and vermicompost

waste (55.7–96.6) at zero day and after vermiprocessing in the vermicompost (21.8–37.3).

Vermicompost had higher potassium (TK) content, as compared to feedstocks. The TK content of the feedstocks was in the range 7.77–9.01 g/kg and in the vermicompost it was in the range of 12.04–12.75 g/kg depicting a considerable increase in TK (Fig. 5). An increment of micronutrients like potassium in the vermicompost may be due to the worm activity which increases the degradation of waste and releases assailable metabolites (Khwairakpam and Bhargava 2009). Production of acids by the microorganisms and an enhanced mineralization rate through increased microbial activity during the vermicomposting process play a key role in the solubilization of insoluble potassium (Hartenstein and Hartenstein 1981; Garg et al. 2006; Yadav et al. 2013).

Heavy metal content in the vermicomposts was significantly higher ($P < 0.05$) than that in the feedstocks (Fig. 6) Fe content increased by 42–48% in different vermibins. Fe content was maximum in the vermibin no. 3 followed by vermibin no. 2, and minimum increment was recorded in vermibin no. 4 (Fig. 6a). Variations in the copper concentration (mg/kg) for different vermibins are given in Fig. 6b. Initial Cu concentration was in the range 18.45 to 26.20 mg/kg which increased in the range of 32.99 to 47.86 mg/kg after earthworm activity. Total Zn content (Fig. 6c) at the start of experiment in vermibin no. 1 was 123 ± 13.45 mg/kg, in vermibin no. 2 was 94.33 ± 0.51 mg/kg, in vermibin no. 3 was 77.67 ± 3.21 mg/kg and in vermibin no. 4 was 61.78 ± 3.85 mg/kg. After vermicomposting, Zn content was increased from 63.06% (vermibin no. 4) to 72.66% (vermibin no. 1) in different vermibins. In the vermicompost, Ni concentration increased 83–130% as compared to the initial concentration (Fig. 6d). Minimum Ni concentration was in vermibin no. 4 (75% VW + 25% BW; 18.45 ± 0.79 mg/kg) and maximum Ni content was in vermibin no. 3 (50% VW + 50% BW; 21.43 ± 0.96 mg/kg). Garg and Gupta (2011) have also reported an increase in the heavy metals content after vermiprocessing of VW. A similar pattern regarding heavy metal content has been reported by other authors during the vermicomposting of different wastes (Elvira et al. 1996; Garg

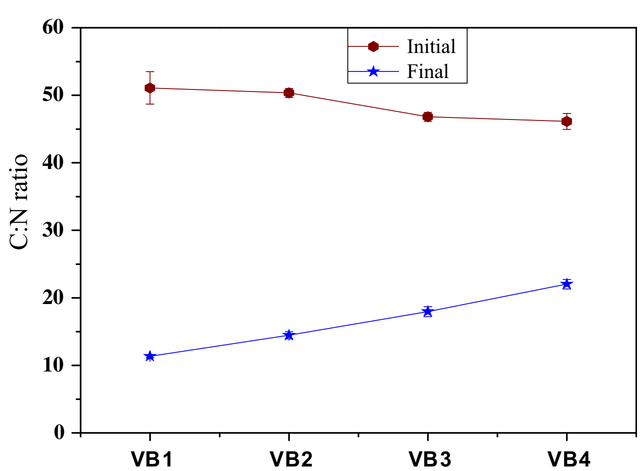

Fig. 3 C:N ratio in the initial waste mixtures and vermicompost

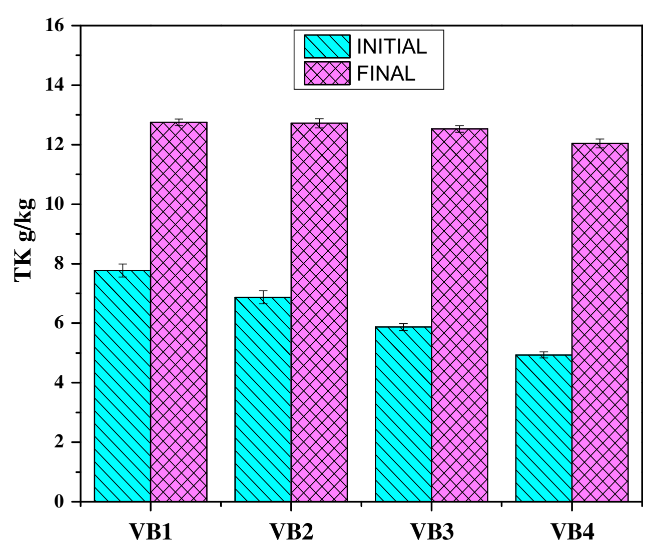

Fig. 5 Potassium content in the initial waste mixtures and vermicompost

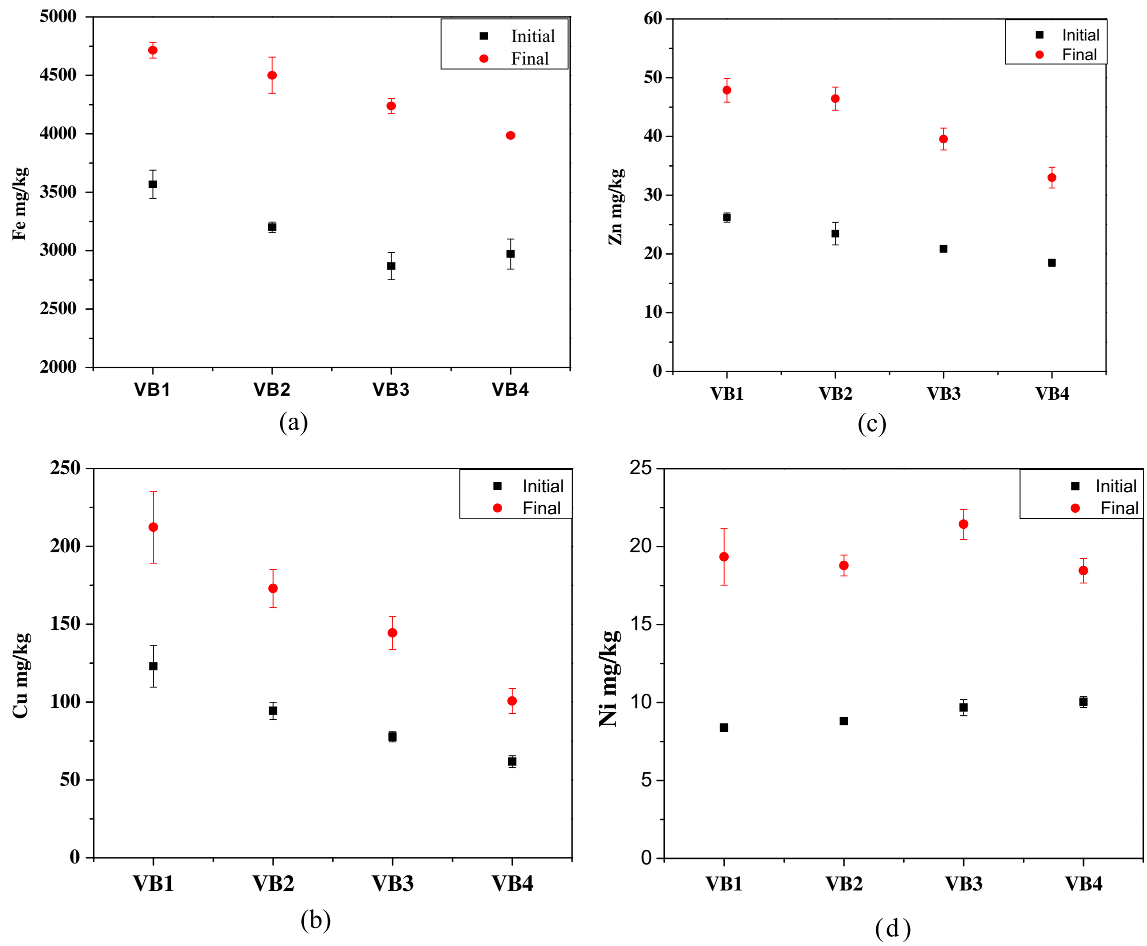

Fig. 6 Total Fe (**a**), total Cu (**b**), total Zn (**c**) and total Ni (**d**) in the initial wastes and vermicompost

and Kaushik 2005; Hait and Tare 2012). Reduction in the mass and volume of the waste and the carbon loss by mineralization at the end may probably be the reasons for an increment in the metal content (Yadav and Garg 2011).

Earthworm growth and reproduction

Results of earthworm growth and reproduction are given in Table 3. Earthworm biomass in all the vermibins increased significantly. Among different feedstocks, the best biomass gain and reproduction of the earthworm were found in 100% BW. Maximum worm biomass gain (78.30 ± 0.75 g) was in vermibin no. 1 containing 100% BW, and minimum worm biomass gain was 5.88 ± 0.25 g in vermibin no. 4 containing 75% VW + 25% BW. Similarly, maximum worm hatchlings found were 811 in vermibin no. 1, and minimum worm hatchlings were found 117 in vermibin no. 4.

Conclusion

In recent years, use of vermitechnology has been professed for the effective waste management of non-toxic organic wastes

Table 3 Growth and reproduction of *E. fetida* in different vermibins (mean ± SD, *n* = 3)

Biological parameter	Treatment			
	VB 1	VB 2	VB 3	VB 4
Initial wt. of worms (g)	9.69 ± 0.53^{a}	13.29 ± 0.78^{b}	12.44 ± 0.41^{b}	11.15 ± 0.23^{c}
Final wt. of worms (g)	78.30 ± 0.75^{a}	67.90 ± 2.40^{b}	37.53 ± 0.88^{c}	15.67 ± 0.44^{d}
Total no. of hatchling (count)	811 ± 11.02^{a}	492 ± 6.43^{b}	314 ± 6.43^{c}	117 ± 4.93^{d}
No of hatchling/worm	40.58 ± 0.55^{a}	24.63 ± 0.32^{b}	15.73 ± 0.32^{c}	5.88 ± 0.25^{d}

Mean value followed by different letters is statistically different (ANOVA; Tukey's *t* test, $P < 0.05$)

and sustainable agriculture. It can be inferred for the results of this study that food and vegetable waste spiked with buffalo waste is a good feedstock for vermicomposting. It was also concluded that buffalo dung can prove a good alternate to cow dung as bedding material. Vermiconversion of millions of tonnes of waste, produced annually, may help in the recycling of nutrients, conversion into worm biomass, production of vermicompost and in the mitigation of environmental pollution.

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