Heliyon 9 (2023) e19908

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Vermistabilization of mango tree pruning waste with five earthworm species: A biochemical and heavy metal assessment

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ARTICLE INFO

Keywords:
Mango tree pruning waste
Earthworm
Vermicomposting
Macronutrients
Heavy metals
Microbial properties

ABSTRACT

Mango tree pruning results in high biomass output, which is a serious agricultural and environmental problem. Vermicomposting is a potential, fast and sustainable tool to address these challenges. For sixty days, the experiment was carried out in six vermireactors containing five earthworm species by *Eudrilus eugeniae*, *Eisenia fetida*, *Aporrectodea rosea*, *Lumbricus rubellus*, and *Lampito mauritii*, as well as composting (without earthworm) using mango tree pruning waste biomass along with cattle dung as an instant preferred feeding material for earthworms. The pH, TOC, C/N and C/P ratios of the waste were substantially reduced by the earthworm activity. However, after vermicomposting, the levels of macronutrients (N, P, K, Ca, Mg, S) and micronutrients (Fe, Mn, Zn, and Cu) and microbial count substantially increased. The TOC content of waste was reduced by 42–55%, and the C/N of vermicompost ranged from 5.58 to 11.38. The results showed that earthworm fecundity was highest in vermireactors containing *Eudrilus eugeniae* and *Eisenia fetida*. The current study was ultimately determine that vermicomposting using *Eudrilus eugeniae* or *Eisenia fetida* is an effective strategy for utilising mango tree pruning waste, ensuring environmental sustainability and improving farmer revenue.

1. Introduction

The tree canopy is a barrier to mango orchard productivity due to overcrowded and unproductive growth with age. Pruning is an important process performed at either a critical growth stage of a tree or after fruit harvest to maintain a healthy and productive tree. Sizable pruning waste is generated over the course of several cycles of the pruning process. A study conducted by Roslim et al. [1] estimated that the pruning waste of mango was produced 0.676 kg per plant, which equated to 146.4 kg per greenhouse with a total of 40.8 tonnes expected from 50 greenhouses. The disposal of such a pruning waste, which includes leaves, twigs, and woody biomass, is a dilemma in today's modern farming as well as environmental concern. If it is stay in the field occupy a huge area of orchard, causing problems with tillage, fertilization, and other operations, and is prone to burn in the field. This solid waste is being burned, which is generating environmental issues. Gajalakshmi et al. [2] has carried out experiment to resolve the problem of leaf litter of mango into compost and vermicompost not included pruning waste. However, no particular effort has been noted globally to address the problem of pruning waste. For this reason, managing and transforming solid waste into real worth products, like biofuel, compost, and vermicompost, among others, is crucial for resolving these concerns. Composting and vermicomposting are two biowaste treatment

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https://doi.org/10.1016/j.heliyon.2023.e19908
Received 15 March 2023; Received in revised form 23 August 2023; Accepted 5 September 2023

strategies that are commonly recognised as being an environmentally friendly and safe method for handling organic waste [3].

Vermistabilization is a green method for managing solid waste that has been promoted by several studies for its potential and sustainability [4–6]. During vermicomposting, detritivorous earthworms engage intensely with microorganisms, accelerating the convergence of organic matter and significantly altering its physico-chemical and biological properties [7]. Vermicomposting is a degradation process in which earthworms and microorganisms interact with organic matter. While earthworms break down and condition the material, increasing its surface area for biodegradation and significantly altering its microbiological activity, earthworms are essential drivers of the process that takes place. Microbes are largely responsible for the biochemical breakdown of organic matter. Earthworms act as mechanical mixer, modifying the biological, physical, and chemical status of organic matter by lowering its C/N ratio, increasing the exterior area available to microorganisms, and building it much more encouraging for microbes and promote transformation. Vermicomposting is widely utilised worldwide to break down various organic resources into environmentally acceptable products [4]. There have been claims that vermicompost is better than standard compost in terms of agrochemical properties [8]. Vermicompost, the final product, is a stabilized, crystalline peat-like substance with a low C:N ratio, high water-holding capacity, and high porosity that retains the majority of nutrients in forms that plants can readily absorb. These earthworms cast have high in organic matter and rate of mineralization, indicating increased plant availability of nutrients, particularly ammonium and nitrate nitrogen [9].

Multiple earthworm species, such as deep burrowing and surface inhabitants, have been suggested for use in vermicomposting by various researchers [10,11] and it has been established that the epigeic species (surface dwellers) of earthworms are the most suitable form for vermicomposting. High organic waste feeders that are suggested for vermicomposting include several composting earthworm species, such as *Eisenia fetida*, *Eudrilus eugeniae*, and *Perionyx excavatus* [12–14]. Native earthworm species have recently received much attention in the conversion of organic waste to vermicomposting [15]. The type of earthworm used for vermiculture has a significant impact on the volume of compost that results [16], as well as the quality of the finished product [10]. Exotic earthworm species *Eudrilus eugeniae* and *Eisenia fetida* were tested against native earthworm species, *Pontoscolex corethrurus*, *Megascolex chinensis* and *Perionyx sansibaricus* for their efficiencies in biodegrading organic wastes such as cow-pea, banana, and cassava [17]. Mango tree pruning waste is soft woody in nature and it has wide C/N ratio which is the major concern to converting into compost. However, no research has been conducted on the vermicomposting/composting of mango tree pruning waste blended along with cattle dung using five earthworm species to produce high-quality vermicompost. Therefore, this study aims to comparison of the biodegradation capacity of with five species of earthworms and without earthworm by using mango tree pruning waste to obtain good quality vermicompost.

2. Materials and methods

2.1. Collection of earthworm species

For this investigation, five different earthworm species were gathered. *Eisenia fetida* was collected from the commercial Vermicompost Unit at Amalsad, Navsari district of India. *Eudrilus eugeniae*, on the other hand, was obtained directly from the Vermicompost Unit at the Livestock Research Station (LRS), Navsari Agricultural University (NAU), Navsari, India. Moreover, *Aporrectodea rosea, Lumbricus rubellus*, and *Lampito* mauritii three local earthworm species were obtained from distinct compost pits and soils of different farm sites in NAU, Navsari. These species were verified by local Zoological department before culturing and multiplication in laboratory. Each earthworm species of pure cultures was kept and well adapted to laboratory conditions for 90 days before being inoculated into different experimental treatments with a feed mixture of cattle dung and mango leaf litter.

Table 1
Details of physico-chemical properties of cattle dung and mango tree pruning waste before pre-composting.

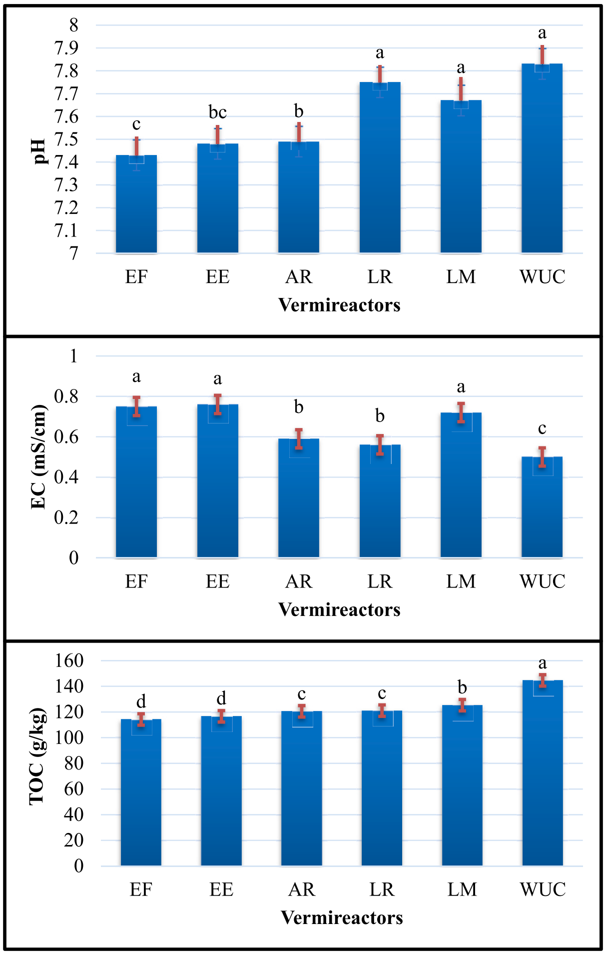
Parameters	CD	MTPW	Mixture of waste (Initial)
$pH_{(1:10)}$	7.79	7.81	7.92
$EC_{(1:10)}$ (mS/cm)	0.55	0.42	0.38
TOC (g/kg)	274.7	281.4	253.5
TKN (g/kg)	7.90	6.10	5.90
TAP (g/kg)	4.80	2.70	8.90
TK (g/kg)	5.20	3.20	7.30
Ca (g/kg)	1.50	1.30	1.50
Mg (g/kg)	0.80	0.70	0.80
S (g/kg)	0.08	0.10	0.14
Fe (g/kg)	1.90	2.80	3.70
Mn (mg/kg)	145	117	186
Zn (mg/kg)	83	73	158
Cu (mg/kg)	28.5	27.3	50.0
C/N ratio	34.77	46.13	42.97
C/P ratio	57.23	104.22	48.28

2.2. Collection of waste

For this experiment, mango tree pruning waste (MTPW) was collected from the mango orchard at NAU's Research Farm in Navsari, India. This was dried in the shade for 30 days before being finely chopped into 5–7 cm pieces with a chopper. Another waste that was used as a blending material was cattle dung (CD), which was collected from LRS, NAU, Navsari, India and stored in a shed for 30 days. To reduce the C/N ratio, the MTPW was blended with cattle dung. The resulting mixture (feedstock) was used as the starting material for the vermicomposting process and the main characteristics of the initial feed stock are presented in Table 1.

2.3. Experimental set-up

Six treatments were used in the study, namely, EF: *Eisenia fetida*, EE: *Eudrilus eugeniae*, AR: *Aporrectodea rosea*, LR: *Lumbricus rubellus*, LM: *Lampito mauritii* and WUC: Worm un-work compost (Control) with four replicates. The experiment was conducted in an ambient environment of a laboratory temperature ranging from 27.5 to 30 °C and humidity ranging from 85 to 97% during the experiment. Each vermireactor (plastic container) was filled with a mixture of 5 kg CD and 3 kg dried finely chopped MTPW in all treatments on dry weight basis. Vermireactor, a 20 L cylindrical plastic container with a diameter of 50 cm and a depth of 20 cm, was used for the experiment. Total 8 kg of waste material was put in each vermireactor. From the stock culture, fifty fully developed clitellum earthworm individuals were introduced into the experimental vermireactor. Furthermore, the optimum moisture level in the vermireactor was maintained at 70–80% by sprinkling tap water in it when needed. A similar WUC setup was also maintained in the absence of earthworms. The vermireactors were covered with a gunny jute bag to avoid light and to protect moisture loss and direct action from flies and other insects. The vermicompost was collected after 60 days, which started when black granules appeared on the surface of the vermireactor. The production of vermicompost from each treatment was based on dry weight. Earthworms were manually separated during the sieving process by hand sorting. On the 60th day, the earthworm reproductive parameters, such as the number of clitellate, non-clitellate and hatchlings, were manually counted [18]. The vermicompost was harvested, sieved, weighed,



EF: *Eisenia fetida*,
EE: *Eudrilus eugeniae*,
AR: *Aporrectodea rosea*,
LR: *Lumbricus rubellus*,
LM: *Lampito mauritii* and
WUC: Worm un-work compost

Fig. 1. Deviations in pH, EC and TOC in different treatments produced from MTPW and CD mixture. Values are mean, n = 4, error bars indicate SD. Significant differences indicated by different letters.

and used to assess various parameters.

2.4. Vermicompost, compost and waste material analysis

To achieve sample homogeneity of vermicompost, compost, and raw material, approximately 200-g samples were gently mixed and sprayed on paper in the laboratory for air drying for subsequent physico-chemical analysis, while 100 g wet samples were kept in a polythene bag and frozen at −20 °C for biological properties analysis. The samples were collected and analyzed from all four replications of each treatment. The pH and conductivity (EC) values in a 1:10 (w/v) water suspension were determined using a digital pH (Systronic 352) and conductivity meter (Systronics 308), respectively. A sample (0.5 g) was placed in a silica crucible and combusted in a muffle furnace at 550 °C for 60 min, and TOC content was calculated using values of ash content as per the procedures outlined by Ref. [19]. The nitrogen content was determined after digesting the sample with H_2SO_4 and $HClO_4$ (9: 1, v/v) by Kjeldhal method using auto distillation unit. The total available phosphorus in the samples was determined in terms of colour by UV-VIS spectrophotometer (Systronics 117) following acid digestion with Conc. HNO_3-using vanadomolybdo phosphoric acid technique. The total potassium content of the samples was determined using a flame photometer (Systronics 128) after HNO_3 acid digestion. The versenate method was used to determine total calcium and magnesium and total sulphur concentration in the same digest by developing turbidity-using barium chloride [20]. Amount of heavy metals (Fe, Mn, Zn, and Cu) was measured using an atomic absorption spectrophotometer (AAS 4141), in accordance with the procedure recommended by Ref. [21] after digestion with HNO_3. The C/N and C/P ratios were calculated using the total organic carbon and nitrogen and phosphorous content values. Total bacterial, fungal and actinomycetes count using the serial dilution plate technique suggested by Ref. [22].

2.5. Statistical analysis

The data reported in table and figure are the mean of four replicated vermireactors.Tukey's HSD test was employed as a post hoc analysis to compare the means after one way analysis of variance (ANOVA) was used to assess if there was a significant difference ($P < 0.05$) between all reactors (with and without earthworms) and parameters evaluated during the research using online software (OPSTAT) [23].

3. Results and discussion

3.1. Changes in physico-chemical characteristics of waste during vermicomposting

3.1.1. Change in pH, EC and TOC

During vermicomposting earthworms induced decomposition and significantly altered the physico-chemical parameters of the waste mixtures. At the end of the experiment, the vermicompost produced in each treatment was fine, earthy, homogeneous, and nutrient-rich. All the earthworm species were found to prefer mixture of feed stock up to 60 days. The feedstock initial pH was close to 8.0, which is thought to be the optimal pH for the breakdown of organic matter in waste degradation systems [24]. In the present experiment, pH of all vermireactor was found lower than that of initial value. At starting, pH of the waste mixture was 7.92, which reduced to 7.43–7.75 after vermicomposting by different earthworm spp. (Fig. 1). The pH decrease might be caused by the transformation of complex organic molecules into simpler ones, as well as the release of humic acids throughout the process [25]. During vermicomposting, nitrogen and phosphorus mineralize into nitrates and orthophosphate, which can cause a pH change [6]. The pH values in the vermireactor were significantly ($P < 0.05$) different among each other and were found to be lowest in the EF vermireactor.

Initial EC of MPTW and CD mixture (0.38 mS/cm) that were composted with and without earthworm treatment had EC readings in the 0.56–0.75 mS/cm range, showing considerable increases (47.37–97.37%) throughout the vermicomposting process (Fig. 1). Earthworm spp. treatment differed significantly in terms of the percentage rise in EC during vermicomposting ($P < 0.05$). Since all treatments had EC values below the top limit of 4 mS/cm, they were all considered to employed as a fertiliser value [26]. The current study's findings support the findings of earlier studies carried out by Badhwar et al. [27], which showed that vermicomposting of 60% CD + 40% paper mill sludge can result in near to 222.34% increased EC.

Organic matter in the feed mixture was initially high (253.50 g/kg), but decreased significantly during vermicomposting. Vermicomposting reduced total organic carbon (TOC) by 54.96–50.56%, with the EF vermireactor having the highest reduction (54.96%), followed by the EE vermireactor (53.99%), and the WUC vermireactor having the lowest reduction (42.96%) from the initial waste mixture. Organic matter reduction was in the following order in the different vermireactors: EF > EE > AR > LR > LM > WUC (Fig. 1). The release of carbon dioxide by microorganisms during respiration may reduce the TOC level of vermicompost [28]. The largest reduction in TOC content in *Eisenia fetida* vermicompost in the current experiment might be due to its voracious eating and greater excretion rate than other earthworm species [11]. Similar line of work done by Badhwar et al. [27]and reported that the reduction in organic carbon in the range of to 35–46% during 90 days of vermicomposting of feed stock ratios of agri-industrial waste may have been caused by the metabolism and absorption of carbon by earthworm EF and microbes community. The TOC reduction was greater in vermicomposting than in traditional composting, possibly due to earthworms' greater assimilating ability. Microbes biochemically degrade organic carbon and possess enzymes for organic waste degradation in earthworm guts, lowering the TOC content of vermicompost by respiration [29]. The variability in carbon losses of vermicompost processed by earthworm species might be related to species-specific changes in organic matter mineralization ability [12].

3.1.2. Change in major nutrients (N, P and K)

Vermicompost seemed to have a substantially greater kjeldhal nitrogen (TKN) concentration than both the original waste combination and compost. In various vermireactors, it ranged from 11.43 to 20.45 g/kg whereas it only reached 8.42 g/kg in compost (Supplementary Table 1). The EF vermireactor that produces vermicompost has the highest TKN (20.45 g/kg). Following vermicomposting, TKN improvements in various vermireactors were in the following order: EF (247%)> EE (212%)> AR (128%)> LM (94%)> LR (81%)>WUC (43%) (Fig. 2). TKN content showed significant difference among all vermireactors, with EF having the highest TKN concentration (20.45 g/kg) compared to the original TKN level (5.90 g/kg) in initial waste. Vermicompost has a higher and more soluble concentration of major nutrients while composting of *Lantana camara* waste with *Eisenia fetida* than *Eudrilus euginae* [5]. In comparison to compost (WUC), vermicompost mediated vermireactors have a substantially greater TKN concentration. Probably, very high net nitrification rates were observed in the vermicomposting treatments compared to lack of earthworm [30] while working with and without presence of earthworms during the vermicomposting of fruit and vegetable wastes. The increase in N in vermicompost was most usually related to mineralization of organic matter including proteins [6] and the conversion of ammonia to nitrate during vermicomposting is enhanced by a range of ammonia-oxidizing bacteria and archaea [30]. The total N content of vermicompost produced by all five earthworm species differed significantly ($P < 0.05$), which could be attributed directly to the species specific feeding preferences of individual earthworm species and indirectly to the mutually beneficial relationship between ingested microorganisms and digestive mucus [31].

Comparing vermicompost to compost and the raw waste combination, vermicompost exhibited a much higher level of available phosphorus (TAP). TAP content ranged from 13.42 to 23.92 g/kg at completion of the composting process and 8.90 g/kg at commencement (Supplementary Table 1). The EE vermireactor (169%) had the highest TAP increase, which was accompanied by EF (157%), AR (79%), LM (66%), LR (51%) and WUC (29%) vermireactors (Fig. 2). TAP content was significantly differing ($p < 0.05$) in each vermireactor and the lowest TAP content (11.50 g/kg) was recorded in the WUC vermireactor. Earlier studies have also reported the increased phosphorous content of waste after vermicomposting by Kumar et al. [27] found that vermicompost may increase 212%–410% phosphorus than initial waste feedstock. The conversion of insoluble phosphate into soluble phosphate by phosphate solubilizing microbes via phosphatases in the earthworm gut may have increased TAP of vermicompost [32]. The TAP content in the vermicompost of *Eudrilus eugeniae* was increased by up to 108% and 169% over WUC and waste mixture, respectively, which could be attributed to the production of total phosphorus from complex formed by humic acid through earthworm and microorganism activities [33]. The increase in total phosphorous content of vermicompost may be ascribed to enzymes possess by earthworm digestive system and microbial activity [34].

The TK content of all the treatments significantly ($P < 0.05$) increased from their initial levels (7.30 g/kg), with EE vermireactor with the highest TK content (16.15 g/kg) among them (Supplementary Table 1). The TK content rose from 72.33 to 121.23% in vermicomposting treatments (Fig. 2). TK content in vermicompost increases by 23%–58% when compared to compost (WUC). The TK content in vermicompost produced by *Eudrilus eugeniae* increased up to 58% and 121% over compost and waste mixture, respectively. According to Khwairakpam and Bhargava [35], potassium conversion in vermicompost is a complicated process that is influenced by earthworm species. The acid generated by microorganisms and the large quantity of microbiota in earthworm guts may have helped raise the TK concentration in vermicompost [36]. The microflora in the earthworm gut, which secretes mucus and water, promotes organic matter decomposition and thus increases the TK content of vermicompost [37].

3.1.3. Change in secondary nutrients (Ca, Mg and S)

The Ca (2.08–3.12 g/kg), Mg (1.23–1.52 g/kg), and S (0.20–0.36 g/kg) content in vermicompost was higher than that of the waste mixture (1.50, 0.80, and 0.40, respectively) and compost (1.89, 1.00 and 0.16, respectively). The maximum Ca, Mg, and S (3.12, 1.52, and 0.36 g/kg) in the vermicompost produced in the EF vermireactor and vermicompost were found to be significantly different in each vermireactor (Table 2). Total calcium concentration in vermicompost was greater than in the WUC and waste mixture in this study, probably because earthworm species secrete calcareous fluids that help in the pH buffering of biodegradable waste [38]. The

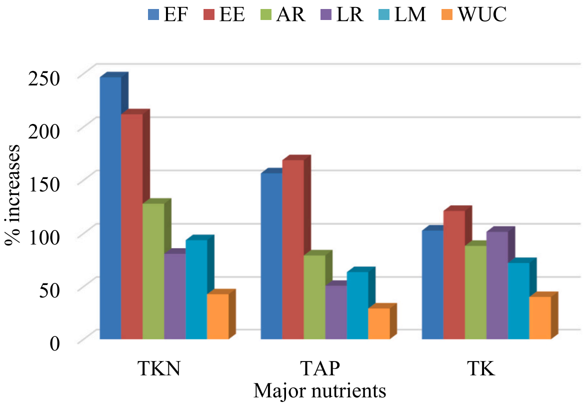


Fig. 2. TKN, TAP and TK increased due to treatment produced from initial waste mixture (MTPW and CD).

Table 2
Secondary nutrients of vermicompost and worm unwork-compost produce from MTPW and CD mixture under different treatments (Mean, n = 4).

Vermireactor	Total Ca (g/kg)	Total Mg (g/kg)	Total S (g/kg)
EF	3.12^{a}	1.52^{a}	0.36^{a}
EE	2.89^{b}	1.51^{a}	0.31^{c}
AR	2.08^{d}	1.34^{b}	0.32^{b}
LR	2.26^{c}	1.23^{c}	0.29^{d}
LM	2.30^{c}	1.35^{b}	0.20^{e}
WUC	1.89^{c}	1.00^{d}	0.16^{f}

EF: *Eisenia fetida*, EE: *Eudrilus eugeniae*, AR: *Aporrectodea rosea*, LR: *Lumbricus rubellus*, LM: *Lampito mauritii* and WUC: Worm un-work compost.

incremental effect of Ca, Mg, and S content of vermicompost because of concentration effect due to dry weight biomass loss during mineralization of waste [36]. The 55.27%–25.47% increment in Ca was found in vermicompost made from *Ageratum conyzoids* + cow dung using EF earthworm from the initial value [33].

3.2. Stabilization and maturation of compost

The C/N ratio is often used to describe the degree of maturing and stabilization of organic wastes since carbon is released as CO_2, but nitrogen is lost at a slower rate, and so the more decomposed organic wastes, the lower the C/N ratio [8]. The initial C/N ratio of waste mixture (42.97) and it was reduced to 87-75% in vermicomposting vermireactor at the end of experiment. The highest reduction in the C/N ratio was in EF vermireactor (5.58) followed by EE (6.35), AR (8.96), LM (10.97), LR (11.38) and WUC (17.13) vermireactors (Fig. 3). In this study, the C/N ratio of all substrates dropped significantly from the beginning value to less than 20, and the C/N ratio of all vermireactors was less than 15 except for (WUC). When the C/N ratio is < 20, it indicates that the finished product is mature enough, and a number of the <15 is considered to be optimum for the agricultural utility of the finished products as fertilisers [39] Secondly, lower C/N ratio obtained in vermicompost because of the loss of organic carbon in the form of CO_2 and an increase in TKN content in vermicompost, composting by different earthworm species treatments gradually lowered the C/N ratio. Significantly lowest C/N ratio (5.58) was found in EF vermireactor in the current investigation. Khan et al. [13] showed consistent observations and the lowest C/N ratio (7.40 ± 0.2) in finished vermicompost processed with poplar plant biochar. The significantly lower C/N ratio in EE and EF vermicompost suggested that this species improved organic matter mineralization quickly than other earthworm species [40] Results further suggest that vermicompost had lowest C/N ratio, which was more stabilized end product compared to WUC reactor (Compost). Similar outcomes were also reported by Ref. [41]while composting and vermicomposting studied on various organic wastes.

Initially, the C/P ratio of the waste combination (MTPW + CD) was 48.28, compared to 4.88–9.03 after vermicomposting and 12.58 in compost after composting without earthworm. The largest C/P ratio decrease was in the EE vermireactor (4.88), while the least decline was in the LR (9.03) and WUC (12.58). Vermicompost has a statistically ($P < 0.05$) different C/P ratio from other each of them (Fig. 3). The breakdown of organic matter (reducing TOC level) and increases in phosphorus concentration brought about by the reduction of waste volume were the causes of these changes in the C/P ratio.

3.3. Changes in the heavy metal content in different vermireactors

Compared to compost and waste combinations, all vermicompost contained more heavy metals (Fig. 4). Vermicompost had a Fe concentration that ranged from 30.27 to 174.32% higher than compost and 78.63–179.30% higher than the waste mixture. Mn concentration varied from 186 mg/kg in the feed mixture to 261.25 mg/kg in vermicompost, although it was in the range of 261.25–519.50 mg/kg in compost. In contrast, vermicomposting increased the Zn content by 15.82–134.65%. The WUC vermireactor

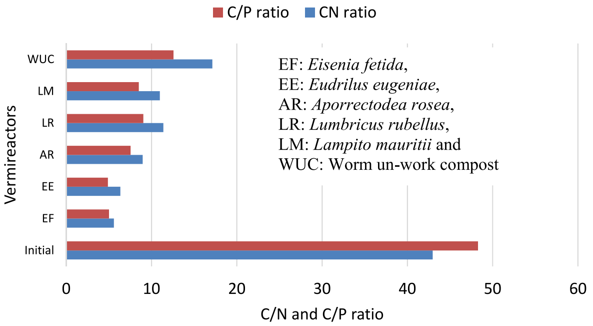


Fig. 3. Changes in C/N and C/P ratio in different vermireactors from initial waste at 60 days.

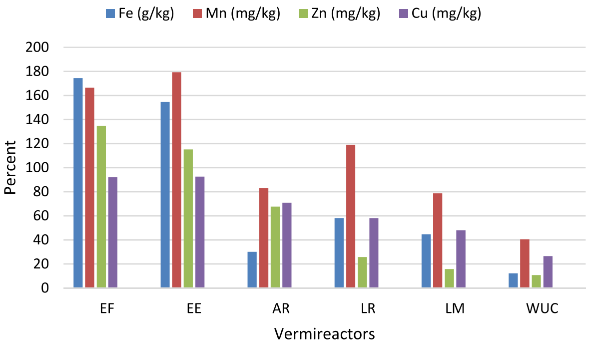


Fig. 4. Percent heavy metal changes in different vermireactors from initial waste at 60 days.

had the lowest observed Zn level (175 mg/kg). Vermicompost had 48.0–92.60% higher copper content than the feed mixture. The Fe, Mn, Zn and Cu in various vermicompost were statistically ($P < 0.05$) different from each other. The increase in Fe, Mn, Zn and Cu content of vermicompost is due to the reduction of waste quantity during the vermicompost process. An increase in stable fractions of heavy metals relative to mobile fractions throughout the vermicomposting process may have enhanced the total amount of heavy metals including micronutrient content in vermicompost [42].

3.4. Changes in the microbial population in different vermireactors

In this study, vermicomposting from the initial waste mixture resulted in a significantly ($P < 0.05$) higher number of bacterial, fungal, and actinomycetes colonies (Table 3). After completion of vermicomposting in vermireactors (60 days), the total bacterial count improved by 68.23–137.70% compared to the initial feed mixture, while the gain was highest in the EF-treated substrate (Table 3). The bacterial counts were considerably greater in vermicompost (143.50–202.75 cfu x 10^6/g) than compost (92.75 cfu x 10^6/g). An effective earthworm species (*Eisenia fetida*), a good bulking agent (cow dung), and a moisture level (70–80%) led to an end product that was enriched in nutrients and microorganisms [43]. Similarly, total fungal count was also recorded in EF vermireactor (36.50 cfu x 10^4/g) followed by EE, AR, LR and LM. The fungal count recorded in the range of 11.00–36.50 cfu x 10^4/g in vermicompost while, compost recorded 7.75 cfu x 10^4/g at the termination of the experiment. The highest count of actinomycetes increases in EE (109.18%) vermireactor followed by EF (89.09%), LR (84.63%), AR (70.30%) and LM (46.05%) in vermireactors. The lowest actinomycetes count was recorded in a WUC vermireactor (85.75 CFU x 10^4/g). Devi et al. [49] recorded higher bacterial and fungal counts in vermicompost made by EF while, actinomycetes count higher in vermicompost made by EE compared to other earthworm species. The results of this experiment showed significantly higher numbers of total bacterial, fungal and actinomycetes counts of vermicompost over compost might be due to the symbiotic interaction of earthworms and microorganisms necessary for the breakdown of organic waste [44]. Changes in microorganisms in vermicompost were related to the microorganisms in the earthworm gut. The gut of the worm provides a thermally stable protective layer for microorganisms in the gut, which leads to their proliferation even under difficult conditions, as indicated by Paul et al. [14].

3.5. Vermicompost production under different vermireactors

Vermicompost production was in the range of 4.17–5.21 kg in different vermireactors from the initial waste mixture (8.00 kg). The maximum vermicompost (5.21 kg) was produced in EF vermireactor followed by EE (5.02 kg), LR (4.47 kg), AR (4.35 kg) and LM (4.17 kg) vermireactors (Table 4). Vermicompost production increase 33–56% compared to compost (WUC) while, vermicompost recovery was recorded the highest in EF vermireactor (65.13%) followed by EE (62.75%), LR (55.88%), AR (54.38%) and LM (52.13%). The vermicompost production in different vermireactors were statistically different from each other ($P < 0.05$). Earthworm species were crucial in the production and recovery of vermicompost generated from the waste mixture in this investigation. The earthworms *Eisenia fetida* and *Eudrilus eugeniae* outperformed over *Aporrectodea rosea, Lumbricus rubellus* and *Lampito mauritii*. These

Table 3
Microbial population in vermicompost and worm unwork-compost produce from MTPW and CD mixture under different treatments (Mean, n = 4).

Vermireactor	Total bacterial count (cfu × 10^6/g)	Total fungal count (cfu × 10^4/g)	Total actinomycetes count (cfu × 10^4/g)
EF	202.75^a	36.50^a	148.25^b
EE	185.50^b	34.50^b	164.00^a
AR	183.50^b	23.25^c	133.50^c
LR	170.50^d	16.75^d	144.75^b
LM	143.50^c	11.00^e	114.50^d
WUC	92.75^e	7.75^f	85.75^e

EF: *Eisenia fetida*, EE: *Eudrilus eugeniae*, AR: *Aporrectodea rosea*, LR: *Lumbricus rubellus*, LM: *Lampito mauritii* and WUC: Worm un-work compost.

Table 4

Vermicompost production, recovery and conversion rate of vermicompost and worm unwork-compost produce in various vermireactors (Mean, n = 4).

Vermireactor	Vermicompost production (kg)	Vermicompost recovery (%)	Conversion rate of compost (g/day)
EF	5.21[a]	65.13	86.83
EE	5.02[a]	62.75	83.66
AR	4.35[bc]	54.38	72.50
LR	4.47[b]	55.88	74.50
LM	4.17[c]	52.13	69.50
WUC	3.63[d]	45.38	60.50

EF: *Eisenia fetida*, EE: *Eudrilus eugeniae*, AR: *Aporrectodea rosea*, LR: *Lumbricus rubellus*, LM: *Lampito mauritii* and WUC: Worm un-work compost.

could be due to increases in earthworm biomass of *Eisenia fetida* and *Eudrilus eugeniae*, which have produced more earthworms with larger body weights and voracious appetite for food, and which have contributed to dead tissue in the form of compost when it is died during vermicomposting. This earthworm also increased their total biomass much faster than other species that thrive in moist organic waste [45]. Compared to the vermicompost vermireactor (52.13–65.13%), WUC vermireactor had the lowest compost recovery (45.38%). Similar trends also reported in case of conversion rate of compost. Compost is mostly made up of thermophilic (heat-loving) organisms, whereas vermicompost is predominantly made up of mesophilic processes [46].

3.6. Earthworm population reported under different vermireactors

Earthworm growth and reproduction should be considered a key factor in the vermicomposting investigation [47]. In this study, Earthworm's population in terms of reproduction was evaluated in terms of the number of clitellate, non-clitellate and hatchlings of earthworm. The findings of the reproduction and earthworm population are shown in Table 5. In this research, where MTPW + CD were utilised as waste materials, 50 earthworms of each species were originally introduced for the vermicomposting of the waste material. Despite the fact that different earthworms have diverse biology, the results in this case demonstrated a substantial difference. The clitellate earthworm number gain in different vermireactors varied in the following order: EE (285) > EF (229) > AR (107) > LR (100) > LM (71) were significantly different among each other ($P < 0.05$). The maximum clitellate earthworm was recorded in EE vermireactor (285) which was statistically at par with EF vermireactor (229). The EE and EF population had increased by 5.70 and 4.58 fold, respectively, compared to 2.14, 2.0 and 1.42 fold in the case of AR, LR and LM vermireactors. Likewise, the total number of non-clitellate earthworm was 818, 535, 191, 185 and 183 in EE, EF, AR, LM and LR vermireactors, respectively. Significantly higher numbers of non-clitellate was recorded in EE vermireactor ($P < 0.05$) compared to other earthworm species. Similarly, the maximum number of hatchlings were also recorded in EE (1024) followed by EF (847), LR (216), AR (202) and LM (198) vermireactors. Boruah et al. [48] reported the 2.1 fold increases in the population of *Eisenia fetida* earthworm during vermicomposting of agro-industrial waste. Ganeshkumar et al. [50] observed a high rate of juvenile production in *Eudrilus eugeniae* and *Eisenia fetida*, averaging 2.1 and 2.4 offspring per day, respectively.

4. Conclusion

According to this study, all five species of earthworms are capable of turning the waste from mango tree pruning into vermicompost. Although both *Eisenia fetida* and *Eudrilus eugeniae* outperformed in terms of more nutrient-rich vermicompost production. The highest increase in TKN, TAP and TK was observed in EE and EF vermireactors. Similar trend was observed for other nutrients. The TOC was declining most rapidly in EF (54.96%), followed by EE (53.99%). The presence of earthworms promoted the bacterial, fungal and actinomycetes populations compared with compost. According to the study, the populations of *Eisenia fetida* and *Eudrilus eugeniae* were superior to those of *Aporrectodea rosea*, *Lumbricus rubellus*, and *Lampito mauritii* in vermicompost systems for the production and recovery of vermicompost. Vermicomposting can be added to the overall approach to managing mango tree pruning waste by using *Eisenia fetida* or *Eudrilus Eugenia*.

Author contribution statement

1 - Conceived and designed the experiments;
2 - Performed the experiments;
3 - Analyzed and interpreted the data;
4 - Contributed reagents, materials, analysis tools or data;
5 - Wrote the paper.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests

Table 5
Earthworm population reported in various vermireactors (Mean, n = 4).

Vermireactor	No. of Clitellate	No. of Non- clitellate	No. of Hatchlers
EF	229^{ab}	535^{b}	847^{b}
EE	285^{a}	818^{a}	1024^{a}
AR	107^{bc}	191^{c}	202^{c}
LR	100^{bc}	183^{c}	216^{c}
LM	71^{c}	185^{c}	198^{c}
WUC	–	–	–

EF: *Eisenia fetida*, EE: *Eudrilus eugeniae*, AR: *Aporrectodea rosea*, LR: *Lumbricus rubellus*, LM: *Lampito mauritii* and WUC: Worm un-work compost.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e19908.

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