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Vermicompost Potential of Common Earthworms (*Eudrilus eugeniae*) and Red Wiggler (*Eisenia fetida*) Worm on the Decomposition of Various Organic Wastes

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Authors' contributions

This work was carried out in collaboration between all authors. Author ZG designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author TA managed the analyses of the study. Authors LA and BA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Purpose: To evaluate the vermicomposting potential of *Eudrilus eugeniae* and *Eisenia fetida* earthworms on decomposition of various organic wastes through worm growth and production of nutrient rich vermicompost.
Methods: Two local *Eudrilus eugeniae* earthworms (*Debrezeit* and *Keshmando*) and commercial *Eisenia fetida* earthworm were evaluated using different agricultural (maize and haricot bean straws), urban (khat, food and fruits peels) and industrial (bamboo) wastes. Seven types of wastes (each mixed with cow manure) were used and with three earthworm types which gave a total of twenty one treatments. The experiment was laid out in a factorial completely randomised design (CRD).
Results: Earthworm growth and nutrient composition of the final vermicompost was significantly (p <0.05) affected by the main and interaction effects of worm and type of organic feed. High numbers

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of cocoons and worms, as well as worm biomass, were recorded with *Keshmando* and *Eisenia fetida* when fed into khat and maize straw, while the least count and biomass of worms were recorded in an industrial waste feed. The chemical compositions of vermicomposts of all earthworm types produced for each substrate were more than that of their respective initial feed mixture. A significant increase in available plant nutrients and a rapid decomposition of dissolved organic C content were observed in all the vermicompost treatments. The highest % N (0.84) with decreased C: N ratio was found in *Debrezeit* with khat substrate, while the highest P (370 ppm) and K (12.6 g/kg) contents were found in *Eisenia fetida* with maize straw.

Conclusion: Results clearly indicated that the type of substrate significantly influenced worm growth and quality of the end product. Worms showed no drastic difference in a decomposition of wastes which exhibited the potential and candidature of local earthworms with *Eisenia fetida* for vemicomposting. Further, the study revealed the suitability of maize straw for better worm growth and production of nutrient-rich vermicompost.

Keywords: Earthworms; vermicompost; substrate; nutrient; organic wastes.

1. INTRODUCTION

In Ethiopia, agricultural productivity remains low which is greatly attributed to inadequate sustainable soil fertility management practices [1]. Particularly, soils in western Ethiopia including Assosa area are highly weathered and farmers apply traditional strategies for soil fertility management such as fallowing. The situation is worsened by the rapid decomposition of organic matter and the fact that farmers often do not apply enough organic fertiliser to maintain soil organic matter pools [2]. Clearly, the need for a reforming approach to soil fertility and agricultural wastes management is critical for sustainable crop production as well as to improve soil health and soil structure. Nagavallemma et al. [3] reported that tropical soils are deficient in all necessary plant nutrients and on the other hand large quantities of such nutrients contained in domestic wastes and agricultural by-products are wasted. In countries with intensive agriculture farming like Ethiopia, there is a huge amount of animal excreta as well as crop residues being generated. Proper utilisation of these wastes can improve soil physical condition and environmental quality besides providing the nutrients for plants [4].

In recent years, emphasis on the use and management of different organic waste such as those originated from agricultural and municipal practices in crop production has assumed increased importance due to pressure on organic agriculture [5]. Large amounts of plant residues (agriculture wastes) can serve as potential sources of plant nutrients using earthworms which are a cost effective and sustainable technology of waste management [6]. Recently, due to high cost of fertilisers and reduced availability of organic manures, the recycling of organic wastes using epigeic earthworms, so called vermicomposting for increasing soil fertility has gained importance all over the world [7]. Zucco et al. [8] also reported that vermicompost is often used in sustainable farming systems to improve soil physical properties, provide plant nutrients, and recycle organic wastes and have been shown to increase plant growth and crop yields.

Vermicompost is a nutrient-rich, microbiologically active organic amendment that results from the interactions between earthworms and microorganisms during the breakdown of organic matter [9]. It is a stabilised, finely divided peat-like material with a low C: N ratio, high porosity and high water holding capacity, in which most nutrients present are in readily available form for plant uptake [10]. Obtaining earthworms from vermiculture activity would be one-time cost in any vermiculture technology as the earthworms multiply rapidly creating huge population of worms which further promote and enhance the process [11]. When the organic material passes through the gut of the earthworm it again increases the surface area of the material so that the microorganisms can break it down further. The undigested materials, or castings, are fertile and rich in nutrients [12]. They contain nutrients such as nitrates, exchangeable phosphorus, and soluble potassium, calcium, and magnesium for plant growth [11]. Studies on the production of vermicompost using biodegradable wastes indicated its efficiency and cost-effectiveness in reducing the application of chemical fertilisers up to 100% for various vegetables and crops [13]. Nagavallemma et al. [3] also reported that vermicompost plays a significant role in improving growth and yield of different field crops, vegetables, flowers and fruit crops. The process is faster than composting; because the material passes through the earthworm gut, a significant but not yet fully understood transformation takes place [3]. As manure or compost is not always environmentally safe fertiliser, farmers can easily adopt vermicompost production, because composting reduces the agronomic value of compost and contributes to greenhouse gas emission due to nutrients losses during compost making [9]. Moreover, composting requires human labour or fuel in order to turn the compost heap to ensure aeration. On the other hand, earthworms in vermicomposting process serve as an agent for turning, fragmentation, and aeration of the manure; therefore, it drastically increase the rate of microbial activities [13]. Rameshwar and Argaw [14] conducted cement tanks vermicomposting experiments of khat wastes along with crop residues and different animal manures with the primary focus of studying the decomposition process and manurial value of the khat leaf waste using the earthworm *Eisenia fetida*. The authors reported khat to be a suitable substrate for vermicomposting thereby making efficient utilisation of urban wastes. Ndegwa et al. [15] reported in a demonstration work that the feeds for vermicompost varied greatly not only with earthworm species but also with the feed type. The growth and reproduction of earthworms have significant differences in numerous organic materials during decomposition as the materials quality especially in relation to C:N ratio directly affect the efficacy of vermicompost. Aira et al. [16] reported that food quality influences not only the size of earthworm populations but also their growth and reproduction rates.

For successful vermicomposting, selection of suitable earthworm species is an important step and need effort, especially its potential to feed upon different wastes which are suitable for worm growth should be known. The composting efficiency and biology of only a few epigeic earthworm species has been studied such as *Eisenia fetida* [17]. Moreover, the potential of some commonly known earthworms for locally available agriculture and urban wastes degradation has not been explored. Especially, there is lack of study on comparing the performance of locally available earthworm species and the known earth worm species (*Eisenia fetida*) using different agriculture (crop residues) and urban (food and fruits peels) wastes on vermiculture and production of nutrient rich vermicompost. Therefore, the present study aimed to evaluate the growth and decomposition potential as well as the influence on nutrient content of vermicompost products using local *Eudrilus eugeniae* earthworms (*Debrezeit* and *Keshmando*) and commercial *Eisenia fetida* earthworm cultured in different treatments of organic wastes.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The experiment on vermicomposting was conducted during June to September of 2016 at Assosa agricultural research center (EIAR), Assosa, Ethiopia. Assosa is the capital city of Benishangul Gumuz regional state in western Ethiopia and lies on altitude of 1,480 m above sea level, and located at 09°58'41.7" N, 034°38'09.5" E coordinates.

2.2 Collection of Earthworms and Feed Wastes

Two types of locally collected earthworms (*Keshmando* and *Debrezeit*) were used for vermicomposting expected to be characterised under African night crawlers (*Eudrilus eugeniae*) and were previously collected from places called Keshmando- Benishangul-Gumuz Region and Debrezeit- Oromia Region, Ethiopia. A survey was conducted in 2012/13 across different regions of Ethiopia to collect and identify suitable species of earthworms to develop for vermiculture. *Keshmando* and *Debrezeit* earthworms were isolated as the best earthworms for vermicomposting from the collected worms. The common commercially cultured earthworm in temperate countries *Eisenia fetida* [18], were obtained from Ambo Agricultural Research Center. Agricultural wastes (straws of maize, haricot bean) were collected from the agricultural fields of Assosa Agricultural Research Center. The other wastes (khat, fruit peels and food wastes) were also collected from restaurants, municipal wastes and bamboo agro industry at Assosa.

2.3 Experimental Design

Seven types of wastes including locally available agricultural wastes (straws of maize, haricot bean) and urban wastes such as khat, fruit peels (consisted of banana-50% and papaya-50%), fresh food and pre-composted food and also industrial wastes from bamboo agro-forestry processing were used for the study. Performance

Table 1. Feed mixture components, amount (ratio) added and chemical composition of initial feed mixture (2 weeks after mixing) for vermicomposting

No.	Feed type	Amount added (kg)	Amount of cow manure added (kg)	Amount of soybean added (kg)	Ratio of mixture (cow manure: feed)	Total feed mixture added (kg)	Chemical composition of the initial feed mixture			
							pH	OC (%)	N (%)	C:N
1	Khat	4.50	14	1.50	7:3	20	7.23	28.4	0.56	51:1
2	Maize straw	4.50	14	1.50	7:3	20	6.98	26.6	0.54	49:1
3	Pre-composted	4.50	14	1.50	7:3	20	7.46	22.7	0.61	37:1
4	Fresh food	4.50	14	1.50	7:3	20	7.60	23.8	0.58	41:1
5	Haricot bean	4.50	14	1.50	7:3	20	7.08	21.8	0.62	35:1
6	Industrial waste	4.50	14	1.50	7:3	20	7.52	26.7	0.58	46:1
7	Fruit peels	4.50	14	1.50	7:3	20	7.28	27.4	0.62	44:1

N.B. Soybean straw was mixed and added as basal for all treatments and for each treatment box, individually 1000 earthworms from each earthworm type were counted and added of earthworm species over different substrates were investigated through criteria suitable for vermicomposting which included: vermicast (vermicompost) biomass per box, number of cocoons, number of adults, worm biomass, pH, organic carbon, N, P and K concentrations. The experiment was laid out in a factorial completely randomised design (CRD) with seven substrates indicated above and three earthworm species one the known earthworm (*Eisenia fetida,* commonly known as red wigglers) and two locally collected earthworms (*Keshmando* and *Debrezeit*) with a total of twenty one treatments with two replications.

The experiment was performed in a box (1m length x 0.5 m width x 0.5m depth) which provided 0.50 m^2 of the uncovered top surface. Feeds (substrates) consisted of cow manure seven parts to three parts of different agricultural and urban wastes (total 7 types), by dry weight were used. These seven types of wastes were used to provide bedding for the earthworms as well as a carbon supplement. The dried plant residues were chopped and then individually mixed with cow manure (in ratio of 7 parts of cow manure and 3 parts of waste, dry weight basis). The 7:3 ratios of cow manure and plant residues and/or urban waste were chosen, because it is the recommended ratio for vermicompost output and maintaining earthworm's health. Keeping the 7:3 ratios of cow manure and residues and/or wastes, a total mixture of 14 kg of cow manure and 4.50 kg of wastes (agricultural and municipal) and 1.50 kg of soybean as additional bedding material were used for each box on dry weight basis and kept for about two weeks. After 14 days, a total of 1000 adult earthworms of each earthworm type were added to the content of each wooden box. All the systems were fed in once with enough feedstock for the entire 90 days in which the experiment was conducted. The moisture content was maintained at 60-70% by regular addition of water using water cans. At the end of the experiment, adult worms and cocoons were counted separately. The worms were separated from the vermicompost and earthworm biomass determined. All the worms > 5cm were counted separately (adults and juveniles) and newly hatched worms (< 5cm) and cocoons were counted together at harvest [19]. The cast biomass (vermicompost yield) was determined after casts of each boxes were harvested. Vermicompost sample from each box was then air dried, sieved and stored for physico-chemical analysis.

2.4 Chemical Analysis

Determination of pH was made potentiometrically in a 1:10 (vermicompost sample : de-ionised water). Total organic carbon (OC) content was determined by the Walkley and Black [20] method and the organic matter was calculated by multiplying % OC by 1.724. Total nitrogen was measured by micro Kjeldahl method [21]. Extractable phosphorous was determined by following Olsen's sodium bicarbonate extraction method [22]. Potassium was determined after extracting the sample using ammonium acetate extractable method and analysed by flame photometer [23]. The C:N ratio was calculated by dividing the percentage of carbon in the substrates by the percentage of nitrogen in the same substrates.

2.5 Statistical Analysis

The analysis of variance was carried out using SAS statistical software version 9.01 [24]. All main effects and their interactions were determined via *F*- tests and means were separated using Tukey's procedure ($P < 0.05$) at the 5% probability level.

3. RESULTS AND DISCUSSION

3.1 Growth and Reproduction of Earthworms

In the present study, the number and weight of adult earthworms were taken as indicators of growth and biomass production, whereas the numbers of cocoons were taken as a parameter for reproductive performance. ANOVA showed that earthworm main effect had significantly ($p < 0.05$) affected number of adult worms and worm biomass but did not affect vermicompost biomass and number of cocoons (Table 2). The experimental results showed that with the exception of the cast (compost) biomass produced the type of substrate affected the survival and reproduction of earthworm during the period of vermicomposting (Table 2). The interaction between earthworm species and substrate significantly ($p < 0.05$) affected number of cocoons, adults and worm biomass (Table 2). The number of adult worms and worm biomass of the earthworm species *Eisenia fetida* were significantly higher than local worm *Keshmando*, but significantly the same as the *Debrezeit* earthworm. Significant increases in the number of cocoons, adults and earthworm biomass were observed in the substrates of khat, maize straw and fruits peels each mixed with cow manure at the end of decomposition. The least number and biomass of worm were observed in the haricot bean straw and industrial waste substrates.

Most of the parameters taken were significantly ($P < 0.05$) affected by main effect of earthworm species and feeding material (substrate), but the two-way interaction significantly affected growth and reproduction of worms more than individual effects (Table 3). Cocoon production at the end of the experiment was significantly ($p < 0.05$) affected by the interaction effect between type of worm and substrate added. The highest number (613) of cocoons were recorded in *Keshmando* worms which fed on khat, followed by *Eisenia fetida* and *Debrezeit* which fed on fresh food and maize straw, respectively. The least number (54) of cocoons were counted when *Keshmando* fed on industrial waste. Among the seven substrate types studied, the most locally available agricultural waste (maize straw) significantly responded to higher cocoon production for all earthworms (Table 3). It was observed that in all substrates, the earthworms showed variable degree of growth and reproduction with minimum performance in industrial waste and haricot bean straw. An increase in worm population in maize straw might be due to the suitability of the material; while a continuous increase in population, but with lower reproduction rates, in industrial waste and haricot bean straw might have been due to the steady temperature and worm's choice on feeding materials. As reported by Suthar [6], waste decomposition and earthworm production were associated strongly with the quality of the substrate, especially with their chemical as well as biological composition.

Greater worm biomasses of 85.2 and 73.3% over industrial waste were recorded in the substrates of khat and maize, respectively. The highest number and biomass of adult worms produced in the khat substrate might be due to the hatching success of the cocoons attributed to the highest N content of the substrate. The results are also supported by the findings of Suthar [6] that the nitrogen amount of substrates as an important factor related to cocoon production. Sharma et al. [25] have observed that food source greatly influences growth rate and cocoon production. Survival, biomass formation and reproduction of earthworms are the best sign to analyse the vermicomposting process [26]. Therefore, increase in adult worms and the presence of significant development of cocoons into baby worms in khat substrate indicate that their reproductive activities are enhanced in the substrate. Interestingly, fruit peels exhibited greater number of adult worms (3200) and better worm biomass (2.84 kg) which resulted in an increase of 73.5 and 68.0% respectively over the industrial waste. In addition to industrial waste, legume straw (haricot bean) substrate recorded significantly lower number (2269) of worms and earthworm biomass (2.03 kg).

Table 2. Main effect of earthworm type and feeding material on vermiculture and cast (vermicompost) biomass

Treatment	Cast biomass (kg)	No. of cocoon	No. of adult	Biomass of earthworms (kg)
Earthworm type				
Eisenia fetida	21.60	341.71	2848.93^{a}	2.55^{a}
Debrezeit (Eudrilus eugeniae)	22.71	359.79	2656.79^{ab}	2.41^{ab}
Keshmando(Eudrilus eugeniae)	21.64	343.21	2501.43^{b}	2.27^{b}
LSD	NS	NS	215.55	0.179
Feed material				
Khat	20.66	313.00^{abc}	3607.5^{a}	3.13^{a}
Maize straw	20.16	465.50^{a}	3199.2^{a}	2.93^{a}
Pre-composted	21.33	302.33^{bc}	1835.5^{d}	1.71^{c}
Fresh food	22.41	450.00^{ab}	2725.8^{b}	2.54^{b}
Haricot bean	22.00	273.83^{c}	2269.5^{c}	2.03^{c}
Industrial waste	22.66	273.67^{c}	1845.5^{d}	1.69^{c}
Fruits peels	21.33	359.33^{abc}	3200.3^{a}	2.84^{ab}
LSD	NS	156.85	424.64	0.354
F-value:				
Earthworm (E)	0.29^{NS}	0.20^{NS}	8.29^{**}	7.56^{**}
Feed material (F)	0.78^{NS}	5.54^{**}	58.21^{***}	60.30^{***}
ExF	1.78^{NS}	7.92^{***}	18.62^{***}	16.21^{***}
CV(%)	8.38	23.90	8.47	7.81

The growth and reproduction of earthworm population also specifically depend upon the earthworm species [27]. Although *Eisenia fetida* showed the highest number and biomass of earthworm, similar contents were found by the local type of earthworms. Therefore, growth performance for the worm types studied was in the descending order: *Eisenia fetida* > *Debrezeit* > *Keshmando*. Several other species apart from *Eisenia fetida* applicable for vermiculture have been found by many researchers. Domínguez et al. [28] suggested a reproductive isolation between *E. fetida* and *E. Andrei*, and they found the earthworms as distinct species with different life histories. The authors finally considered that in vermiculture or vermicomposting *E. Andrei* is more recommended since its growth and reproduction rates are higher.

In other study, by Chaudhuri et al. [29] the reproductive capabilities of species of earthworms were studied and *Perionyx excavatus, Eudrilus eugeniae* and *Eisenia fetida* species were compared. The authors reported a significant difference in the growth rates and cocoon production and found *Eudrilus eugeniae* earthworm as best species for vermiculture in rubber leaf litters substrate. Therefore, extending the range of local and commercial earthworm species and search for new local and potential earthworms with valuable technological properties can be successful. Similar to the present study, Aalok et al. [30] reported a non significant difference between exotic and local earthworm species in number of cocoons, number and weight of worms during a comparative study for evaluation of their efficacy in vermicomposting. All aspects of the worm biology such as feeding habit, reproduction and biomass production potential must be known in order to utilise the earthworms successfully in vermiculture. The number and weight of adult earthworms were significantly ($p < 0.05$) affected by interaction effect between the type of worm and substrate added. Both maximum number of adult worms (4222) and earthworm biomass (3.59 kg) were recorded in combination of *Debrezeit* with fruit peels feed, but showed a figure significantly at par with both *Eisenia fetida* and *Keshmando* worms in substrates of khat and maize straw. While the least earthworm number and biomass was recorded in all earthworms fed into industrial waste. Accordingly, *Debrezeit* with fruit peels increased worm number and biomass by 3.7 and 1.5 fold over industrial waste, respectively. *Eisenia fetida* with khat and maize increased earthworm number by 1.7 and 1.5 times and worm biomass by 1.5 and 1.4 fold,

Table 3. Interaction effects of earthworms type and feeding materials on cocoon production and earthworm biomass

Earthworm type	Feed	Number of cocoon	Number of adult	Biomass of earthworms (kg)
Eisenia fetida	Khat	207.5^{bcd}	4115.5^{ab}	3.45^{ab}
	Maize straw	474.0^{ab}	3791.0^{abc}	3.41^{abc}
	Pre-composted food	244.0^{bcd}	1522.5^{hi}	1.41^{kl}
	Fresh food	610.0^{a}	3125.5^{cde}	2.98^{abcdef}
	Haricot bean	209.0^{bcd}	1813.0^{ghi}	1.61^{ijkl}
	Industrial waste	250.0^{bcd}	2690.0^{defg}	1.61^{jkl}
	Fruit peels	397.5^{abc}	2885.0^{cdef}	2.62^{defg}
Debrezeit *(Eudrilus eugeniae)*	Khat	121.5^{cd}	3243.0^{bcde}	2.69^{cdefg}
	Maize straw	502.5^{ab}	2466.5^{efg}	2.37^{efghi}
	Pre-composted food	330.0^{abcd}	2090.0^{fgh}	1.93^{ghijk}
	Fresh food	480.0^{ab}	2530.0^{efg}	2.40^{efgh}
	Haricot bean	297.0^{abcd}	3147.5^{cde}	2.75^{bcdef}
	Industrial waste	470.5^{ab}	898.5^{i}	1.41^{kl}
	Fruit peels	270.0^{bcd}	4222.0^{a}	3.59^{a}
Keshmando *(Eudrilus eugeniae)*	Khat	613.5^{a}	3464.0^{abcd}	3.25^{abcd}
	Maize straw	420.0^{abc}	3340.0^{abcde}	3.00^{abcde}
	Pre-composted food	333.0^{abcd}	1894.0^{gh}	1.78^{hijkl}
	Fresh food	260.0^{bcd}	2522.0^{efg}	2.22^{fghij}
	Haricot bean	315.0^{abcd}	1848.0^{gh}	1.73^{hijkl}
	Industrial waste	54.5^{d}	1948.0^{gh}	2.69^{cdefg}
	Fruit peels	410.0^{abc}	2494.0^{efg}	2.32^{efghij}
LSD		338.39	916.13	0.763

respectively over pre-composted food scraps. In addition, *Keshmando* with khat and maize increased earthworm number by 85 and 75% and biomass by 85 and 70%, respectively over the pre-composted food. Data revealed that the interaction strongly affected all the growth and reproduction parameters of earthworms more than their respective main effect, worm and substrate type. The performance of earth worms growth and productivity differed with respect to the type of substrates which indicated that the diversity of earthworm species varies with different organic materials and therefore, the species suited to a particular feed type can be identified. The significance of the interaction effect between earthworm type and feeding material on earthworm growth and cocoon formation showed preference of earthworms towards different culture substrates. Dominguez and Edwards [31] also reported that different earthworm species were suitable for vermicomposting and found quite different requirements of worms for their optimal development, growth and productivity in organic wastes. Furthermore, Sharma et al. [25] reported that earthworms of different species and ecological categories differed greatly in their ability to digest various organic residues. The authors found several other species of earthworms to be applicable for vermiculture apart from *Eisenia fetida*, with high production capacity and efficient processing of a wide range of organic materials.

3.2 Chemical Properties of Vermicompost

Quality of vermicompost produced at the end of the experiment was assessed through chemical analysis of its pH, organic carbon (OC) and macro nutrients (N, P and K) composition. pH, OC, N, and P content of vermicompost were significantly ($p< 0.05$) affected by the main effect of earthworm species used in the decomposition process, except K content (Table 4). The chemical properties were significantly ($p< 0.05$) affected by the feeding material (substrate) decomposed. The interaction effect between earthworm type and feeding material significantly ($p< 0.05$) affected the chemical composition of the final product except pH (Table 4). pH, OC and P contents of vermicompost were significantly higher with *Eisenia fetida* and *Debrezeit*, while *Keshmando* resulted with lower pH, OC and P contents. On the other hand, *Keshmando* recorded higher N percentage than *Debrezeit* and *Eisenia fetida* worms.

pH varied significantly among the different substrates, and was higher in pre-composted food with lower content of OC and N compared to the other feed types. Among the substrates tested, maize straw showed consistently better chemical composition (pH, OC, N, P and K) than the other feed types.

Table 4. Main effect of earthworm type and feeding substrate on chemical properties of vermicompost

Treatment	pH	OC (%)	N (%)	P (ppm)	K (g kg^{-1})
Earthworm type					
Eisenia fetida	7.888^{a}	9.513^{a}	0.5628^{b}	308.7^{a}	9.65
Debrezeit (Eudrilus eugeniae)	7.764^{a}	9.638^{a}	0.6443^{a}	270.5^{b}	9.20
Keshmando (Eudrilus eugeniae)	7.621^{b}	9.227^{b}	0.6600^{a}	243.5^{c}	8.82
LSD	0.142	0.223	0.0361	14.65	NS
Feed material					
Khat	7.646^{b}	9.541^{a}	0.7216^{a}	243.72^{b}	9.58^{b}
Maize straw	7.786^{ab}	9.813^{a}	0.6716^{ab}	303.70^{a}	10.85^{a}
Pre-composted	7.933^{a}	8.591^{c}	0.4983^{bc}	288.12^{a}	9.12^{ab}
Fresh food	7.636^{b}	9.906^{a}	0.6200^{bc}	274.93^{a}	8.42^{b}
Haricot bean	7.845^{ab}	9.350^{b}	0.5666^{cd}	237.49^{b}	8.55^{b}
Industrial waste	7.680^{ab}	9.525^{ab}	0.6433^{b}	289.92^{a}	9.29^{ab}
Fruits peels	7.778^{b}	9.490^{ab}	0.6350^{bc}	282.40^{a}	9.75^{ab}
LSD	0.281	0.439	0.0711	28.87	1.84
F-value					
Earthworm (E)	11.15***	11.37***	26.56***	63.47***	2.49^{NS}
Feed material (F)	3.24*	20.12***	21.89***	15.35***	4.60**
ExF	1.68^{NS}	12.40***	8.09***	15.73***	2.29*
CV(%)	1.93	2.47	6.08	5.61	10.65

Fig. 1

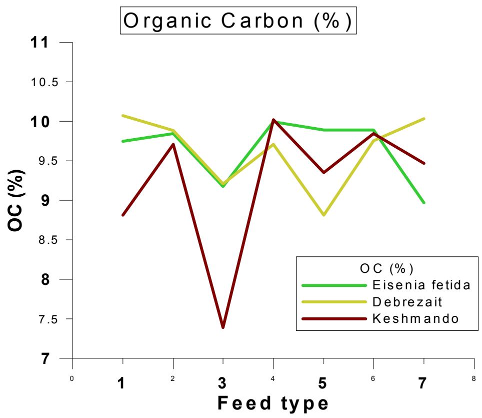


Fig. 2

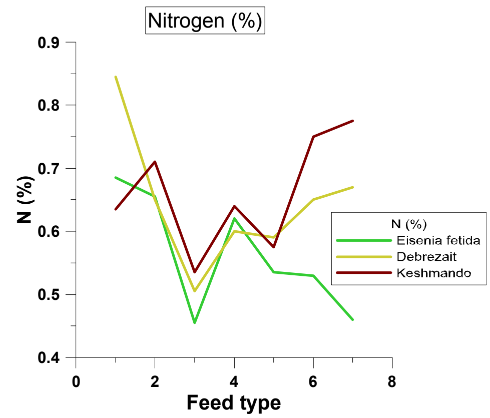
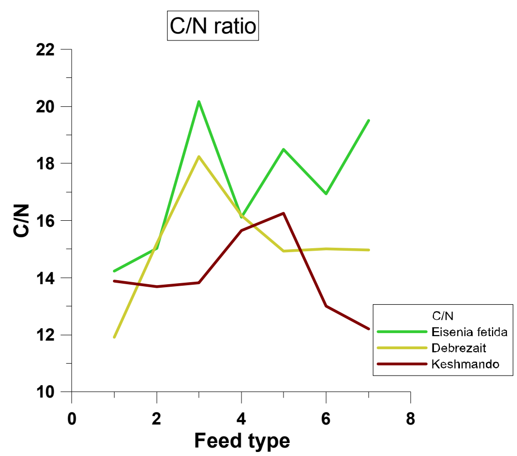


Fig. 3



Feed (substrate) type

1. Khat
2. Maize straw
3. Pre-composted food
4. Fresh food
5. Haricot bean
6. Industrial waste
7. Fruits peels

Fig. 4

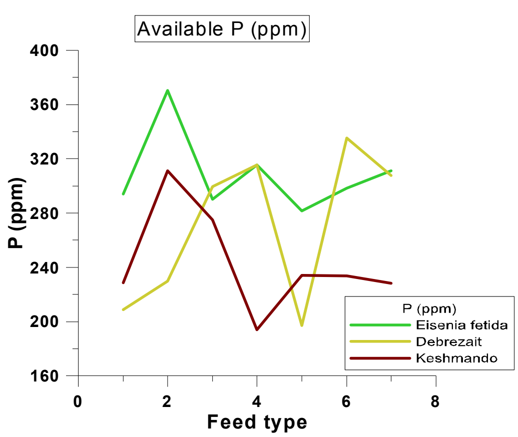
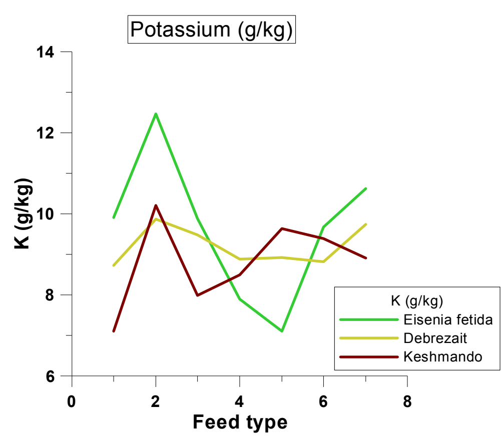


Fig. 5



Figs. (1,2,3,4 and 5). Chemical properties and nutrient acquisition of vermicompost as affected by the interaction effect of earthworm and feed type

The chemical analysis showed pH of the final vermicompost ranged from 7.6 to 7.9 and was higher in *Eisenia fetida* species followed by *Debrezait* and *Keshmando* which indicated higher mineralisation in local earthworms with decreased pH value. The C:N ratio in Fig. 3 showed the decomposition of all substrates resulting in carbon losses by mineralisation which produced a decrease in the amounts of total organic carbon especially with *Keshmando* species. According to Dominguez [32], the effects of earthworms on pH of wastes during vermicomposting is probably related to increases in the N content of the substrates, changes in the ammonium-nitrate (NH_4^+-NO_3^-) equilibrium, and accumulation of organic acids from microbial metabolism or from the production of fulvic and humic acids during decomposition. Ndegwa et al. [15] also explained that a shift in pH might be related to the mineralisation of the N and P in to nitrites/nitrates and orthophosphates.

The interaction effect between earthworm and feed type caused significant effect on the nutrient properties of vermicompost. The highest % of OC was recorded with *Debrezeit* which fed on khat (10.07%) and fruit peels (10.03%), but the lowest % of OC was recorded in haricot bean straw. Both *Eisenia fetida* and *Keshmando* recorded high % of OC with fruit peels. Besides, maize straw responded to enrichment of OC for all earthworms. Like % OC, the highest % of total nitrogen was obtained when *Debrezeit* worms fed on khat and fruit peels which increased % N by 67.3 and 32.7%, respectively over the same worms fed on pre-composted food. *Eisenia fetida* recorded higher % N when fed on khat and increased the % N by 50.5% over pre-composted food. *Keshmando* recorded higher % N (0.775 and 0.710) with both fruit peels and maize straw substrates and increased the % N by 44.8 and 32.7% over pre-composted food, respectively. Vermicompost made from pre-composted food substrate had yielded significantly lower total N for all the tested earthworms.

The interaction effect between earthworm and substrate type on nutrient composition of vermicompost (Fig. 1 to Fig. 5) showed significant variation in type of substrate and worm used for decomposition. Earthworms reduced OC concentration significantly during decomposition irrespective of the substrates used. However, reduction in OC was higher in pre-composted food substrate with *Keshmando* species (Fig. 1). In a similar study Chatterjee et al. [33] also reported reduction in OC with legume substrate. Worms strongly improved decomposition rates by modifying microbial composition, and increasing microbial enzymatic activity by enhancing microbial biomass and nutrient release [34]. In the present study, faster decomposition of organic matter were found in substrates of khat and maize straw for all earthworm species. Thus enhancing decomposition rates by the decrease in C:N ratio (Fig. 3). Furthermore, lower C:N ratio was obtained in substrates of fruit peels with both local earthworm tested. This might be due to the fact that the substrate had reduced C and with relative increase in N content after vermicomposting (Fig. 2). The nutritional quality of vermicompost depend on the quality of the feed resource and the earthworm species [31]. Ndegwa and Thompson [5] also found that different earthworm species were impacted differently by C:N ratio and feed mixture type. All the earthworms tested recorded significantly higher N content with substrates of khat, maize straw and fruit peels, especially *Debrezeit* recorded significantly higher N content with substrates of khat. Previous research by Rameshwar and Argaw [14] using earthworm *Eisenia fetida* with khat substrate found that nutrient content of the vermicomposts was rich with khat and reported khat to be as a suitable substrate for vermicomposting. Earthworms accelerate microbial-mediated N transformation during vermicomposting. They also enhance N amount by adding their excretory products, mucus, body fluid, enzymes etc. [35]. In general, N enrichment pattern and mineralisation activities depend up on the total amount of N in the initial substrate and on the earthworm activity in the waste decomposition [6]. It is also known to enhance the degree of polymerisation of humic substances in vermicompost along with a decrease of ammonium N and increase of nitric N and total nitrogen [36]. But according to Aalok and Tripathi [35] the increase in total N content during vermicomposting might be due to the activity of N-fixing bacteria which was expected to exist in the compost unit.

Eisenia fetida and *Keshmando* had significantly higher extractable P (370 and 313ppm, respectively) with maize straw but *Debrezeit* showed higher P (311 ppm) when fed into fruit peels. While vermicompost using *Keshmando* and *Debrezeit* from fresh food and haricot bean substrates were found with lower P content, 194 and 197ppm, respectively. The highest amount of extractable K in vermicompost samples were obtained in maize straw substrate for all types of worms. Thus, *Eisenia fetida* and *Keshmando* worms resulted in increased K content by 75.5 and 43.8% over haricot bean and Khat substrates, respectively. Vermicompost made using *Eisenia fetida* responded to higher P content for all substrates compared to P content produced by the two local earthworms. On contrary, with all the substrates *Debrezeit* recorded higher amount of K, but significantly higher K (9.87 g/kg) in maize straw substrate. Earthworm increase OM mineralisation by fragmentation but also by activation of microorganisms during passage through the gut as they secret intestinal mucus that stimulates microbial activity [31]. The products of this digestion are excreted in to casts which are enriched in partially digested organic matter and available nutrients. The analysis of vermicompost showed that the available P and exchangeable K contents were significantly higher for both *Eisenia fetida* and *Keshmando* with substrate of maize straw (Fig. 4 and 5). But *Debrezeit* with fruit peels also recorded higher available P as well as higher K content. The increased P and K in worm casts clearly indicate earthworm mediated P mineralisation. According to Pathma and Sakthivel [37] during vermicomposting the organic matter that passes through the gut of earthworm results in a significant increase in the amount of P and exchangeable K nutrients. In addition, Aalok and tripathi [35] reported that the release of P in available form is partly by earthworm gut phospahatase, and further release of P may be by P-solublising microorganisms in worm casts. The nutrient status of vermicomposts of all earthworm species produced from the three wastes was found more than that of other studied substrates. Accordingly, vermicompost produced by *Debrezait* with substrates of khat and fruit peels, *Keshmando* with maize straw and fruit peels and *Eisenia fetida* with maize straw and khat possessed higher nutrient contents. The difference in quality of vermicompost produced from the selected plant residues and fruit peels suggest an insight into influence of the initial material on the nutrient status in the vermicompost produced. Therefore, the present study revealed earthworm biomass production and reproduction are the best indicators to evaluate the vermiculturing process and enhancement in quality plant nutrients of the final product (vermicompost). The changes in biomass and number of cocoon production as well as nutrient composition of vermicast produced differ depending on the substrate (food and bedding material). Factors relating to the growth of earthworms may also be considered in terms of physico-chemical and nutrient characteristics of waste feed stocks which finally influence the nutrient quality of the final product, vermicopost. Thus organic waste delectableness for earthworms is directly related to the chemical nature of the organic waste, thus affects earthworm growth parameters.

4. CONCLUSION

In the present study, local and exotic earthworm species in different feed mixtures significantly affected the growth and production as well as the nutrient content of vermicompost produced. Of the three species tested for vermiculture and quality of vermicompost using seven substrates, all the earthworms showed better performance and promise for culture with good growth and survival as well as production of quality vermicompost. Among the substrates, maize straw, khat and fruit peels are better for the reproduction and growth of worms. The nutrient composition of the different vermicompost varied according to the initial substrates and earthworm species used for decomposition. In terms of percentage of N, khat substrate combined with *Debrezeit* species was superior to the other substrates. However, the local earthworm *Keshmando* was superior with all the substrates except khat substrate in N content of vermicompost. But maize straw with exotic earthworm *Eisenia fetida* resulted in highest concentration of extractable P and K in the vermicompost. In addition, among the substrates maize straw was the best in showing consistency for the reproduction and growth of worms as well as production of nutrient rich vermicast for all earthworm species tested. Substrate materials differed in their characteristics and influenced differently the performance of worms. Of the three species tested for vermiculture and quality of vermicompost using the seven substrates, all earthworms showed better performance and promise for culture with good growth and survival as well as production of quality vermicompost. Therefore, species of earthworms with their preference of suitable substrate were: *Debrezeit* with khat and fruits peels, *Eisenia fetida* with maize and khat and *Keshmando* with maize and fruit peels.

Different agricultural and urban wastes are rich sources of nutrients and organic matter when converted through the aids of composting with earthworms. Especially, using local worms which are adaptable to local wastes for fast growth rate and high reproduction is needed. Therefore, there should be an urgent need to generate awareness on the issue of vermicomposting and more attention should be paid to demonstrate the production of this nutrient rich organic fertiliser as quickly as possible on smallholder farm.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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