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Comparative Analysis of Vermicompost Quality Produced from Different Organic Materials

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Abstract
Present study was undertaken to investigate the vermicomposting of different organic waste (Deciduous tree leaves, biogas slurry, paddy straw and cow dung) employing, *Eisenia fetida*. The experiment was comprised of six treatments replicated thrice in a randomized block design. The following treatments were kept T1: 50% Deciduous tree leaves + 50% Cow dung, T2: 50% Deciduous tree leaves + 25% Cow dung + 25% Biogas slurry, T3: 50% Paddy straw + 50% Cow dung, T4: 50% Paddy straw + 50% Biogas slurry, T5: 100% Cow dung and T6: Farm yard manure (control). It has been observed that vermicompost prepared from deciduous tree leaves, took 8 months to reach the maturity and the results showed that NPK and micronutrient content was higher in the deciduous tree leaves vermicompost followed by paddy straw vermicompost and cow dung vermicompost. The lowest particle and bulk density was observed in deciduous tree leaves vermicompost and porosity was increased. The highest total organic carbon was observed in deciduous tree leaves vermicompost. The Results further demonstrate that the nutrient content increased from pre- composting stage to maturity stage. The heavy metal content was decreased from pre composting stage to maturity stage. The maximum bacterial count was observed in paddy straw vermicompost and the maximum fungal count was observed in deciduous tree leaves vermicompost. The maximum dehydrogenase activity was observed in the cow dung vermicompost.

Keywords: Deciduous tree leaves; Biogas slurry; Paddy straw; Cow dung; Vermicompost; *Eisenia fetida*

Introduction

Due to rapidly growing population, intensive resource use and other factors during the past few years, the issue of effective disposal and management of organic wastes has grown more challenges (Hussein et al., 2018; Jasim et al., 2022; Kumari and Thakur, 2024; Jasim and Hariz, 2023; Alryahil and Jasim, 2022). Large scale organic waste production around the world causes serious environmental and disposal problems. Global crop waste availability is expected to be around 3.8 billion tonnes per year, with grains accounting for 74%, beans accounting for 8%, oil crops accounting for 3%, sugar crops accounting for 10%, and tubers accounting for 5% of total crop waste availability. Punjab (51MT), Maharashtra (46MT) and Uttar pradesh (60MT) are the three states with the biggest production of crop wastes. The highest amount of crop wastes are produced by cereals (352 MT), followed by fibers (66 MT), oilseeds (29 MT), pulses (13 MT), and sugarcane (12 MT). Cereal crops (rice, wheat, maize, and millets) account for 70% of the crop, with rice making up 34% of it (Singh et al., 2016). Kumar et al. (2010) observed that solid waste is also to blame for the environmental issues that most Indian cities are experiencing. When it rains, the solid trash clogs the waterways and causes numerous issues. Scientists are constantly looking for environmentally friendly options to manage solid waste. A sizable portion of the waste generated by various industries is biodegradable waste. This biodegradable waste can be used as a potential raw material for a number of biological processes, including vermicomposting, composting and biomethanation. Due to technical simplicity and efficiency, vermicomposting has recently attracted attention on a global scale. Vermicomposting can be done using a variety of wastes, including animal waste, agricultural waste, industrial waste and municipal waste (Hussain et al., 2018). Earthworms and microorganisms work together to mineralize organic waste substrates and transform them into nutrient-rich organic manure during the bio-oxidative, mesophilic decomposition process known as vermicomposting (Pramanik and Chung 2011). The biochemical breakdown of organic materials is carried out by microorganisms and earthworms are involved in the conditioning of the substrate (Fernandez et al., 2010). Earthworms consume organic waste as part of the process of treating waste to boost their population and create vermicompost (Brown et al., 2000).

It usually takes approximately 28-125 days. Vermicompost's primary characteristics include a greater surface area, a low carbon to nitrogen ratio, increased porosity and maximum nutrient availability (Lim et al., 2015). The amount of trash (Waste materials + Cow dung) ingested by earthworms has a significant impact on the stability of the casts (Dhamodharan et al., 2015). Sequeria and Chandrashekar (2015) observed that *Eudrilus sp* converted domestic waste from food, paper, vegetables and garden into vermicompost, the compost had a rich beneficial microbial community comprising bacteria, fungi, actinomycetes, pseudomonas, P-solubilizers and N_2 fixers. Synthetic chemicals used carelessly cause a variety of issues in the agroecosystem and have an impact on organisms that are not intended targets. Vermicompost can be used as a soil conditioner and earthworms can be utilized as food for fish ponds. Vermicompost is beneficial to crops and offers a number of advantages over chemical fertilizers. Vermicompost is used widely as an organic fertilizer on a big scale in organic farming because it includes nutrients, humic acid and growth hormones (Dominguez and Edwards 2011).

Vermicomposting can boost seed germination, crop vegetative development and production without harming the soil, according to research by a number of writers. Intensive farming had a negative impact on the fertility and health of soil. Application of vermicompost can help to maintain the soil's physical, chemical and biological qualities, which can help to maintain the soil's fertility and health (Sharma and Garg 2018). Present study aimed to utilize different crop residues for vermicomposting and testing the physical, chemical and microbiological properties of prepared vermicompost. The vermicomposting process's ability to transform farm organic waste into farm resources makes it an attractive strategy. Earthworms and their excreta (vermicompost) have numerous benefits and can significantly improve the physical, chemical, and biological characteristics of soil. Vermicompost basically boosted soil fertility and soil health, which increased farming output, increased soil biodiversity, and reduced environmental risks. Keeping all these points in view present study was designed to investigate the vermicomposting prospective of different crop residues. This study will provide information pertaining to vermicompost production by different crop residues.

Materials and methods

Collection of waste material and earthworms

Paddy straw was collected from Integrated farming system unit, Punjab Agricultural University, Ludhiana (India). Deciduous tree leaves were collected from near the department of School of Organic Farming, Punjab Agricultural University, Ludhiana (India). Biogas slurry was collected from the post-methanation storage tank of an on-farm biogas plant, Ludhiana (India). Cow dung was collected from the dairy farm unit, Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana (India). Earthworm, *Eisenia fetida* were collected from stock cultures maintained by authors in the laboratory using cow dung as culture medium.

Preparation of experimental media

Vermicomposting was carried out in high density polyethylene vermibeds with dimension of 12 feet (length), 3 feet (breadth) and 2 feet (height) at Vermicompost Unit, PAU, Ludhiana (India). Six different experimental treatments were prepared using deciduous tree leaves, paddy straw, biogas slurry and cow dung. Deciduous tree leaves and paddy straw were chopped into small pieces prior to use and mixed in various ratios as given in Table 1. A feedstock was taken in one vermibed and pre- composted for 3 weeks. Waste was manually turned to remove foul odour and gases. Followed pre- composting earthworms were introduced in each vermibed. Each experiment was replicated three times and the process of vermicomposting lasted for 130 days and during this period moisture content was monitored periodically and maintained at 60-70% by sprinkling water manually.

Vermicompost analysis

To evaluate the changes in physical, chemical and biological characteristics of vermicompost at different stages (mesophilic, thermophilic, second mesophilic and maturity), following parameters were analyzed:

a) Physical parameters

Parameters	Method used
Temperature	Temperature was recorded at 7 days interval by portable digital thermometer.
Time taken for maturity (no. of days)	The total number of days that is starting from the day of introduction of the material was recorded.
Weight of vermicompost	Initial weight of wastes was recorded at the time of filling and final weight was recorded. The rate of production was calculated using the formula : $\frac{[\text{weight of harvested compost (g) / weight of original substrate (g)}]}{\text{Time taken to decompose (days)}}$
Moisture content	The moisture percentage recorded by gravimetric method
Bulk density	The Core technique was as described by Blake and Hartge (1986).
Particle density	PAU soil moisture gauge was used as described by Prihar and Sandhu (1968).
Porosity	$\text{Total porosity} = 1 - \frac{\text{Bulk density}}{\text{Particle density}} \times 100$

b) Chemical parameters

Parameters	Method used
pH	The pH was measured using a pH meter (Jackson, 1967).
EC (dS m^{-1})	The EC was determined using a conductivity bridge in a 1:10 ratio (vermicompost sample : water suspension) (Jackson, 1967).
Total organic carbon	The total organic carbon was evaluated using a Muffle furnace. (Nelson and Sommers, 1996).
Total nitrogen	The total nitrogen was determined using the Kjeldahl digestion process described by Bremner and Mulvaney (1982).
Total phosphorus	The diacid (HNO_3: $HClO_4$ 3:1) procedure was followed for determining the phosphorus content (Jackson, 1967).
Total Potassium	The same digested material (used for phosphorus analysis) was used for potassium (Jackson, 1967)
Micronutrients (Fe, Cu, Mn, Zn)	The Lindsey and Norvell (1978) approach was used to determine the micronutrient content.
Heavy metals	The heavy metals were analyzed on ICAP-MS.
C:N ratio	Total organic carbon divided by total nitrogen content.

c) Microbiological parameters

Parameters	Method used
Microbial (Bacteria, Fungi and Actinomycetes)	The serial dilution plate technique was used to measure the microbial population (Dingra and Sinclair, 1993).
Dehydrogenase activity	The method of Casida et al. (1964) was applied to measure the activity of dehydrogenase.
Alkaline phosphatase	Tabatabai and Bremner (1969) approach was used to measure phosphatase activity.

Statistical analysis

The different parameters were statistically analyzed using the analysis of variance (ANOVA) approach (Gomez and Gomez, 1984) for randomized block design with the aid of CPCS-1 software developed by the Department of Mathematics and Statistics, PAU, Ludhiana (Cheema and Singh, 1991).

Results and Discussion

Physical characteristics of vermicompost

Changes in temperature (°C) at 7 days interval

Temperature plays an important role in the composting process. Different bacterial species become more or less active when the temperature in the compost rises and falls. The initial temperature observed during the process of vermicomposting was from 29.0 to 41.8°C (Fig 1). Mesophilic bacteria rapidly breakdown soluble and easily degradable carbon sources during this period and are joined by fungi and actinomycetes that are involved in the metabolism of cellulose, hemicellulose and proteins. The maximum temperature was recorded at 14 DAF (days after filling) in all the treatments of vermicomposting. This phase is called thermophilic phase, where almost all of the organic matter was destroyed. In this stage, the decomposition continues to be fast and accelerates until a temperature of about 62°C is reached. At 21 DAF, the temperature was starting to decline. In the third phase (second-mesophilic phase), temperature was stabilized below 30°C, during which earthworms were inoculated. At maturation stage, the temperature was in the range from 19.7 to 25.6°C, which was favorable for earthworm activity.

Table 1. Treatments details of experiment

Treatments	Symbols used
Deciduous tree leaves + Cow dung (1:1)	DL:CD (50:50)
Deciduous tree leaves + Cow dung + Biogas slurry (2:1:1)	DL:CD:BS (50:25:25)
Paddy Straw + Biogas slurry (1:1)	PS:BS (50:50)
Paddy Straw + Cow dung (1:1)	PS:CD (50:50)
Cow Dung (100%)	CD
Control	FYM

Time taken for maturity (no. of days)

The results revealed that T_5 (100% Cow dung) mature earlier, i.e. in 61 days and T_1 (50% Deciduous tree leaves + 50% Cow dung) takes more time to reach the maturity stage i.e. (90 days) (Table 2) due to high lignin content in leaves and higher C:N ratio. Decomposition of deciduous tree leaves is very slow as compared to paddy straw. When compared to other cereal crop waste, it took 8 months to entirely decay. This might be owing to the fact that leaves are hard and hydrophobic (Sannigrahi, 2009).

Table 2. Maturity days taken by vermicompost produced from different organic materials

Treatments	Maturity (DAF)
DL:CD (50:50)	90
DL:CD:BS (50:25:25)	87
PS:CD (50:50)	65
PS:BS (50:50)	67
CD	61
FYM	120

Harvest productivity of vermicompost

Weight changes were noted at the time of bed filling and after the harvesting of beds (Table 3). The maximum productivity (%) was recorded 77.5% in T_1 (50% Deciduous tree leaves + 50% Cow dung) and the lowest productivity was observed in T_6 (FYM Control). The productivity (%) of harvested vermicompost was based on the choice of substrates. Aynehband et al. (2017) indicated that the variations in productivity percentages are indicative of the potential influence of substrate choice on the amount of compost produced during the vermicomposting process. The slow decomposition rate produced the most when compared to other vermicompost treatments. The lowest yield of the control treatment might be attributed to a shortage of earthworms for composting.

Table 3. Harvest productivity of vermicompost produced by different organic materials

Treatment	Initial mass (Kg)	Harvested vermicompost (Kg)	Productivity of vermicompost (%)	Rate of production (g/kg)
DL:CD (50:50)	400	310	77.5	0.005
DL:CD:BS (50:25:25)	300	224	74.6	0.008
PS:CD (50:50)	300	220	73.3	0.011
PS:BS (50:50)	500	340	68.0	0.011
CD	240	180	75.0	0.011
FYM	250	165	66.0	0.005

In this study, the formula was used to compute the rate of production in order to determine if the presence of *Eisenia fetida* in vermicompost causes it to be digested quicker every day or not. The experimental treatments were observed for higher rate of production when compared to the control treatment. The lowest rate was recorded in T_1 (50% Deciduous tree leaves + 50% Cow dung) due to the slow rate of decomposition (Fig 2).

Moisture content of vermicompost

The moisture content recorded in vermicompost lies in the range from 25.6 to 29.8% in different compost types. The highest moisture content was 29.8% in T_4 (50% Paddy straw + 50% Biogas slurry) (Table 4). This might be because of high water content present in biogas slurry (Kumar et al., 2021). Saba et al. (2023) measured the moisture content in various vermicompost mixtures, revealing distinct values for each. The moisture content varied within the range of 35-45%, falling within the broad spectrum of optimal moisture levels, indicating successful composting of animal manure. The authors' report of this extensive optimal moisture range suggests that there is no universally applicable, singular optimal moisture level for diverse composting materials.

Table 4. Moisture content of maturity

Treatments	Moisture (%)
DL:CD (50:50)	26.5
DL:CD:BS (50:25:25)	29.1
PS:CD (50:50)	28.9
PS:BS (50:50)	29.8
CD	26.7
FYM	25.6

Table 5. Bulk density, Particle density and Porosity of vermicomposts

Vermicompost	Bulk density (g/cc)	Particle density (g/cc)	Porosity (%)
DL:CD (50:50)	0.56	2.2	74.5
DL:CD:BS (50:25:25)	0.61	2.3	73.4
PS:CD (50:50)	0.75	2.6	71.1
PS:BS (50:50)	0.63	2.3	72.6
CD	0.75	2.8	73.2
FYM	0.84	2.9	71.0
CD	**0.06**	**0.39**	**0.84**

CD, Critical Difference at 5% level

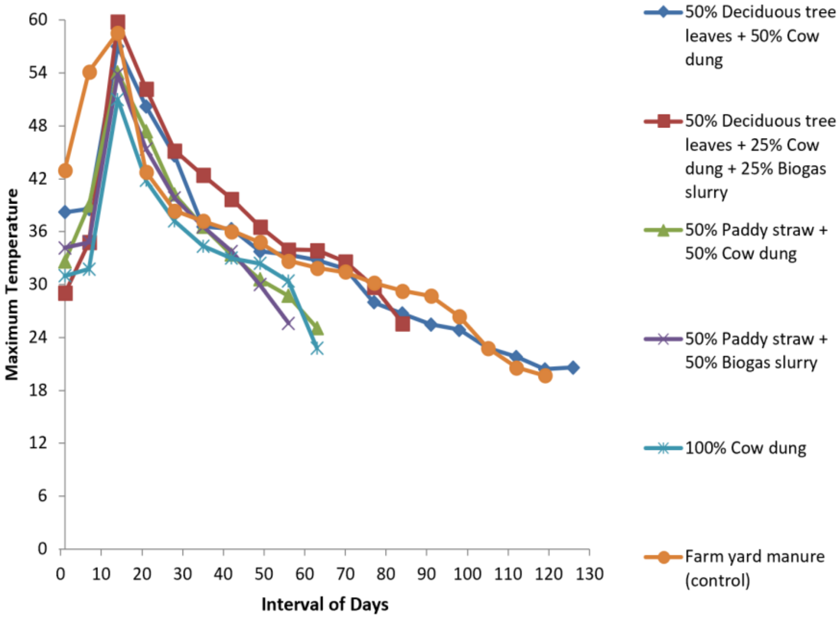

Fig. 1. Changes in mean temperature (°C) of vermicomposts produced by different materials (7 days interval)

Bulk density, Particle density and Porosity

Results revealed that bulk density of vermicompost was found to vary from 0.56 to 0.84 g cm^{-3} (Table 5). The highest value of bulk density 0.84 g cm^{-3} was observed in T_6 (FYM control) and the lowest value of bulk density 0.56 g cm^{-3} in T_1 (50% Deciduous tree leaves + 50% Cow dung). Perera and Nanthakumaran (2015) found that the bulk density of vermicompost was 0.5 g cm^{-3} after researching the practicality and efficacy of vermicomposting at the home level. The highest particle density 2.9 g cm^{-3} was recorded in T_6 (Control treatment) and the lowest particle density (2.2 g cm^{-3}) in T_1 (50% Deciduous tree leaves + 50% Cow dung) (Table 5). Hussain et al. (2020) found that the vermicompost made with noxious weed ipomoea recorded with particle density of 1.6 g cm^{-3}. The porosity (%) values ranged from 71.0 to 74.5% for different vermicompost types (Table 5). The highest porosity was observed in T_1 (50% Deciduous tree leaves + 50% Cow dung) i.e. 74.5% and the lowest porosity 71.0% in T_6 (FYM Control). The porosity depends on bulk density. The porosity decreases with increasing bulk density due to reduction in pore space (Dominguez and Edwards

2011). It produces organic acids and binding agents when it decomposes, increasing the vermicompost's aggregation and porosity and lowering its bulk and particle densities

Table 6. Changes in pH and EC (dS m^{-1}) content during vermicomposting of different wastes

Vermicompost	Mesophilic stage		Thermophilic stage		Second mesophilic stage		Maturity stage	
	pH	EC	pH	EC	pH	EC	pH	EC
DL:CD (50:50)	7.63	1.08	7.40	1.31	7.25	1.97	7.03	2.63
DL:CD:BS (50:25:25)	7.68	0.98	7.45	1.21	7.34	1.76	7.07	2.54
PS:CD (50:50)	7.60	2.01	7.52	2.36	7.43	2.94	7.24	4.30
PS:BS (50:50)	7.64	1.89	7.56	2.02	7.47	2.76	7.27	4.01
CD	7.52	1.66	7.33	1.86	7.18	2.34	7.03	2.76
FYM	7.99	0.50	7.62	1.06	7.53	1.56	7.30	2.36
C.D at 5%	**NS**	**0.10**	**NS**	**0.10**	**0.22**	**0.10**	**NS**	**0.10**

CD, Critical Difference at 5% level

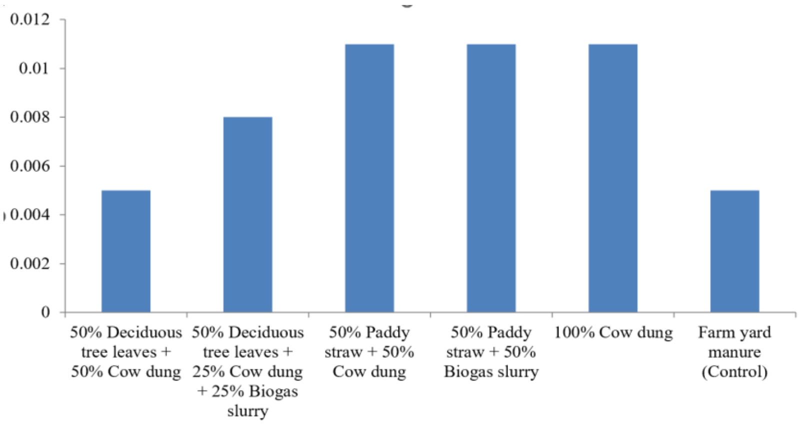

Fig. 2. Rate of compost production in the control and experimental treatment groups

Chemical characteristics of vermicompost

pH

The slight changes were observed from initial stage to maturity stage. At the initial stages of vermicomposting, pH was slightly alkaline. The pH changed from alkaline to slightly acidic or neutral in all the vermin beds (Table 6). This reduction in pH was caused by the fermentation process producing simple organic acids (Sharma and Garg 2018). At mesophilic and thermophilic stage of vermicomposting, no considerable differences were observed in different types of vermicompost. But at second-mesophilic stage, the lowest pH range was observed in cow dung vermicompost. However, highest pH was recorded in control treatment. At maturity stage, no considerable differences were observed among all the treatments. The mineralization of N and P into nitrates/nitrites and orthro-phosphates, as well as the bioconversion of organic molecules into intermediate organic acid species, are two possible causes of the pH's characteristic decline from alkaline to neutral or acidic (Tejada and Benitez 2020). Vermicompost made from deciduous tree leaves had a slightly acidic pH (6.2 to 6.3) (Sannigrahi 2009).

Table 7. Changes in total organic carbon (%) content during vermicomposting of different wastes

Vermicompost	Mesophilic stage (%)	Thermophilic stage (%)	Second mesophilic stage (%)	Maturity stage (%)
DL:CD (50:50)	43.5	42.3	34.3	31.8
DL:CD:BS (50:25:25)	38.2	35.2	34.8	28.3
PS:CD (50:50)	42.4	40.9	29.8	26.5
PS:BS (50:50)	35.5	32.9	32.0	24.4
CD	34.9	32.6	25.7	20.5
FYM	32.5	30.8	24.9	18.5
C. D at 5%	**6.34**	**6.49**	**7.12**	**8.22**

CD, Critical Difference at 5% level

EC (dS m^{-1})

The electrical conductivity (EC) was increased in the different feed mixtures after vermicomposting. This increase in EC might have been due to loss of organic matter and release of different mineral salts, such as phosphate, ammonium, potassium etc. At mesophilic stage, the EC content lies in the range from 0.50 to 2.01 dS m^{-1}. The maximum EC content was observed in paddy straw vermicompost (2.01) as presented in Table 6. At maturity stage, the highest EC content was recorded in paddy straw vermicompost (2.99) and lowest was observed in control treatment.

Yuvaraj et al. (2019) indicated that the rise in soluble salt levels brought on by bacteria and worms was the source of the final vermicompost's higher EC values. Waste mineralization is indicated by the increase in EC. Ammonium, phosphate, potassium, nitrate, and calcium ions are produced during the breakdown of organic substrates, generating an increase in EC.

Table 8. Changes in total nitrogen, phosphorus and potassium (%) content during vermicomposting of different wastes

Vermicompost	Mesophilic stage			Thermophilic stage			Second mesophilic stage			Maturity stage		
	TN	TP	TK	TN	TP	TK	TN	TP	TK	TN	TP	TK
DL:CD (50:50)	0.75	0.45	1.09	1.20	0.67	1.19	1.61	0.88	1.38	1.69	1.02	1.45
DL:CD:BS (50:25:25)	0.63	0.41	2.21	0.75	0.56	2.40	1.18	0.55	2.42	1.61	0.98	2.52
PS:CD (50:50)	0.53	0.38	1.02	0.72	0.51	1.12	1.09	0.71	1.16	1.61	0.96	1.22
PS:BS (50:50)	0.47	0.35	0.98	0.55	0.42	1.04	0.74	0.52	1.11	1.20	0.91	1.18
CD	0.41	0.38	0.99	0.52	0.49	1.09	0.62	0.68	1.14	1.06	0.92	1.20
FYM	0.39	0.32	0.84	0.43	0.35	0.98	0.58	0.48	1.05	0.70	0.77	1.11
CD	**0.06**	**NS**	**0.20**	**0.09**	**0.15**	**0.16**	**0.07**	**0.10**	**0.14**	**0.04**	**0.13**	**0.10**

TN, Total Nitrogen; **TP,** Total Phosphorus; **TK,** Total Potassium; **CD,** Critical Difference at 5% level

Table 9. Change in heavy metal content content during vermicomposting of different wastes

Vermicompost	Mesophilic stage (mg/kg)					Thermophilic stage (mg/kg)					Second mesophilic stage (mg/kg)					Maturity stage (mg/kg)				
	As	Cd	Cr	Ni	Pb	As	Cd	Cr	Ni	Pb	As	Cd	Cr	Ni	Pb	As	Cd	Cr	Ni	Pb
DL:CD (50:50)	Nil	8.0	38.6	39.3	55.6	Nil	2.5	31.7	26.6	49.9	Nil	Nil	8.1	14.8	39.2	Nil	Nil	4.9	5.2	22.6
DL:CD:BS (50:25:25)	Nil	5.1	36.6	38.9	57.0	Nil	Nil	30.0	24.0	48.6	Nil	Nil	9.4	14.0	41.6	Nil	Nil	5.2	3.9	25.9
PS:CD (50:50)	Nil	7.2	36.0	37.0	40.0	Nil	4.3	22.4	21.3	33.9	Nil	2.1	7.3	12.9	29.8	Nil	Nil	3.6	2.4	21.7
PS:BS (50:50)	Nil	6.4	38.2	25.4	39.3	Nil	2.8	24.1	19.1	32.2	Nil	2.4	7.7	11.2	28.4	Nil	Nil	4.3	2.2	23.1
CD	Nil	6.8	38.6	36.6	31.6	Nil	2.5	21.5	21.6	27.3	Nil	Nil	6.9	12.1	22.7	Nil	Nil	3.5	2.4	16.4
FYM	Nil	14.3	32.3	41.6	62.0	Nil	5	27.5	28.3	52.0	Nil	Nil	14.2	21.9	45.3	Nil	Nil	9.2	7.1	34.9
Maximum permissible limit (mg/kg)	**10**	**5**	**50**	**50**	**100**	**10**	**5**	**50**	**50**	**100**	**10**	**5**	**50**	**50**	**100**	**10**	**5**	**50**	**50**	**100**

Table 10. Changes in C:N ratio during vermicomposting of different wastes

Vermicompost	Mesophilic stage (C:N)	Thermophilic stage (C:N)	Second mesophilic stage (C:N)	Maturity stage (C:N)
DL:CD (50:50)	120.1	96.1	51.4	20.2
DL:CD:BS (50:25:25)	112.7	83.3	45.5	19.5
PS:CD (50:50)	80.0	66.6	39.3	18.3
PS:BS (50:50)	79.7	48.2	32.5	17.4
CD	46.6	31.7	25.3	16.4
FYM	61.8	40.5	29.0	17.1
CD at 5%	**1.64**	**4.86**	**4.69**	**0.94**

CD, Critical Difference at 5% level

TOC (%)

The changes in total organic carbon content during the composting of different organic wastes are presented in table 7. The initial organic carbon in different treatments varied from 32.5% to 42.4%. TOC decrease from original to final product, may be attributable to organic matter mineralization. At maturity stage, the lowest organic carbon was observed in the control treatment and highest was observed in T_1 (50% Deciduous tree leaves + 50% Cow dung) (31.8 per cent) due to high lignin content present in deciduous tree leaves. The TOC reduction was due to the carbon loss by the rapid respiration rate. However, carbon loss was greater in control than other vermibeds. The release of CO_2 via microbial respiration is another factor in the loss of carbon. Additionally, feedstock degradation and conversion to stabilized product are shown by the decrease in TOC (Sharma and Garg 2017).

Total Nitrogen (TN) (%)

At the beginning of composting, the total N content of different organic wastes varied from 0.20% to 0.75% (table 8). The lowest N content was recorded in control treatment and highest in T_1 (50% Deciduous tree leaves + 50% Cow dung). The results revealed that the total nitrogen concentration increased from the pre-composting stage to the maturity stage. Earthworms contribute to active nitrogen mineralization, which raises vermicompost's nitrogen content (Mistry et al., 2015). Early decomposition losses of N in the form of ammonia caused the TN content to fall; this is dependent on the kind of material and its C:N ratio (Goyal et al., 2005). At maturity stage, the highest nitrogen was observed in T_1 (50% Deciduous tree leaves + 50% Cow dung) (1.69%) and lowest was observed in control treatment (0.70). The composting of materials with low C:N ratio result in more N losses than in high C:N ratio wastes.

Total Phosphorus (TP) (%)

The table 8 indicates that the total phosphorus content was increase in all vermibeds from mesophilic stage to maturity stage. At mesophilic stage, no considerable differences were observed among different treatments of vermicompost. At maturity stage, the highest P content 1.02% was observed in T_1 (50% Deciduous tree leaves + 50% Cow dung) and lowest 0.77% was observed in control treatment Increased phosphorus levels in vermicomposts that have been prepared may be associated with decreased body weight and the emission of CO2 to break down labile organic components (Malinska et al., 2016). Earthworms' phosphatase enzyme and phosphate-solubilizing bacteria are the main enzymes that release phosphorus from the feedstock into an accessible state (Swarnam et al., 2016).

Table 11. Changes in microbiological count in prepared vermicomposts

Vermicompost	Bacterial count (log_{10} CFU g^{-1})	Fungal count (log_{10} CFU g^{-1})	Actinomycetes (log_{10} CFU g^{-1})
DL:CD (50:50)	7.36	5.5	5.00
DL:CD:BS (50:25:25)	7.33	5.4	5.30
PS:CD (50:50)	7.53	5.1	5.20
PS:BS (50:50)	7.53	4.8	5.10
CD	7.46	4.6	5.10
FYM	7.23	4.3	5.10
C.D at 5%	**0.14**	**0.50**	**NS**

CD, Critical Difference at 5% level

Table 12. Changes in enzyme activity in prepared vermicomposts

Vermicompost	Dehydrogenase activity (µg TPF g^{-1} h^{-1})	Alkaline phosphatase (µg PNP g^{-1} h^{-1})
DL:CD (50:50)	16.5	8.6
DL:CD:BS (50:25:25)	15.6	9.2
PS:CD (50:50)	17.6	9.6
PS:BS (50:50)	16.6	9.5
CD	22.5	12.1
FYM	11.4	7.8
CD at 5%	**3.46**	**NS**

CD, Critical Difference at 5% level

Total Potassium (TK) (%)

At initial stages, the potassium content lies in the range from 0.84% to 2.21% (Table 8). The highest potassium content was observed in T_2 (50% Deciduous tree leaves + 25% Cow dung + 25% Biogas slurry) (2.21%) and lowest was observed in control treatment (0.84%). At maturity stage, the maximum increase in potassium content was noted in T_2 (50% Deciduous tree leaves + 25% Cow dung + 25% Biogas slurry) (2.53%) and lowest was observed in control treatment (1.11%). Moustafa et al. (2021) said that the waste material utilized in the vermicomposting process determines the maximum K content. The highest potassium content in vermicompost is due to the high rate of mineralization caused by microbial activity in the earthworm stomach.

Micronutrients (Fe, Mn, Cu, Zn) (mg/kg)

The micronutrient content (Fe, Zn, Cu, Mn) of different stages of vermicompost as influenced by different organic materials:

Fe

The prepared vermicomposts have maximum Fe content as compared to pre-composting stage. At initial stage of vermicompost, the Fe content lies in the range from 1181.9 to 7452.0 mg/kg (fig 3). The maximum Fe content (7452.0 mg/kg) was observed in T_1 (50% Deciduous tree leaves + 50% Cow dung) vermicompost and lowest (1181.9 mg/kg) was observed in control treatment. At the maturity stage, the highest Fe content (9859.6 mg/kg) was recorded in T_1 (50% Deciduous tree leaves + 50% Cow dung) and lowest (2879.6 mg/kg) was observed in control treatment. The maximum Fe content in tree leaves vermicompost might be due to the lower pH value in deciduous tree leaves vermicompost. The researchers said that the high pH decrease availability of Fe content (Sannigrahi 2009).

Zn

The Zn content was higher in prepared vermicomposts as compared to pre- composting stages. The fig 4 showed that the total Zn content at all different stages were exhibited a significant difference among the different treatments. At initial stage, the Zn content was in the range from 25.1 to 750.9 mg/kg. In prepared vermicompost (maturity stage), the maximum total Zn was recorded in T_1 (50% Deciduous tree leaves + 50% Cow dung) (6417.0 mg/kg) and lowest was observed in control treatment (415.9 mg/kg). High concentrations of total nitrogen, phosphorus, potassium, microbe activity, enzyme activity, and growth regulators may be the cause of the greatest Zn content in leaves vermicompost as a micronutrient (Sharma and Garg 2017).

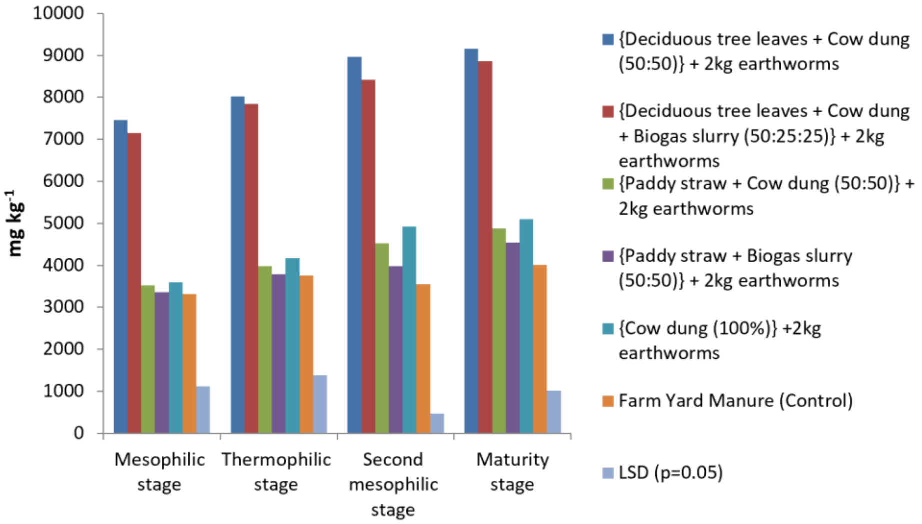

Fig. 3. Changes in Fe content during vermicomposting of different wastes [**LSD,** Least Significant difference (p=0.05)]

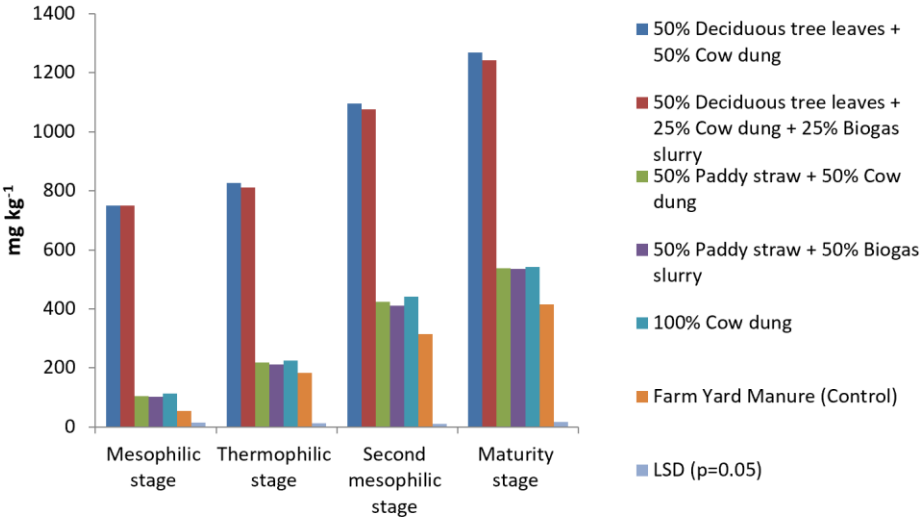

Fig. 4. Changes in Zn content during vermicomposting of different wastes [**LSD,** Least Significant difference (p=0.05)]

Cu

The highest Cu content was observed in prepared vermicomposts as compared to pre- maturing stages. At mesophilic stage, the total Cu content lies in the range 7.5 to 17.6 mg/kg (fig 5). The highest Cu content was observed in T_1 (50% Deciduous tree leaves + 50% Cow dung) (17.6 mg/kg) and the lowest Cu content was recorded in FYM (7.5 mg/kg). The Cu content started to increase from initial stage to maturity stage. At maturity stage, the maximum total Cu content was recorded in T_1 (50% Deciduous tree leaves + 50% Cow dung) (48.8 mg/kg) might be due to the microbial decomposition of organic matter in the composting process can lead to the mobilization and concentration of copper (Singh and Kalamdhad, 2011).

Mn

The increase in Mn content has shown the increased trend from mesophilic stage to maturity stage. At mesophilic stage, the Mn lies in the range from 24.4 to 121.6 mg/kg (fig 6). The maximum Mn content was observed in T_5 (100% Cow dung) (121.6 mg/kg). At maturity stage, the highest Mn content was recorded in T_1 (50% Deciduous tree leaves + 50% Cow dung) (971.5 mg/kg) might be due to presence of more humic substances and organic compounds. The breakdown of organic matter and mineralization are the main causes of the rise in micronutrient content. Volume reduction in waste also helps to concentrate the trash and contributes to the micronutrient content increase (Sharma and Garg, 2017) and lowest was in FYM (control) (108.7 mg/kg).

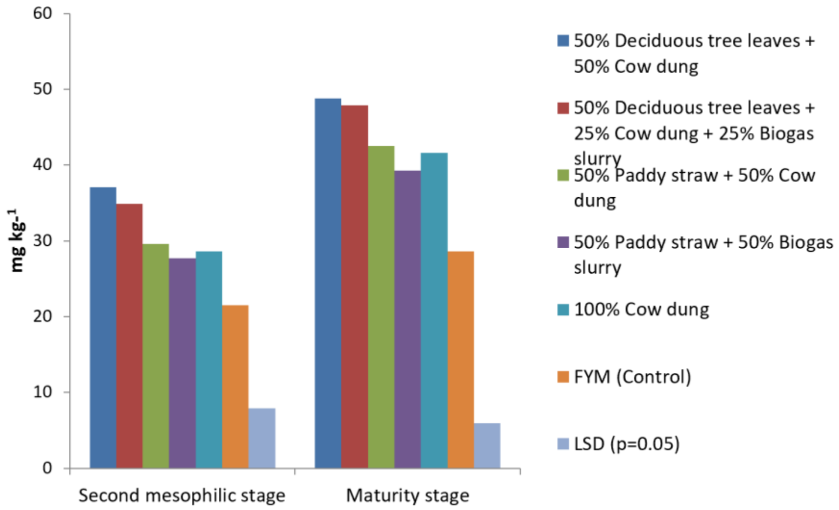

Fig. 5. Changes in Cu content during vermicomposting of different wastes [**LSD,** Least Significant difference (p=0.05)]

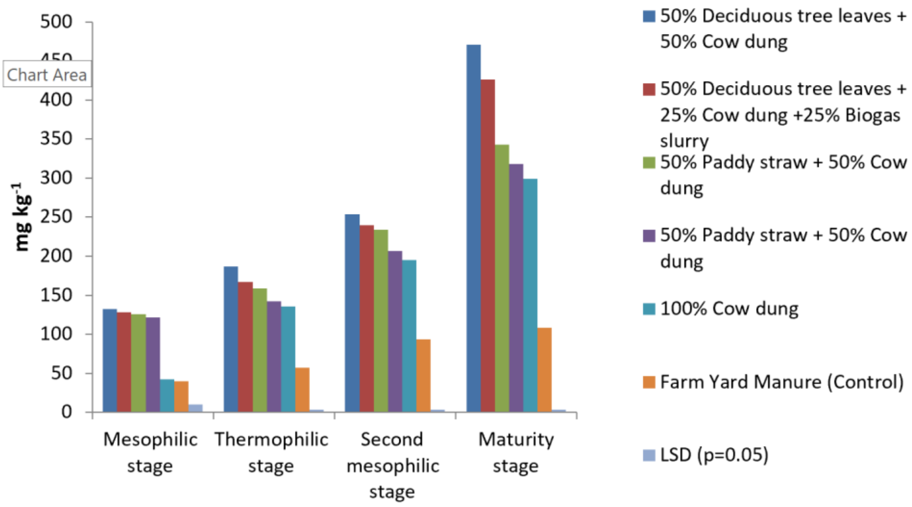

Fig. 6. Changes in Mn content during vermicomposting of different wastes [**LSD,** Least Significant difference (p=0.05)]

Heavy metal content (mg/kg)

Heavy metals' content may increase or decrease in the vermicomposts due to decrease in mass and volume after vermicomposting (Malinska et al., 2016).

As

Arsenic is a ubiquitous element that is detected at low concentrations in virtually all environmental matrices. The table 9 shows the nil amount of arsenic from pre-composting stage to maturity stage in all six treatments of vermicompost.

Cd

At initial stage of composting, the Cd range was higher than permissible limits in all six treatments. When composting progresses, the cadmium range started to decrease from permissible limit and at maturity stage, the cadmium range was nil in all six treatments of vermicompost as shown in table 9. The reduction in heavy metal content from pre composting stage to maturity stage might be due to the earthworm selective consumption pattern. Earthworms' selective consumption can cause notable variations in the residual quantities of trace organics and heavy metals in the vermicompost (Suthar et al., 2014).

Cr

The table 9 showed that, at the beginning of vermicomposting, the Cr range was less than permissible limit in all different vermicompost treatment except control treatment. The cadmium range started to decrease from pre composting stage to maturity stage. In all different stages of composting, the cadmium range was lower than permissible limit. Earthworms are more likely than other species to acquire and accumulate one particular form of heavy metal. The buildup of heavy metals in earthworms' guts is also influenced by physiochemical parameters including pH, calcium concentration, and the amount of organic matter in the feces (Lim et al., 2014).

Ni

At different stages of vermicompost, all treatments of vermicompost showed lower Ni range than permissible limit as shown in table 9. Within an increasing in composting period, the nickel range further started to decrease and becomes lower than permissible limit in all types of vermicomposts. This was due to the binding of metals to humic acids limits the reduction of metals through leaching and bio-concentration (Song et al., 2014).

Pb

The lead concentration was also lower than permissible range at initial stages of vermicomposts as shown in table 9. At the maturity stage, the lead concentration further decreased. Through their epidermis and digestive system, earthworms effectively absorb heavy metals from the water-soluble and extractable fractions; they also store heavy metals from the oxidizable fraction through the ingestion of organic material (Wu et al., 2018).

C:N ratio

The initial C:N ratio of the vermicompost of different treatments ranged from 46.6 to 120.1 (Table 10). As the decomposition progressed due to losses of carbon mainly as carbon dioxide, the carbon content of the compostable material decreased with time and N content per unit material increased, which resulted in the decrease of C: N ratio. After 90 days of composting (maturity stage) of different organic wastes the C: N ratio of end product varied from 16.4 to 20.2. The considerable differences were observed among all the treatments. The lowest value of C: N ratio (20.5) was recorded in T_5 (100% cow dung) and highest C: N ratio (20.2) was obtained in T_1 (50% Deciduous tree leaves + 50% Cow dung). Sannigrahi (2009) Vermicomposting of dry leaves gathered from deciduous trees took roughly 8 months, according to the findings. The greatest C:N ratio was found in tree leaves vermicompost due to the slow pace of decomposition.

Microbiological characteristics of vermicompost

Microbial analysis (Bacteria, Fungi and Actinomycetes)

Under biological properties, population count of bacteria, fungi and actinomycetes are presented in table 11. The result indicated that the maximum bacteria (7.53 $\log_{10}$ CFU g^{-1}) was observed in T_3 (50% Paddy straw + 50% Cow dung) which were similar with T_4 (50% Paddy straw + 50% Biogas slurry). The earthworm digestive tract's conductive environment and the product's high nutritional content might be the cause of the highest bacterial concentration (Ravindran et al., 2015). Whereas, the maximum fungal count (5.5 $\log_{10}$ CFU $g^{-1)}$ was observed in T_1 (50% Deciduous tree leaves + 50% Cow dung). The maximum fungal count was due to less multiplication of earthworms in this vermicompost. The less the earthworms multiply, the less microorganisms they consume, mainly fungus, for their protein/nitrogen requirements. This might explain why there is less fungal variety (Nagavallemma et al., 2004). Actinomycetes count recorded among different treatments had shown no significant differences.

Enzyme activities (Dehydrogenase and Alkaline phosphatase)

Enzyme activities were studied in vermicompost shown in Table 12. It was noticed that the maximum dehydrogenase activity (22.5) was observed in T_5 (100% Cow dung), might indicate more respiration activity is performed by earthworms in the vermicomposts. The minimum dehydrogenase activity was observed in control treatment. Because earthworm gut-associated mechanisms in vermicompost promote greater degradative rates, the lowest dehydrogenase activity may imply a lesser stability of the vermicompost (Kumari et al., 2020). Whereas the result had shown that no significant difference was observed in alkaline phosphatase activity among different treatments. Therefore, the highest alkaline phosphatase activity may have been caused by an increase in microbial biomass. These enzymes help bound phosphorus become soluble and mineralize so that plants can use it (Gorde et al., 2022).

Conclusion

Present study found that the different organic wastes can efficiently be converted into vermicompost. Based on the results of the present experiment conducted to evaluate the best organic residue to produce quality vermicompost. Deciduous tree leaves were most feasible for production of quality vermicompost followed by paddy straw and cow dung. Vermicompost prepared from deciduous tree leaves vermicompost was better with physical, chemical and biological properties followed by deciduous tree leaves vermicompost using biogas slurry, paddy straw vermicompost and cow dung vermicompost. But the limitation is, among all the organic wastes, the rate of decomposition of deciduous tree leaves was slower followed by paddy straw and cow dung. To overcome this limitation, shredding or chopping leaves to increase surface area, allowing microorganisms to break them down faster and maintaining optimal moisture and oxygen level in the compost pile.

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