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Accumulation of Heavy Metals from the Combination of Different Biological Wastes by Earthworm *Lampito mauritii* Kinberg

Fatima Nishat and Singh Keshav*

Vermibiotechnology Laboratory, Department of Zoology and Environmental Science, Deen Dayal Upadhyaya Gorakhpur University, Gorakhpur 273009, Uttar Pradesh, India

**Corresponding Author*

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Abstract: Heavy metals are a serious problem that caused several health problems in humans and animals. They also affect the diversity of soil fauna as well as the environment. The proper management of heavy metal concentrations can be managed by the inoculation of earthworms in their habitats. Through bioaccumulation of heavy metals in their body, earthworms reduce the toxic level of heavy metal concentration. *Lampito mauritii* is common earthworm species that accumulate heavy metals in its body tissues. Heavy metal concentration was observed in different animal dung with municipal solid waste (MSW) and final vermicompost as well as in earthworm bodies. A significant decrease in heavy metals concentration such as cobalt (Co), chromium (Cr), lead (Pb), nickel (Ni), and cadmium (Cd) was observed in all the combinations of different animal dung with MSW after vermicomposting by earthworm *Lampito mauritii*. A significant reduction of cobalt (Co) was observed in the vermicomposts obtained from buffalo dung, whereas cow dung only has a significant maximum reduction in the level of chromium (Cr) (91.48%, 0.072 ± 0.002 mg/kg). The maximum reduction of lead (Pb) concentration was observed in the vermicomposts obtained from the combination of buffalo dung with municipal solid waste in the ratio (1:1) (96.61%, 0.060 ± 0.003 mg/kg). There was a significant decrease in the concentration of nickel (Ni) in vermicomposts of all combinations of animal dung with municipal solid wastes. Whereas, the concentration of cadmium (Cd) is significantly reduced in the vermicomposts obtained from goat dung (95.62%, 0.017 ± 0.005 mg/kg). The result of this study clearly illustrated that during vermic-activity, *Lampito mauritii* considerably decreases different heavy metals in the final vermicompost and can act as a biological indicator of soil quality. With the help of this technique, MSW can be managed effectively while also being protected from toxic levels of heavy metal contamination in the human diet.

Keywords: Animal Dungs, Bioaccumulation, Earthworms, Heavy Metals, *Lampito mauritii*, Municipal Solid Wastes (MSW), Vermibiotechnology, Vermicomposting

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Introduction

Rapid urbanization and industrialization in Asia's developing nations have made waste disposal a major issue (ISWA and UNEP, 2002). Municipal solid waste (MSW) is rapidly increasing in emerging nations like India as a result of urbanization and population growth (Pamnani and Srinivasarao, 2014). In India, treating municipal solid waste is a significant environmental concern (Gupta *et al*., 2015). Municipal solid waste often consists of both residential and commercial waste that is generated by the native community (Rajkumar *et al*., 2010). By 2050, it is anticipated that there will be 3.40 billion metric tonnes of MSW generated globally, increasing drastically from today's 2.01 billion tons (Kaza *et al*., 2018). In Indian cities, the average yearly growth rate of MSW generation is estimated to be around 1.3% (Bhide and Shekdar, 1998;Shekdar, 1999; Imura *et al*., 2005).

The generation of MSW on a global scale has a variety of negative effects on the environment, including the emission of greenhouse gases and nitrogen pollution (Chen *et al*., 2020). Other severe problems for society are industrial sludge and livestock manure (Elvira *et al*., 1998; Gajalakshmi *et al*., 2002; Garg *et al*., 2005). Increased manure generation by a growing population of cattle is linked to health and environmental issues as well as insufficient consumption rates in low-income nations (Jjagwe *et al*., 2019). The accumulation of heavy metals in soils is directly caused by municipal solid waste (Popova, 2019). The most hazardous elements of MSW are heavy metals, which are caused by an increase in heterogeneous waste, which is also a determinant of soil pollution (Kabata and Pendias, 2016). If municipal solid waste is not managed appropriately, it could be a threat to public health (Vinti *et al*., 2021).

Due to their toxicity, prolonged atmospheric stability, and tendency to bioaccumulate in the human body, heavy metals are well-known environmental contaminants (Mitra *et al*., 2022). Various heavy metals have a variety of adverse health effects on humans. MSW contains mostly Co, Cr, Pb, Ni, and Cd as its chief heavy metals. Heavy metal exposure has increased as a result of anthropogenic, industrial, and agricultural activities, as well as modern industrialization, all of which have negative consequences for human health (Balali-Mood *et al*., 2021). Various human organs are affected by numerous acute and long-term harmful effects of heavy metals. Exposure to two or more metals simultaneously may have cumulative consequences (Fernandes Azevedo *et al*., 2012; Cobbina *et al*., 2015; Costa, 2019; Gazwi *et al*., 2020). Cobalt has both beneficial and adverse effects on the human body. Low concentrations of cobalt often have no detrimental effects, but large-scale environmental exposures can be lethal (Domingo, 1989). Chromium is a disease-transmitting metal that affects human health and can cause skin ulcers and breathing issues like asthma, coughing, and wheezing. Pb is not a necessary component of the human body, and excessive Pb consumption can affect the neurological, skeletal, enzymatic, endocrine, immunological, and circulatory systems (Kankia and Abdul-hamid, 2014). The International Agency for Research on Cancer (IARC) has determined that cadmium is carcinogenic for humans (Group I) (Kim *et al*., 2020). Cadmium can make people sick if they consume contaminated food, breathe poisonous air, or drink water that contains the metal. By regulating several cancer-causing mechanisms, including gene regulation, transcription factor control, and the production of free radicals, nickel acts as a carcinogen (Mitra *et al*., 2022). Due to their toxicity at specific concentrations, transportation through food chains, and non-biodegradability, which induces their accumulation in the biosphere, heavy metals have significant ecological implications (Sridevi *et al*., 2012).

Lampito mauritii, an earthworm species, accumulates more heavy metals in its body tissues and may be a more accurate indicator of metal contamination due to bioaccumulation (Hobbelen *et al*., 2006). A significant amount of metals, including heavy metals, can accumulate in the tissues of earthworms primarily *Lampito mauritii*, with no negative effects on their physiology. The ecology and decomposing efficiency of *Lampito mauritii* are documented in past research. Studies showed that *Lampito mauritii* can vermicompost a wide range of organic wastes (Suthar and Singh, 2008). Heavy meals like Cu, Cd, Pb, and Zn can be accumulated by earthworms (Wang *et al*., 2018). Heavy metals in contaminated soils can be accumulated by earthworms, simulating the effects of vital substances in the body and resulting in illness (Seribekkyzy *et al*., 2022). Earthworms have a tremendous potential for rehabilitating soil that has been contaminated with heavy metals (Sizmur and Hodson, 2009; Ahadi *et al*., 2020; Yuvaraj *et al*., 2020).

Eisenia fetida, *Lumbicus rubellus*, *Perionyx excavatus*, and *Lampito mauritii* are among the most prevalent earthworms used in vermicomposting. They have a substantial bioaccumulation capacity for Cd, Hg, Pb, Cu, Mn, Ca, Fe, and Zn, as well as very high concentrations of Pb, Co, and Cd (Panday *et al*., 2014). Metallothionein activation was examined by Maity *et al*. (2011) as an analysis method for assessing metal exposure. Since all biodegradable MSW can be converted into manure by epigeic earthworms like *Eisenia fetida*, they have little use in altering the soil's structure. In comparison, anecic earthworms like *Lampito mauritii* can both assimilate organic waste and transform the soil's composition (Kaviraj and Sharma, 2003). Vermicomposting is regarded as one of the sustainable techniques for disposing of non-toxic and biodegradable MSW, particularly when there is limited space (Sim and Wu, 2010).

By evaluating the level of content in initial vermibed and final vermicomposted materials, the present research seeks to investigate the heavy metal concentrations accumulated by the earthworm *Lampito mauritii* from the combination of various animal dungs and MSW. Consequently, the concentration of heavy metals in the earthworm's body is measured both before and after vermicomposting.

Materials and Methods

Collection of Animal Wastes: Animal wastes (cow, buffalo, and goat dung) were collected from different farmhouses in the Gorakhpur district (Uttar Pradesh, India).

Municipal Solid Wastes: Municipal solid wastes were collected from different parts of Gorakhpur city and exposed to sunlight for 5 to 10 days for the removal of various harmful organisms and noxious gases.

Collection of Earthworms: Earthworms *Lampito mauritii,* an anecic species were cultured in the Vermiculture Research Laboratory, Department of Zoology, D.D.U. Gorakhpur University, Gorakhpur, India. The collected earthworms were reared in laboratory conditions, at a temperature ranging from 20°C to 30°C with proper aeration. The moisture was maintained up to 50-70% RH for proper growth and survival of the earthworms.

Experimental Setup for Vermicomposting:

The vermicomposting was conducted on the cemented earth's surface by the method of Bhartiya and Singh (2012). Different combinations of animal dung with municipal solid wastes viz., in 1:1, 1:2, and 1:3 ratio was performed. The size of each vermibed was 3 m × 1 m × 9 cm. After the formation of vermibed, it was moist and inoculated with 1 kg of cultured *Lampito mauritii* in each bed. The beds were covered with jute packets and moistened daily for 40 to 50 days to maintain the proper moisture content. The mixture of beds was manually turned up for 3 weeks at one-week intervals. Vermicompost looks like granular tea which develops on the surface of the bed after 50 to 60 days. The prepared vermicomposts and inoculated earthworms were used for experiments.

Analysis of Heavy Metals:

Analysis of heavy metals in the initial feed mixture and final vermicompost:

The heavy metal concentrations (Co, Cr, Pb, Ni, and Cd) in the initial feed mixture and final vermicompost were measured by the method of Maboeta (2003). About 1 g of initial feed mixture and final vermicompost were required for the samples. These samples were subjected to digestion by adding an excess of nitric acid (1:1) and were placed on a hot plate and heated for 4 hours at 90°C to 100°C and care was taken to ensure that sample did not dry out during the digestion. After digestion, each sample was filtered through Whatman No 41 filter paper and poured into a 100 ml flask, then injected into Flame Atomic Absorption for determination of the heavy metal concentration.

Analysis of heavy metals in earthworm body:

The heavy metals in the earthworm body tissue were digested by the method of Katz and Jennies (1983) and Bhartiya and Singh (2012). Earthworms were individually dried, ground, and burn to ash at high temperatures. Thereafter, the ash was placed in a test tube of 15 ml and 55% nitric acid was added to it. This solution was left for 12 h at room temperature. After that, the sample was heated at 40°C to 60°C for 2 h and the solution was cooled at room temperature. The sample was again reheated at 90-95°C and then 1 ml of 70% perchloric acid was added. The sample was allowed to cool before adding 5 ml of distilled water. Samples were again reheated up to 130°C until white fumes come out. Consequently, the sample was cooled before it was micro-filtered. The solution was filtered through Whatman No 41 filter paper in a glass vial to 100 ml flasks and was subjected to Flame Atomic Absorption.

Statistical Analyses:

All the data are expressed as mean ± SD of 6 replicates. Students 't'-test was applied to determine the significance ($P<0.05$) between the initial feed mixture of different animal dung with municipal solid waste and final vermicompost, as well as in the earthworm body (Sokal and Rohlf, 1973).

Results and Discussion

When compared to the initial feed mixture, there was a considerable reduction ($P < 0.05$) in the heavy metals (Co, Cr, Pb, Ni, and Cd) in the final vermicompost prepared from combinations of municipal solid wastes with various animal dungs (Tables 1-3). A significant reduction of cobalt (Co) was observed in the vermicomposts obtained from buffalo dung, whereas cow dung only has a significant maximum reduction in the level of chromium (Cr) (91.48%, 0.072 ± 0.002 mg/kg) (Table 1). The maximum reduction of lead (Pb) concentration was observed in the vermicomposts obtained from the combination of buffalo dung with municipal solid waste in the ratio (1:1) (96.61%, 0.060 ± 0.003 mg/kg). Table 2 shows that there was a significant decrease in the concentration of nickel (Ni) in vermicomposts of all combinations of animal dung with municipal solid wastes. Whereas, the concentration of cadmium (Cd) is significantly reduced in the vermicomposts obtained from goat dung (95.62%, 0.017 ± 0.005 mg/kg) (Table 3). Heavy metals are a long-term, covert, chronic pollutant of the environment (Ali *et al*., 2019). The concentrations of hazardous metals in a specific medium and the duration of exposure determine the health connected with those metals. Mercury, cadmium, arsenic chromium, nickel, copper, and lead are among the most commonly detected heavy metals that contaminate the environment (Ali *et al*., 2019).

Vermicomposting, which uses earthworms to transform biodegradable solid waste into a valuable product (vermicompost or vermicast), occupies a special place in the discipline of environmental engineering because it is the only technique for reducing pollution that uses a multicellular animal as the dominant bioagent (Abbasi *et al*., 2009). In addition to enhancing soil qualities and providing crop nutrients, cattle manure also provides an important source of energy and building material (Teenstra *et al*., 2014). The manure from camels, buffaloes, and donkeys can be combined with waste from cows,

Table 1: Concentration of Cobalt (Co) and Chromium (Cr) (mg/kg) in different combinations of animal dung with municipal solid wastes in initial feed mixture and final vermicompost

Heavy metals (mg/kg)							
		Co			Cr		
Vermicompost	**Ratio**	**Initial**	**Final**	**% Decrease**	**Initial**	**Final**	**% Decrease**
MSW	-	0.178 ± 0.005	0.160 ± 0.004*	10.11	0.862 ± 0.004	0.139 ± 0.002*	83.87
Buffalo Dung	-	0.016 ± 0.005	BDL	100.0	0.673 ± 0.003	0.084 ± 0.003*	87.51
Buffalo Dung + MSW	**1:1**	0.025 ± 0.006	0.005 ± 0.003*	80.00	0.706 ± 0.004	0.107 ± 0.005*	84.84
Buffalo Dung + MSW	**1:2**	0.038 ± 0.003	0.010 ± 0.002*	73.68	0.752 ± 0.005	0.126 ± 0.005*	83.24
Buffalo Dung + MSW	**1:3**	0.036 ± 0.004	0.012 ± 0.003*	66.66	0.739 ± 0.002	0.097 ± 0.005*	86.87
Cow Dung	-	BDL	BDL	-	0.846 ± 0.003	0.072 ± 0.002*	91.48
Cow Dung + MSW	**1:1**	0.031 ± 0.005	0.010 ± 0.002*	67.74	0.870 ± 0.003	0.108 ± 0.002*	87.58
Cow Dung + MSW	**1:2**	0.060 ± 0.005	0.016 ± 0.003*	73.33	0.750 ± 0.003	0.085 ± 0.004*	88.66
Cow Dung + MSW	**1:3**	0.051 ± 0.006	0.006 ± 0.002*	88.23	0.797 ± 0.004	0.086 ± 0.004*	89.20
Goat Dung	-	BDL	BDL	-	0.858 ± 0.006	0.106 ± 0.004*	87.64
Goat Dung + MSW	**1:1**	0.020 ± 0.002	0.003 ± 0.002*	85.00	0.841 ± 0.005	0.092 ± 0.003*	89.06
Goat Dung + MSW	**1:2**	0.074 ± 0.005	0.007 ± 0.003*	90.54	0.905 ± 0.006	0.100 ± 0.003*	88.95
Goat Dung + MSW	**1:3**	0.067 ± 0.003	0.014 ± 0.004*	79.10	0.843 ± 0.005	0.093 ± 0.005*	88.96

MSW= Municipal Solid Wastes, BDL= Below Detection Limit; Each value is the Mean ± SD of six replicates; *Significant $P<0.05$ "t" test between initial feed mixture and final vermicompost

sheep or goats to be used as feed. Singh and Kumar (2006) suggest that the types of waste, topography, runoff and degree of scavenging all have an impact on the concentrations of heavy metals in the soil near waste dumpsites. Raw MSW is indigestible to earthworms due to its hard components, foul odor, temperature, etc. As a consequence, proportionate quantities of numerous organic wastes, like cow dung from dairy farms, pressmud from sugar mills, and clay soil containing significant nutritional components, were supplemented to be used as bedding material (Ananthakrishnasamy and Gunasekaran, 2014). Heavy metals, including Cd, Co, Cu, Fe, Hg, Mn, Pb, Ni, Cr, and Zn are found in municipal solid waste that is deposited in landfills. When these heavy metals are leached out of landfills, they sink into the soil (Alloway and Jackson, 1990). Some

Table 2: Concentration of Lead (Pb) and Nickel (Ni) (mg/kg) in different combinations of animal dung with municipal solid wastes in initial feed mixture and final vermicompost

Heavy metals (mg/kg)							
		Pb			Ni		
Vermicompost	Ratio	Initial	Final	% Decrease	Initial	Final	% Decrease
MSW	-	0.967 ± 0.003	0.065 ± 0.003*	93.27	0.087 ± 0.004	0.017 ± 0.004*	80.45
Buffalo Dung	-	BDL	BDL	-	0.124 ± 0.004	BDL*	100.0
Buffalo Dung + MSW	**1:1**	1.775 ± 0.005	0.060 ± 0.003*	96.61	0.098 ± 0.003	BDL*	100.0
Buffalo Dung + MSW	**1:2**	0.183 ± 0.004	0.031 ± 0.004*	83.06	0.091 ± 0.004	BDL*	100.0
Buffalo Dung + MSW	**1:3**	0.784 ± 0.005	0.045 ± 0.003*	94.26	0.107 ± 0.003	BDL*	100.0
Cow Dung	-	0.022 ± 0.004	0.007 ± 0.005*	68.18	0.105 ± 0.006	BDL*	100.0
Cow Dung + MSW	**1:1**	0.028 ± 0.005	0.010 ± 0.003*	64.28	0.190 ± 0.003	BDL*	100.0
Cow Dung + MSW	**1:2**	0.087 ± 0.004	0.016 ± 0.003*	81.60	0.122 ± 0.007	BDL*	100.0
Cow Dung + MSW	**1:3**	0.094 ± 0.004	0.025 ± 0.003*	73.40	0.126 ± 0.006	BDL*	100.0
Goat Dung	-	BDL	BDL	-	0.842 ± 0.004	BDL*	100.0
Goat Dung + MSW	**1:1**	0.186 ± 0.004	0.044 ± 0.003*	76.34	0.113 ± 0.004	BDL*	100.0
Goat Dung + MSW	**1:2**	1.672 ± 0.004	0.107 ± 0.003*	93.60	0.115 ± 0.006	BDL*	100.0
Goat Dung + MSW	**1:3**	0.276 ± 0.005	0.055 ± 0.004*	80.07	0.088 ± 0.004	BDL*	100.0

MSW= Municipal Solid Wastes, BDL= Below Detection Limit; Each value is the Mean ± SD of six replicates; *Significant $P<0.05$ "t" test between initial feed mixture and final vermicompost

heavy metals that are susceptible to bioaccumulation when compost made from MSW is used as manure could pose a risk to human health if they enter the food chain (Esakku *et al*., 2003). Therefore, heavy metals must receive substantial consideration before MSW compost is utilized. The presence of cadmium, cobalt, manganese, nickel, lead, and zinc in MSW compost has been reported by Ciba *et al*. (1999). The result of the analysis shows that there was a significant reduction in the concentration of heavy metals in the final vermicompost prepared from different animal dungs and MSW. It is evident that this significant decline in metal concentrations was caused by earthworm activity in the system used to decompose waste. The amount of heavy metal decreased substantially more in the vermicompost forms of various wastes than in the initial

Table 3: Concentration of Cadmium (Cd) (mg/kg) in different combinations of animal dung with municipal solid wastes in initial feed mixture and final vermicompost

Heavy metals (mg/kg)				
		Cd		
Vermicompost	**Ratio**	**Initial**	**Final**	**% Decrease**
MSW	**-**	0.286 ± 0.004	0.026 ± 0.003*	90.90
Buffalo Dung	**-**	0.397 ± 0.006	0.040 ± 0.003*	89.92
Buffalo Dung + MSW	**1:1**	0.291 ± 0.003	0.021 ± 0.003*	92.78
Buffalo Dung + MSW	**1:2**	0.086 ± 0.003	0.015 ± 0.004*	82.55
Buffalo Dung + MSW	**1:3**	0.079 ± 0.005	0.013 ± 0.003*	83.54
Cow Dung	**-**	0.156 ± 0.004	0.016 ± 0.004*	89.74
Cow Dung + MSW	**1:1**	0.089 ± 0.005	0.008 ± 0.003*	91.01
Cow Dung + MSW	**1:2**	0.826 ± 0.006	0.116 ± 0.004*	85.95
Cow Dung + MSW	**1:3**	0.256 ± 0.004	0.014 ± 0.004*	94.53
Goat Dung	**-**	0.389 ± 0.004	0.017 ± 0.005*	95.62
Goat Dung + MSW	**1:1**	0.448 ± 0.004	0.029 ± 0.005*	93.52
Goat Dung + MSW	**1:2**	0.164 ± 0.002	0.019 ± 0.003*	88.41
Goat Dung + MSW	**1:3**	0.135 ± 0.004	0.015 ± 0.004*	88.88

MSW= Municipal Solid Wastes; Each value is the Mean ± SD of six replicates; *Significant P<0.05 "t" test between initial feed mixture and final vermicompost

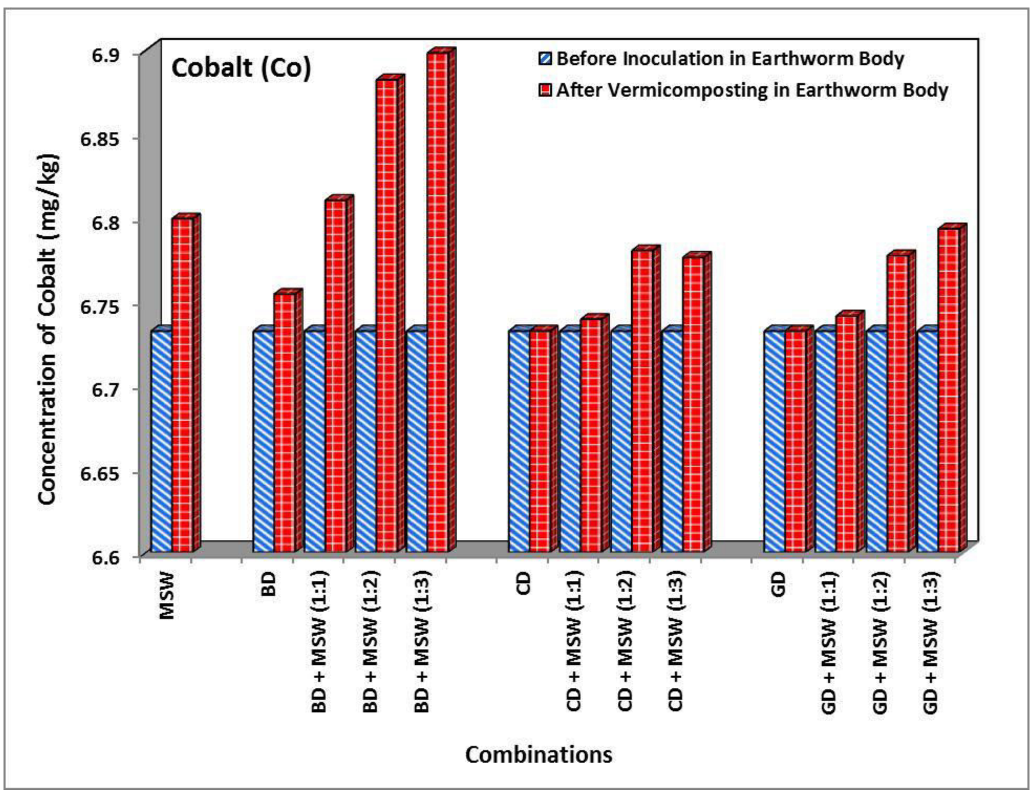

Fig. 1: Concentration of Cobalt (Co) (mg/kg) in the body of an earthworm before and after inoculation of earthworm *Lampito mauritii* into vermibeds with various combinations of animal dung with municipal solid wastes.

Table 4: Concentration of Cobalt (Co), Chromium (Cr) and Lead (Pb) (mg/kg) in earthworm body before inoculation in vermibeds and after final vermicomposting of different combinations of animal dung with municipal solid wastes

Heavy metals (mg/kg)							
Vermicompost	**Ratio**	**Co**	**% increase**	**Cr**	**% increase**	**Pb**	**% increase**
During inoculation Earthworm body Before vermicomposting (Control)		6.732 ± 0.004	-	114.513 ± 0.005	-	9.432 ± 0.005	-
MSW+Lm	**-**	6.799 ± 0.005*	0.98	115.247 ± 0.003*	0.63	10.257 ± 0.003*	8.04
Buffalo Dung+Lm	**-**	6.754 ± 0.003*	0.32	115.015 ± 0.002*	0.43	10.105 ± 0.004*	6.66
Buffalo Dung + MSW+Lm	**1:1**	6.810 ± 0.004*	1.14	115.083 ± 0.004*	0.49	11.017 ± 0.002*	14.38
Buffalo Dung + MSW+Lm	**1:2**	6.882 ± 0.002*	2.17	115.106 ± 0.003*	0.51	9.497 ± 0.004*	0.68
Buffalo Dung + MSW+Lm	**1:3**	6.898 ± 0.004*	2.40	114.996 ± 0.003*	0.42	9.432 ± 0.002*	0.00
Cow Dung+Lm	**-**	6.732 ± 0.003	0.00	115.250 ± 0.004*	0.63	9.440 ± 0.004*	0.08
Cow Dung + MSW+Lm	**1:1**	6.739 ± 0.002*	0.10	115.273 ± 0.005*	0.65	9.443 ± 0.003*	0.11
Cow Dung + MSW+Lm	**1:2**	6.780 ± 0.003*	0.70	115.099 ± 0.002*	0.50	9.477 ± 0.002*	0.47
Cow Dung + MSW+Lm	**1:3**	6.776 ± 0.004*	0.64	115.135 ± 0.004*	0.54	9.489 ± 0.005*	0.60
Goat Dung+Lm	**-**	6.732 ± 0.002	0.00	115.293 ± 0.003*	0.67	9.432 ± 0.003*	0.00
Goat Dung + MSW+Lm	**1:1**	6.741 ± 0.003*	0.13	115.220 ± 0.005*	0.61	9.497 ± 0.005*	0.68
Goat Dung + MSW+Lm	**1:2**	6.777 ± 0.002*	0.66	115.334 ± 0.003*	0.71	11.007 ± 0.004*	14.30
Goat Dung + MSW+Lm	**1:3**	6.793 ± 0.004*	0.89	115.215 ± 0.003*	0.60	9.515 ± 0.003*	0.87

MSW = Municipal Solid Wastes, Lm = inoculation with *Lampito mauritii*; Values are expressed as Mean ± SD (six replicates); *Significant $P<0.05$ "t" test between earthworm body before inoculation in vermibeds and after vermicomposting

feedstock.

The concentration of several heavy metals (Co, Cr, Pb, Ni, and Cd) in the body of inoculated earthworm *Lampito mauritii* has significantly increased after the preparation of vermicompost from all the combinations of various animal wastes with municipal solid wastes (Tables 4, 5). The maximum increased concentration of Co was observed in the combination of buffalo dung with MSW in the ratio of 1:3 inside the body tissue of *Lampito mauritii* (2.40%, 6.898 ± 0.004 mg/kg) (Table 4, Fig. 1). The maximum concentration of Cr was observed in the combination of goat dung with MSW in the ratio of 1:2 (0.71%, 115.334 ± 0.003 mg/kg) (Table 4, Fig. 2). The increased concentration of Pb was observed inside the body of *Lampito mauritii* in the combination of buffalo dung with MSW in the ratio of 1:1 (14.38%, 11.017 ± 0.002 mg/kg) (Table 4, Fig. 3) and Ni concentration was observed in the earthworm body of *Lampito mauritii* in the goat dung (11.91%, 7.192 ± 0.002 mg/kg) (Table 5, Fig. 4). Data emerging from results show that there was a significantly increased concentration of Cd

Table 5: Concentration of Nickel (Ni) and Cadmium (Cd) (mg/kg) in earthworm body before inoculation in vermibeds and after final vermicomposting of different combinations of animal dung with municipal solid wastes

Heavy metals (mg/kg)					
Vermicompost	**Ratio**	**Ni**	**% Increase**	**Cd**	**% Increase**
During inoculation Earthworm body Before vermicomposting (Control)		6.335 ± 0.002	-	61.640 ± 0.005	-
MSW+Lm	**-**	6.397 ± 0.003*	0.96	61.805 ± 0.005*	0.26
Buffalo Dung+Lm	**-**	6.460 ± 0.004*	1.93	61.859 ± 0.002*	0.35
Buffalo Dung + MSW+Lm	**1:1**	6.431 ± 0.004*	1.49	61.707 ± 0.003*	0.10
Buffalo Dung + MSW+Lm	**1:2**	6.427 ± 0.005*	1.43	61.687 ± 0.005*	0.07
Buffalo Dung + MSW+Lm	**1:3**	6.442 ± 0.004*	1.66	61.684 ± 0.003*	0.07
Cow Dung+Lm	**-**	6.439 ± 0.003*	1.61	61.740 ± 0.005*	0.16
Cow Dung + MSW+Lm	**1:1**	6.425 ± 0.002*	1.40	61.718 ± 0.004*	0.12
Cow Dung + MSW+Lm	**1:2**	6.458 ± 0.004*	1.90	62.338 ± 0.003*	1.11
Cow Dung + MSW+Lm	**1:3**	6.464 ± 0.003*	1.99	61.723 ± 0.005*	0.13
Goat Dung+Lm	**-**	7.192 ± 0.002*	11.91	61.817 ± 0.003*	0.28
Goat Dung + MSW+Lm	**1:1**	6.445 ± 0.004*	1.70	61.929 ± 0.002*	0.46
Goat Dung + MSW+Lm	**1:2**	6.450 ± 0.003*	1.78	61.701 ± 0.003*	0.09
Goat Dung + MSW+Lm	**1:3**	6.423 ± 0.005*	1.37	61.737 ± 0.004*	0.15

MSW = Municipal Solid Wastes, Lm = inoculation with *Lampito mauritii*; Values are expressed as Mean ± SD (six replicates); *Significant P<0.05 "t" test between earthworm body before inoculation in vermibeds and after vermicomposting

observed in the combination of cow dung with MSW in the ratio of 1:2 inside the earthworm body of *Lampito mauritii* (1.11%, 62.338 ± 0.003 mg/kg) (Table 5, Fig. 5).

Eisenia fetida, *Lumbricus rubellus*, *Perionyx excavatus*, and *Lampito mauritii* are the four most prevalent earthworms used for vermicomposting. Numerous studies have focused on the impact of heavy metals in soils on earthworms and their bioaccumulation over a very long period (Bouché, 1984; Morgan and Morgan, 1999; Kennette *et al*., 2002). Particularly when the metals are essentially non-bioavailable, earthworms (mainly *Lampito mauritii*) can bioaccumulate significant amounts of metals, including heavy metals, in their tissues without altering their physiology. They may easily bioaccumulate significant concentrations of Zn, Pb, and Cd, as well as Hg, Cu, Mn, Ca, Co, Fe, and Ni. According to Dai *et al*. (2004), the two species of earthworms (*Aporrectodea caliginosa* and *Lumbricus rubellus*) have different patterns of metal bioaccumulation that are associated with their ecological functions in contaminated soils. According to Jambhekar (1992), organic wastes including cow dung, pig manure, horse manure, chicken manure, and sugarcane waste can all be decomposed by earthworms. It has been stated that

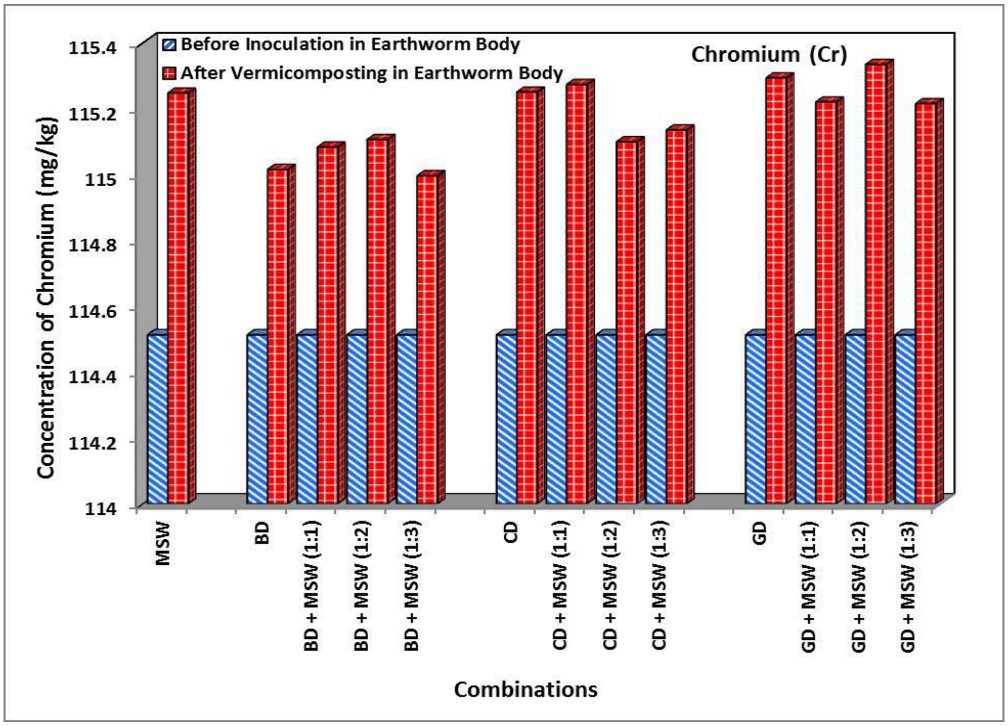

Fig. 2: Concentration of Chromium (Cr) (mg/kg) in the body of an earthworm before and after inoculation of earthworm *Lampito mauritii* into vermibeds with various combinations of animal dung with municipal solid wastes.

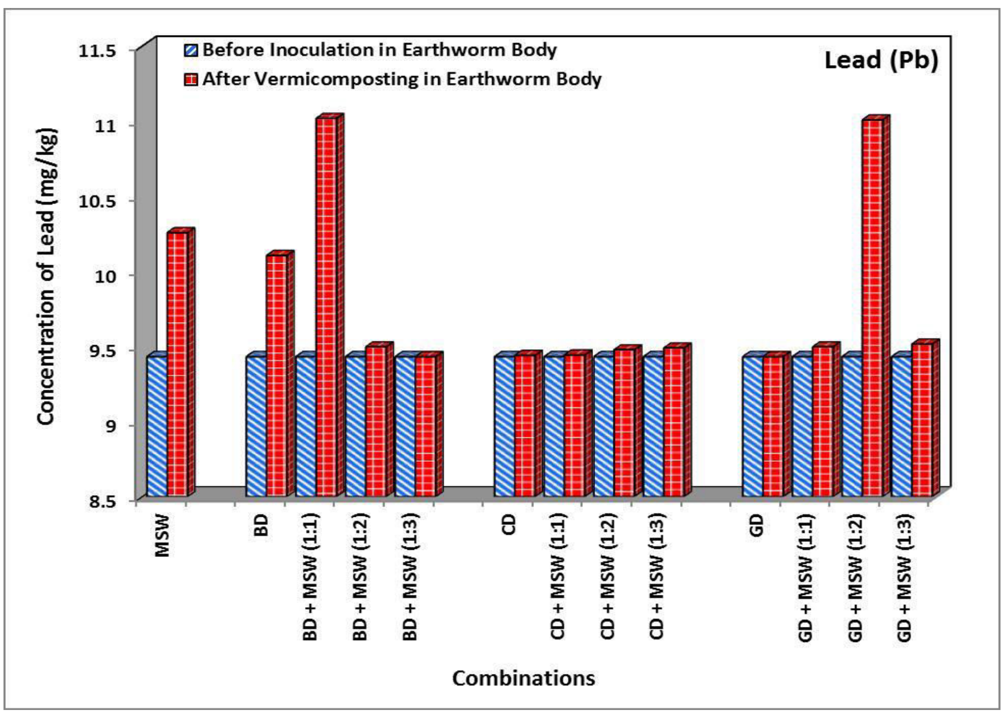

Fig. 3: Concentration of Lead (Pb) (mg/kg) in the body of an earthworm before and after inoculation of earthworm *Lampito mauritii* into vermibeds with various combinations of animal dung with municipal solid wastes.

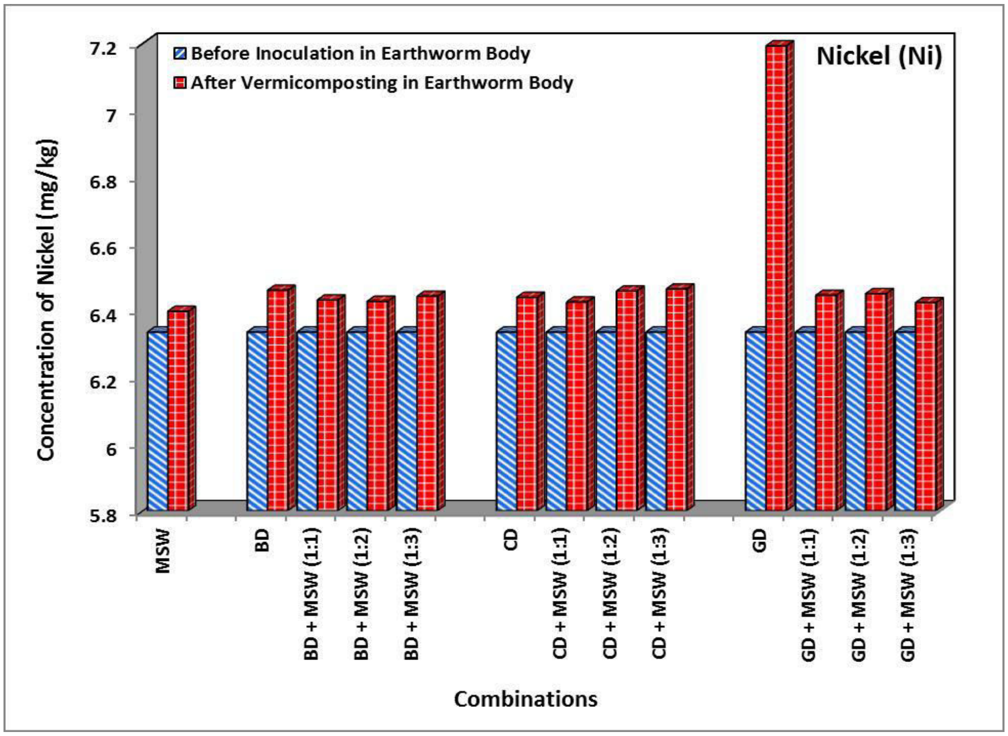

Fig. 4: Concentration of Nickel (Ni) (mg/kg) in the body of an earthworm before and after inoculation of earthworm *Lampito mauritii* into vermibeds with various combinations of animal dung with municipal solid wastes.

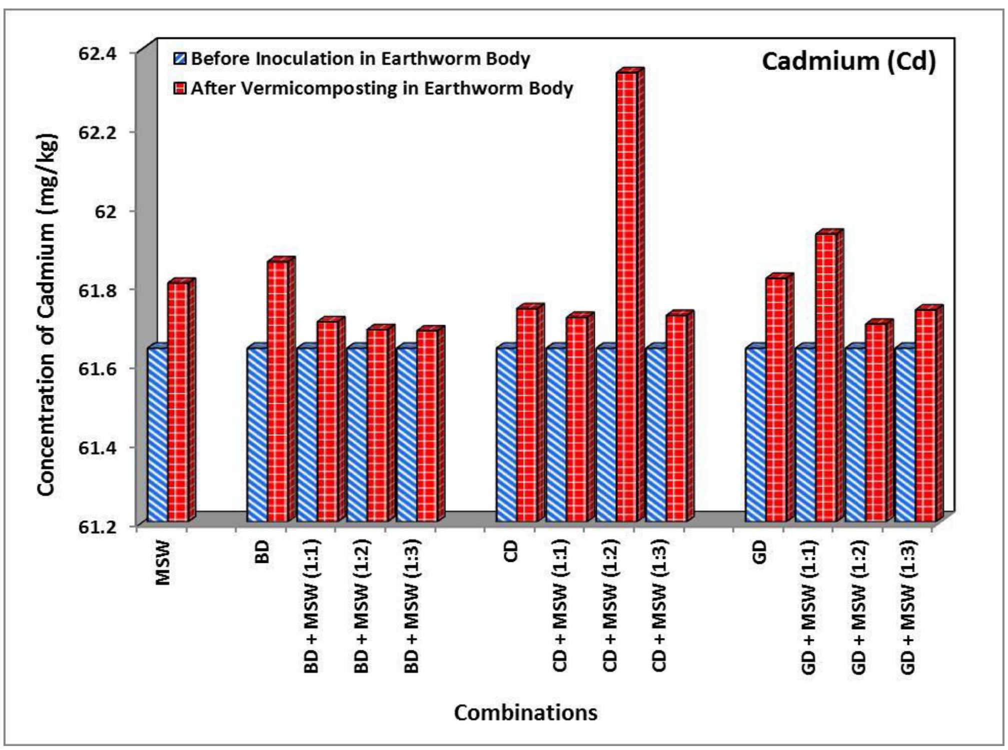

Fig. 5: Concentration of Cadmium (Cd) (mg/kg) in the body of an earthworm before and after inoculation of earthworm *Lampito mauritii* into vermibeds with various combinations of animal dung with municipal solid wastes.

vermicomposting, which is the biodegradation of organic wastes using earthworms and microorganisms is an efficient and cost-effective approach to managing cattle manure (Dominguez and Edwards, 2004; Nagavallemma *et al*., 2004; Mahaly *et al*., 2018; Chew *et al*., 2019; Yadav and Garg, 2019).

Earthworms were capable of vermicomposting local MSW (Kaviraj and Sharma, 2003). After 42 days of vermicomposting, *Eisenia fetida* and *Lampito mauritii* reduced carbon to the highest degree (44.3% and 44.1%, respectively). After 70-85 days of vermicomposting, Pramanik *et al*. (2007) observed that the vermicompost made from MSW had a substantially lower nitrogen value than expected. This finding may be related to the lower initial nutritional quality and C/N ratio of municipal solid waste. The dominant earthworm species varied between MSW and cow dung. When compared to other dominant earthworm species in MSW, *Lampito mauritii* seemed to have the highest density (82.3 ind.m^{-2}), biomass (46.2 m^{-2}), and relative density (87.2%) (Debnath and Chaudhuri, 2019). Due to its ability to bioaccumulate heavy metals in its ecosystem, *Lampito mauritii* has a high density and biomass potential in MSW (Koul *et al*., 2015). The presence of five earthworm species, such as *Lampito mauritii*, *Metaphire houlleti*, *Perionyx excavatus*, *Dichogaster bolaui*, and *Metaphire posthuma*, in both cow dung and MSW, suggests that these organisms are effective in the breakdown of organic wastes due to their wide range of environmental tolerance (Debnath and Chaudhuri, 2019).

According to Kaur *et al*. (2010), mixing bedding materials enhanced the acceptability of MSW as a feed substrate for microorganisms and earthworms. Earthworm decontamination is a simplified, inexpensive technology that employs earthworms to remove metal from polluted environments. Due to their proven tendency to accumulate metals and the fact that they come into direct interaction with the substrate they consume, earthworms are particularly appropriate for the assessment of contaminant bioavailability (Govindarajan *et al*., 2010). Through the mechanism of vermicomposting, which was accompanied by maximum earthworm reproduction and development, sewage sludge (SS) and spent mushroom compost (SMC) led to the removal of heavy metals, particularly Cr, Cd, and Pb, to 90% of the initial concentration (Azizi *et al*., 2013). Urban areas should implement vermicomposting to effectively manage MSW more sustainably, particularly in areas without centralized or other waste disposal facilities.

When comparing the concentrations of heavy metals in the initial feed mixture and the inoculated earthworm bodies with the final vermicompost, it is feasible to see that the earthworm bodies have a difference. This difference may be influenced by the presence of heavy metals that were leached with the water that was poured over the vermicompost bed to sustain the moisture during vermicomposting. Because the earthworm tissue accumulates the heavy metals during vermic-activity, the heavy metal concentration in the bodies of inoculated earthworms after vermicomposting in all the combinations of animal dung with MSW increased substantially (Jordao *et al*., 2006; Shahmansouri *et al*., 2005).

The potential of earthworm bodies to accumulate heavy metals (Co, Cr, Pb, Ni, and Cd) may be increased by the mixing of MSW with dung from buffalo, cow, and goat. The study of Barrera *et al*. (2001) showed that the concentration of Ni in earthworm egesta was higher than that in topsoil. Because Ni is quickly absorbed into the earthworm *Lampito mauritii* body tissue during metabolism, its overall Ni accumulation capacity is higher than that of inoculated earthworms in all combinations of animal dung with MSW.

Conclusion

The result revealed that the *Lampito mauritii* is capable of bioaccumulating heavy metals in its body tissue and substantially reducing the concentrations of heavy metals in the final vermicompost obtained from different animal manures combined with municipal solid waste. The earthworm *Lampito mauritii* was one of the most significant invertebrates to accumulate higher concentrations of heavy metals by the application of vermicompost of various animal dung (buffalo, cow, and goat) with MSW, making it safe for the environment and human health.

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