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Biostabilization of Tannery Sludge Compost by Vermicomposting

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ABSTRACT

The aim of this study is to investigate the stabilization of tannery sludge compost mixed with cattle manure at the different ratios by employing an epigeic earthworm *Eisenia foetida* and bioaccumulation of Cr in tannery sludge by earthworms. Organic cattle manure (M) and sludge compost (S) were mixed in certain proportions, moistened and *Eisenia foetida* worms were added. Mixing ratios were as follows: 100% M ($M_{100}S_0$), 70% M + 30% S ($M_{70}S_{30}$), 50% M + 50% S ($M_{50}S_{50}$) and 30% M + 70% S ($M_{30}S_{70}$). The experiment was carried out at a constant temperature of 24 ºC and in a dark environment according to a randomized plot design with three replicates. The experiment ended after 120 days and the following parameters were evaluated in vermicomposts: pH, electrical conductivity (EC), total nitrogen (TN), total organic carbon (TOC), C:N ratio, and total macro and micro elements. In addition, it was determined total Cr, Cr (VI) in vermicomposts and total Cr in *E. foetida* body. The results for TOC, C:N ratio and total Cr showed decreases in their values at the end of the vermicomposting process, whereas values for pH, EC, TON, Ca, and Mg increase, indicating that the vermicomposting reached the maturity level. All values of Cr (VI) of vermicomposts were below the detectable level. During the vermicomposting process, the reduction rates of the total Cr amounts were 96% ($M_{70}S_{30}$), 96% ($M_{50}S_{50}$) and 30% ($M_{30}S_{70}$), respectively. While the highest total Cr amount in the earthworm body was determined in $M_{30}S_{70}$ treatment, the amount of this element in the earthworm body decreased due to the decreasing doses of tannery sludge compost. These results show that *E. foetida* can bioacumulate the chromium in tannery sludge compost. As a result, it was determined that vermicomposting can be an alternate technology for the recycling and environmentally safe disposal/management of tannery sludge compost using an epigeic earthworm *E. foetida.*

Keywords: Chemical properties, *Eisenia foetida*, Tannery sludge compost, Total chromium, Vermicomposting

1. Introduction

Turkey is one of the biggest producers of high quality leather products in the world. One billion 181 million USD leather and related products were exported in 2020 (TÜİK 2021). However, the leather production increased the amount of industrial waste which known as tannery sludge, generated during the processes. Tannery sludge can include heavy metals (mainly Cr), leather fragments, soluble proteins, hairs, lime, sodium sulphate, sodium hydroxide and phenolic substances depending on the treatment process (Gupta and Sinha 2007; Küçükpelvan et al. 2017). The characteristics and pollution load of the wastes vary according to the quality and quantity of the chemicals used in the treatment. About 90 % of hides/skins in the world and Turkey are still tanned with Cr^{3+}, because of giving a high hydrothermal stability and other use properties to leather compared to the other tanning materials (IPPC, 2003). In soils with pH values above 5.0, Cr is in the trivalent form (Cr^{3+}), which is more stable, and has a low solubility and mobility (Alcântara & Camargo 2001). But Cr^{3+} can be oxidized to the hexavalent form (Cr^{6+}) which is very toxic, mutagenic, and carcinogenic for humans (Kolomaznik et al. 2008). Therefore, safe disposal of tannery waste requires special attention and is one of the major environmental troubles worldwide.

Currently, tannery sludge is disposed by land filling or land application techniques (Signh & Agrawal, 2010). However, land filling is not a suitable method because a large volume of soil is needed to fill the waste. Since land filling is an expensive method, the industries consequently want to choose for cheaper alternatives to dispose their wastes. Therefore, there is a need the research on cheap and usable new techniques for recycling of organic waste (Ahlberg et al. 2006). Composting is one of the cheapest and effective alternative method for organic waste recycling (Singh & Agrawal 2010). There are some studies that the amounts of hazardous chemicals in tannery wastes can be reduced by composting. Onyuka et al. (2012) were found 73% degree of humification and C/N ratio of 29/1 in composted tannery hair waste. Shukla et al. (2009) determined that the tannery effluent treated with aquatic macrophyte *Vallisneria spiralis* L. provided significant improvement in physico-chemical properties and reduction in Cr content. During the composting process, Cr^{6+} was transformed to Cr^{3+} by the microbial activity. Haroun et al.

(2007) studied the heavy metal concentrations in tannery sludge during a 50-day composting process and determined an increase in the removal of Cr, Cd, Pb, Zn and Cu in the final product.

Besides of conventional composting, vermicomposting is also suggested as an alternative method for recycling tannery wastes. Organic solid wastes can be efficiently managed by converting into organic manure/soil conditioners by vermicomposting (Garg et al. 2005). Earthworms can be used for solid waste management, organic matter stabilization, soil detoxification, and vermicompost production (Gupta & Garg 2008). Cardossa - Vigueros & Ramirez - Camperos (2006) determined that electrical conductivity (EC) value in tannery sludge decreased from 13.88 to 12.50 dS m^{-1} and Cr concentration from 3240 to 562 mg kg^{-1} after vermicomposting for 8 months. It is suggested that the organic matter in sludge must be stabilized with a biological process as composting and vermicomposting for landfill disposal. The tannery sludge was vermicomposted after mixed with sawdust, cardboard and straw and a decline in water extracted chromium was noted in result of vermicomposting. In addition, chromium concentration in *E. foetida* body tissues was significantly positively correlated with its content in sludge (Gondek 2008). The mixtures of tannery solid waste (TSW), cow dung and agricultural residues were vermicomposted for 50 days and a notable increase in earthworm biomass was determined. The tannery solid waste was converted into nutrient-enriched products by the earthworm *E. foetida* (Ravindran et al. 2008). In another study, fermented animal fleshing mixed with cow dung and leaf litter was vermicomposted with the earthworm *E. eugeniae* and the FT-IR analyses showed the complete mineralisation of polypeptides, polysaccharides, aliphatic methyl groups and lignin in vermicompost compared to without earthworm treatment realized (Ravindran et al. 2013). Additionly, they recorded a decrease of 58.5% in Cu, 55.8% in Cr, 35.7% in Zn, 23.4% in Mn and 19% in Fe in SSF (+worms) treatment (Ravindran et al. 2014). Nunes et al. (2016) determined that Cr^{6+} concentration in vermicompost obtained from tannery residues was below the detectable level and the Cr^{6+} content had probably been biologically converted into Cr^{3+}. The authors suggested that vermicomposting could be used as an effective technology for recycling of industrial tannery waste.

There are also some difficulties in the management of industrial tannery waste and sludge in Turkey and are needed the studies on the stabilization of such wastes. The aim of this study was to study the stabilization of tannery sludge compost mixed with cattle manure at the different ratios by employing an epigeic earthworm *Eisenia foetida*. Moreover, bioaccumulation of Cr in earthworm and the management of the end product as a soil conditioner or a waste that can be safely disposed to the land were investigated.

2. Material and Methods

2.1. Tannery sludge, cattle manure and Eisenia fetida

The tannery sludge (S) collected from Sepiciler Caybaşı Leather Inc. in Torbalı, İzmir, Turkey is dehydrated treatment sludge formed by the treatment of wastewater generated during production. It contains vegetable tanned leather shavings and protein phase of skinning waste. Before the experiment, sludge was composted aerobically, and the thermophilic stage has been completed. Cattle manure (M) was mixed with the tannery sludge compost to constitute an organic nutrient source and to support for earthworms and microorganisms inside the vermicomposters. Organic cattle manure (Eco-Fert) has been stabilized under aerobic conditions for 40 - 60 days and then passed through a separator. Non-clitellated earthworm *Eisenia foetida,* weighing 500–600 mg live weight, were randomly picked from a stock culture maintained in a vermicomposting farm. Chemical properties of tannery sludge compost (S) and cattle manure (M) are given in Table 1.

2.2. Experimental design

Styrofoam boxes (30 cm x 40 cm) were filled with the mixtures including different ratios of organic cattle manure (M) and tannery sludge compost (S). Mixing ratios were as follows: 100% M ($M_{100}S_0$), 70% M + 30% S ($M_{70}S_{30}$), 50% M + 50% S ($M_{50}S_{50}$) and 30% M + 70% S ($M_{30}S_{70}$). The total amounts of mixing were calculated as 4 kg dry weight basis. A cheesecloth was used to prevent the earthworms escaping from the boxes. The feed materials were mixed manually every day for 14 days to vapour the toxic gases. After 14 days, 200 non-clitellated *E. fetida* were left in each box. The moisture content of feeds was maintained to 70–80% during the vermicomposting process by adding of adequate quantity of water. The experiment was carried out under laboratory conditions in a dark environment with a constant temperature of 24 ºC according to the randomized plot design with 3 replicates. Before the earthworms were removed, samples were taken from the mixtures for chemical analysis. The vermicompost was air dried and sieved for chemical analysis. The vermicomposting process was performed for 120 days. At the end of the experiment, earthworms were removed and counted.

Table 1- Initial chemical properties of tannery sludge compost (S) and cattle manure (M)

Parameters	***S***	***M***
pH	7.75	8.25
EC (dS m^{-1})	6.16	3.18
Total C, %	18.00	44.00
Total N, %	1.85	1.00
C/N	10	44
Total P, %	0.20	0.55
Total K, %	0.10	1.78
Total Ca, %	1.88	2.58
Total Mg, %	1.91	0.96
Total Fe, mg kg^{-1}	1920.7	204.1
Total Zn, mg kg^{-1}	194.4	344.8
Total Cu, mg kg^{-1}	12.5	178.7
Total Mn, mg kg^{-1}	400.5	184.7
Total Cr, mg kg^{-1}	1862.10	<0.05
Cr^{6+}, mg kg^{-1}	6.20	<0.05

2.3. Chemical analysis

The pH and electrical conductivity (EC) of samples were measured using a pH-meter (WTW 526) and conductivity meter (WTW 720). Total organic carbon (TOC) was measured using the method of Nelson and Sommers (1982). Total N (TN) was determined by the Kjeldahl method (Bremner & Mulvaney, 1982). Total P was analysed using the colorimetric method with molybdenum in sulphuric acid. Total K and Ca were determined flame-photometrically, while Mg, Fe, Cu, Zn, Mn, and Cr were determined by atomic absorption spectrometry after wet digestion with HNO_3-$HClO_4$ (4:1) mixing solution (Kacar & Inal 2010). Cr (VI) was analysed using UV/VIS spectrometer (US EPA 1992).

2.4. Statistical analyses

The results given in the study are the means of three replicates (n=3). All data were subjected to ANOVA analysis using SPSS 16.0 (SPSS Inc., Chicago, IL, USA) to find significant differences between treatments at different sampling times with Duncan's multiple range test (P<0.05).

3. Results and Discussion

3.1. Changes of some chemical parameters by vermicomposting

Some chemical properties of initial mixtures and vermicomposts were given in Table 2. The treatments of $M_{100}S_0$ and $M_{70}S_{30}$ had higher pH values compared to the other two treatments ($M_{50}S_{50}$ and $M_{30}S_{70}$) in both sampling times due to the higher pH of cattle manure. During the vermicomposting, pH increased significantly in the treatments of $M_{100}S_0$, $M_{70}S_{30}$ and $M_{50}S_{50}$, probably due to excess of ammonia not required by microbes (Rynk 1992; Vig et al. 2011). The reason for a slight decrease in pH in the application of $M_{30}S_{70}$, where the wastewater sludge is more and both bacteria and earthworm activity are less, can be resulted from the formation of organic acids during the biotransformation of organic material (Ndegwa et al. 2000). While $M_{100}S_0$ treatment had higher EC value compared to the other treatments at the beginning of the experiment, the EC difference among the treatments was disappeared at the end of the experiment and EC values of all the treatments varied between 1.85 to 2.47 dS m^{-1}. Although the EC values of the treatments containing tannery sludge compost increased during the vermicomposting, the EC values of the final products remained below the limit value (<10 dS m^{-1}) (Official Newspaper No: 30341). The loss of organic matter and release of different mineral salts during vermicomposting process probably increased EC in the vermicomposts (Kaviraj & Sharma 2003). Gunadi & Edwards (2003) have suggested that EC and pH of feed could be the limiting factor for the survival and growth of *E. foetida*. *E. foetida* could not survive in the cattle manure with pH of 9.5 and EC of 5.0 dS m^{-1} (Mitchell 1997). pH and EC values of vermicomposts obtained in our study were suitable for the survival and growth of *E. foetida*. Total organic carbon (TOC) of the final vermicompost significantly decreased as compared to the initial feed materials (Table 2). TOC loss occurred between 1.70% and 38.8%. The decrease in TOC during vermicomposting indicates organic matter stabilization in the feed materials due to combined action of *E. foetida* and microbiota (Gupta and Garg, 2008). Other co-workers (Elvira et al. 1998; Kaushik & Garg 2003; Garg & Kaushik 2005) who have reported 20-45% loss of TOC during vermicomposting of different industrial sludges support our data. In our study, the highest TOC loss was determined in $M_{100}S_0$ treatment and TOC loss decreased due to increasing doses of tannery sludge compost (38.8% in $M_{100}S_0$, 18.5% in $M_{70}S_{30}$, 16.2% in $M_{50}S_{50}$ and 1.7% in $M_{30}S_{70}$). In the treatment of $M_{30}S_{70}$ where the lowest TOC loss was found, probably negatively affected the population of heterotrophic microorganisms and earthworms due to the high rate of tannery sludge. Total nitrogen (TN) content in the vermicomposts was higher than initial feed materials. The initial TN content of the initial feed materials was in the range of 1.0% – 1.35%. Whereas TN content of vermicomposts was in the range of 1.85% - 2.10% after vermicomposting. TN increased 1.4-

2.1 fold at the end of vermicomposting process. Earthworms accelerate the nitrogen mineralization in organic material. In addition, they produced the substances including nitrogen such as mucus and excretory substances during the digestion of organic matter (Hobson et al. 2005; Suthar 2006). These substances, which are not found in raw materials, later contribute as an additional nitrogen source because of vermicomposting. The initial C/N ratio of raw materials was in the range of 23.0 to 43.9, but after 120 days C/N ratio significantly decreased in all the treatments. Final C/N ratio was between 12.8 and 16.5%. The reduction in C/N ratio was determined 1.4 – 3.4 fold in final vermicomposts. The C/N ratio indicates the level of stabilization of a waste, as carbon is lost as CO_2 during vermicomposting whereas nitrogen content is enhanced during this process and these factors contributes to the lowering of C/N ratio (Yadav & Garg 2011). The C/N ratio below 20 is indicator of acceptable maturity (Morais & Queda 2003). The vermicomposts obtained in our study had the C/N ratio within the acceptable limit for composts.

3.2. Changes of total element amounts by vermicomposting

The change of total P, K, Ca, and Mg amounts during vermicomposting process were given in Table 3. Since cattle manure contains higher total P and K than tannery sludge compost (Table 1), the highest total P and total K amounts were obtained in $M_{100}S_0$ treatment, while the lowest amount of these elements was determined in $M_{30}S_{70}$ treatment. Although it was not statistically significant, a slight increase in the total P amounts was determined at the end of the vermicomposting. This increase was probably due to the mineralization of P depending on the bacterial and faecal phosphatase activity of the earthworms (Edwards and Lofty, 1972). Satchell & Martin (1984) suggested that an increase in the total P amount of vermicomposts is directly related to gut enzymes of earthworms and indirectly with the stimulation of microorganisms. Otherwise, the total K content of vermicomposts did not significantly change or slightly decreased during vermicomposting. There are different results regarding the total K content in the vermicomposts obtained from different wastes. Delgado et al. (1995) have reported a higher content of total K in the sewage sludge vermicomposts. Whereas Orozco et al. (1996) determined a decrease in total K in coffee pulp waste vermicomposts. These differences in the results may have resulted from the different chemical properties of the feed materials. The total Ca and Mg amounts were slightly higher in the vermicomposts than their raw materials for all treatments except total Mg amount under $M_{100}S_0$ treatment. These increases may have resulted from the decrease in compost volume during the vermicomposting process as reported by Malafaia et al. (2015). Veras & Povinelli (2004), who detect increases in Ca and Mg amounts in vermicomposts but could not detect in composts without *E. foetida*, also confirmed this hypothesis.

The change of total Fe, Zn, Cu, and Mn amounts during vermicomposting process were given in Table 4. Total Fe and Mn amounts significantly increased depending on increasing the dose of tannery sludge compost and the highest Fe and Mn amounts were found in $M_{30}S_{70}$ treatment as 2110.1 mg kg^{-1} and 468.4 mg kg^{-1}, respectively. The opposite results were obtained for Zn and Cu and the highest amounts of these elements were determined in $M_{100}S_0$ treatment as 362.1 mg kg^{-1} and 224.5 mg kg^{-1}, respectively, because the cattle manure contains higher Zn and Cu elements compared to tannery sludge compost (Table 1). The amount of microelements did not change significantly during the vermicomposting process.

3.3. Changes of total Cr and Cr (VI) amounts by vermicomposting and total Cr amount in earthworm body

Table 5 shows the amounts of total Cr and Cr (VI) during vermicomposting process and total Cr amount in earthworm body. The results for total Cr were 6.20-9.19, 554.60-23.29, 920.30-35.28 and 1311.60-920.59 mg kg^{-1} for $M_{100}S_0$, $M_{70}S_{30}$, $M_{50}S_{50}$ and $M_{30}S_{70}$ treatments, respectively. All treatments that included tannery sludge compost showed significant decreases in their Cr content. During vermicomposting, the reduction rates of the total Cr amounts were 96% ($M_{70}S_{30}$), 96% ($M_{50}S_{50}$) and 30% ($M_{30}S_{70}$), respectively. While the highest total Cr amount in the earthworm body was found in $M_{30}S_{70}$ treatment, the amount of this element in the earthworm body decreased due to the decreasing doses of tannery sludge compost. The lowest total Cr content was determined in $M_{100}S_0$ treatment. These results show that *E. foetida* can bioaccumulate Cr in tannery sludge compost. Similar results have been reported by Cardossa - Vigueros & Ramirez - Camperos (2006) during the vermicomposting of tannery wastes and sewage sludge by *E. foetida* and Cr concentration decreased from 3240 mg kg^{-1} to 562 mg kg^{-1} after vermicomposting for 8 months. In addition, Gondek (2008) found that the amount of water extractable chromium in the final product decreased because of vermicomposting of the mixture of tannery sludge and sawdust, straw and cardboard by *E. foetida* for 12 months. It was also found that Cr accumulated 13-20 times more in earthworm tissue compared to control and there was a positive relationship between the amount of Cr in earthworms and the amount of Cr in vermicompost. Malecki et al. (1982) suggested that *Eisenia foetida* can tolerate relatively great contents of heavy metals in the substrates and Hartenstein et al. (1980) explained that Cr in sewage sludge is not harmful for redworm growth, even in high concentrations. Earthworms change the physico-chemical structure of ingested organic materials and convert it more available forms to organisms. So, the metal content reduces in digested organic material due to bioaccumulations of more soluble fractions of metals (Suthar 2006). The concentration of Cr (VI) was lower from detectable level in all treatments (Table 5), probably due to the high pH levels of raw materials and vermicomposts (Table 2). Bartlett and James (1977) found lower pH increased the formation of Cr^{6+}, and at pH 3.2 all Cr^{3+} was oxidized to Cr^{6+}.

Table 2 - pH, electrical conductivity (EC), the amounts of total organic C (TOC) and total N (TN) and C/N ratio of initial feed mixtures and vermicomposts

	pH		*EC (dS m^{-1})*		*TOC, %*		*TON, %*		*C/N ratio*	
	Initial	*End*	*Initial*	*End*	*Initial*	*End*	*Initial*	*End*	*Initial*	*End*
$M_{100}S_0$	8.25 a B	8.41 a A	3.18 a A	2.47 a B	43.88 a A	26.83 a B	1.00 b B	2.10 a A	43.9 a A	12.8 a B
$M_{70}S_{30}$	8.27 a B	8.55 a A	1.74 b B	1.85 a A	33.99 ab A	27.69 a B	1.27 a B	1.86 a A	26.8 b A	14.9 a B
$M_{50}S_{50}$	7.85 b B	7.94 b A	1.68 b B	2.05 a A	31.12 b A	26.06 a B	1.34 a B	1.88 a A	23.2 b A	13.9 a B
$M_{30}S_{70}$	7.77 b A	7.73 b A	1.62 b B	2.44 a A	31.10 b A	30.58 a B	1.35 a B	1.85 a A	23.0 b A	16.5 a b

Lowercase letters in each sampling period represent the statistical difference between treatments; uppercase letters in each treatment represent the statistical difference between sampling periods (P= 0.05, Duncan's test).

Table 3- The amounts of total P, K, Ca and Mg of initial feed mixtures and vermicomposts

	Total P, %		*Total K, %*		*Total Ca, %*		*Total Mg, %*	
	Initial	*End*	*Initial*	*End*	*Initial*	*End*	*Initial*	*End*
$M_{100}S_0$	0.55 a A	0.58 a A	1.88 a A	1.78 a A	2.58 a B*	3.23 a A	0.96 c A	1.07 b A
$M_{70}S_{30}$	0.37 b A	0.48 b A	1.06 b A	1.06 b A	2.65 a B	3.33 a A	1.23 b B	2.29 a A
$M_{50}S_{50}$	0.40 b A	0.49 b A	0.90 c A	0.80 b A	2.57 a B	2.89 a A	1.56 ab B	2.14 a A
$M_{30}S_{70}$	0.25 c A	0.37 c A	0.64 d A	0.59 c A	2.66 a B	3.28 a A	2.20 a B	2.89 a A

Lowercase letters in each sampling period represent the statistical difference between treatments; uppercase letters in each treatment represent the statistical difference between sampling periods (P= 0.05, Duncan's test).

Table 4- The amounts of total Fe, Zn, Cu and Mn of initial feed mixtures and vermicomposts

	Total Fe, mg kg^{-1}		*Total Zn, mg kg^{-1}*		*Total Cu, mg kg^{-1}*		*Total Mn, mg kg^{-1}*	
	Initial	*End*	*Initial*	*End*	*Initial*	*End*	*Initial*	*End*
$M_{100}S_0$	204.1 b A	282.6 b A	344.8 a A*	362.1 a A	178.7 a A	224.5 a A	184.6 b A	212.9 c A
$M_{70}S_{30}$	1597.6 ab A	1600.5 ab A	318.9 ab A	282.3 b A	100.8 b A	105.4 b A	387.6 ab A	439.2 b A
$M_{50}S_{50}$	1644.4 ab A	1708.4 ab A	297.1 ab A	248.2 b A	66.6 c A	79.5 c A	418.7 ab A	456.2 ab A
$M_{30}S_{70}$	1984.7 a A	2110.1 a A	263.4 b A	266.7 b A	50.5 c A	59.9 d A	456.6 a A	468.4 a A

Lowercase letters in each sampling period represent the statistical difference between treatments; uppercase letters in each treatment represent the statistical difference between sampling periods (P= 0.05, Duncan's test).

Table 5- The amounts of total Cr and Cr (VI) of initial feed mixtures and vermicomposts and the amount of total Cr of *E.foetida* body

	Total Cr, mg kg^{-1}		*Cr (VI), mg kg^{-1}*		*Total Cr in earthworm body, mg kg^{-1} fresh matter*
	Initial	*End*	*Initial*	*End*	
$M_{100}S_0$	6.20 d A	9.19 b A	< 0.05	< 0.05	2.68 d
$M_{70}S_{30}$	554.60 c A	23.29 b B	< 0.05	< 0.05	31.46 c
$M_{50}S_{50}$	920.30 b A	35.28 b B	< 0.05	< 0.05	163.39 b
$M_{30}S_{70}$	1311.60 a A	920.59 a B	< 0.05	< 0.05	523.26 a

Lowercase letters in each sampling period represent the statistical difference between treatments; uppercase letters in each treatment represent the statistical difference between sampling periods (P= 0.05, Duncan's test).

3.4. The growth of Eisenia foetida by vermicomposting

At the beginning of the experiment, the number of 200 earthworms were left in each box. After 4 months, they were counted and higher number of earthworms were found in $M_{100}S_0$, $M_{70}S_{30}$ and $M_{50}S_{50}$ treatments (Figure 1). The numbers for earthworms were 186, 204, 205 and 139 for $M_{100}S_0$, $M_{70}S_{30}$, $M_{50}S_{50}$ and $M_{30}S_{70}$ treatments, respectively. The lowest earthworm number was found in $M_{30}S_{70}$. It was observed that sufficient cocoon formation occurred in $M_{100}S_0$, $M_{70}S_{30}$, $M_{50}S_{50}$ treatments and these cocoons later hatched (Figure 2 and 3). In the last treatment where the highest treatment sludge dose was applied ($M_{30}S_{70}$), very few cocoons were observed. These results show that there is no problem in the development and reproduction of *Eisenia foetida* in tannery sludge composts mixed in the rates of 30% and 50% of cattle manure. However, when the ratio of tannery sludge compost increased to 70%, the earthworms had trouble staying alive. Vig et al. (2011) have reported similar observations during vermicomposting of tannery sludge and cow dung that the number of earthworms decreased from 15th day of experiment in the treatments including high concentrations of tannery sludge. The maximum mortality of earthworms was determined as 60% in 75% tannery sludge+25% cow dung feed mixture. The kind and quality of feed materials directly affected the survival, growth, and reproduction of earthworms (Gajalakshmi et al. 2005). Therefore, vermicomposting and cattle manure acting as a complementary waste improved its quality of tannery sludge compost and converted it to into a compost that can be used as a soil conditioner and being dispose into the land more safely.

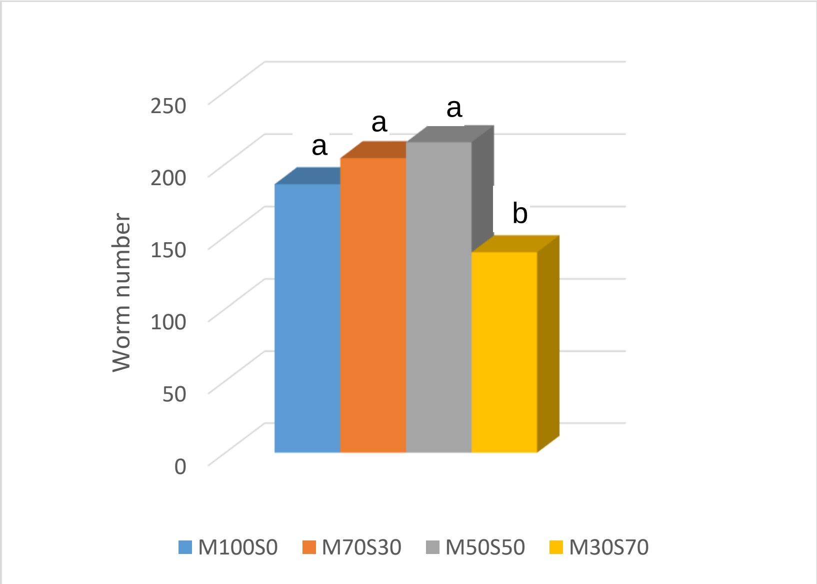

Figure 1- The numbers of *E. foetida* at the end of the vermicomposting process. The difference in mean values between the treatments followed by the same letter are not statistically different at P<0.05 from each other, according to Duncan's test.

Figure 2- The view of cocoons in $M_{70}S_{30}$ treatment.

Figure 3- The hatchlings emerging from the cocoons

3. Conclusions

This study was carried out to investigate the usage possibilities of vermicomposting technology for waste management of tannery sludge. Different combinations of tannery sludge compost with cattle manure were vermicomposted using an epigeic earthworm (*E. fetida*) and some chemical properties and growth of earthworms were determined in vermicomposts. pH and EC values of vermicomposts increased slightly but they remained within accepted limit values. The vermicomposts had higher amounts of nutrients such as N, Ca, Mg and lower C:N ratio than 20 which indicate their stabilization. The amounts of P, K, Fe, Zn, Cu and Mn did not change during vermicomposting. Total Cr content of mixing combinations significantly decreased and toxic Cr^{6+} content was lower than the detectable level for all treatments. The decreasing of total Cr content in vermicompost but the increasing in earthworm body indicated that the Cr element can bioaccumulate in earthworms. As a result of this study, it was determined that vermicomposting can be an alternative technique for the recycling and safe disposal/management of tannery sludge compost by using *E. foetida*.

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References

Ahlberg O, Gustafsson P & Wedel P (2006). Leaching of metals from sewage sludge during one year and their relation to particle size. Environmental Pollution 144:545-553. https://doi.org/10.1016/j.envpol.2006.01.022

Alcântara MAK & Camargo OA (2001). Retarding factor and dispersion-diffusion coefficient for chromium (III) in highly weathered soils, influenced by pH, texture and organic matter. Revista Brasileira de Ciência do Solo 25 (1):209-216

Bartlett R & James B (1979). Behavior of chromium in soils: III. Oxidation 1. J ournal of Environmental Quality 8 (1):31–35. https://doi.org/10.2134/jeq1979.00472425000800010008x

Bremner J M & Mulvaney C S (1982). Nitrogen-total. In: Page AL, Miller RH, Keeney DR (editors). Methods of Soil Analysis: Part II. Chemical and Microbiological Properties. Madison, WI, USA: American Society of Agronomy, pp. 595-641

Cardossa-Vigueros L & Ramirez-Camperos E (2006). Tannery wastes and sewage sludge biodegradation by composting and vermicomposting process. Ingenieria Hidraulica En Mexico. 21(2):93-103

Delgado M, Bigeriego M, Walter I & Calbo R (1995). Use of California redworm in sewage sludge transformation. Turrialba. 45: 33-41

Edwards C A & Lofty J R (1972). Biology of Earthworms. Chapman and Hall, London. https://doi.org/10.1007/978-1-4899-6912-5_7

Elvira C A, Sampedro L, Benitez E & Nogales R (1998). Vermicomposting of sludges rom paper mill and dairy industries with Eisenia andrei: a pilot scale study. Bioresource Technology 63:205–211. https://doi.org/10.1016/s0960-8524(97)00145-4

Gajalakshmi S, Ramasamy E V& Abbasi S A (2005). Composting-vermicomposting of leaf litter ensuing from the trees of mango (*Mangifera indica*). Bioresource Technology 96 (9): 1057-1061. https://doi.org/10.1016/j.biortech.2004.09.002

Garg P, Gupta A & Satya S (2005). Vermicomposting of different types of waste using *Eisenia foetida*: A comparative study. Bioresource Technology 97: 391–395. https://doi.org/10.1016/j.biortech.2005.03.009

Garg V K & Kaushik P (2005). Vermistabilization of textile mill sludge spiked with poultry droppings by an epigeic earthworm *Eisenia foetida*. Bioresource Technology 96:1063-1071. https://doi.org/10.1016/j.biortech.2004.09.003

Gondek K (2008). Chromium bioaccumulation from composts and vermicomposts based on tannery sludges. J. Central European Agriculture 9(1): 129-140

Gunadi B & Edwards C A (2003). The effects of multiple applications of different organic wastes on the growth, fecundity, and survival of *Eisenia fetida* (Savigny) (Lumbricidae). Pedobiologia 47(4):321-329

Gupta A K & Sinha S (2007). Phytoextraction capacity of the plants growing on tannery sludge dumping sites. Bioresource Technology 98:1788-1794. https://doi.org/10.1016/j.biortech.2006.06.028

Gupta R & Garg V K (2008). Stabilization of primary sewage sludge during vermicomposting. J. Hazard. Mater. 162:430-439. https://doi.org/10.1016/j.jhazmat.2007.09.055

Haroun M, Idris A & Omar S R S (2007). A study of heavy metals and their fate in the composting of tannery sludge. Waste Management, 27: 1541-1550. https://doi.org/10.1016/j.wasman.2006.09.006

Hartenstein R, Neuhauser E F & Collier J (1980). Accumulation of heavy metals in the earthworm *Eisenia fetida*. J. Environ. Qual., 9: 23-26. https://doi.org/10.2134/jeq1980.00472425000900010007x

Hobson A M, Frederickson J & Dise N B (2005). CH_4 and N_2O from mechanically turned windrow and vermicomposting systems following in-vessel pre-treatment. Waste Management, 25(4): 345-352. https://doi.org/10.1016/j.wasman.2005.02.015

IPPC (2003). Reference Document on Best Available Techniques for the Tanning of Hides and Skins. European Commission: Integrated Pollution Prevention and Control (IPPC). 246 p.

Kacar B, İnal A (2010). Plant Analysis (in Turkish). 2nd ed., Nobel Publishing, Ankara, Turkey.

Kaushik P & Garg V K (2003). Vermicomposting of mixed solid textile mill sludge and cow dung with the epigeic earthworm *Eisenia fetida*. Bioresource Technology 90(3):311-316. https://doi.org/10.1016/s0960-8524(03)00146-9

Kaviraj S S & Sharma S (2003). Municipal solid waste management through vermicomposting employing exotic and local species of earthworms. Bioresource Technology 90:169–173. https://doi.org/10.1016/s0960-8524(03)00123-8

Kolomaznik K, Adamek M, Andel I & Uhlirova M (2008). Leather waste - potential threat to human health and new technology of its treatment. Journal of Hazardous Materials 160:514-520. https://doi.org/10.1016/j.jhazmat.2008.03.070

Küçükpelvan H, Yarımtepe C C & Öz N A (2017). Treatment Methods for Tannery Wastewater. (in Turkish) Çanakkale Onsekiz Mart University Journal of Science Institute, 3(1):59-96. https://dergipark.org.tr/tr/download/article-file/308096

Malafaia G, Jordão C R, de Araújo FG, Leandro W M & de Lima Rodrigues A S (2015). Vermicomposting of tannery sludge mixed with cattle dung using Eisenia fetida. Eng. Sanit. Ambient. 20(4):709-716. https://doi.org/10.1590/s1413-41522015020040134645

Malecki M R, Neuhauser E F & Loehr R C (1982). The effect of metals on the growth and reproduction of *Eisenia fetida* (*Oligochaeta, Lumbricidae*). Pedobiologia 24: 129-137

Mitchell A (1997). Production of *Eisenia fetida* and vermicompost from feed-lot cattle manure. Soil Biol. Biochem. 29(3-4): 763-766

Morais F M C & Queda C A C (2003). Study of storage inXuence on evolution of stability and maturity properties of MSW composts. In: Pro-ceedings of the fourth International Conference of ORBIT Association on Biological Processing of Organics: Advances for a Sustainable Society Part II, Perth, Australia

Ndegwa P M, Thompson S A & Das K C (2000). Effects of stocking density and feeding rate on vermicomposting of biosolids. Bioresource Technology 71(1):5–12. https://doi.org/10.1016/s0960-8524(99)00055-3

Nelson D W & Sommers L E (1982). Total carbon, organic carbon and organic matter: In: Page AL, Miller RH, Keeney DR (editors). Methods of Soil Analysis: Part II. Chemical and Microbiological Properties. Madison, WI, USA: American Society of Agronomy, pp. 539-579

Nunes R R, Bontempi R M, Mendonça G, Galetti G & Rezende M O O (2016). Vermicomposting as an advanced biological treatment for industrial waste from the leather industry, *Journal of Environmental Science and Health*, Part B 51(5):271-277. https://doi.org/10.1080/03601234.2015.1128737

Official Newspaper No: 30341. Regulation on Organic, Mineral and Microbial Fertilizers used in agriculture. Ministry of Food, Agriculture and Livestock, 23 February 2018.

Onyuka A S, Bates M, Attenburrow G, Covington A D & Antunes A P M (2012). Paremeters for composting tannery hair waste. J. of the American Leather Chemists Associaton 107: 159-166

Orozco F H, Cegarra J, Trujillo L M & Roig A (1996). Vermicomposting of coffee pulp using the earthworm Eisenia fetida: effects on C and N contents and the availability of nutrients. Biol. Fert. Soils 22: 162-166. https://doi.org/10.1007/bf00384449

Ravindran B, Contreras-Ramos S M, Wong J W C, Selvam A & Sekeran G (2014). Nutrient and enzymatic changes of hydrolysed tannery solid waste treated with epigeic earthworm *Eudrilus eugeniae* and phytotoxicity assessment on selected commercial crops. Environ Sci Pollut Res., 21:641–651. https://doi.org/10.1007/s11356-013-1897-1

Ravindran B, Dinesh S L, John Kennedy L & Sekeran G (2008). Vermicomposting of solid biodegradation by composting and vermicomposting process. Ingeneria Hidraulica En Mexico, 21(2): 93-103

Ravindran B, Sravani R, Mandal A B, Contreras-Ramos S M & Sekeran G (2013). Instrumental evidence for biodegradation of tannery waste during vermicomposting process using *Eudrilus eugeniae*. J Therm Anal Calorim., 111:1675–1684. https://doi.org/10.1007/s10973-011-2081-9

Rynk R (1992). On farm composting handbook. Northeast Regional Agricultural Engineering Service (NRAES-54), New York, USA, pp.54.

Satchell J E & Martin K (1984). Phosphatase activity in earthworm faeces. Soil Biol Biochem 16:191-194. https://doi.org/10.1016/0038-0717(84)90111-1

Shukla O P, Rai U N & Dubey S (2009). Involvement and interaction of microbial communities in the transformation and stabilization of chromium during the composting of tannery effluent treated biomass of *Valissneria spiralis L*. Bioresource Technology, 100:2198-2203. https://doi.org/10.1016/j.biortech.2008.10.036

Singh R P & Agrawal M (2010). Variations in heavy metal accumulation, growth and yield of rice plants grown at different sewage sludge amendment rates. Ecotoxicology and Environmental Safety 73:632-641. https://doi.org/10.1016/j.ecoenv.2010.01.020

SPSS Inc. Released 2007. SPSS for Windows, Version 16.0. Chicago, SPSS Inc.

Suthar S (2006). Potential utilization of guargum industrial waste in vermicompost production. Bioresource Technology 97:2474-2477. https://doi.org/10.1016/j.biortech.2005.10.018

TÜİK (2021). Turkish Statistical Institute. (in Turkish) Number: 37414. Publication date: 31 March 2021

US EPA (1992). United States Environmental Protection Agency, Method 7196A. Chromium, Hexavalent (colorimetric). https://www.epa.gov/sites/default/files/2015-12/documents/7196a.pdf

Veras L R V & Povinelli J (2004). A Vermicompostagem do Lodo de Lagoas de Tratamento de Efluentes Industriais Consorciada com Composto de Lixo Urbano. Revista Engenharia Sanitária e Ambiental 9(3):218-224. https://doi.org/10.1590/s1413-41522004000300008

Vig A P, Singh J, Wani S H & Dhaliwal S S (2011). Vermicomposting of tannery sludge mixed with cattle dung into valuable manure using earthworm *Eisenia fetida* (Savigny). Bioresource Technology 102: 7941–7945. https://doi.org/10.1016/j.biortech.2011.05.056

Yadav A & Garg V K (2011). Recycling of organic wastes by employing *Eisenia fetida*. Bioresource Technology 102:2874-2888. https://doi.org/10.1016/j.biortech.2010.10.083