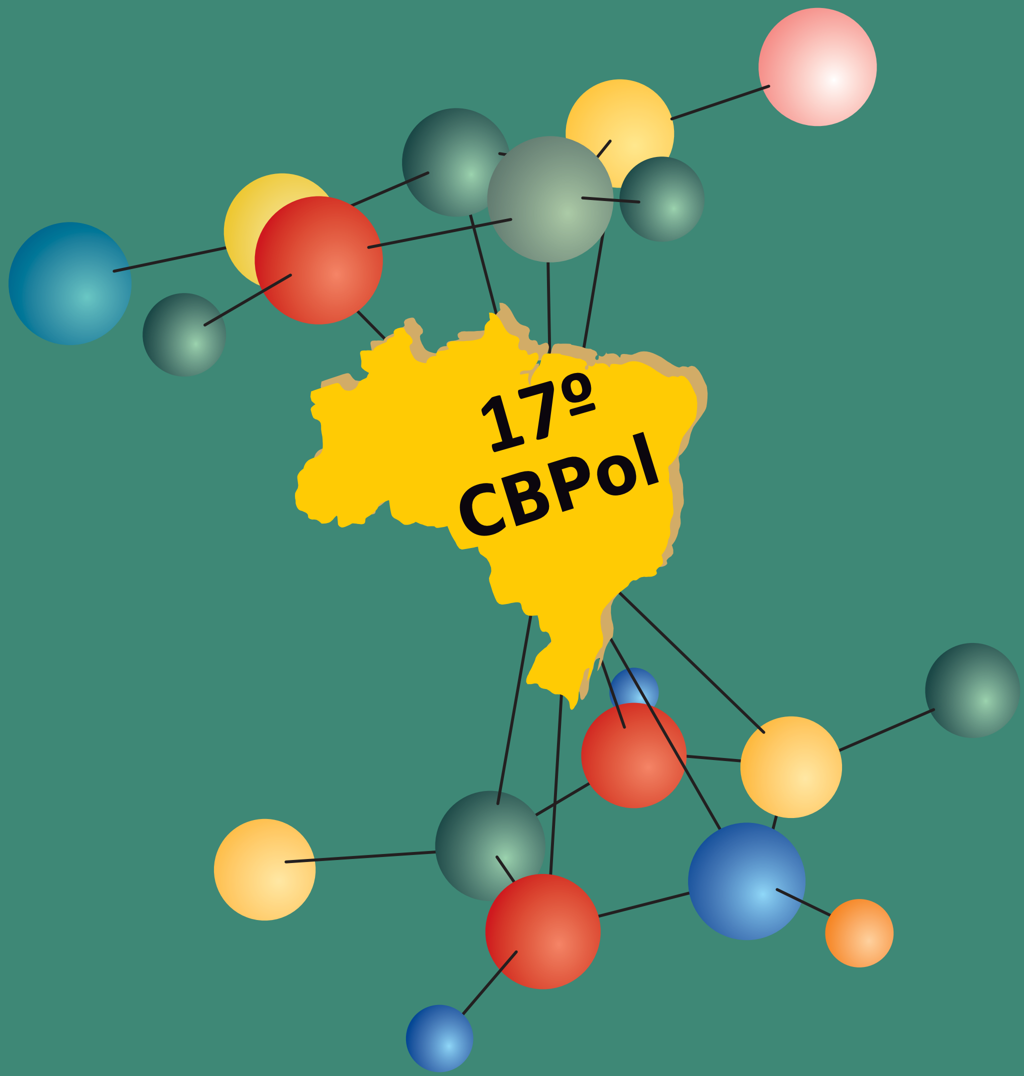

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EVALUATION OF COMPOSTING AND VERMICOMPOSTING IN THE DEGRADATION OF HDPE FILMS

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Abstract - The gravimetric composition of a landfill consists of approximately 10% polymers, with plastic bags used to contain organic waste being a significant contributor. Exploring alternatives to mitigate the impacts resulting from the improper disposal of these residues is deemed necessary. The films used in these bags are durable and impermeable, which hinders the degradation of the enclosed organic fraction. Therefore, employing methods that facilitate the segregation of these materials enhances the lifespan of landfills, leading to positive environmental effects. This also allows for the valorization of organic waste through processes like composting and vermicomposting. This study aims to analyze the biodegradation and deterioration of HDPE films through the use of such methods. Vermicomposting employed annelids of the *Eisenia fetida* species to determine their efficiency in breaking down the polymeric material. The biodegradation of the polymeric materials was assessed through FTIR, tensile mechanical testing, and optical microscopy. The crystallinity of the materials was evaluated using DSC. The obtained results revealed material degradation and an efficiency increase in the vermicomposting environment compared to composting.

Keywords: *Biodegradation, Vermicomposting, Composting, Polyethylene, Eisenia fetida.*

Introduction

Synthetic polymers derived from petrochemicals have very low degradation rates and become an environmental problem when improperly discarded, posing a risk to ecosystem balance [1-3]. Global consumption of plastic bags is estimated at 0.5 to 1 trillion bags per year, or 1 to 2 million bags every minute [1]. In Brazil, it is estimated that about one and a half million plastic bags are distributed per hour in various commercial establishments such as shops and supermarkets. A small portion of these bags is recycled, while a significant amount ends up in landfills [4]. The high productivity and indiscriminate use of these bags, combined with improper disposal, have worsened environmental problems, especially in soil and water. It is estimated that about 10% of all organic waste collected in cities consists of single-use plastic bags, as it is common practice to use them to contain organic waste [5]. These bags are resistant and impermeable, which hinders the degradation of organic matter [6]. Given these circumstances, it is important to seek alternatives to mitigate the impacts resulting from the use of plastic bags as waste containers. Through composting and vermicomposting, these bags can be more easily separated in landfills. This allows for the valorization of organic waste while extending the lifespan of the landfill, reducing environmental impacts [7]. Composting is an exothermic aerobic biooxidation process of a heterogeneous organic substrate in solid state. It involves the production of carbon dioxide, water, mineral substances, and the stabilization of organic matter [8]. On the other hand, vermicomposting is a method for treating and valorizing the organic fraction of waste using species of earthworms [9]. These annelid animals are found in moist soils worldwide. They create tunnels and channels in the soil, where they reside and ingest plant residues along with significant amounts of soil. This ingestion results in the production of humus, which is decomposed organic matter and is considered an excellent nutrient source for plant growth [9]. The research conducted in this study aims to analyze the biological degradation and breakdown of high-density polyethylene plastic bags in a composting environment and a vermicomposting environment, using Eisenia fetida earthworms.

Experimental

Structure of Vermicomposting and Composting

Two identical structures were used, one for composting and the other for vermicomposting. The structure consists of two digestion boxes measuring 60 x 42 cm and a leachate collection base. The total height of the structure is 78 cm, with a volume of 45 liters, as shown in Fig 1. In both containers, garden soil (without additives or fertilizers), fruits, vegetables, greens, dry leaves, and cow manure were added in the same quantities. Temperature, pH, and soil moisture measurements were taken using a measurement sensor, Smart brand, model 4.1 Soil Survey Instrument, ISO 9001:2000.

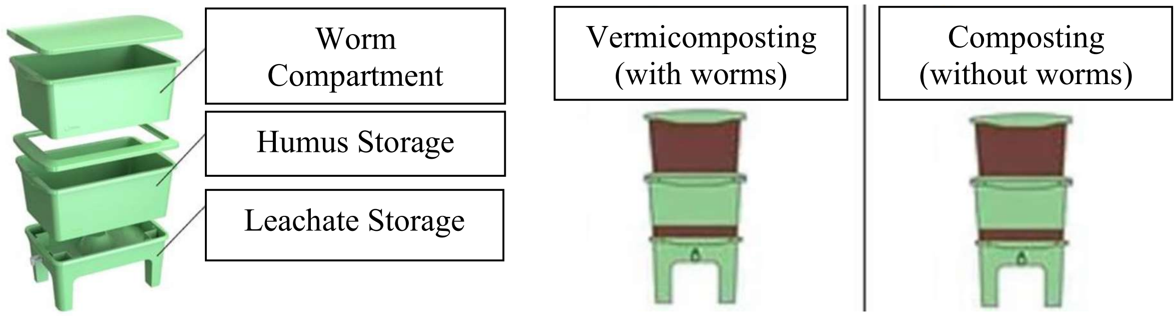

Figure 1 Structure Vermi/composting Humi. Source: https://composteirahumi.eco.br/

In the vermicomposting container, 942 adult worms of the species *Eisenia fetida* were added, as shown in Fig 2.

Figure 2 Minhocas *Eisenia fetida.*

Polymeric Samples

The samples, cut into strips measuring 20 x 5 cm, consist of an HDPE film collected from a supermarket, produced by Altaplast Embalagens, certified according to ABNT NBR 14937. The samples were collected in triplicate at 30, 60, and 90-day intervals.

Caracterization

The samples were analyzed using the following techniques: Fourier-transform infrared spectroscopy (FTIR) using a Perkin Elmer FT-IR spectrometer frontier with an attenuated total reflection (ATR) accessory; differential scanning calorimetry (DSC) using a Perkin Elmer DSC 6000 instrument; universal testing machine (tensile mechanical testing) using an Emic DL 20000 model; optical microscope (OM) using a 400X Series Digital Microscope.

Results and Discussion

The FTIR characterization was performed on the initial samples and after 30, 60, and 90 days of vermicomposting and composting. Fig 3 and Fig 4 show the FTIR spectra of the HDPE samples subjected to vermicomposting and composting, respectively.

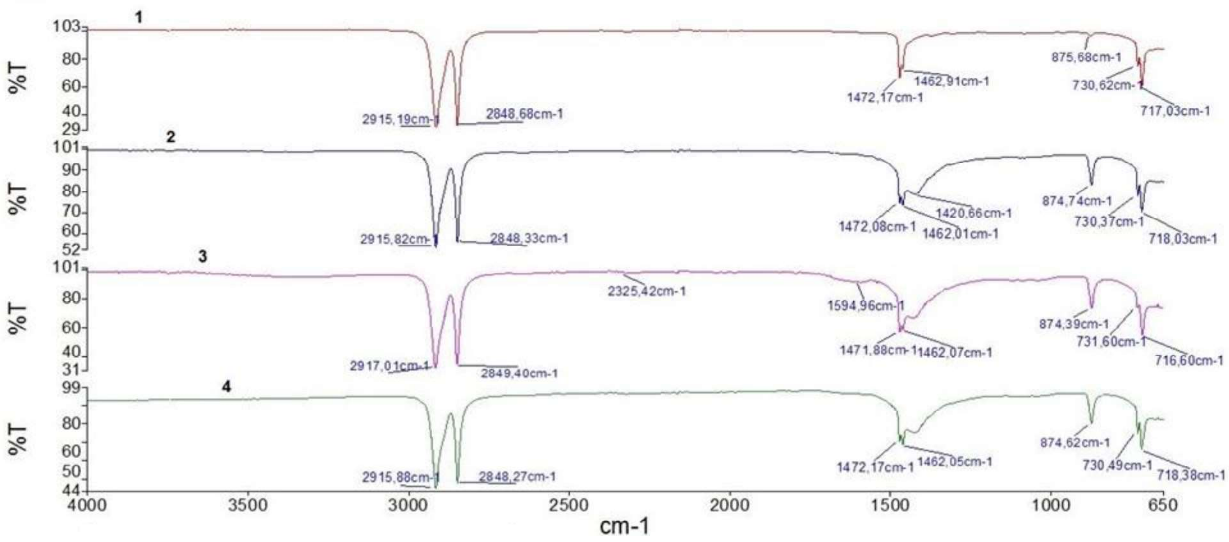

Figure 3 FTIR PEAD vermicomposting (1=0, 2=30, 3=60 e 4=90 days).

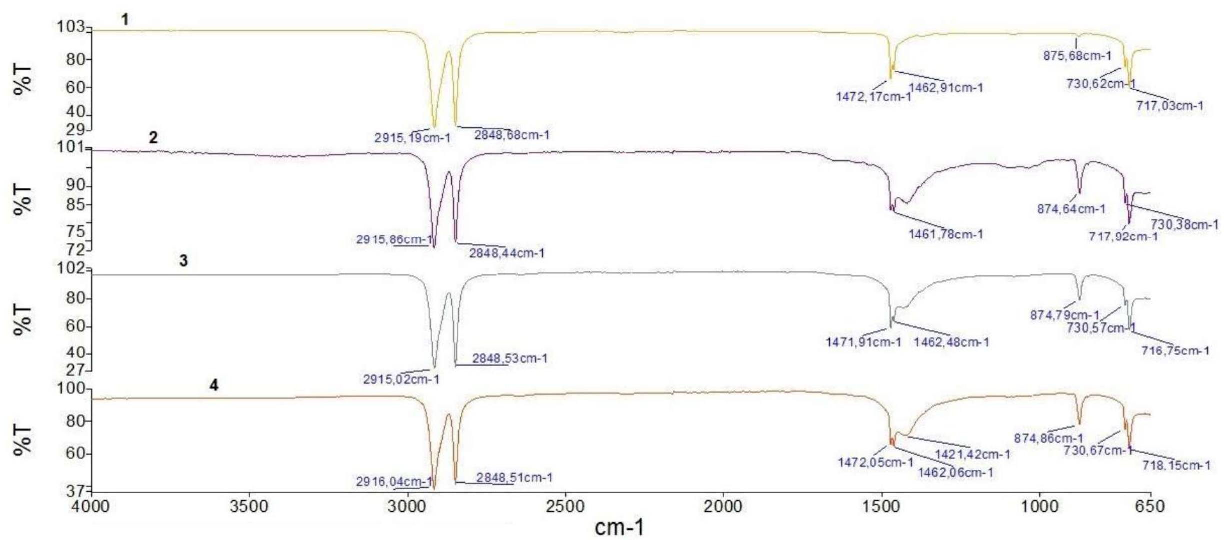

Figure 4 FTIR PEAD composting (1=0, 2=30, 3=60 e 4=90 days).

In the degradation of HDPE, the formation of carbonyl compounds and alkenes can be observed. In the spectra of 30, 60, and 90 days, this can be seen in the emergence of a peak in the 1420 cm-1 band, reflecting the formation of carbonyls, and the 874 cm-1 band indicating the formation of alkenes. Therefore, it can be inferred that degradation occurred in the polymeric chain of HDPE, both in vermicomposting and composting. Fig 5 presents the results of the tensile testing of the samples subjected to composting and vermicomposting.

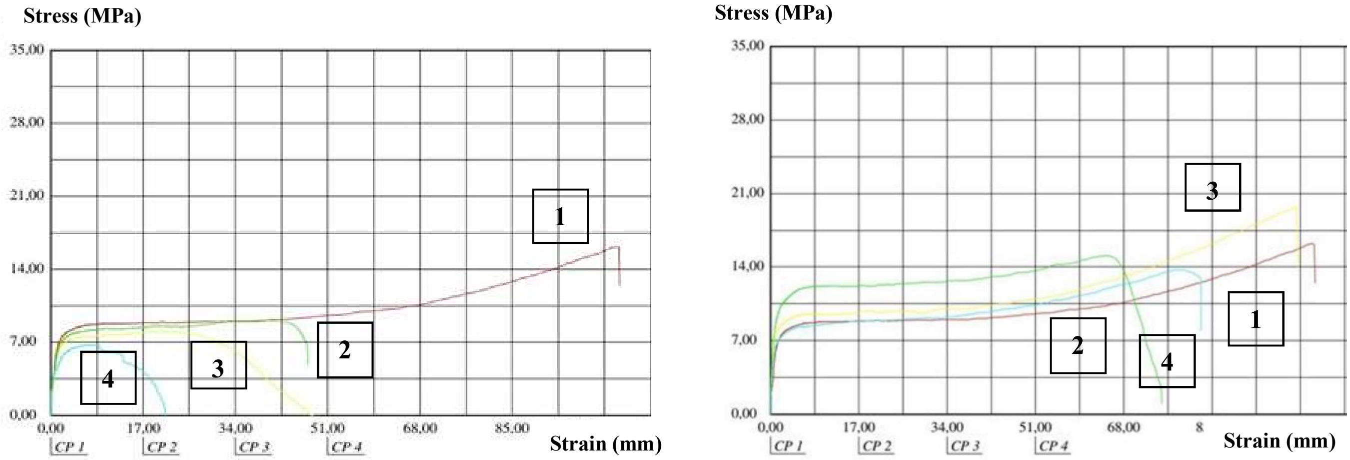

Figure 5 Tensile Testing of HDPE: Vermicomposting (left) and Composting (right) (1=0, 2=30, 3=60, and 4=90 days).

It can be inferred that the duration of vermicomposting and composting made the samples more fragile, with a lower modulus of elasticity. When analyzing the stress-strain graphs, a loss of mechanical properties can be observed in a large portion of the samples, with this effect being more pronounced in the vermicomposting samples. Significant reductions in maximum tensile stress (58.34%) and deformation (79.81%) are observed in the vermicomposting samples, while the yield stress remains stable. These results indicate significant changes in the mechanical properties after the vermicomposting process. In the composting process, the HDPE showed a 15.1% reduction in maximum tensile stress, an increase in yield stress, and a 20.7% reduction in deformation. Based on the data obtained from the DSC tests, Table 1 was prepared, showing the reductions in crystallinity of HDPE in relation to the method used, either vermicomposting or composting.

Table 1 Reduction in HDPE crystallinity.

Method	Material (days)	Ton	Tc	Tend	ΔHc	Ton	Tf	Tend	ΔHf	Xc (%)
Composting	HDPE 0	117,7	115,7	110,5	-117,9	120,1	127,4	130,1	107	**37**
	HDPE30	117,7	116	111,8	-128,8	120,5	128	130,5	126,8	**43,5**
	HDPE60	117,4	114,5	107,8	-132,9	121	129,9	132,7	113,3	**38,9**
	HDPE90	117,4	114,9	108,7	-120,1	121,1	129,5	132,4	106,3	**36,5**
Vermicompost.	HDPE 0	117,7	115,7	110,5	-117,9	120,1	127,4	130,1	107	**37**
	HDPE30	117,5	115,7	111	-82,2	120,9	128,3	130,9	87	**29,9**
	HDPE60	117,4	114,6	106,9	-105	120,9	130,2	133,3	99	**34**
	HDPE90	117,5	114,8	108	-95,2	120,6	128,9	131,6	89,1	**30,6**

There is a reduction in crystallinity observed only in the samples taken from vermicomposting. The 30-day sample showed a reduction of 7.1%, the 60-day sample showed a reduction of 3%, and the 90-day sample showed a reduction of 6.4%. These results corroborate with the findings from the mechanical tests, as a reduction in polymer crystallinity leads to a decrease in the elastic modulus.

On the other hand, the HDPE samples from composting showed small variations in the percentage of crystallinity, which was also observed in the mechanical tests with little variation in the material's elasticity. The images obtained by the optical microscope, Fig 6, highlight the change in the material's surface over time. It is possible to observe that more changes occurred in the surface of the samples subjected to vermicomposting. The tear in sample d, from vermicomposting, is a result of the passage of the annelid.

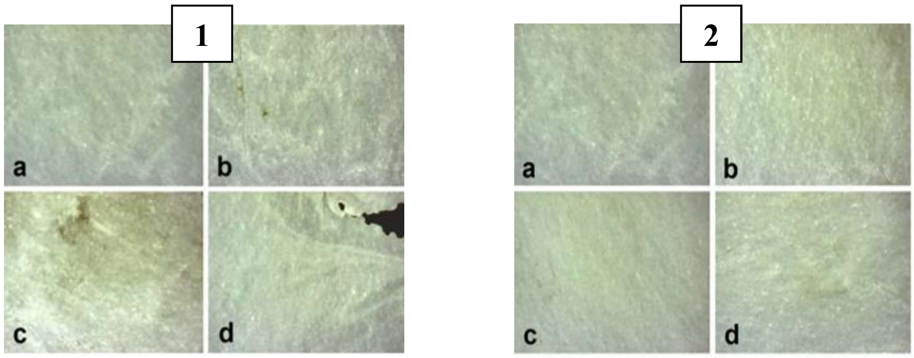

Figure 6 Optical microscopy (OM) HDPE vermicomposting (1), HDPE composting (2); after (a=0 day, b=30 days, c=60 days, d=90 days). Magnification scale 50X.

Conclusions

Based on the conducted tests, it can be concluded that degradation occurred in the polymeric films, with a notable effect in the vermicomposting process. In the case of HDPE samples, after 90 days, there was a decrease in maximum stress from 16.2 to 6.75 MPa, a reduction in elastic deformation from 104 to 21 mm, and a 6.4% decrease in crystallinity. In composting, after 90 days, there was a decrease in maximum stress from 16.2 to 13.75 MPa, a reduction in elastic deformation from 104 to 82.5 mm, and no significant reduction in crystallinity. FTIR analysis of both vermicomposting and composting samples revealed the formation of carbonyl compounds and alkenes, indicating polymer chain degradation. However, it can be concluded that vermicomposting showed higher efficiency in terms of biodegradation.

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