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Evaluating the efficiency of composting and vermicomposting for organic solid waste with the addition of biodegradable material

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ABSTRACT

Improper disposal of solid waste leads to environmental and socioeconomic damages. In Brazil, approximately 45.3% of urban solid waste destined for landfills and "dumpsites" consists of organic waste, resulting in a reduced lifespan of sanitary landfills. This study aimed to analyze the efficiency of composting and vermicomposting processes for organic waste with the addition of biodegradable material. Composters were monitored for 100 days, analyzing physicochemical parameters such as temperature, pH, moisture, and organic matter. Microbial activity was also monitored through analysis of compost basal respiration, microbial biomass carbon, and metabolic quotient. Throughout the research, it was observed that temperature exhibited similar behavior during composting and vermicomposting. At the end of the process, composting pH showed better results; however, vermicomposting yielded more satisfactory results in terms of moisture and organic matter content. Microbial activity remained active, showing expected results, with a decrease in basal respiration rates and microbial biomass carbon, along with an increase in the metabolic quotient. After the study, it was concluded that the addition of biodegradable material did not interfere with the processes, demonstrating compostability potential. Thus, it was possible to ascertain that composting and vermicomposting techniques for organic solid waste, combined with the use of biodegradable material, contribute to the valorization of the circular economy, providing improvements for urban environmental sustainability.

KEY-WORDS: Organic waste. Waste Management. Composting. Vermicomposting.

1 INTRODUCTION

The increase in waste generation has been intensified in recent decades due to urbanization and technological development processes, leading to changes in population lifestyles and consumption habits. Improper disposal of Municipal Solid Waste (MSW) poses risks to public health and the environment; therefore, it should be taken into account in the planning and implementation of public policies to assist in waste management.

In Brazil, the disposal of waste on the ground, without any technical basis for environmental conservation, is still a common practice. According to the Associação Brasileira de Empresas de Limpeza Pública (ABRELPE), in 2022, waste generation in Brazil reached a total of 81.8 million tons. Of the collected waste, approximately 61% was sent to sanitary landfills, totaling 46.4 million tons. However, 39% were improperly disposed of in "dumpsites" and controlled landfills, corresponding to 29.7 million tons (ABRELPE, 2022). Regarding organic waste, these represented, on average, 45.3% of the MSW generated in the country in 2020, totaling just over 36 million tons of food scraps and pruning waste, which are predominantly disposed of in sanitary landfills (ABRELPE, 2021).

In this scenario, the National Solid Waste Policy (PNRS) stands out, established by Law No. 12,305, regulated by Decree No.10,936, which encompasses a set of principles, objectives, and guidelines for the integrated management and environmentally-sound management of solid waste (BRASIL, 2010; 2022). The PNRS defines composting as an environmentally appropriate final disposal method for organic waste (BRASIL, 2010).

According to NBR No. 13,591 and CONAMA Resolution No. 481, composting is a process of biological decomposition of organic matter under controlled conditions, which include active degradation and maturation phases, resulting in a stabilized material with characteristics different from those originally presented (ABNT, 1996; BRASIL, 2017). Similarly to composting, vermicomposting is also a process of organic waste decomposition, but it involves the addition of earthworms and their interaction with microorganisms to accelerate the biodegradation process of waste.

The compounds and vermicomposts produced from organic waste can be reused as nutrient-rich fertilizers. In this context, Favarin, Ueno, and Oliveira (2015) analyzed vegetable production in relation to alternative substrates and observed that the substrate prepared with composting demonstrated superiority compared to the other substrates evaluated. This can be explained by its more efficient physicochemical characteristics for seedling development. In addition to contributing to a significant reduction in organic waste sent to landfills, the composting technique also has low installation and operation costs (LIM, LEE, WU, 2016).

Considering the advantages of composting, Onwosi *et al*. (2017) assert that public authorities play a fundamental role in promoting the use of this technique by supporting programs and initiatives for composting plants. These efforts contribute to the reduction of improperly disposed organic waste and also generate direct and indirect employment, resulting in socioeconomic and environmental benefits. In this context, the National Solid Waste Policy (PNRS) establishes the implementation of composting systems as part of the Municipal Integrated Solid Waste Management Plan (PMGIRS), as well as the methods for utilizing the produced compost (BRASIL, 2010).

In this context, Pestana and Ventura (2023) conducted a study in consorted municipalities in the state of São Paulo and identified composting as one of the greatest challenges for public management. Given that no actions aimed at this initiative were observed, it demonstrates that composting is not effectively implemented in these municipalities. Thus, it becomes increasingly necessary to promote technologies that can contribute to the management of municipal solid waste (MSW) and promote urban sustainability.

The adverse impacts resulting from the increase in the generation of municipal solid waste (MSW), especially plastics, represent a serious problem for waste management, as most of these materials are difficult to degrade under natural conditions, accumulating in the environment for decades (YUAN *et al*., 2020). In this regard, more sustainable alternatives for the use of plastic materials are being widely studied (LAVAGNOLO *et al*., 2020; NOMADOLO *et al*., 2022; ASHOKKUMAR *et al*., 2022). In this scenario, biodegradable materials emerge as a viable option, as they can degrade within a defined period without causing negative environmental impact (NOMADOLO *et al*., 2022). Consequently, the hypothesis posits that composting represents an effective technique to enhance the decomposition of biodegradable materials, as well as for the treatment of the organic fraction of MSW.

Furthermore, composting, combined with the use of biodegradable materials, constitutes a crucial tool for the circular economy. It enables the reintegration of materials into the production cycle, adding value to organic waste, minimizing socio-environmental impacts, and contributing to sustainable development (OBERLINTNER *et al*., 2021; SANTOS *et al*., 2022). In this context, Karl (2022) asserts that the practice of composting plays a significant role in achieving the goals of the Sustainable Development Goals (SDGs) outlined in the United Nations' 2030 Agenda (UN, 2023). Therefore, the proper management of MSW is essential for environmental preservation, the promotion and protection of health, as well as for improving the environmental quality of municipalities.

2 OBJECTIVES

The present study aimed to analyze the efficiency of composting and vermicomposting of organic solid waste with the addition of biodegradable material, evaluating physicochemical and microbiological parameters.

3 METODOLOGY

The experiments were conducted at the Universidade Estadual do Centro-Oeste (UNICENTRO), Irati campus. The waste used for the composting and vermicomposting processes consisted of 70% dry materials such as pruning branches, leaves, and tree bark found at UNICENTRO, 25% organic waste from the campus dining hall, and 5% biodegradable material. This biodegradable material was provided by a research group from the natural polymers development and application laboratory at the Universidade Estadual de Ponta Grossa (UEPG) and was composed of 60% thermoplastic starch, 40% poly(butylene adipate-co-terephthalate) (PBAT), and vitamin E.

For the implementation of the experiment, two commercial domestic composters were used. One composter was designated for composting and the other for vermicomposting. The process was monitored over a period of 100 days (approximately 15 weeks). In the vermicomposting process, an initial pre-composting phase occurred over 68 days, after which *Eisenia fetida* worms were added for a period of 32 days. According to Lim, Lee, and Wu (2016), *Eisenia fetida* worms are the most suitable for the vermicomposting process because they are considered more efficient in the biodegradation of organic waste and the release of nutrients into the soil. Additionally, they have wide distribution, are resistant, and tolerant to temperature variations.

3.1 Monitoring of physicochemical parameters

The process was monitored by analyzing the physicochemical parameters of temperature, pH, moisture, and organic matter. The temperature of the composter was measured daily using an analog thermometer. Aeration of the composters was performed manually by turning the contents, always after recording the temperature readings. It is noteworthy that turning helps eliminate biological contamination and ensures the uniformity of the compost.

The pH determination was carried out daily by measuring with a pH meter with an electrode immersed in a mixture of compost sample and distilled water (TEIXEIRA *et al*., 2017). The readings were conducted using a benchtop pH meter.

The moisture content was monitored daily based on the gravimetric difference between the weight of the sample before and after drying in an oven. Meanwhile, the organic matter content was calculated weekly by using the gravimetric difference between the weight of the sample dried in an oven and after its incineration in a muffle furnace (TEIXEIRA *et al*., 2017).

3.2 Monitoring of microbiological parameters

The efficiency of the composting process is directly related to aerobic decomposition and microbial activity. In the present study, monthly monitoring was conducted of Basal Compost Respiration (BCR), Microbial Biomass Carbon of Compost (C-MBC), and Metabolic Quotient (qCO_2).

The analysis of BCR was conducted according to the method of Jenkinson and Powlson (1976), where respiration is determined after incubating the samples for 7 days. C-MBC was obtained based on the induced respiration method proposed by Anderson and Domsch (1978). qCO_2 is the ratio between BCR and C-MBC, following the methodology of Anderson and Domsch (1993).

3.3 Data analysis and experimental design

For the analysis of the physicochemical parameters of temperature, pH, moisture, and organic matter, the data obtained throughout the process were used, and arithmetic means were calculated for both composting and vermicomposting.

During the study, three collections were made for microbial analysis, constituting a type of sampling known as dependent or repeated measures. In this sampling configuration, Analysis of Variance (ANOVA) for repeated measures was used, where the dependent variables were: BCR, C-MBC, and qCO_2. The collections formed the factor, i.e., the effect of the time the material remained confined on the aforementioned dependent variables was evaluated. Pairwise mean contrasts were checked using the Tukey test.

After 67 days of confinement (second collection), part of the material underwent vermicomposting. To compare the statistical differences between the confined material without and with vermicomposting after 93 days of the experiment (third collection), the Student's t-test for independent samples was calculated. The microbial variables compared were the same as those used to check the effect of confinement time.

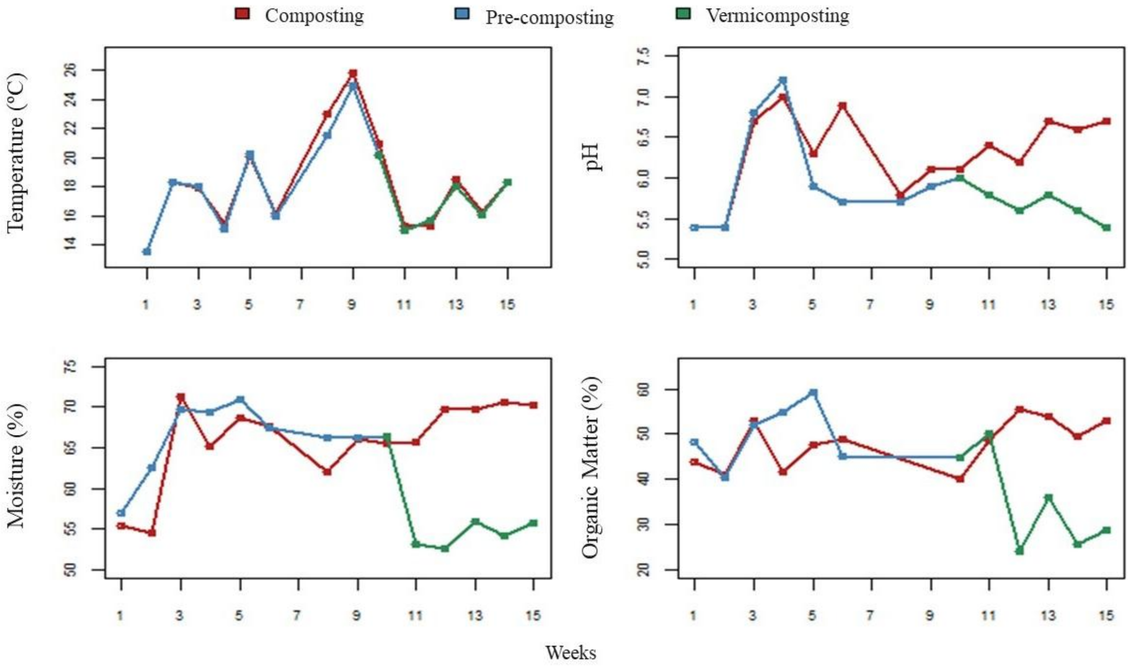
For the statistical tests, significance was considered for values of $p < 0.05$ (95% confidence level). The assumptions of sphericity and normality, inherent to Repeated Measures ANOVA, were assessed through Mauchly's sphericity test and Shapiro-Wilk's test for normality. For the Student's t-test, homogeneity of variances was verified. When assumptions were violated, data transformation via square root was chosen (ZAR, 1999). Analyses and graphical representations were conducted using Rstudio© software, version 0.99.903–2009-2016 (R CORE TEAM, 2023).

4 RESULTS AND DISCUSSION

Throughout the composting process, it was observed that, after 30 days, the biodegradable material had decomposed almost entirely, with no detriment to the process's progression. This highlights a compostable material with features conducive to sustainable management of such materials. The efficacy of composting for breaking down materials based on biodegradable polymers is also evidenced in the studies by Taiatele Junior (2014), Toro (2015), and Piai (2022).

Through the analysis of physicochemical parameters, differences in the mean values of pH, moisture, and organic matter were noted, whereas temperature remained consistently close throughout the monitoring period. The mean results for the physicochemical parameters can be observed in Figure 1.

Figure 1 - Mean values of temperature, pH, moisture, and organic matter during the process.



Source: Authors (2023).

Temperature is one of the key parameters for monitoring composting, serving as an indicator of process functionality. Thus, it can be observed that throughout the entire period, temperature exhibited similar behavior in both composting and vermicomposting processes (Figure 1).

The results of this study indicate that, during the initial weeks, temperatures did not reach the optimal range of 45-65°C (PARANÁ, 2020). This may have been due to the environment in which the composters were placed, potentially leading to heat loss to the surroundings. According to Lim, Lee, and Wu (2016), composting can exhibit low temperatures when the layer of decomposing material is not thick enough to retain a significant amount of heat, leading to rapid heat transfer, also influenced by low ambient temperature or the properties of the materials used for composting. However, in this study, satisfactory temperature results were obtained throughout the process, as for vermicomposting, it is necessary to maintain temperatures not excessively high or low to ensure the survival of earthworms and the viability of the process (DAL BOSCO *et al.*, 2017).

The pH is an important parameter as it affects microbial activities during the process. According to Pereira Neto (2007), the ideal range for the final compost is considered to be between 7.5 and 9.0. In this study, it is observed that composting exhibited a pH reduction at the beginning of the process, followed by an increase until reaching a final stabilization close to neutrality (Figure 1).

In this regard, Toro (2015) evaluated the degradation of organic solid waste through the composting method in windrows, with the presence of compostable packaging, and observed discrepancies in pH values. The author noted that the results of this parameter were influenced by various factors, such as the difference in organic waste used or the selected monitoring point not uniformly representing the entire material. It was also found that over time, the biodegradable packaging did not significantly interfere with the process, exhibiting similar behaviors when compared to composting results without the packaging.

In the present study, it was observed that in the final phase of the process, vermicomposting followed a trend towards a more acidic pH; however, it maintained conditions acceptable for the survival of the earthworms. According to Lourenço (2010), earthworms of the species *Eisenia fetida* exhibit relative tolerance to pH variations, particularly between 5.0 and 9.0; outside of this range, their activities may be compromised.

Moisture content is a critical parameter in the composting process. For this parameter, moisture levels in the range of 55% are considered satisfactory (PARANÁ, 2020). It can be observed in Figure 1 that, in the initial phase, composting exhibited a high moisture content, remaining relatively stable throughout the process until the final phase, where it reached a value of 70%. The vermicomposting process showed similar behavior initially; however, there was a considerable reduction after the addition of earthworms, reaching a moisture content close to 55%. According to Beltrame (2018), an increase in moisture can occur due to the composition of the organic matter used in composting, as vegetables and plant stems contain excess water. Another factor to highlight is inefficient aeration, which also directly affects the moisture of the compost.

Despite composting presenting moisture values considered above the ideal range at the end of the process, in the present study, vermicomposting achieved satisfactory values, which is crucial for the maintenance of earthworms, as excessive or insufficient moisture can cause their mortality (LOURENÇO, 2010).

During the composting process, organic matter undergoes mineralization, reducing in quantity as degradation occurs (KIEHL, 1998). Figure 1 illustrates the decomposition of organic matter during the experiment, showing differences between the means of composting and vermicomposting.

From the results obtained in this study, it is noticeable that, compared to vermicomposting, the composting process did not exhibit the same efficiency regarding the decomposition of organic matter. This discrepancy may have occurred due to fluctuations in temperature and moisture throughout the process, which could have influenced microbial activity and degradation rates. On the other hand, it was observed that the decomposition process was more pronounced for vermicomposting. This is attributed to the earthworms' ability to process large quantities of organic matter, particularly in the final phase when they have higher biomass and are more active in the decomposition process (LOURENÇO, 2010).

During composting, organic matter decomposes and stabilizes, leading to the formation of CO_2, primarily by bacteria and fungi (SILVA; AZEVEDO; DE-POLLI, 2007). Table 1 shows the values and significance tests for the microbiological parameters of BCR, C-MBC, and qCO_2.

Table 1 - Means and significance tests of BCR, C-MBC, and qCO_2 at different sampling periods.

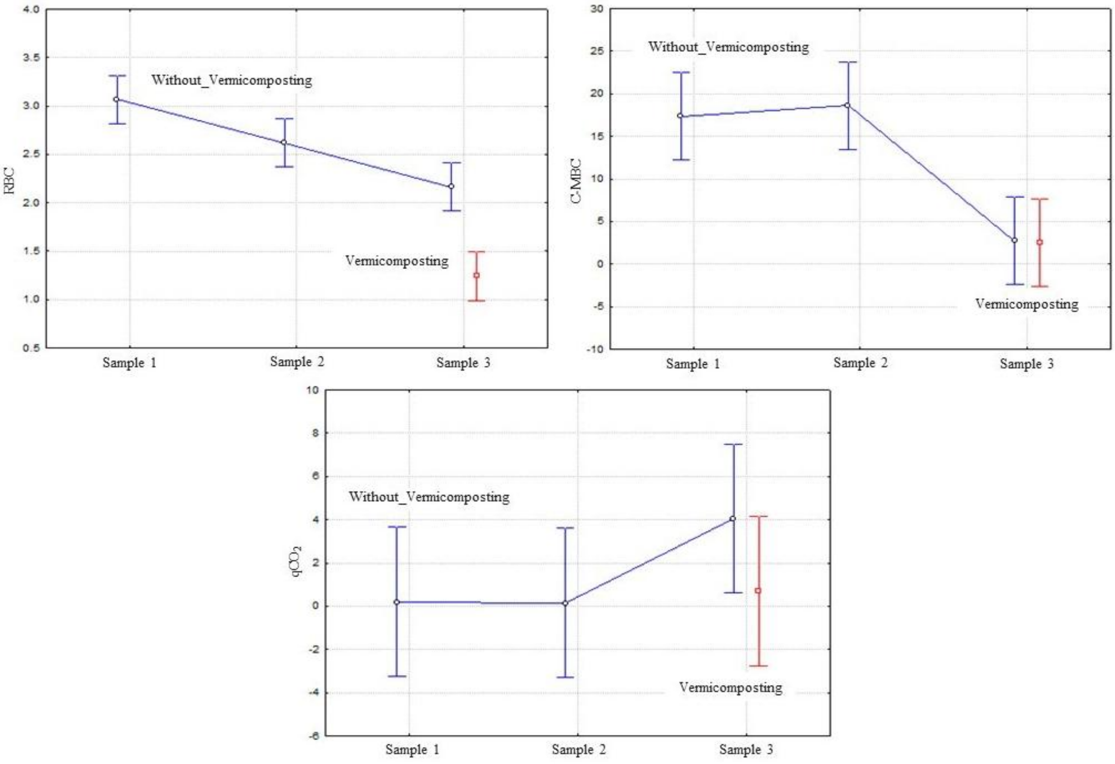
Parameters	Samples	Means and Tukey Test	Student's t-test
BCR	Sample 1	3,07 a	-
	Sample 2	2,62 ab	-
	Sample 3	2,17 b	a
	Vermicomposting	1,24	b
C-MBC	Sample 1	17,38 a	-
	Sample 2	18,64 a	-
	Sample 3	2,74 b	a
	Vermicomposting	2,49	a
qCO_2	Sample 1	0,19 b	-
	Sample 2	0,15 b	-
	Sample 3	4,06 a	a
	Vermicomposting	0,70	b

Note: Means followed by the same letter do not differ statistically at the 5% significance level.
Source: Authors (2023).

Based on Table 1, it is noted that there was variation in the microbiological parameters over the composting period, showing statistical differences between the first and third collections. In this context, BCR presented statistically different means between the last composting collection and vermicomposting ($t = -5.493$; p-value = 0.005). Similarly, it was observed that the means of composting and vermicomposting for qCO_2 differed statistically ($t = -5.119$; p-value = 0.006). On the other hand, the analysis of C-MBC did not show a statistically significant difference between the means of the material with and without vermicomposting ($t = -0.108$, p-value = 0.912).

The variation of microbiological parameters at different sampling periods can be observed in Figure 2.

Figure 2 - Means and standard deviations for BCR, C-MBC, and qCO_2 at different sampling periods



Source: Authors (2023).

In the present study, BCR significantly fluctuated over the confinement period (Figure 2), showing a statistically higher mean after the first collection (Table 1), decreasing until the last day of confinement. BCR is directly related to substrate availability and microbial biomass. Therefore, it is expected that CO_2 release decreases over time. According to Viceli (2017), a high BCR index indicates increased microbial activity and decomposition of organic substances, while a low index indicates a reduction in activity and organic matter degradation. Thus, the higher the metabolic activity of the microorganisms, the greater the production of CO_2.

Vermicomposting demonstrated a significant effect on respiration, as the mean BCR values in this study were statistically higher for the compost without vermicomposting, possibly due to the action of earthworms influencing substrate availability for microorganisms. According to Domínguez *et al*. (2019), vermicompost is the result of the joint action of earthworms with microorganisms, which can promote changes in the functions and composition of microbial communities.

Microbial biomass analysis serves as an important indicator of changes in the quantity and state of organic matter (REIS JUNIOR; MENDES, 2007). In Figure 2, it is observed that the carbon present in microorganisms significantly decreased, with lower means in the last collection when contrasted with the other collection dates. Vermicomposting did not show a significant effect, as the means of vermicompost and compost did not differ in terms of carbon present in microorganisms (Table 1).

Throughout the composting and vermicomposting processes, it is natural to observe a decrease in the C-MBC content, similar to what occurs in BCR, due to the reduction of substrate, which reduces microbial activity and growth. Microorganisms play a role in the processes of mineralization and immobilization of nutrients. Therefore, during the decomposition of organic matter, part of the nutrients can be immobilized in the microbial biomass, which is considered one of the fundamental elements in controlling the degradation of organic matter (REIS JUNIOR; MENDES, 2007).

The metabolic quotient expresses the respiration rate per unit of microbial biomass. In this study, it can be observed that qCO_2 differed between the first two collections and the last one, significantly increasing in average value (Figure 2). Vermicomposting showed a significant interference (Table 1). It is important to note that the data related to qCO_2 violated the principles of normality and sphericity; therefore, they were transformed by square root and then adhered to the assumptions of the analysis.

The qCO_2 rate can be used as an indicator of changes in C-MBC and also to assess the efficiency of substrate utilization by microorganisms (SILVA; AZEVEDO; DE-POLLI, 2007). Thus, BCR and C-MBC directly influence qCO_2 because a reduction in microbial biomass also results in reduced respiration and consequently an elevation in qCO_2. According to Reis Junior and Mendes (2007), an increase in qCO_2 values may indicate some form of metabolic stress in microbial communities. In samples with the same biomass values, the one with the lower qCO_2 rate is considered the most efficient.

In this context, Dornelles *et al*. (2017) stated that microbiological parameters are directly influenced by the sensitivity of microorganisms to the environment they are exposed to. The authors evaluated the use of Municipal Solid Waste (MSW) and Liquid Swine Manure (LSM) in the dynamics of biomass and biological activity in soil from the northern region of Rio Grande do Sul, Brazil. They observed that the influence of MSW organic compost was greater compared to LSM, stimulating microbial activity, regardless of the quantity. Thus, the authors found that basal respiration and microbial biomass carbon proved to be sensitive indicators for monitoring changes in soil due to the type of waste, dosage, and application time.

Based on the results obtained in this study, it was possible to affirm that the practice of composting on a household scale represents an efficient alternative for the disposal of organic solid waste together with biodegradable material based on thermoplastic starch, PBAT, and vitamin E. Thus, sustainable actions focused on composting can contribute to reducing the amount of organic waste disposed of in landfills, minimizing greenhouse gas emissions, promoting waste valorization, and reducing public sector expenses on solid waste management.

In this context, Santos *et al*. (2022) state that domestic composting contributes to sustainable development by reducing the socio-environmental impacts resulting from the generation of solid waste, fostering more circular cities, and promoting more sustainable consumption patterns, in line with the goals established by the Sustainable Development Goals (SDGs).

5 CONCLUSIONS

With the completion of the present study, it was noted that although composting is not a recent technology, it has been gaining prominence due to the increasing concern for sustainability and being considered, by the National Solid Waste Policy (PNRS), as an environmentally appropriate destination for organic waste.

In this research, it was observed that composting and vermicomposting resulted in the complete breakdown of the biodegradable material. The earthworms also demonstrated good development in the compost mixture. Therefore, it was found that the introduction of the biodegradable material did not interfere with the composting and vermicomposting processes, showing good compostability. Thus, the viability of using the material in composting and vermicomposting processes was confirmed, providing an alternative capable of contributing to MSW management and facilitating the process in composting plants, as there is the possibility of disposing of this material along with household organic waste destined for the plant.

In light of the above, it can be concluded that, in a situation such as that reproduced in this study, the implementation of composting emerges as an effective proposition for treating the organic fraction of MSW. This is because it is a viable, highly efficient, low-cost, and easily monitored technique that can be deployed domestically by waste generators themselves. In this scenario, composting holds the potential to significantly contribute to the SDGs, addressing various dimensions of sustainability to meet the targets of the 2030 Agenda at the local level. Thus, it represents a crucial tool for sustainable development, offering socio-economic and environmental benefits while promoting public health protection and urban environmental sanitation.

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