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SUSTAINABLE MANAGEMENT OF CIGARETTE WASTE: EFFECTS ON VERMICOMPOSTING

GESTÃO SUSTENTÁVEL DE RESÍDUOS DE CIGARROS: EFEITOS NA VERMICOMPOSTAGEM

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ABSTRACT

The improper disposal of confiscated cigarette waste represents an emerging environmental challenge due to the presence of nicotine, heavy metals and trace elements and other potentially toxic compounds. In this study, we evaluated the feasibility of co-processing cigarette residues with household organic waste through vermicomposting, assessing the biological performance of the system using *Eisenia fetida* as an indicator species. Three experimental treatments were established: a control with plant-based organic residues, a treatment incorporating cigarette waste, and a treatment combining cigarette waste with biological accelerators. Earthworm abundance and body length were monitored throughout the vermicomposting process as proxies for substrate suitability and system stability.The results indicate that cigarette residues can be biologically processed via vermicomposting; however, their presence was associated with reduced earthworm growth and population dynamics compared to the control treatment. The addition of biological agents partially mitigated these adverse effects, resulting in earthworm body lengths comparable to the control group, although population increases remained lower. These findings suggest that cigarette waste imposes biological constraints on decomposer organisms, likely associated with residual toxic compounds, but that targeted biological strategies may attenuate these limitations. Overall, this study provides biological evidence supporting the potential reuse of confiscated cigarette waste within circular waste management frameworks. Nevertheless, complementary chemical and ecotoxicological assessments are necessary to ensure the environmental safety and agronomic viability of the resulting compost.

Keywords: waste reuse; soil fauna; circular economy; biological agentes; abundance.

RESUMO

A destinação inadequada de resíduos de cigarros apreendidos representa um desafio ambiental emergente devido à presença de nicotina, metais pesados, elementos-traço e outros compostos potencialmente tóxicos. Neste estudo, avaliou-se a viabilidade do coprocessamento de resíduos de cigarros com resíduos orgânicos domésticos por meio da vermicompostagem, utilizando Eisenia fetida como espécie indicadora. Foram estabelecidos três tratamentos experimentais: um controle com resíduos orgânicos de origem vegetal, um tratamento com incorporação de resíduos de cigarros e um tratamento combinando resíduos de cigarros com aceleradores biológicos. A abundância e o comprimento corporal das minhocas foram monitorados ao longo do processo de vermicompostagem como indicadores da adequação do substrato e da estabilidade do sistema. Os resultados indicaram que os resíduos de cigarros podem ser processados biologicamente por meio da vermicompostagem; entretanto, sua presença esteve associada à redução do crescimento das minhocas e da dinâmica populacional em comparação ao tratamento controle. A adição de agentes biológicos atenuou parcialmente esses efeitos adversos, resultando em comprimentos corporais das minhocas semelhantes aos observados no grupo controle, embora os aumentos populacionais tenham permanecido inferiores. Esses resultados sugerem que os resíduos de cigarros impõem limitações biológicas aos organismos decompositores, provavelmente associadas à presença de compostos residuais potencialmente tóxicos, mas que estratégias biológicas direcionadas podem atenuar essas limitações. De modo geral, este estudo fornece evidências biológicas que apoiam o

potencial de reutilização de resíduos de cigarros apreendidos em estratégias de gestão circular de resíduos. Entretanto, avaliações químicas e ecotoxicológicas complementares são necessárias para garantir a segurança ambiental e a viabilidade agronômica do composto resultante.
Palavras-chave: reutilização de resíduos; fauna do solo; economia circular; agentes biológicos; abundância.

INTRODUCTION

The use of organic fertilizers and composting processes are well established as sustainable and low-cost practices in agriculture, promoting the recycling of organic residues as alternatives to conventional chemical fertilizers (Oliveira et al., 2025; Lins et al., 2025). In addition to reducing production costs (Guse et al., 2012), composting enhances farmers' autonomy by enabling on-farm production of agricultural inputs and supports more ecologically and economically sustainable management of agricultural systems (Francelin and Cortez, 2014). Within this context, organic waste recycling, aligned with circular economy principles, plays a fundamental role in mitigating contemporary environmental challenges (Barbosa Gazzola et al., 2025), as it prevents improper waste disposal, reduces emissions of polluting gases in landfills—such as methane (Lima et al., 2023; Scharff et al., 2024)—and transforms residues into value-added products (Oyedeji et al., 2024).

In this context, composting stands out as an efficient biotechnological process for converting organic residues into nutrient-rich fertilizers (Luo et al., 2024). Once incorporated into the soil, these materials contribute to improvements in physical structure (Al-Omran et al., 2021), fertility (Reimer et al., 2023), and water-holding capacity (Fornes et al., 2024), thereby promoting plant development at reduced costs (Ansar et al., 2025). Thus, integrating composting with circular economy principles and the reuse of by-products supports the transition toward more sustainable and resilient agricultural systems (Romero-Perdomo et al., 2022; Selvan et al., 2023).

In addition to food waste, the improper disposal of seized cigarettes constitutes a relevant environmental problem that demands technically and environmentally viable solutions. In 2021, the Brazilian Federal Revenue Service destroyed more than BRL 1.5 billion worth of smuggled cigarettes, a measure that is legally and socially necessary, yet associated with significant environmental impacts due to the presence of nicotine, trace metals, and other potentially toxic compounds (Pauletti, 2022).

Composting can be associated with bioremediation strategies, as the degradation of organic matter promotes the development of microbial communities capable of transforming and degrading toxic compounds present in residues (Fernandes and Silva, 2021; Uebel et al., 2018). This approach not only contributes to environmental recovery (Souza et al., 2024), but also enhances the safety of the final products obtained, provided that the process is properly evaluated (Da Silva et al., 2018). Against this background, the treatment of cigarette waste through composting emerges as a promising alternative to reduce environmental contamination and potentially generate sustainable agricultural inputs, aligned with principles of reuse and waste valorization.

The primary purpose of the compost is its application as a fertilizer in pots or directly in soil (Ferreira et al., 2013; Souza et al., 2024).

However, to ensure its agronomic and environmental viability, it is essential to evaluate appropriate application rates, nutritional benefits, and compost quality, aspects that depend directly on the nature of the raw materials used. In this regard, chemical and biological analyses are essential both before and after soil application, allowing for the assessment of agroecosystem sustainability. Integrative tools, such as BioAS technology, based on biological and enzymatic indicators, have been developed to evaluate microbial activity, organic matter dynamics, and soil functionality (Mendes et al., 2021).

Compost quality depends on the characteristics of the raw materials and on appropriate management, and it is well documented that adherence to technical recommendations is critical to obtaining a stable and safe product (Ansorena et al., 2014; Silva et al., 2022; Manea et al., 2024).

A recent development involves the use of commercial composting products that provide consortia of beneficial microorganisms, such as yeasts, lactic acid bacteria, and spore-forming bacteria, which are widely recognized for their role in accelerating organic matter decomposition (Oliveira and Melo, 2015). These microorganisms enhance microbial metabolism, favor the degradation of assimilable compounds (Roni and Soni, 2007), and stimulate enzyme production (da Silva Gaspar et al., 2023), contributing to the generation of a high-quality final product with positive effects on soil biodiversity and health (Tran et al., 2015). For the safe incorporation of organic residues as nutrient sources, it is essential to understand process outcomes and evaluate whether the economic investment in such products is justified.

In recent years, there is increasing pressure to promote the reuse of by-products that would otherwise be discarded, driven by the growing demand for more sustainable production systems. However, implementing such strategies is often challenging, as their feasibility depends largely on the nature and characteristics of the material intended for reuse. In other words, the potential for valorization is directly influenced by the type of raw material being considered. Transforming tobacco-derived residues (*Nicotiana tabacum* L.) into raw material for biological processes such as composting represents a challenge. These residues exhibit toxic potential primarily due to the presence of nicotine (Geada et al., 2010) and residual heavy metals associated with agrochemical use, which may affect not only plants but also other living organisms involved in biological degradation processes (Mendoza-Escalona et al., 2021; Ortega-Moctezuma et al., 2023). Nevertheless, these residues also contain nutrients inherent to the tobacco plant, making them materials of interest within composting-based bioremediation strategies, provided that they are properly stabilized prior to use in vermiculture systems.

Within this framework, composting microorganisms play a key role in the degradation of potentially toxic organic compounds through enzymatic activity, temperature increases, and intensified microbial activity (Wong and Pangging, 2023).

Therefore, vermicomposting represents a potential alternative to conventional composting by incorporating earthworms as active biological agents. This process can improve compost quality, enhance nutrient availability for agricultural use, and benefit from synergistic interactions with microbial communities. Its combined application with traditional composting contributes significantly to the recovery of areas affected by industrial and agricultural residues. Bioremediation, understood as a biological process that employs living organisms such as microorganisms and earthworms to transform toxic substances into less harmful compounds, has been shown to be an effective approach for the rehabilitation of contaminated environments (Chachina et al., 2023).

According to Bonacina (2020), these strategies stand out as efficient and low-cost alternatives for environmental recovery, offering more sustainable options than incineration or final disposal in landfills. Moreover, the use of organisms such as the red Californian earthworm not only promotes the degradation of toxic compounds but also contributes to the restoration of soil physicochemical properties (Baldeon Coronado et al., 2025), although outcomes depend on the residue dose to which these organisms are exposed. Thus, composting can enhance the degradation of contaminant substances and promote more robust environmental recovery, as highlighted by Fernandes and Silva (2021).

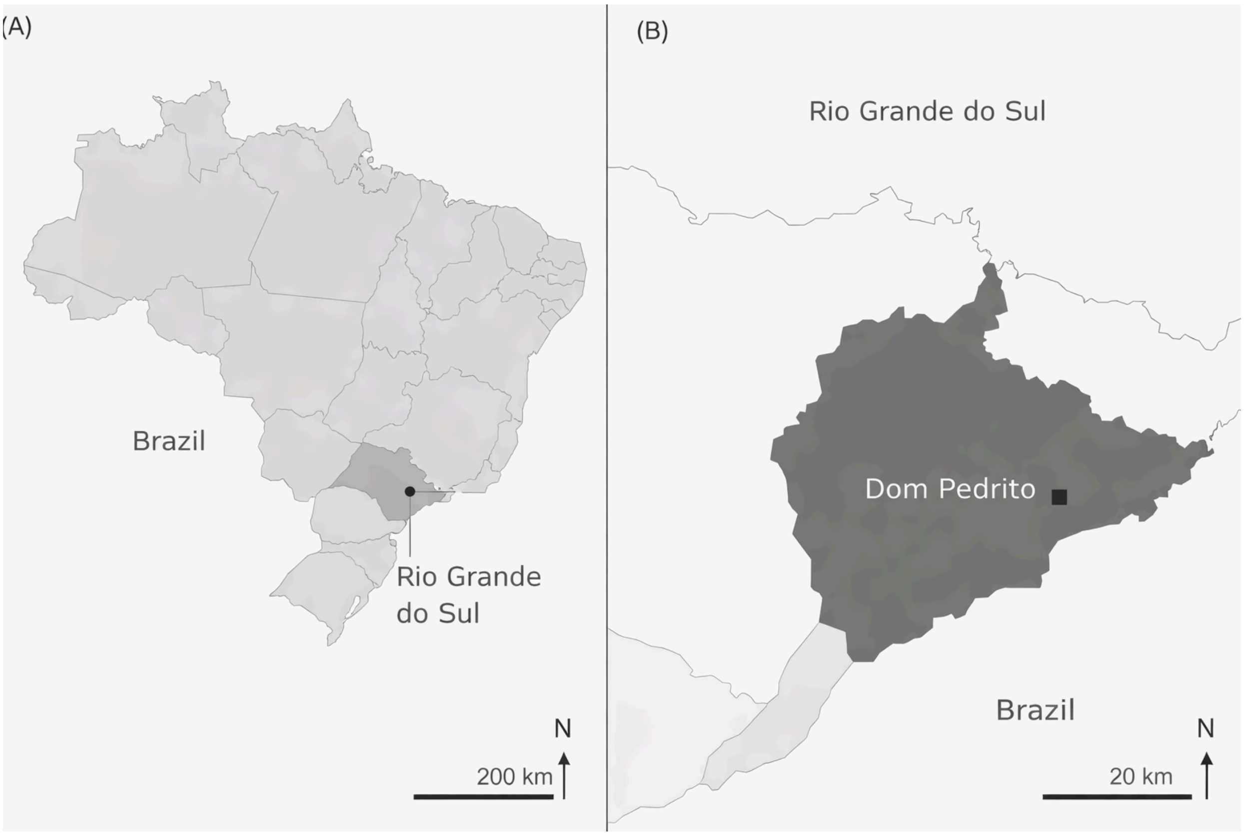
In this context, considering the strong agricultural vocation of southern Brazil and the growing demand for organic inputs to improve soil fertility, as well as the environmental challenges associated with the improper disposal of organic waste and seized cigarettes by the Brazilian Federal Revenue Service, this study aimed to evaluate the effectiveness of composting seized cigarettes in combination with household food waste. Specifically, two vermicomposting variants were analyzed, with emphasis on the viability of the residual raw material and its effects on earthworm abundance and size, in order to determine whether this process constitutes a safe and effective alternative for producing high-quality organic compost. Although conducted in southern Brazil, the findings are applicable to broader contexts involving tobacco-related waste management worldwide.

Materials and Methods

Study area

The study was conducted in the municipality of Dom Pedrito, located in the Southwest mesoregion of the state of Rio Grande do Sul, Brazil, and part of the Campanha Meridional microregion. The municipality lies within the Uruguay River Hydrographic Region, specifically in the Santa Maria River watershed (Figure 1).

Figure 1. Location of the study area in Dom Pedrito, Rio Grande do Sul, southern Brazil. Map boundaries are for visualization purposes only and do not imply official territorial claims.



Source: adapted from IBGE (2023).

Dom Pedrito is bordered to the north by Rosário do Sul, São Gabriel, and Lavras do Sul; to the east by Bagé; to the south by the city of Rivera, in the Oriental Republic of Uruguay; and to the west by Santana do Livramento (Nascimento et al., 2020). The study area is located in the Campanha Gaúcha region, which is historically linked to agricultural and livestock production (César, 2025) and holds significant regional productive relevance (Hanke et al., 2022).

Although Dom Pedrito does not present local tobacco production, the state of Rio Grande do Sul concentrates a substantial portion of national tobacco production, with southern Brazil representing one of the main tobacco-producing regions in the country (Vargas et al., 2012).

The study region is part of the Pampa Biome, one of the main natural domains of southern South America, characterized by grassland landscapes and high biodiversity. This biome occupies approximately 63% of the territory of Rio Grande do Sul and extends into areas of Argentina and Uruguay (Suertegaray and Silva, 2009).

Raw materials for composting

According to Höfig et al. (2022), the co-composting of organic materials represents an effective alternative for producing regionally based organic fertilizers, promoting the sustainable use of local resources. These authors report that residues such as sawdust, fruit waste, and coffee husks allow the production of compost with high nutrient content and adequate biological stability, with potential to improve soil chemical, physical, and biological properties while reducing dependence on chemical inputs and fossil fuels.

In the present study, the raw materials used for composting consisted of household organic waste, including fruit peels, yerba mate residues, coffee grounds, and eggshells. Additionally, leaf litter collected from a native forest was incorporated in order to enhance microbial diversity within the system. Prior to incorporation, food waste was weighed to standardize the quantities applied across all experimental units. Subsequently, these materials underwent a biological transformation process, and the resulting material was used in the different experimental treatments.

Experimental design and sampling

The experiment was conducted using six composting boxes distributed among three experimental treatments, with two replicates per treatment. The composters were made of polypropylene and featured a vertical design composed of three stacked compartments, each with an individual capacity of 50 L, resulting in a total volume of 150 L per composter. Two compartments were designated for the solid composting process, while the lower compartment was used for the collection of liquid biofertilizer.

Two composters were assigned to the control treatment. For data analysis, the mean values of both experimental units were calculated. These composters contained exclusively plant-based organic waste, composed of fruit and vegetable residues, including peels, infusion residues (yerba mate and coffee grounds), and eggshells. No animal-derived residues, such as meat, dairy products, or prepared food leftovers, were included.

In the second treatment (b), cigarettes were incorporated into the composting boxes in addition to the organic residues described for the control treatment. Cigarettes were used with intact paper wrappers; however, the filters were removed prior to weighing and incorporation. Cigarette addition was performed through monthly applications, totaling four applications between July and December. In each application, a constant amount of 65 g of cigarettes per box was used, resulting in a cumulative total of 260 g per box over the entire experimental period.

Both cigarettes and organic raw materials were weighed using a digital scale to ensure consistent and standardized application across treatments. No commercial accelerator was used in this treatment.

In the third treatment (c), in addition to the components included in treatment (b), a combination of a commercial liquid biological product—composed of beneficial microorganisms (yeasts, lactic acid bacteria, and spore-forming bacteria)—and a solid supplement used as a microbial activator was applied. Both products were previously mixed and subjected to a 48 h fermentation process prior to incorporation into the composting boxes.

The liquid biological product was combined with the commercial solid supplement at a dose of 5 L of microbial inoculant per 750 g of fermentable organic substrate. The resulting mixture was incubated for 48 h under controlled conditions to promote microbial activation and multiplication before application to the composting system.

Initially, both products were diluted and mixed with chlorine-free water and left to rest for 48 h to allow microbial proliferation.

Subsequently, the mixture was applied directly to the composting boxes. The products are commercially marketed as a combined formulation and were used according to the manufacturer’s recommendations, acting as a nutrient source for the system microbiota.

The application of this product combination aimed to stimulate organic residue fermentation, promote faster and more controlled decomposition, and reduce the formation of undesirable compounds such as ammonia and hydrogen sulfide, thereby minimizing odor emissions and losses of volatile nutrients, particularly nitrogen and sulfur.

The initial mixture consisted of: (a) the previously described food residues; (b) wood sawdust, used to control moisture and supply carbon; and (c) 10 g of native forest leaf litter, intended to introduce microbial diversity into the composting boxes. All food residues were weighed beforehand to ensure standardized input among experimental treatments.

Earthworm abundance was assessed through manual counting of the total number of individuals present in each compartment of the composter. Each experimental unit started the trial with 25 juvenile earthworms per box. Counts were performed weekly during the first month of the experiment and subsequently on a biweekly basis between July and October. Mean values were calculated for each treatment.

The analyzed variables included biweekly earthworm counts, initiated seven days after the start of the vermicomposting process. To standardize the temporal analysis, Day 1 was defined as the moment when seven days had elapsed since the initial incorporation of food residues and earthworms into the composters. Monitoring was carried out systematically until the end of the experimental cycle.

During the final week of the experiment, a biometric evaluation of the earthworms was conducted. For this purpose, 75 individuals per experimental unit (composter) were randomly selected, a number defined to obtain a representative sample of the population while maintaining operational feasibility. The evaluated earthworms constituted subsamples within each experimental unit and were not considered independent replicates.

Biometric measurements were performed using a digital caliper, and results were expressed in millimeters (mm). This evaluation was conducted for all experimental units across treatments.

The obtained data were analyzed using descriptive statistics, including calculation of means and medians, as well as tests for comparison of means. Analyses were performed using Excel and SAS software. Additionally, R software was used to apply Tukey's test at a 5% significance level after verifying the presence of significant differences among treatments through analysis of variance (ANOVA).

Results and discussion

This study demonstrated that confiscated cigarettes can be effectively co-processed with food waste through vermicomposting, representing a viable alternative for the valorization of this solid residue. The biological results obtained allowed the evaluation of process performance and the effects of the residue on decomposer organisms; however, a detailed chemical characterization of the final compost was not conducted in this study.

Although substantial information is available regarding compost safety and its effects on soil fertility, several aspects still require further investigation (Gilmour et al., 2003; Long et al., 2017). In this context, complementary analyses addressing the chemical quality, biological attributes, and agronomic phytotoxicity of the final compost produced using cigarette residues are being conducted in parallel with the present study.

The scientific literature indicates that, although studies have demonstrated high biodegradability of the carbon fraction associated with nicotine, most investigations focus on the environmental behavior of nicotine as an isolated compound rather than on the comprehensive chemical characterization of cigarette residues as a complex matrix. Consequently, such approaches do not allow direct inference regarding the persistence of other potentially toxic substances following biological processes such as vermicomposting, reinforcing the need for complementary analyses when the objective is to assess the final quality of the compost (Seckar et al., 2008).

In addition, tobacco-derived residues are part of a highly complex chemical system composed of a wide range of volatile and semi-volatile organic compounds, as well as substances associated with particulate matter, whose composition and persistence depend on dynamic physicochemical processes. However, most studies focus on the gaseous and particulate phases of tobacco smoke rather than on the solid residue from a nutritional or agronomic perspective, limiting their direct applicability to composting systems (Daisey, 1999).

Conversely, recent studies evaluating solid tobacco residues in composting processes through detailed physicochemical analyses have reported high contents of organic matter, organic carbon, and nitrogen, along with a progressive reduction in the C:N ratio and a significant decrease in nicotine concentration throughout the process. These studies also reported the absence of mutagenic effects in the final compost, suggesting potential agricultural use once the initial toxic compounds are adequately controlled (Piotrowska-Cyplik et al., 2009; Mandić et al., 2023). Nevertheless, the authors emphasize that compost suitability must be confirmed through specific chemical analyses of the final residue, including nutrient availability and heavy metal concentrations.

In agreement with these findings, recent investigations have shown that the incorporation of cigarette residues into biological systems may negatively affect the development of Californian earthworms when these residues are used without complementary treatments. Reduced mean body length observed under such conditions has been associated with less favorable environments for organism development, due to the presence of potentially toxic compounds such as nicotine, other alkaloids, and trace metals linked to both plant material and tobacco industrial processes (Liu et al., 2025).

Within this framework, the results obtained in the present study provide relevant biological evidence supporting the feasibility of co-processing cigarette residues through vermicomposting, while simultaneously highlighting the need for future research focused on comprehensive chemical characterization of the final compost. Such analyses will enable a more complete assessment of the quality, safety, and agronomic potential of the material produced, strengthening the reuse of this residue as an environmentally sustainable strategy.

Several studies have demonstrated that nicotine may exert cytotoxic and antimicrobial effects, altering metabolic activity and microbial respiration, thereby directly affecting organic matter decomposition processes (Seckar et al., 2008; Daisey, 1999). However, more recent research evaluating solid tobacco residues in composting systems has shown that this material presents high levels of organic matter, organic carbon, and nitrogen, and that, under suitable conditions, nicotine concentrations can be significantly reduced, resulting in compost with physicochemical characteristics compatible with agricultural use (Mandić et al., 2023; Briški et al., 2012).

In this context, the treatment combining cigarette residues with biological agents exhibited a tendency toward earthworm length values similar to those observed in the control treatment, suggesting an attenuation of the initial toxicity of the residue. Although differences were not statistically significant, this behavior is consistent with reports indicating that the addition of specialized microorganisms may accelerate nicotine degradation and reduce its negative impact on composting organisms (Radojičić et al., 2009; Mandić et al., 2023).

Recent studies have provided a relevant conceptual framework to interpret these results, demonstrating that the effects of nicotine during composting are strongly dependent on its initial concentration. At low concentrations, nicotine may act as a metabolic modulator, stimulating certain microbial processes, whereas at higher concentrations it behaves as a strong inhibitor of biological activity, impairing mineralization and humic substance formation (Zhu et al., 2024; Zhang et al., 2025). This hormetic behavior explains the high variability and apparently contradictory results reported in the literature regarding tobacco residue composting, as well as the absence of significant differences among treatments in studies where initial concentrations fall within intermediate ranges.

From a waste management perspective, the results reinforce the idea that cigarette residues should not be regarded exclusively as problematic materials, but rather as potential resources that can be valorized through appropriate management strategies. The combination of tobacco residues with other organic wastes and the application of biological agents emerge as promising alternatives to mitigate initial negative effects and enhance composting system stability, thereby contributing to the reduction of waste volumes destined for final disposal.

It is important to note, however, that the evaluation performed in this study focused on biological parameters associated with the development of an indicator species and did not include detailed chemical analyses of the final compost. In this regard, the literature emphasizes that validation of the agricultural use of composts derived from tobacco residues requires the determination of additional parameters, such as the C:N ratio, macro- and micronutrient concentrations, heavy metal content, and the assessment of potential phytotoxic effects (Mandić et al., 2023; Zhu et al., 2024). These aspects constitute a priority line of future research aimed at consolidating the safe and sustainable reuse of cigarette and tobacco residues in composting and vermicomposting processes.

An increase in earthworm numbers was observed both in composters containing cigarette residues and in the control treatment, although the latter showed higher overall abundance. Regarding body size at the end of the process, the control and the treatment supplemented with microorganisms exhibited the largest earthworms, whereas the treatment without biological additives showed significantly smaller individuals. These results indicate that, despite the potentially harmful effects of cigarette residues, the waste was successfully treated, opening an alternative pathway for managing this residue beyond current disposal practices.

Table 1. Earthworm body length under different experimental treatments

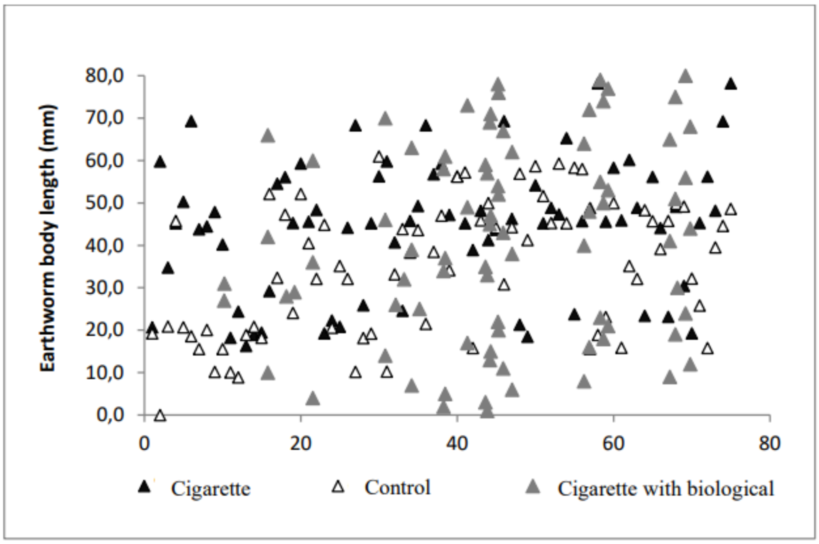
Treatment	Mean length (mm)	Min–Max (mm)
Control	44.9^{a}	16.3–78.2
Cigarette residue	35.5^{b}	8.9–61.0
Cigarette residue + biological agents	45.7^{a}	10.2–69.8

Notes: Values represent mean body length of *Eisenia fetida*. Different superscript letters indicate statistically significant differences among treatments ($p < 0.05$).

The treatment containing cigarette residues resulted in the lowest mean earthworm body length (35.47 mm), differing significantly from both the control and the cigarette residue + biological agents treatments (Table 1). This finding suggests an adverse effect of the exclusive use of cigarette residues on organism growth. In the control treatment, mean body length reached 44.92 mm, reflecting more favorable conditions for earthworm development in the absence of potentially toxic compounds. In turn, the cigarette residue + biological agents treatment exhibited the highest mean body length (45.70 mm); however, this difference was not statistically significant relative to the control, indicating a positive trend rather than a conclusive effect. This pattern suggests that the incorporation of biological agents may have attenuated the toxic effects associated with cigarette residues, possibly through the degradation of compounds such as nicotine and other contaminants, as reported in the literature for composting and vermicomposting systems involving microorganisms and soil fauna.

Earthworm body size varied significantly among the evaluated treatments, indicating a potential influence of the materials added to the composting boxes on organism development (Table 1). Fraser et al. (1996) highlight the importance of investigating the effects of different types of organic amendments on biological growth, emphasizing that assessing both earthworm abundance and body size is essential to understanding population dynamics and their positive impacts on agroecosystems.

Figure 2. Earthworm body length (mm) of *Eisenia fetida* across experimental treatments.



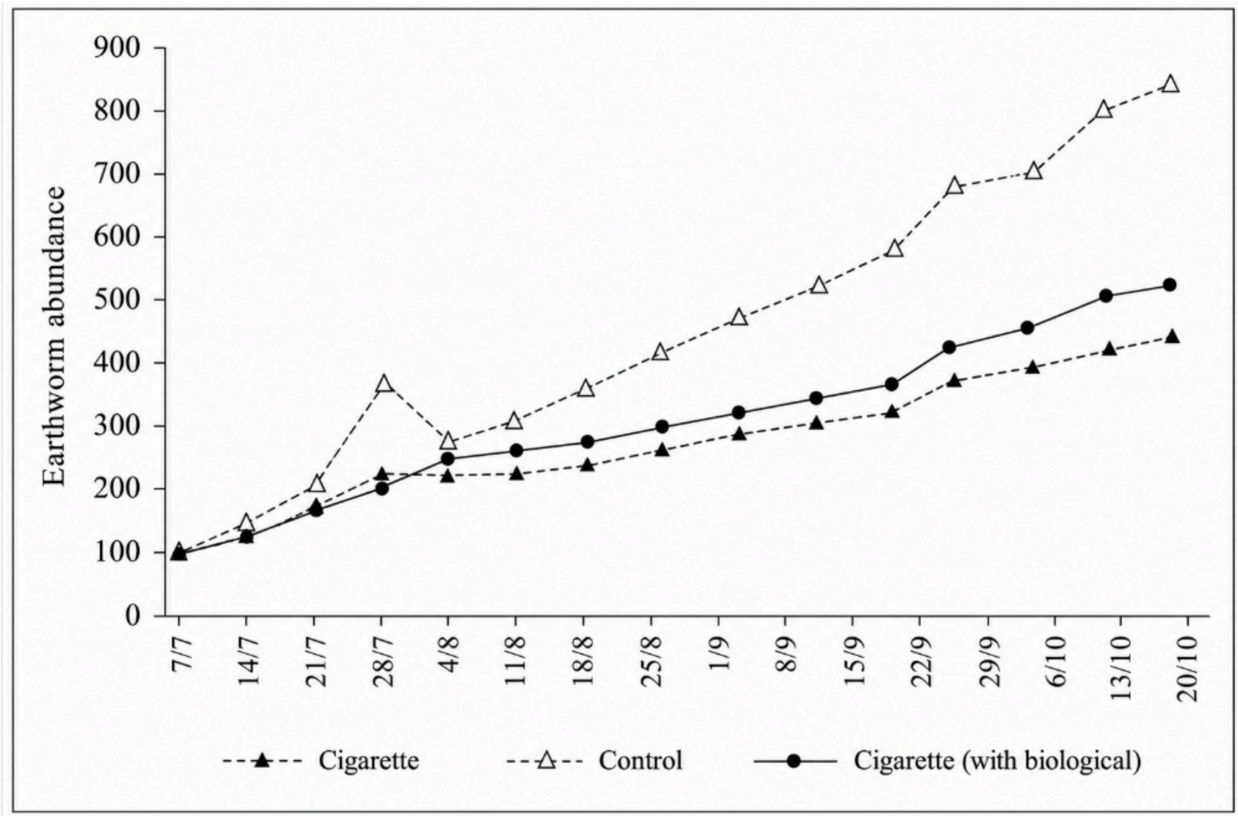
Overall, earthworm abundance increased progressively throughout the entire vermicomposting period across all evaluated treatments (Figure 3), indicating that the general conditions of the system were compatible with organism survival and reproduction. However, clear differences were observed among treatments regarding the magnitude of population growth.

The control treatment, composed exclusively of plant-derived organic residues, consistently exhibited the highest earthworm counts throughout the experiment, differing significantly from the treatments that included cigarette waste. This pattern suggests that the absence of potentially toxic compounds created a more favorable environment for earthworm establishment and population expansion.

In contrast, treatments containing cigarette residues, both with and without the addition of biological agents, showed more moderate population increases and did not differ significantly from each other. This response indicates that the presence of cigarette waste acted as a limiting factor for earthworm population dynamics, regardless of the application of biological accelerators during the evaluated period.

From an ecological and functional perspective, these results suggest that although earthworms were able to survive and reproduce in substrates containing cigarette residues, population growth rates were reduced compared to the control treatment. The lack of a significant effect of biological agents on earthworm abundance indicates that, under the experimental conditions adopted, these inputs were insufficient to fully overcome the constraints imposed by cigarette residues on population dynamics during vermicomposting.

Figure 3. Temporal evolution of earthworm abundance during the vermicomposting process as a function of monitoring time for the different experimental treatments.



These results indicate that, although the Cigarette treatment exhibited a more modest population growth compared to the other treatments, the Control treatment showed the greatest increase in earthworm abundance, suggesting a more favorable environment for organism development. In contrast, the treatment with the commercial accelerator showed a steady increase in earthworm numbers, although the final population size remained lower than that observed in the Control treatment. This pattern suggests that the use of biological accelerators may have exerted a positive, albeit moderate, influence on the development of decomposer fauna (Figure 3). Rather than promoting competition, the inoculated microorganisms appear to have enhanced substrate quality, suggesting a facilitative relationship with *Eisenia fetida* that may have contributed to mitigating the adverse effects of cigarette residues on earthworm development.

Overall, the results of this study indicate that, under the experimental conditions evaluated, the presence of cigarette residues in the composting process was associated with reduced growth of Californian earthworms. The Cigarette treatment exhibited the lowest mean body length (35.47 mm) among the evaluated treatments, suggesting that substrates containing these residues imposed less favorable conditions for organism development.

This adverse effect may be linked to the presence of potentially toxic compounds, such as nicotine and trace metals, which are widely described in the literature as stress factors for soil fauna under environmental conditions similar to those of the present study (Fraser et al., 1996; Ngo et al., 2012). Exposure to these substances can disrupt earthworm metabolism and biological activity, thereby compromising growth and performance within composting systems. With respect to trace metals, the composting process does not promote their degradation but rather their stabilization and relative immobilization, primarily through complexation with organic matter and the consequent reduction in bioavailability, contributing to greater stability of the final material.

Regarding population dynamics, the results showed that the Control treatment presented the highest number of individuals, followed by the Accelerator treatment, whereas the Cigarette treatment exhibited the lowest earthworm abundance. This pattern reinforces the hypothesis that the incorporation of cigarette residues may negatively affect earthworm reproduction and survival during the vermicomposting process. Nevertheless, the higher abundance observed in the Accelerator treatment suggests that the addition of biological agents may partially mitigate these effects, possibly by enhancing the degradation of organic compounds and improving the microbiological conditions of the substrate.

Taken together, these findings highlight the strong influence of residue composition on earthworm performance and underscore the modulatory role of biological strategies in composting systems that incorporate materials with potential toxicity. Future studies integrating chemical characterization and ecotoxicological assessment will be essential to fully validate the environmental safety of this approach.

Final considerations

In summary, the results obtained allow us to conclude that the objective of this study was achieved. Under the experimental conditions evaluated, the presence of cigarette waste in the vermicomposting process was associated with reduced growth and altered population dynamics of *Eisenia fetida*. The incorporation of biological agents showed a tendency to attenuate these effects;

however, it did not result in statistically significant differences when compared with the control treatment.

Taken together, these findings highlight the importance of appropriate management of organic residues, particularly those with potential toxicity, and suggest that biological strategies may contribute to mitigating negative impacts on earthworms during vermicomposting. Nevertheless, a comprehensive assessment of the final compost quality requires the determination of additional chemical and biological parameters, as well as phytotoxicity assays using plant species—aspects that were not addressed in the present study.

Complementary studies are currently underway to further characterize the chemical and biological properties of the compost produced, including the evaluation of microbial biodiversity and the potential presence of heavy metals and nutrients. In addition, future experiments under controlled laboratory or greenhouse conditions may contribute to assessing the potential of this compost as a soil amendment and its effects on plant survival and development prior to field application.

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