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Comparative evaluation of microbial activity in the decomposition of organic matter from solid household waste in Guayaquil

Avaliação comparativa da atividade microbiana na decomposição da matéria orgânica dos resíduos sólidos domiciliares em Guayaquil

Evaluación comparativa de la actividad microbiana en la descomposición de materia orgánica de residuos sólidos domiciliarios de Guayaquil

Carlos Alberto Nieto-Cañarte
https://orcid.org/0000-0003-1817-9742
Professor at the State Technical University of Quevedo, Ecuador. Faculty of Engineering Sciences
cnieto@uteq.edu.ec (correspondence)

Victor Manuel Guaman-Sarango
https://orcid.org/0009-0007-4135-2394
Professor at the State Technical University of Quevedo, Ecuador. Faculty of Engineering Sciences
vguaman@uteq.edu.ec

Angelita Leonor Bosquez-Mestanza
https://orcid.org/0000-0002-3224-884X
Professor at the State Technical University of Quevedo, Ecuador. Faculty of Engineering Sciences
abosquezm@uteq.edu.ec

Carmen Alexandra Sinchi-Rivas
https://orcid.org/0000-0001-9611-2514
Professor at the State Technical University of Quevedo, Ecuador. Faculty of Engineering Sciences
csinchi@uteq.edu.ec

Nelson Luis Mecias-Herrera
https://orcid.org/0000-0002-8397-0517
Professor at the State Technical University of Quevedo, Ecuador. Faculty of Engineering Sciences
nmeciash@uteq.edu.ec

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Pioneers *Trichoderma*-focused bioreactor technology, providing a novel perspective on organic waste treatment with economic and environmental benefits

ABSTRACT

The escalating global population and subsequent rise in consumerism underscore the critical need for proper solid waste management, with a specific focus on the daily disposal of organic waste. Inadequate waste management poses direct threats to public health, as uncontrolled fermentation provides a fertile ground for bacterial growth. This study explores the efficacy of employing Microorganisms, specifically comparing *Trichoderma* to a Microbial Biocatalyst, for the treatment of daily solid organic waste (D.S.O.W.). Following Falconi's (2013a) methodology for the capture, multiplication, and conidial count of microorganisms, a pilot study utilizing a Bioreactor was conducted. The statistical analysis of parameters such as Humidity, Weight, pH leachates, Temperature, Time, and Volume, with corresponding ANOVA significance levels, resulted in the rejection of null hypotheses for most parameters, except pH m.o. The capture and multiplication of *Trichoderma spp*. microorganisms reached a count 7.6×10^9 /ml. Treatment 6 (T6) emerged as more effective and efficient in decomposing organic matter (OM), exhibiting distinct stages of psychrophilic, mesophilic (3 days), thermophilic (6 days), psychrophilic (3 days), and cooling (3 days), culminating in the decomposition of OM in 15 days within the bioreactor. The results validate the working hypothesis, affirming the potential of Microorganisms, especially *Trichoderma*, in enhancing the treatment of daily solid organic waste.

Keywords: Conidial, Psychrophilic, Mesophilic, Thermophilic, solid organic waste.

RESUMO

O aumento da população e, portanto, do consumismo coloca ênfase na forma de gerir adequadamente os resíduos sólidos produzidos diariamente, especialmente os resíduos orgânicos. Dado que o manuseamento inadequado tem efeitos directos na saúde, a fermentação descontrolada cria uma fonte de alimento e um habitat para o crescimento bacteriano. Foi analisada a aplicabilidade do uso de Microrganismos (Trichoderma vs. Biocatalisador Microbiano) para tratamento de D.S.O.D. A Metodologia utilizada para captura, multiplicação e contagem de conídios é descrita por Falconi (2013a). Coleta D.S.O.D., mais a utilização de um Biorreator como Piloto, cujos parâmetros foram analisados estatisticamente, com seus respectivos níveis de significância ANOVA: Umidade, Peso, pH lixiviado, Temperatura, Tempo, Volume, H0 é rejeitado. pH m.o., H0 não é rejeitado. A captura e multiplicação do microrganismo Trichoderma spp foi conseguida. U.F.C. 7,6×109/ml. Na avaliação de Microorganismos, mostrou-se mais Eficaz e Eficiente na decomposição do M.O. o T6. Os microrganismos apresentam estágios psicrofílico, mesofílico (3 dias), termofílico (6 dias), psicrofílico (3 dias) e resfriamento (3 dias), decompondo o M.O. em 15 dias dentro de um biorreator. Com base nos resultados obtidos, aceita-se a hipótese de trabalho.

Palavras-chave: Conídios, psicrófilos, mesófilos, termofílicos, gerenciamento de resíduos sólidos.

RESUMEN

El incremento de la población y por ende el consumismo, pone el énfasis de cómo se realiza el adecuado manejo de los desechos sólidos que producen se diariamente, en forma especial los orgánicos. Ya que un manejo inapropiado de los mismos tiene efectos directos sobre la salud, la fermentación no controlada crea una fuente de alimento y hábitat para el crecimiento bacteriano. Se analizó la aplicabilidad del uso de Microorganismos (Trichoderma vs. Biocatalizador Microbiano) para el tratamiento D.S.O.D. La Metodología utilizada para la captura, multiplicación y Conteo conidial es descrito por Falconi (2013a). Recolección D.S.O.D., más el empleo de un Biorreactor como Piloto, cuyos parámetros se analizaron estadísticamente, con su respectivo nivel de significancia del ANOVA: Humedad, Peso, pH lixiviados, Temperatura, Tiempo, Volumen, H0 se rechaza. pH m.o., H0 no se rechaza. Se logró la captura y multiplicación del microorganismo Trichoderma spp. U.F.C. 7.6×109/ml. En la evaluación de Microorganismos, demostró ser más Eficaz y Eficiente en descomponer la M.O. el T6. Los microorganismos tienen una etapa Psicrófila, Mesófila (3 días), Termófila (6 días), Psicrófila (3 días) y enfriamiento (3 días), descomponiendo la M.O. en 15 días dentro de un biorreactor. En base a los resultados obtenidos se acepta la hipótesis de trabajo.

Palabras clave: Conidial, Psicrófila, Mesófila, Termófila, manejo de desechos sólidos.

INTRODUCTION

The increase in the world's population and therefore consumerism, raises the question of how to properly manage the solid waste produced daily. This demographic expansion is one of the precursors of the social and environmental impact produced on the planet. The uncontrolled fermentation of garbage creates a food source and habitat for bacterial growth. In this environment, insects, rodents and some bird species proliferate and act as passive vectors in the transmission of some infectious diseases (Rastogi et al., 2020).

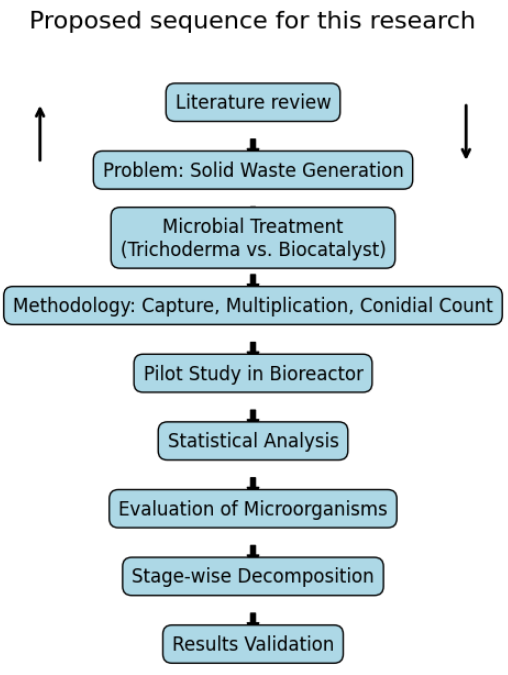
The decomposition of organic matter contained in household solid waste is essentially a microbial process. Microorganisms, mainly bacteria and fungi, have the capacity to use organic compounds as a source of carbon and energy. The metabolic activity of these microorganisms allows the mineralization and stabilization of the organic fraction of the waste (Barrena et al., 2006).

Waste treatment incorporates any method, technique or process that changes the physical, chemical and/or biological character of a waste. There are many alternatives for the proper management of solid waste, especially organic waste. The best option is composting, a natural process in which decomposition occurs through a significant microbial population in an aerobic environment. It allows the return to the soil of organic matter, nutrients and vital microorganisms for plants. The generation of large volumes of waste is related to the depletion of most non-renewable resources (Bernal et al., 2009).

Recognizing the microbial foundation of organic waste decomposition, this study delves into the intricate processes orchestrated by bacteria and fungi to mineralize and stabilize the organic fraction of household waste. Amid various waste treatment options, composting, a natural and aerobic microbial-driven process, stands out as an environmentally friendly method that facilitates the return of essential organic matter, nutrients, and microorganisms to the soil, thereby fostering sustainable resource cycles (Liu et al., 2023; Bao *et al*., 2023).

The primary objective of this research is to assess and optimize the microbial processes involved in the decomposition of organic household waste, with a specific focus on the application of *Trichoderma spp*. microorganisms and a novel biocatalyst in a designed Aerobic Bioreactor. By capturing, multiplying, and utilizing *Trichoderma spp*., we aim to enhance the efficiency of organic waste decomposition and evaluate its cost-effectiveness compared to conventional methods. The study also encompasses an in-depth analysis of the microbial activity throughout the waste treatment stages, offering insights into the intricate dynamics of temperature, humidity, and pH, crucial factors influencing the overall efficacy of the process. Through these investigations, we seek to contribute to the advancement of sustainable waste management practices and the development of environmentally conscious technologies. Figure 1 presents a comprehensive visual representation of the research process cycle proposed in this article, illustrating the sequential stages undertaken in this study for the effective treatment of Daily Solid Organic Waste (D.S.O.W.).

Figure 1. Visual representation of the research steps



Source: own elaboration (2023)

MATERIALS AND METHODS

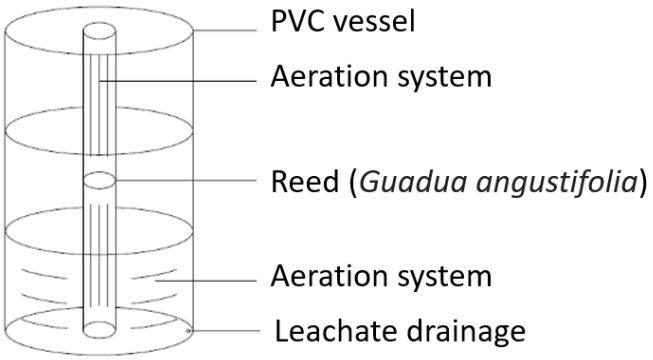
The technique and methodology used for the capture (preparation of traps for microorganisms, trapping for microorganisms, harvesting of traps), multiplication (systems for conidial production of *Trichoderma spp*. type fungi by means of solid fermentation and application of pyramidal matrices, harvesting of production units) and counting of conidia is the one described by Falconi (2013a). A vertical Aerobic Bioreactor was also designed and built to treat previously collected household organic solid waste. For the statistical processing of the different parameters and their significance level of the analysis of variance (ANOVA), obtained from the pilot data collection. It was processed with SPSS software (Tukey 95%).

Our hypothesis suggests that the biocatalyst, particularly in Treatment 6, would demonstrate superior efficacy in decomposing organic matter, as reflected in weight reduction and optimized microbial activity. The analysis also considers cost-effectiveness, comparing the expenses associated with *Trichoderma spp*. and the biocatalyst, providing valuable insights for practical application in sustainable waste management systems.

Pilot in organic waste bioreactor

Psychrophil: 00º Start, day in which the bioreactors were filled equally (weight and volume) and the treatments under study were applied. The initial temperature is the ambient temperature. Mesophilic: 01º It could be observed that there was a great microbiological activity inside the bioreactor, since through the chimney it was possible to feel the heat coming out (flaring). And the presence of leachate descending from the bioreactor. 02º The fire emanating from the chimney had increased, as well as its temperature. As well as the presence of leachate. 03º Temperature increase, therefore, it is presumed that the microbiological activity has not ceased (it is entering its climax). H_2 O was added, since this activity was consuming it. Thermophilic: 04º Bad odor emanation was perceived, coming out of the bioreactor, through the chimney. 05º Bad odor emanation continues. 06º Bad odor emanation continues. 07º It is believed that the bad odor emanating is not methane, since a lighter was lit and placed next to the chimney and nothing was produced. 08º The bad odor is disappearing. 09º The bad odor has totally disappeared. Psychrophilic: 10º Significant drop in temperature. 11º The temperature that dropped is maintained. 12º The temperature is still low. Cooling 13º The fire that emanated from the chimney is ceasing, activity is felt, but it is already very slight. 14º The temperature continues to drop, it is presumed that the compost is in its maturation stage. 14º It can be observed that treatment 7 (t7) has decomposed all the organic material contained in the bioreactors (Figure 2).

Figure 2. Bioreactor



Source: own elaboration (2023)

The bioreactor employed for waste management comprises a PVC vessel equipped with a specialized aeration system. The system optimizes microbial activity, promoting the decomposition of organic waste effectively. Within the PVC vessel, reeds, specifically Guadua angustifolia, play a vital role in enhancing the microbial processes. The aeration system, a key component, ensures the maintenance of an aerobic environment, facilitating the microbial breakdown of organic matter. Additionally, the design incorporates a leachate drainage system, managing the liquid byproduct efficiently. This innovative bioreactor structure aligns with sustainable waste treatment practices, emphasizing the utilization of natural elements and efficient aeration for organic waste decomposition.

RESULTS AND DISCUSSION

Capture and Multiply Microorganisms (*Trichoderma spp.*): It was possible to capture and multiply with great success, *Trichoderma spp*. microorganisms, this was carried out in the laboratory of Biotechnology "FIAJJCZ". Analysis for

isolation and identification was carried out by the laboratory PLANTSPHERE LABORATORIES, of which three strains were located *in situ*, they could not be identified, but they were characterized (Table 1).

Table 1. Laboratory analysis (Biogram)

Strain	Gender / Species	Main taxonomic features	Agronomic Biocatalytic Significance
1	*Trichoderma sp.*	Hyphae 5-12µm. Diameter 3.3-4.5×3.0-4.0µm. Chlamydospores 10.0-15.0µm.	Potential fungal antagonist, biomineralizes organic matter.
2	*Trichoderma sp.*	Pustules, phialides 4.5-9.5×3.5-4.5 µm. Conidium 3.0-5.0×2.0-3.8 µm.	Predigester of organic N-P, highly variable by pH conditions.
3	*Trichoderma sp.*	Crusts green, Phialides 7.5-12.0×2.5-3.5µm. Conidium 3.2-5.5×2.0-3.0µm. Optimum growth at 24ºC.	Breaks down complex fractions of organic matter, assembles organic complexes into simple ones.

Source: Plantsphere Laboratories

In alignment with Falconi (2013c), who notes that Trichoderma components can be readily found in various ecosystems. Moreover, in agreement with Porta; López and Roquero (1994), who highlight that since humans discovered the ability to trap and manipulate microorganisms, they have found favor in numerous areas, capitalizing on their capacity to degrade organic matter and secrete substances. This utilization spans critical domains such as Agriculture, Environment, and Medicine.

Consistent with Falconi (2013b), who emphasizes that the primary objective of applying pyramidal matrices for the management of Trichoderma germplasm (MPGT) is to maintain the material intact, possessing qualities such as purity and freedom from microbial contamination agents.

Biocatalyst: In the comparative evaluation of the microorganisms, Treatment 6 (Biocatalyst at a concentration of 1.50 ml/kg) proved to be more effective and efficient in decomposing organic matter. These would be the costs to invest, to implement the technology (bioreactor and mycoorganisms), and thus treat organic solid waste at the source. Table 2 below evaluates the cost-benefit of the use of *Trichoderma* vs. biocatalyst:

Table 2. Cost – Benefit Analysis

Trichoderma			**Biocatalyst**	
Materials	**Cost**		**Materials**	**Cost**
Tank (200 liters)	$ 25.00		Tank (200 liters)	$ 25.00
Rod (6 meters)	$ 2.00	**vs**	Rod (6 meters)	$ 2.00
Microorganism (liter)	$ 30.00		Microorganism (liter)	$ 50.00
Investment	$ 57.00		Investment	$ 77.00

Source: own elaboration (2023)

In accordance with Peña and Carrión (2002), who assert that organic solid waste encompasses various materials such as leaf litter, leguminous remains, fruits, vegetables, among others, all considered compostable. Furthermore, these results aligns with the findings of Grant and Long (1989), who emphasize the crucial role of microorganisms in the process of converting matter into energy.

Determining the activity of microorganisms in the decomposition of organic matter: Statistical processing of the different parameters and significance level of the analysis of variance (ANOVA), obtained from the pilot data collection in this research work (Table 3), giving the following result:

Table 3. Measured pilot parameters

Parameters	Description
Humidity	There is significant variation among treatments (0.007), but T_5 has the most adequate moisture content (61.92%), although no treatment was greater than 70%. H_0 is rejected.
Weight	If there is significant variation between treatments (0.000), the T_6 (36.681) being the one that decomposed more organic matter, therefore it will weigh less, unlike the T_7 (73.155) which weighs more, it is understood for not having decomposed much. H_0 is rejected.
pH leachate	Significant variation among treatments (0.006), although the pH in all treatments was close to neutral (±7.00). H_0 is rejected.
pH m.o.	There is no significant variation among treatments (0.133), but pH in all treatments is close to neutral (±7.00). H_0 is not rejected.
Chimney Temperature	If there is significant variation between treatments (0.000), T_1 (25.968) being the lowest temperature, as opposed to T_3 (31.984) with the highest temperature. H_0 is rejected.
Temperature Mesophila	If there is significant variation between treatments (0.000), T_1 (37.589) being the lowest temperature, as opposed to T_6 (41.975) with the highest temperature. H_0 is rejected.
Temperature Psychrophilic	If there is significant variation between treatments (0.000), T_7 (20.305) being the lowest temperature, as opposed to T_2 (27.779) with the highest temperature. H_0 is rejected.
Thermophilic Temperature	If there is significant variation between treatments (0.000), T_7 (41.411) being the lowest temperature, as opposed to T_6 (61.780) with the highest temperature. H_0 is rejected.
Weather	If there is significant variation between treatments (0.000), T_7 (66.000) is the one that takes the longest to decompose organic matter, unlike T_6 (99.000). H_0 is rejected.
Volume	If there is significant variation between treatments (0.000), the T_7 (82.525) being the one with the highest volume of organic matter, unlike the T_6 (164.586) which has the lowest volume, it is understood to have decomposed more material. H_0 is rejected.

Source: own elaboration (2023)

The results are in strong concordance with Cánovas (1993), who emphasizes the significance of saprophytic microorganisms in feeding on decomposing organic matter.

This aligns with the findings of Ruiz (1998), who notes that the pH initiates with values around ±5, undergoes evolution to a range between 8 and 9 during the decomposition process, and decreases as the compost matures.

Diverging from the perspective of Barradas (2009), who asserts that the organic fraction of municipal solid waste (MSW) generally maintains an appropriate C/N ratio (both organic and inorganic) to support the microbiological transformation of such waste. However, certain commercial wastes may deviate from the ideal C/N ratio, requiring judicious nutrient supplementation for optimal microbial growth and the complete degradation of organic solid waste.

The microbial activity involved in organic waste decomposition is contingent on various factors, encompassing the chemical composition of the substrate, carbon/nitrogen ratio, moisture, oxygen, temperature, and pH (Armijo de Vega et al., 2008). Bacteria take center stage in the initial stages of decomposition, while fungi play a pivotal role in the later stages, breaking down more resistant polymers like lignin and cellulose (Tuomela et al., 2000).

Microbial populations undergo transformations throughout the process. Initially, mesophilic and thermophilic bacteria dominate, succeeded by actinobacteria, and ultimately, filamentous fungi take charge (Vazquez et al., 2007). This microbial succession facilitates the thorough degradation of organic material, resulting in stabilized organic matter with a substantial content of humic and fulvic acids (García et al., 1994).

CONCLUSIONS AND RECOMMENDATIONS

The capture and multiplication of the microorganism (*Trichoderma spp.*) was achieved with a colony forming unit (cfu) of 7.6×10^9 /ml (value obtained with the Neubauer chamber). From the comparative evaluation of the *Trichoderma* vs. Biocatalyst, it was shown to be more effective and efficient in decomposing the organic matter, the treatment 6 (Biocatalyst at a concentration of 1.50 ml/kg). In the decomposition of organic matter inside a bioreactor, the microorganisms have a Psychrophilic stage (Start), Mesophilic (3 days), Thermophilic (6 days), Psychrophilic (3 days) and cooling (3 days), with a total of 15 days to decompose. In the work developed and based on the results presented, the working hypothesis is approved.

The municipality should implement a plan for the integrated management of household solid waste, especially organic waste, at the source in order to improve its final disposal. Periodically train the personnel of the garbage collection company and the community on the proper management of solid waste, especially organic waste. Use any treatment with

microorganisms for the production of compost with organic matter obtained from household solid waste, but always with the help of a container provided with aeration, in the case of households, in order to minimize possible impacts (odor, pests, etc.). I would advise that the tube (reed) that goes inside the bioreactor, which provides aeration, be replaced by a much more resistant material, preferably thick corrugated and perforated plastic. For future research on related topics, the most important parameter to modify or manipulate is the Carbon/Nitrogen ratio in household organic solid waste, for the elaboration of compost from microorganisms, in order to obtain a quality product.

Microbial decomposition of organic matter from solid waste is a complex process that depends on the sequential action of various microbial groups. Bacteria initiate the degradation of soluble and easily metabolizable compounds. Subsequently, fungi and actinobacteria act on more recalcitrant polymers. The microbial succession allows complete mineralization of the organic material (Negrete-Yankelevich, 2007).

In envisioning a roadmap for future studies, Table 4 delineates a robust research agenda designed to enhance our understanding of Daily Solid Organic Waste (D.S.O.W.) management. The proposed studies, addressing waste decomposition efficiency, temperature variations, community participation, and alternative treatment technologies, aim to provide comprehensive insights into sustainable waste practices.

Table 4. Proposed research agenda for future studies

Dependent Variable	Independent Variable	Methods	Context or Situation	Future Study Suggestions
Waste Decomposition Efficiency	Microbial Treatment (Trichoderma vs. Biocatalyst)	Statistical Analysis, Evaluation of Microorganisms	Urban Organic Waste Management	1. Investigate the long-term effects of microbial treatment on soil health, specifically focusing on changes in nutrient levels and microbial diversity in urban waste environments.
Waste Decomposition Efficiency	Temperature Variation	Experimental Studies, Climate Impact Analysis	Various Climate Zones	2. Explore the influence of temperature variations on waste decomposition efficiency in different climate zones to provide insights into climate-resilient waste management practices.
Waste Decomposition Efficiency	Community Participation in Recycling Programs	Surveys, Community Engagement Analysis	Urban and Suburban Residential Communities	3. Assess the impact of community participation in recycling programs on waste decomposition efficiency, emphasizing the role of community engagement in sustainable waste practices.
Waste Decomposition Efficiency	Alternative Organic Waste Treatment Technologies	Comparative Analysis, Technology Adoption Studies	Diverse Waste Treatment Contexts	4. Evaluate the effectiveness of alternative organic waste treatment technologies and compare their decomposition efficiency, offering insights into diversified and sustainable waste management.

Source: own elaboration (2023)

Finally, it is essential to recognize the inherent limitations of the current article. The study's findings are context-specific, and the proposed research agenda may not encompass all potential variables influencing waste management systems. Additionally, the scope of the article focuses on microbial treatments, leaving room for exploration of other factors in future investigations. Despite these limitations, the outlined research agenda serves as a stepping stone for subsequent studies, fostering a better understanding of waste management dynamics and inspiring a multifaceted approach to address the global challenge of solid waste.

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Task	**A1**	**A2**	**A3**	**A4**	**A5**
A. theoretical and conceptual foundations and problematization:	20%	20%	20%	20%	20%
B. data research and statistical analysis:	20%	20%	20%	20%	20%
C. elaboration of figures and tables:	20%	20%	20%	20%	20%
D. drafting, reviewing and writing of the text:	20%	20%	20%	20%	20%
E. selection of bibliographical references	20%	20%	20%	20%	20%
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