Bionatura
International Journal of Biotechnology and Life Sciences

ISSN 1390-9355
Vol. 9 No. 4 2024
https://revistabionatura.org/

Comparación de tres tratamientos (aerobio, anaerobio y combinado) para la descomposición de la materia orgánica con el fin de obtener biogás y biofertilizante

Comparison of three treatments (aerobic, anaerobic and combined) for the decomposition of organic matter to obtain biogas and biofertilizer

Enrique Salazar [1*], Alexander Barragán [2], Daniel Arias-Toro [3], Fernando Cobos [4]

[1](Technical University of Babahoyo/ Babahoyo / Av. Universitaria km 21/2 Av. Montalvo Babahoyo, Los Ríos); ejsalazar@utb.edu.ec. ORCID (0000-0002-1699-042X)
[2] alexander.barragan.1896@gmail.com (Technical University of Babahoyo/ Babahoyo / Av. Universitaria km 21/2 Av. Montalvo Babahoyo, Los Ríos). ORCID (0009-0003-2469-8925)
[3] dariast@utb.edu.ec. (Technical University of Babahoyo/ Babahoyo / Av. Universitaria km 21/2 Av. Montalvo Babahoyo, Los Ríos). ORCID (0000-0002-8167-2196)
[4] fcobos@utb.edu.ec. (Technical University of Babahoyo/ Babahoyo / Av. Universitaria km 21/2 Av. Montalvo Babahoyo, Los Ríos). ORCID (0000-0001-8462-9022)
*Correspondence: ejsalazar@utb.edu.ec ; Tel.: (0987128999)

DOI: 10.70373/RB/2024.09.04.9

Abstract

This study evaluated the efficiency of different types of decomposition (aerobic, anaerobic and combined) for the production of biogas and biofertilizers from agri-food, livestock, gardening and agricultural wastes. The results indicate that agri-food and livestock wastes are particularly suitable for anaerobic digestion, obtaining biogas and biofertilizers with a high content of nutrients such as nitrogen, phosphorus, potassium and calcium, which significantly improves soil fertility.

The anaerobic process includes phases such as hydrolysis, acidogenesis, acetogenesis and methanogenesis, where macromolecules are broken down into biogas and digestate. Anaerobic co-digestion is the most efficient in biogas production, achieving 0,00128 m^3 per ton of feedstock daily, reaching 0,008 m^3 in 15 days.

On the other hand, aerobic decomposition includes glycolysis and the Krebs cycle, producing CO_2, water, ATP and biofertilizers with high nutrient content. In terms of biofertilizer production, aerobic digestion generates between 0,026 m^3 and 0,030 m^3 per ton of feedstock, surpassing anaerobic co-digestion in efficiency.

Keywords: decomposition 1; digestion 2; organic matter 3

Introduction

ISSN 1390-9355
Vol. 9 No. 4 2024
https://revistabionatura.org/

Germany is one of the leaders in the production of biogas in Europe. The country has developed a robust infrastructure for the generation of biogas from head of cattle. Germany has more of 10.000 plants of biogas, that they generate approximately 1,5 TWh of electricity a year, in 2022 he produced around 1.6 million tons of biogas. **(1)**

Holland has been advancing in the production of biogas from organic residues, mainly in the agricultural sector and of step of residues. The country counts with over 50 plants of biogas that generate electricity and heat from organic residues. In 2022, the production of biogas in Holland belonged to approximately 0,5 TWh. **(2)**

Today, throughout Ecuador, approximately 5 million tons of garbage are generated, which gives an idea of the latent problem, putting on the table the large amount of waste generated in our country, about 14,000 ton generated per day. More specifically, 56,2 % of all this waste corresponds to the organic fraction, which immediately implies a series of questions related to the proper management of the waste itself, with the clear need to implement strategies that openly and practically allow its subsequent treatment and, if necessary, even its valorization. **(3)**

In Ecuador, an average urban resident produces about 0,9 kg of solid waste per day. Of the total solid waste produced in urban areas and classified by the Autonomous Decentralized Municipal Governments (GADM), 55 % is organic waste and 45 % is inorganic. **(4)**

In Pichincha, Ecuador, high population density and urban development generate the greatest amount of organic waste. Food, gardening, and kitchen waste represent between 40 % and 60 % of this waste in urban areas. Yard waste, such as leaves and branches, varies between 20 % and 30 % depending on the season and agricultural activity, while forestry waste makes up between 10 % and 20 % of the total. **(5)**

Under the executive direction of Santiago Andrade, the General Manager of the Metropolitan Public Company for Integral Solid Waste Management (EMGIRS-EP) said that Quito produces approximately 2,000 tons of waste daily, of which about 1,000 ton are organic. Thanks to this plant, biogas is produced, which is composed of methane gas (CH_4), which is 50 times more polluting than CO_2. The operation of the waste treatment plant has mitigated the release of 26 million cubic meters of biogas into the environment, which is equivalent to avoiding the emission of 250,000 tons of carbon dioxide (CO_2). **(6)**

Moreover, the decomposition of organic matter in landfills without oxygen produces methane and other gases that contribute to the greenhouse effect, which in turn causes global warming and climate change.(7) Poorly managed organic waste attracts disease vectors, pests and pathogenic

ISSN 1390-9355
Vol. 9 No. 4 2024
https://revistabionatura.org/

microorganisms, increasing the likelihood of disease transmission, as well as respiratory difficulties due to inhalation of toxic gases. [8] Subsequently, for the management and disposal of these organic wastes, biogas and biofertilizer can be obtained, thus contributing to the reduction of these wastes in the environment.

Organic wastes are biological materials easily decomposed by microorganisms and include kitchen waste (food scraps, husks), agricultural waste (crop residues), garden waste (leaves, grass, branches), livestock waste (manure), forestry waste (fallen leaves, trunks), food processing waste (husks, bagasse) and wastewater treatment waste (sewage sludge). [9]

Anaerobic decomposition is a process in which organic materials are degraded by the action of microorganisms in the absence of oxygen, using various metabolic mechanisms. [10] Among the microorganisms involved are fermentative anaerobic bacteria such as *Clostridium acetobutylicum* and Bacteroides thetaiotaomicron; methanogenic bacteria such as *Methanobacterium formicicum*; acetogenic bacteria such as *Acetobacterium woodii*; and others such as desulfurizing, sulfate-reducing, propionogenic and butyric bacteria. [11]

Aerobic decomposition occurs in the presence of oxygen, where nutrients decompose producing carbon dioxide and water, although in certain cases heavy metals and additional compounds may be generated, as in landfills with waste in plastic bags. [12] The microorganisms involved include aerobic bacteria such as Bacillus subtilis and Pseudomonas aeruginosa; fungi such as *Aspergillus niger* and *Penicillium chrysogenum*; and actinobacteria such as *Streptomyces coelicolor* and *Mycobacterium tuberculosis.* [13]

Combined anaerobic and aerobic decomposition refers to a process of organic matter degradation involving both anaerobic and aerobic organisms in different stages or zones of the system. [14]

The combined decomposition process starts with aerobic biological degradation, where microorganisms break down complex organic compounds into CO_2, H_2O and heat, facilitating anaerobic biodegradation in deeper layers. [15] The heat generated raises the temperature, creating thermophilic conditions that favor microbial activity. In the deep layers, the lack of oxygen causes an anaerobic environment, continuing the degradation into volatile fatty acids, gases and alcohols. In the anaerobic phase, methanogens transform these compounds into methane and carbon dioxide, completing the decomposition and production of biogas in digesters. **(1)**

Bioreactors control parameters such as temperature, pH and agitation to optimize the decomposition of organic matter through biological, physical or chemical processes. [16] Fermenter tanks, both aerobic and anaerobic, combine both processes to maximize the mineralization of matter, producing

ISSN 1390-9355
Vol. 9 No. 4 2024
https://revistabionatura.org/

biogas and biofertilizers; first, through an aerobic phase with microorganisms such as Bacillus subtilis, and then anaerobic, with Clostridium acetobutylicum and methanogenic archaea. [17] Biodigesters are closed systems that allow the anaerobic decomposition of waste such as crop residues or animal excrement, generating biogas and biofertilizer as final products. [18]

Biogas is a renewable energy source produced by the anaerobic fermentation of organic waste such as agricultural waste, manure, sewage sludge and municipal waste, composed mainly of methane (CH_4) and carbon dioxide (CO_2), and used to generate electricity, heat or as a vehicle fuel. [19] Its composition includes between 50 % -75 % methane and 25 % - 50 % CO_2, in addition to small amounts of water vapor, H_2S, ammonia, hydrogen, oxygen and nitrogen, varying according to the substrate and operating conditions. [20]

Biofertilizer is produced by controlled decomposition of organic matter, including plant debris, manure and sludge, and contains essential nutrients such as nitrogen, phosphorus and potassium, as well as beneficial microorganisms to improve soil quality and reduce the use of chemical fertilizers. [21] Their composition includes macroelements (N, P, K), microelements (Ca, Mg, S), organic matter and humic acids that improve soil structure and water retention. The composition varies according to the type of substrate used, such as manure, vegetable or agro-industrial residues, and the conditions of the digestion process. [22]

The anaerobic co-digestion is a method of extraction that is based on the common digestion of two or more substratums of different origins and different compositions, what enriches the contribution of nutrients balancing, therefore, the physicochemical characteristics of the substratum it allows optimizing the stabilization of the system and the performance of the biogas be major. [23]

The aerobic digestion is a waste management organic that is characterized for the destruction of these materials for action of present microorganisms on the air (principally bacteria) in the absence of oxygen. It supposes an oxidation of the same on behalf of these microorganisms, that they have an ample capacity of degradation, and that they turn the organic matter into more simple compounds, what results in a decrease of the contaminating potential of the residues (because the organic residues are turned into CO_2 and Hydrogen Monoxide principally), and in an increase of the volume of the live mass. [24]

ISSN 1390-9355
Vol. 9 No. 4 2024
https://revistabionatura.org/

Materials and methods

Design

A systematic review of documents from scientific organizations dedicated to agricultural, food and forestry research at national and international level, as well as literature reviews and scientific studies was carried out.

Google Scholar was used to search for documentation on the comparison of aerobic, anaerobic and combined treatments for the decomposition of organic matter and obtaining biogas and biofertilizers. The publications reflected relevant information from various authors in Ecuador and internationally. The search was conducted in English, Portuguese and Spanish. In addition, a systematic search in English was used in SpringerLink with the equation: "Aerobic, anaerobic, and combined treatments in organic matter decomposition". Databases of indexed journals such as Scielo, Scopus, Latindex and Web of Science were also consulted. Zotero was used as a reference manager to organize scientific articles, theses, journals, books and web documents selected for the development of the work.

Inclusion and Exclusion Criteria

The selection criteria included original scientific articles published in indexed journals in English, Portuguese and Spanish during a period of fifteen years. The focus was on research on the efficiency of aerobic, anaerobic and combined treatments in the production of biogas and biofertilizer. The selected papers had to meet ethical and methodological quality criteria, include detailed statistical analyses, laboratory or field experimental studies, and a comprehensive discussion of the results obtained.

Data Analysis

A comprehensive analysis was conducted to assess the impact of the three treatments on organic matter decomposition and biogas and biofertilizer production. Key variables included the type of treatment, feedstock composition, and what is obtained from these wastes. The results of different studies were compared in terms of biogas production (m^3/ton), nutrient content in the biofertilizer (N, P, K), days and tons of each treatment. A matrix with author, year and bibliographic source data was used to facilitate comparison and determine how different treatment conditions affect decomposition efficiency and biogas and biofertilizer production.

ISSN 1390-9355
Vol. 9 No. 4 2024
https://revistabionatura.org/

Results

Table 1" shows that agri-food and livestock wastes are suitable for producing biogas through anaerobic digestion, a renewable energy source. Garden and agricultural wastes are the most suitable for obtaining biofertilizer, improving soil fertility. The biofertilizer resulting from the anaerobic digestion of agro-industrial and livestock waste contains essential nutrients, promoting sustainable and efficient agriculture.

Table 1. Types of residues.

Types of residues	Method of decay	Obtaining	Referencias
Residues of Cocina (like foods, peelings remains of fruits and vegetables, coffee grounds and eggshells).	Anaerobic	Biogás and biofertilizer	(25)
Cattle residues (like manure of animals).	Anaerobic	Biogás	(26)
Stover (like remains of cultivations, such like sheets, stems of trees; Rests of harvests and of pruning of trees).	Aerobe and anaerobic	Biofertilizer	(27)
Residues of Jardinería (like sheets, lawn).	Aerobe	Biofertilizer	(28)

In the "table 2" shows up that the anaerobic digestion and the aerobic process are efficient methods to extract biogas and biofertilizer. In the anaerobic digestion, degrade macromolecules in successive phases, producing biogas. In the aerobic process, they catabolize substratums through the glycolysis and the cycle of Krebs, generating CO_2, water and ATP. Both processes offer benefits like the reduction of contamination and the obtaining of nutrient-rich essential biofertilizer.

Table 2. Methods of decay for the obtaining of biogas and biofertilizer.

Methods of decay	Description	Worked out factors	References
Anaerobic digestion (Hydrolysis)	The extra-cell enzymes turn polymeric matter into soluble compounds.	Influenced for pH, biochemical composition	(29)

		and temperature.	
Anaerobic digestion (Acetogenesis)	The bacteria turn fatty acids and ethanol into acetate and hydrogen.	Production of acetate and hydrogen.	(30)
Anaerobic digestion (Metanogénesis)	Final transformation in methane from acetate and acetic acid.	70 % of methane comes from descarboxilation.	(31)
Anaerobic digestion	The microorganisms rust organic residues.	Reduction of the contaminating potential.	(24)

In the "table 3" shows that method of extraction is more favorable as to the performance for the obtaining of biogas and fertilizer. The pal anaerobic digestion has the major performance in biogas, producing 0,008 m for ton in 15 days. For biofertilizer, the pal anaerobic digestion generates 0,018 m for ton in 9 days. However, the aerobic digestion proves better than the pal digestion in the total output of biofertilizer, with performances of 0,026 and 0,030 m for ton for the two analyzed processes.

Table 3. Performance of biogas and biofertilizer according to the method of extraction.

Methods of decay	Obtaining	Production of biogas (m^3)	Days	Tons	References
Anaerobic co-digestion	Biogas	0,00128	15	0,008	(27)
Anaerobic digestion (Acetogénesis)	Biogas	0,000300	13	0,008	(27)
Anaerobic co-digestion	Biogas	0,000274	11	0,008	(27)
Anaerobic digestion	Digestato (biofertilizer)	0,05	9	0,018	(25)
Aerobic Digestion	Biofertilizer	0,074	13	0,026	(32)
Aerobic Digestion	Biofertilizer	0,1	10	0,035	(33)

Discussion

Anaerobic co-digestion generates 0,00128 m³ of biogas per ton of feedstock per day for 15 days. In comparison, a study by Díaz (2022) [(34)] indicates that animal waste, such as manure, can produce between 0,02 m³ and 0,04 m³ of biogas per kg of volatile organic matter (VOM) under optimal conditions. This indicates that your production is relatively low, which could be due to factors such as feedstock composition, organic load, or operating conditions (temperature, pH, etc.).

ISSN 1390-9355
Vol. 9 No. 4 2024
https://revistabionatura.org/

Aerobic digestion produces 0,028 m³ of biofertilizer per ton in 12 days, while anaerobic digestion generates 0,015 m³ of digestate in 7 days. A study by Castro et al. (2022)[35] shows that biofertilizer production is highly dependent on the type of substrate and process. They report yields of up to 0.035 m³ of biofertilizer per ton with fruit and vegetable waste in a 10-day aerobic process. This suggests that your aerobic process is efficient, but the anaerobic process could be improved to increase digestate and thus biofertilizer production.

The hydrolysis, acidogenesis, acetogenesis, acetogenesis and methanogenesis phases coincide with the literature. Osorio et al. (2009)[36] explain that hydrolysis is the limiting step in anaerobic digestion, especially when dealing with lignocellulosic wastes.

Conclusions

The results indicate that both anaerobic digestion and the aerobic process are effective methods for the production of biogas and biofertilizers, although each has specific advantages depending on the type of waste and the desired product. Agri-food and livestock wastes are ideal for anaerobic digestion, which produces biogas and biofertilizers with high efficiency. In contrast, agricultural and garden wastes are more suitable for aerobic digestion, excelling in the production of biofertilizers that improve soil fertility.

Anaerobic co-digestion has shown the highest performance in biogas production, with a generation of 0,008 m³ per ton in 15 days, while, for biofertilizers, aerobic digestion is superior, reaching up to 0,035 m³ per ton in 10 days. These findings underline the effectiveness of anaerobic co-digestion for biogas and aerobic digestion for biofertilizers, highlighting the importance of selecting the appropriate method based on the type of waste and the production target. Both processes contribute significantly to the reduction of pollution and the development of sustainable agricultural practices, thus improving waste management and soil quality.

Proper implementation of these methods can optimize the production of biogas and biofertilizers, fostering a more integrated and efficient approach to the valorization of organic wastes in various agricultural and energy applications.

Author Contributions: Conceptualization, Alexander Barragan; methodology, Enrique Salazar; software, Fernando Cobos; validation, Daniel Toro; formal analysis, Enrique Salazar; research, Daniel Toro; resources, Daniel Toro, Alexander Barragan and Fernando Cobos; formal analysis, Enrique Salazar; research, Alexander Barragan; resources, Daniel Toro; data curation, Fernando Cobos; original drafting, Fernando Cobos; writing, revising and editing, Enrique Salazar;

ISSN 1390-9355
Vol. 9 No. 4 2024
https://revistabionatura.org/

visualization, Danel Toro; supervision, Enrique Salazar; project administration, Fernando Cobos; obtaining funding; Institutional.

Conflicts of Interest: no conflict of interest.

Acknowledgments: my thanks to the Technical University of Babahoyo for promoting research in the area of food security.

References

1. Martínez-Hernández CM, García-López Y, Oechsner H, Martínez-Hernández CM, García-López Y, Oechsner H. Biogas Plants in Germany: Revision and Analysis. Revista Ciencias Técnicas Agropecuarias [Internet]. diciembre de 2021 [citado 21 de agosto de 2024];30(4). Disponible en: http://scielo.sld.cu/scielo.php?script=sci_abstract&pid=S2071-00542021000400009&lng=en&nrm=iso&tlng=es

2. Manager C. Planta de Biogás de 250kW en Biddinghuizen Holanda [Internet]. INDEREN (Ingeniería y desarrollos renovables, S.L.). 2019 [citado 21 de agosto de 2024]. Disponible en: https://inderen.es/es/planta-de-biogas-de-250kw-en-biddinghuizen-holanda/

3. Castallena J. Ministerio del Ambiente, Agua y Transición Ecológica. 2020 [citado 12 de junio de 2024]. Ecuador impulsa la gestión adecuada de residuos orgánicos en las ciudades – Ministerio del Ambiente, Agua y Transición Ecológica. Disponible en: https://www.ambiente.gob.ec/ecuador-impulsa-la-gestion-adecuada-de-residuos-organicos-en-las-ciudades/

4. INEC. Estadística de Información Ambiental Económica en Gobiernos Autónomos Descentralizados Municipales Gestión de Residuos Sólidos 2021 [Internet]. 2021. Disponible en: https://www.ecuadorencifras.gob.ec/documentos/web-inec/Encuestas_Ambientales/Municipios_2021/Residuo_solidos_2021/Presentaci%C3%B3n%20residuos%202021%20v07JA_CGTP%20(Rev%202%20CGTPE)%20(Rev.%20Dicos).pdf

5. Ministerio del Ambiente. Ministerio del Ambiente, Agua y Transición Ecológica. 2020 [citado 22 de junio de 2024]. Ecuador impulsa la gestión adecuada de residuos orgánicos en las ciudades – Ministerio del Ambiente, Agua y Transición Ecológica. Disponible en: https://www.ambiente.gob.ec/ecuador-impulsa-la-gestion-adecuada-de-residuos-organicos-en-las-ciudades/

6. EMGIRS. Empresa Pública Metropolitana de Gestión Integral de Residuos Sólidos (EMGIRS-EP). 2020 [citado 12 de junio de 2024]. Quito se destaca en el Ecuador al producir energía eléctrica de la basura. Disponible en: https://emgirs.gob.ec/index.php/julio/45-travels-3/398-quito-se-destaca-en-el-ecuador-al-producir-energia-electrica-de-la-basura

7. German SJS, Torres JDA, Garcés AR, Oviedo MED. Evaluación energética de la formación de biogás obtenido de residuos sólidos urbanos del relleno sanitario mediante el modelo LandGEM. Investigación e Innovación en Ingenierías. 31 de julio de 2023;11(2):16-27.

8. Lema S, Vega K. "SISTEMA DE GESTIÓN DE LOS RESIDUOS ORGÁNICOS GENERADOS EN LOS MERCADOS DEL CANTÓN SAQUISILÍ PROVINCIA DE COTOPAXI AÑO 2023" [Internet] [Tesis de pregrado (Título de Ingenieras Ambientales)]. [LATACUNGA- ECUADOR]: UNIVERSIDAD TÉCNICA DE COTOPAXI; 2023. Disponible en: https://repositorio.utc.edu.ec/jspui/bitstream/27000/11657/1/PC-003100.pdf

9. Xu P, Shu L, Li Y, Zhou S, Zhang G, Wu Y, et al. Pretreatment and composting technology of agricultural organic waste for sustainable agricultural development. Heliyon. 2023;9(5):undefined-undefined.

10. Indran S, Divya D, Rangappa SM, Siengchin S, Christy PM, Gopinath LR. Perspectives of anaerobic decomposition of biomass for sustainable biogas production: A Review. E3S Web of Conferences. 2021;302:undefined-undefined.

11. Corrales LC, Antolinez Romero DM, Bohórquez Macías JA, Corredor Vargas AM. Bacterias anaerobias: procesos que realizan y contribuyen a la sostenibilidad de la vida en el planeta. Nova. julio de 2015;13(24):55-81.

12. Carrillo-Sancen G, Cuautle-Marin MA, Martínez-Valdez FJ, Saucedo-Castañeda G, Komilis D, Carrillo-Sancen G, et al. Tasa de aireación de la degradación aerobia en la fracción orgánica de residuos sólidos urbanos. Revista mexicana de ciencias agrícolas. noviembre de 2021;12(7):1149-59.

13. Castillo J. Microorganismos y nutrientes en el suelo [Internet]. Innovatione. 2019 [citado 23 de junio de 2024]. Disponible en: https://innovatione.eu/2019/11/26/microorganismos-del-suelo-2/

14. Martinez M, Ortega R. Microorganismos degradadores de materia orgánica y sus efectos sobre la calidad del suelo - Mundoagro [Internet]. 2021 [citado 30 de mayo de 2024]. Disponible en:

ISSN 1390-9355
Vol. 9 No. 4 2024
https://revistabionatura.org/

https://mundoagro.cl/microorganismos-degradadores-de-materia-organica-y-sus-efectos-sobre-la-calidad-del-suelo/

15. Álvarez-Sánchez AR, Llerena-Ramos LT, Reyes-Pérez JJ, Álvarez-Sánchez AR, Llerena-Ramos LT, Reyes-Pérez JJ. Efecto de sustancias azucaradas en la descomposición de sustratos orgánicos para la elaboración de compost. Terra Latinoamericana [Internet]. diciembre de 2021 [citado 23 de junio de 2024];39. Disponible en: http://www.scielo.org.mx/scielo.php?script=sci_abstract&pid=S0187-57792021000100131&lng=es&nrm=iso&tlng=es

16. Vargas B. DISEÑO CONCEPTUAL DE UN BIORREACTOR TIPO BATCH PARA LA OBTENCIÓN DE BIOGÁS Y BIOFERLILIZANTES A PARTIR DE RESIDUOS ORGÁNICOS (URBANOS Y AGRICOLAS) [Internet] [Tesis de pregrado (Ingeniero Químico)]. [Pamplona, Colombia]: Universidad de Pamplona; 2019. Disponible en: http://repositoriodspace.unipamplona.edu.co/jspui/bitstream/20.500.12744/5130/1/Vargas_2019_TG.pdf

17. Acura G. Grupo Acura. 2023 [citado 23 de junio de 2024]. Biorreactores o fermentadores industriales: Tipos y características. Disponible en: https://grupoacura.com/es/blog/biorreactores/

18. Reascos GMER, Alvarez WFG, Villarruel ÉJC, Coyago RFS. Construcción de un biodigestor para generar energía renovable a partir de desechos orgánicos en el camal de Pacto - Ecuador. Esferas. 2022;3:134-53.

19. Kabeyi MJB, Olanrewaju OA. Technologies for biogas to electricity conversion. Energy Reports. 2022;8:774-86.

20. Venegas Venegas JA, Raj Aryal D, Pinto Ruíz R, Venegas Venegas JA, Raj Aryal D, Pinto Ruíz R. Biogás, la energía renovable para el desarrollo de granjas porcícolas en el estado de Chiapas. Análisis económico. abril de 2019;34(85):169-87.

21. Chew KW, Chia SR, Yen HW, Nomanbhay S, Ho YC, Show PL. Transformation of biomass waste into sustainable organic fertilizers. Sustainability (Switzerland). 2019;11(8):undefined-undefined.

ISSN 1390-9355
Vol. 9 No. 4 2024
https://revistabionatura.org/

22. Ramírez LAG, Cabrera FAL, Escobedo MKL, Vásquez CBB, Torres CAL. Biofertilizante “biol”: caracterización física, química y microbiológica. Revista Alfa. 20 de mayo de 2023;7(20):336-45.

23. Benítez Fonseca M, Abafos Rodríguez A, Rodríguez Pérez S, Ramírez Vives F, Benítez Fonseca M, Abafos Rodríguez A, et al. Co-digestión anaerobia de la fracción orgánica de residuos sólidos urbanos y su lixiviado. Revista Colombiana de Biotecnología. diciembre de 2020;22(2):70-81.

24. Sánchez-Llevat IL, Fuerte-Góngora L, Ravelo-Ortega R, Ávila-García O. Estado del arte de los biopreparados por digestión anaerobia como biofertilizantes y bioestimulantes. Ingeniería Agrícola [Internet]. diciembre de 2022 [citado 12 de junio de 2024];12(4). Disponible en: https://www.redalyc.org/journal/5862/586272874007/

25. Luna BEB, Lahura N, Borda S. Generación de Biogás a partir de residuos orgánicos mediante la aplicación del NBS gas home organic reactor, en el anexo 14, distrito de San Ramón Junín, Perú. Revista Científica Pakamuros. 27 de diciembre de 2023;11(4):121-39.

26. Tonato Sangucho JJ. Generación de energía eléctrica a través del biogás para la avícola de la universidad técnica de Cotopaxi campus Salache [Internet] [bachelorThesis]. Ecuador: Latacunga: Universidad Técnica de Cotopaxi (UTC).; 2019 [citado 12 de junio de 2024]. Disponible en: http://localhost/handle/27000/5352

27. Viteri L. PRODUCCIÓN DE BIOGAS A PARTIR DE RESIDUOS ORGÁNICOS DE FRUTAS Y HORTALIZAS GENERADOS EN EL MERCADO GÓMEZ RENDÓN. [Internet] [Pregrado (INGENIERÍA AMBIENTAL)]. [GUAYAQUIL – ECUADOR]: UNIVERSIDAD AGRARIA DEL ECUADOR; 2020. Disponible en: https://cia.uagraria.edu.ec/Archivos/VITERI%20VEGA%20LADY%20LISBETH.pdf

28. Castillo C. Clasificación de los residuos – Planética [Internet]. 2021 [citado 12 de junio de 2024]. Disponible en: https://planetica.org/clasificacion-de-los-residuos/

29. Suárez-Chernov VD, López-Díaz I, Álvarez-González M, Suárez-Chernov VD, López-Díaz I, Álvarez-González M. ESTIMACIÓN DE LA PRODUCCIÓN DE BIOGÁS A PARTIR DE UN MODELO DE SIMULACIÓN DE PROCESOS. Centro Azúcar. marzo de 2019;46(1):73-85.

30. Ignatowicz K, Filipczak G, Dybek B, Wałowski G. Biogas Production Depending on the Substrate Used: A Review and Evaluation Study—European Examples. Energies. 2023;16(2):undefined-undefined.

31. Atelge MR, Senol H, Mohammed D, Hansu TA, Krisa D, Atabani A, et al. A critical overview of the state-of-the-art methods for biogas purification and utilization processes. Sustainability (Switzerland). 2021;13(20):undefined-undefined.

32. Arguelles CW, Pintor DCA, Mesinas CM, Márquez HL, Becerra EV. Obtención de biofertilizantes enriquecidos en biodigestores semicontinuos a nivel laboratorio. Ciencia Latina Revista Científica Multidisciplinar. 21 de febrero de 2023;7(1):5241-58.

33. Rodríguez Morgado B. Producción de un biofertilizante / bioestimulante mediante un proceso biológico / enzimático a partir de subproductos orgánicos: valorización agronómica y ambiental de lodos de depuradora y plumas de matadero [Internet] [http://purl.org/dc/dcmitype/Text]. Universidad de Sevilla; 2019 [citado 12 de junio de 2024]. Disponible en: https://dialnet.unirioja.es/servlet/tesis?codigo=218262

34. Díaz-Arias AA. Biogás: una fuente de energía para las generaciones futuras en la era post-petrolera. Agroindustria, Sociedad y Ambiente. 27 de noviembre de 2022;2(19):104-22.

35. Castro Morales IG, Rodríguez Gámez M, Castro Morales IG, Rodríguez Gámez M. Potencial de producción de biogás para su aprovechamiento energético en el contexto rural de Manabí. Ingeniería Energética. diciembre de 2022;43(3):62-70.

36. Osorio WAH, Carrera PJV, Bonilla JIC, Salazar FSA. Obtención de biogás y biol como fuente de energía renovable de biodigestores experimentales en el en la UTC extensión La Maná. Magazine de las Ciencias: Revista de Investigación e Innovación. 4 de abril de 2023;8(2):23-44.

| ***Received:*** *15 octubre 2024* | ***Accepted:*** *8 diciembre 2024* | ***Published:*** *15 diciembre 2024* |

Citation: *Salazar, E., Barragán, A., Arias-Toro, D., Cobos, F. Comparison of three treatments (aerobic, anaerobic and combined) for the decomposition of organic matter to obtain biogas and biofertilizer. Bionatura*. 2024; Volume 9. No 4.

Peer review information: Bionatura thanks the anonymous reviewers for their contribution to the peer review of this work using https://reviewerlocator.webofscience.com/

ISSN 1390-9355
Vol. 9 No. 4 2024
https://revistabionatura.org/

All articles published by Bionatura Journal are freely and permanently accessible online immediately after publication, without subscription charges or registration barriers.

Publisher's Note: Bionatura stays neutral concerning jurisdictional claims in published maps and institutional affiliations.