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Optimization of Conditions to Produce Biogas Methane from Dog Feces by Anaerobic Digestion: Systematic Re-view and Technological Perspectives

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Abstract

Sustainable organic waste management has spurred research on methane bi-ogas production from various sources, including animal fecal waste. This study presents a systematic review on the anaerobic digestion of dog feces with the aim of optimizing conditions for methane biogas production. Scien-tific databases such as ScienceDirect, Springer, MDPI and ResearchGate were analyzed, selecting a total of 38 studies under the PRISMA methodolo-gy. The results indicate that methane production efficiency is influenced by organic matter composition, temperature, pH and microbial synergy in an-aerobic fermentation. It is concluded that optimization of parameters such as carbon/nitrogen (C/N) ratio and implementation of advanced anaerobic di-gestion technologies can significantly increase biogas production from these wastes. This study contributes to innovation in health and welfare technolo-gies by offering a sustainable solution for animal waste management, reduc-ing pollution and improving environmental quality. In addition, it contrib-utes to the thematic axis of sustainability and environment by demonstrat-ing how organic waste, such as dog feces, can be harnessed as a renewable energy source, promoting the transition to a greener and healthier future.

Keywords: *Biogas Methane, Dog Feces, Anaerobic Digestion, Condition Optimization, Bio-Reactor, Health and Welfare, Renewable Energy.*

Introduction

The conversion of organic waste into methane biogas through anaerobic digestion is an established practice for generating renewable energy and reducing the environmental impact of organic waste [1]. Although the use of animal manure as a source of biogas has been extensively studied, the utilization of dog feces remains an underexplored area despite its high content of organic matter susceptible to anaerobic degradation [2]. Dog feces contain a combination of proteins, carbohydrates, and fats that can be easily broken down in an anaerobic environment, releasing methane through the activity of methanogenic microorganisms [3]. However, the efficiency of the anaerobic digestion process depends on several factors, such as the carbon-to-nitrogen (C/N) ratio, temperature, and pH of the system [4]. Recent studies have shown that optimizing these parameters can significantly improve methane production [5]. This study aims

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to conduct a systematic review on the anaerobic digestion of dog feces, evaluating the optimal conditions that favor methane biogas production. For this purpose, scientific databases such as ScienceDirect, Springer, MDPI, and ResearchGate were analyzed, selecting 38 relevant studies using the PRISMA methodology. Emerging technologies, such as the design of advanced bioreactors, are highlighted as potential solutions to improve methane yields and make the implementation of this process feasible on a larger scale [6]. Furthermore, this study seeks to integrate scientific findings into the creation of sustainable and affordable systems for animal waste management, considering their potential application in urban and rural areas. Research in this area not only contributes to the generation of renewable energy but also offers a viable alternative for reducing the environmental impact associated with the improper disposal of canine excrement [7].

Methodology

Systematic Review on Anaerobic Digestion of Dog Feces for Biogas Production

For systematic review, a comprehensive search was conducted in academic databases such as PubMed, Scopus, Web of Science and Google Scholar. The search terms used included: “dog feces biogas”, “anaerobic digestion dog waste”, “methane production dog waste”, and “bioreactor optimization dog feces”. Articles published in the last ten years that reported experimental data on anaerobic digestion of dog feces and its potential for biogas production were selected.

The selected articles were reviewed in detail to identify key variables affecting methane biogas production. Studies that provided quantitative data on anaerobic digestion operating conditions and methane yields were included in the review. In total, 100 references relevant to addressing conditions for optimizing anaerobic digestion of dog feces were included [8,9].

Review of Scientific Articles in Academic Databases

Databases such as Google Scholar, Scopus, Web of Science and PubMed were used to obtain recent scientific articles on anaerobic digestion and biogas production from organic waste, including dog feces waste. The search included terms such as “anaerobic digestion,” “biogas methane,” “animal waste,” “dog feces,” “optimal biogas production conditions,” among others.The articles selected were from the last 10 years to ensure the relevance and accuracy of the data [10,11].

Experimental Studies and Research Projects.

Experimental studies published in peer-reviewed journals, such as Renewable Energy, Waste Management, Bioresource Technology, and Environmental Technology, were consulted.These studies provided data on temperature, pH, organic loading, and co-digestion conditions affecting methane production in anaerobic digestion processes [12,13]

Review of Technical Reports and Theses.

Theses and dissertations available in university repositories on biogas process optimization, particularly from animal waste with an emphasis on fecal matter, were consulted [14]. A systematic review following PRISMA methodology [15] was conducted, applying inclusion criteria such as publications from 2015 to 2025, experimental studies on anaerobic digestion of fecal waste, biogas production, and optimization, and articles in English or Spanish from indexed journals. Exclusion criteria included studies without quantifiable experimental data, reviews without explicit methodology, and non-English/Spanish studies. Scientific databases such as ScienceDirect, SpringerLink, ResearchGate, MDPI, and Frontiers in Environmental Science were used to ensure quality and timeliness. After applying eligibility criteria, 38 relevant studies were selected and evaluated using Mendeley and Zotero to minimize bias [16]. Data extraction focused on organic matter composition (carbon, nitrogen, carbohydrates, lipids, proteins) [17], environmental factors (temperature, pH, retention time, C/N ratio) [18], and biogas production (methane yield in mL CH_4/g SV) [19,20]. The Cochrane RevMan 5.4 tool was used for statistical analysis, ensuring the meta-analysis' validity.

Data Extraction.

For the analysis of the selected studies, the following key parameters were extracted:

- Organic matter composition: carbon, nitrogen, carbohydrate, lipid and protein content [17].

- Environmental factors: Temperature, pH, retention time and C/N ratio[18].

- Biogas production: methane yield (mL CH_4/g SV) [19,20].

Cochrane RevMan 5.4 tool was used for data extraction and analysis, ensuring the statistical validity of the meta-analysis.

Results

Temperature

Temperature plays a crucial role in microbial activity during anaerobic digestion. Most of the studies reviewed indicate that mesophilic (30-40°C) and thermophilic (50-60°C) digestion are the most effective for methane production. Under thermophilic conditions, a higher rate of biogas production is observed due to higher activity of methanogenic bacteria [17,18].

As seen in Table 1, the results indicate that thermophilic digestion generates 60-100% more methane than mesophilic digestion, but with higher energy costs. Psychrophilic digestion has significantly lower yields.

pH

The optimum pH for anaerobic digestion of dog feces is between 6.5 and 7.5. Outside this range, microbial activity is inhibited, which decreases methane production. Alkalinization of the medium through additives such as lime or ash has been reported as an effective strategy to maintain pH within the appropriate range [21].

Table 1 shows that maximum production occurs between pH 6.5 and 7.5, while values outside this range affect methanogenic activity.

Organic load

The adjustment of the organic load directly influences biogas production. Excessive loading can lead to the accumulation of volatile acids, inhibiting methane production. However, moderate loadings have been shown to be effective, achieving a balance between the process of acidogenesis and methanogenesis [22]. Table 1 shows that the higher the organic load, the higher the methane production, but with the risk of microbial inhibition.

Additives and Combined Substrates

The use of additives, such as manure from other animals or food waste, has been shown to improve the efficiency of anaerobic digestion. These additives provide additional nutrients and balance the carbon to nitrogen ratio, which favors microbial activity and increases methane production [23].

Bioreactors

Advanced bioreactor design is essential to improve process efficiency. Bioreactors with temperature control and recirculation systems have shown better results as shown in Table 1, as they allow more precise control of operating conditions [24]. The integration of technologies such as continuous agitation and real-time monitoring of operating conditions also improves process efficiency.

Bioreactor Type / Factor	**Operating Temperature (°C)**	**Methane Production (mL/gVS/day)**
Continuous Stirred Tank Bioreactor	30-40	200-300
Fixed Bed Bioreactor	50-60	350-500
Recirculation Bioreactor	35-45	300-400
Temperature (Mesophilic)	30-40	150-250
Temperature (Thermophilic)	50-60	300-500
Temperature (Psychrophilic)	20-30	50-100
pH Range	6.0 - 6.5	100-200
pH Range	6.5 - 7.5	250-350
pH Range	7.5 - 8.0	150-200
Organic Load	0.5 - 1.0 gVS/L/day	100-200
Organic Load	1.0 - 2.0 gVS/L/day	200-300
Organic Load	3.0 - 4.0 gVS/L/day	350-500
Additive: Cow Manure (20%-50%)	-	300-400
Additive: Food Waste (10%-30%)	-	250-350

Table 1. Table 1. Consolidated Bioreactor and Methane Production Data

Results of the Statistical Analysis

The results of the meta-analysis are presented in detailed tables, including mean values, standard deviations, and heterogeneity estimates.

Variable	Number of Studies	I^2 (%)
Temperature	25	62
pH	20	48
C/N Ratio	18	70
Organic Load	15	55

Table 2. Measure of Heterogeneity (I^2) in the Analyzed Studies

(Source : Higgins et al., 2003 ; Zhang et al., 2018)

Variable	Coefficient (β)	95% CI
Temperature	0.65	0.45-0.85
pH	0.52	0.33-0.71
C/N Ratio	0.78	0.62-0.94
Organic Load	0.49	0.28-0.70

Table 3. Meta-Analytical Regression: Influence of Environmental Factors on Biogas Production

(Source : Borenstein et al., 2009 ; Ghosh et al., 2020)

Variable	Egger's Statistic	p-Value
Temperature	1.45	0.08
pH	0.92	0.12
C/N Ratio	2.15	0.02
Organic Load	1.78	0.04

Table 4. Egger's Test for Publication Bias

In the Table 5 presents the total number of studies identified in each database before applying inclusion and exclusion criteria. The removal of duplicate studies refines the search and ensures that repeated studies are not included in the analysis. Out of the 660 initially identified studies, only 560 were unique after removing duplicates. This process reduces redundancy and improves the accuracy of the analysis

Data Source	Identified Studies	Duplicate Studies	Studies After Filtering
ScienceDirect	180	30	150
SpringerLink	160	25	135
ResearchGate	100	15	85
MDPI	130	20	110
Frontiers in Environmental Science	90	10	80
Total	**660**	**100**	**560**

Table 5. Initial Study Selection by Data Source

In the Table 6 shows the progressive elimination of studies according to the established inclusion and exclusion criteria. The reduction in studies at each stage highlights the impact of applied filters to ensure that only relevant and high-quality studies are considered. Of the 560 reviewed studies, only 38 met all eligibility criteria, indicating a high exclusion rate based on scientific relevance and methodological quality.

Applied Criteria	**Remaining Studies**
After removing duplicate studies	560
Studies without experimental data	400
Reviews without explicit methodology	300
Studies in languages other than English and Spanish	250
Studies irrelevant to the topic	150
Total Selected Studies	**38**

Table 6. Relevance Assessment Based on Inclusion and Exclusion Criteria

In the Table 7 presents the mean values and standard deviations of key parameters analyzed in the selected studies. The mean and standard deviation provide information about the distribution and variability of environmental parameters and biogas production among the studies. It is observed that temperature and C/N ratio exhibit considerable variability, suggesting that these factors may significantly impact methane production.

Parameter	**Number of Studies**	**Mean**	**Standard Deviation**
Carbon Content (%)	38	55.8	5.0
Nitrogen Content (%)	38	4.2	0.7
C/N Ratio	38	24.8	2.9
Temperature (°C)	38	41.2	7.4
pH	38	6.9	0.4
Methane Production (mL CH_4/g VS)	38	325	40

Table 7: Extracted Parameters from Selected Studies

The table 8 summarizes the statistical models used to assess heterogeneity and reliability of results. The inclusion of random-effects models and heterogeneity tests ensures that methodological differences between studies are considered, reducing the impact of bias. Egger's test indicates possible publication bias, while meta-analytical regression evaluates the impact of key variables such as temperature and C/N ratio.

Statistical Model	**Application**

Heterogeneity Measure (I^2)	Quantification of variability among studies
Random-Effects Model	Consideration of methodological differences
Egger's Test	Evaluation of publication bias
Meta-Analytical Regression	Determination of key variable impacts

Table 8: Statistical Models Applied in the Meta-Analysis

The Table 9 presents the final selected studies, along with the key variables evaluated in each. The comparison of values across studies helps identify trends and patterns in methane production based on environmental parameters. It is observed that the optimal temperature for methane production ranges between 35-55°C, and the ideal C/N ratio is between 24:1 and 30:1. This provides a clear view of the most relevant studies and their impact on biogas production, facilitating the extraction of robust and applicable conclusions for optimizing the anaerobic digestion process.

Author(s)	**Year**	**Article Title**	**Database**	**Temperature (°C)**	**pH**	**C/N Ratio**	**Organic Load (gVS/L/day)**	**Methane Production (mL CH_4/g VS)**
Ghosh et al.	2020	Methane production from animal waste: Optimization of anaerobic digestion process	Energy & Fuels	35-55	6.5 - 7.5	25:1	2.5-3.5	300-450
Wu et al.	2019	Optimization of organic loading rate in anaerobic digestion of dog waste	Environmental Science & Technology	30-50	6.2 - 7.8	22:1	1.8-3.0	250-400
Zhang et al.	2018	Thermophilic anaerobic	Biodegradation	50-60	6.8 - 7.2	30:1	3.0-4.0	350-500

		digestion for biogas production from dog feces						
Kumar et al.	2020	Advances in bioreactor technologies for methane production from organic waste	Renewable Energy	37-52	6.0 - 7.5	28:1	2.0-3.2	270-420

Table 9: Selected Scientific Articles for Meta-Analysis

Conclusions

Optimizing the anaerobic digestion conditions of dog feces is crucial to maximizing methane biogas production. Ideal conditions include mesophilic or thermophilic temperatures, a controlled pH between 6.5 and 7.5, and a moderate organic load. The addition of substrates such as manure and food waste can significantly improve digestion efficiency.

The design of bioreactors with temperature control and recirculation systems is essential for optimizing the process. Technological advancements in bioreactor construction that efficiently manage anaerobic conditions open new opportunities for using dog feces in biogas production, contributing to sustainable waste management and renewable energy generation.

Factors such as the C/N ratio, temperature, pH, and microbial activity must be carefully adjusted to maximize energy yield. The implementation of pretreatment techniques is recommended to reduce ammonia generation and improve the biodegradability of organic matter. Additionally, the meta-analysis conducted helps identify patterns and variations in process efficiency across different studies, providing a quantitative basis for future research.

The use of interspecies electron transfer (IET) has been shown to improve the efficiency of waste-to-biogas conversion, reducing retention times and increasing process stability (IET Review, 2023).

Egger's test revealed publication bias in studies on the C/N ratio and organic load, which may influence the interpretation of results.

The obtained results indicate that temperature and the C/N ratio are the most influential factors in methane biogas production. Moderate heterogeneity was observed in the studies analyzed, suggesting significant methodological differences among the investigations**.**

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