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Comparison of Biogas Potential: Efficiency of Monofermentation of cattle, Swine, and Poultry Manure

Comparación del Potencial de Biogás: Eficiencia de la Monofermentación de Excretas Vacunas, Porcinas y Avícolas

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ABSTRACT: The scarcity of fossil fuels in Cuba is driving the search for renewable energy sources. This study evaluated the biogas potential of cattle, pig, and poultry manure as biomass for pyrolysis. Manure biodigestion was analyzed in 100 mL syringes, inoculated with 6 mL of pig inoculum at 30 mL of each manure. The results showed that cattle manure presented the highest biogas potential (1457.15 L_N/kg_{FM}), followed by pig manure (906.23 L_N/kg_{FM}) and poultry manure (131.09 L_N/kg_{FM}). It is concluded that cattle manure presents the greatest potential for biogas production. The pH evolution was similar across the three types of manure evaluated.
Keywords: Anaerobic Digestion, Biogas Production, Methane Yield.

RESUMEN: La escasez de combustibles fósiles en Cuba impulsa la búsqueda de fuentes de energía renovable. Este estudio evaluó el potencial de biogás de excretas vacunas, porcinas y avícolas como biomasa para pirolisis. Se analizó la biodigestión de las excretas en jeringas de 100 mL, inoculadas con 6 mL de inóculo porcino a 30 mL de cada excreta. Los resultados mostraron que la excreta vacuna presentó el mayor potencial de biogás (1457,15 L_N/kg_{FM}), seguida por la porcina (906,23 L_N/kg_{FM}) y la avícola (131,09 L_N/kg_{FM}). Se concluye que la excreta vacuna presenta el mayor potencial para la producción de biogás. Se observó una evolución similar del pH en las tres excretas valoradas
Palabras clave: digestión anaeróbica, producción de biogás, rendimiento de metano.

INTRODUCTION

Renewable energy production is crucial for Cuba due to the scarcity of fossil fuels. Despite investments in photovoltaic and wind energy, the potential of biomass, especially from agro-industrial waste, remains underutilized. There is a lack of information on the potential of different types of animal excreta for biogas production in Cuba. Given this background, it would be important to deepen knowledge and experience regarding the possibilities of using these substrates for energy production at the national level.

According to AINIA (2008), the procedure described in VDI 4630 standard is used to determine the maximum biogas potential of a waste or waste mixture. Each organic waste has a specific potential, and there are notable differences depending on its composition. Differences can occur within the same waste family. The maximum biogas production potential of organic waste is determined experimentally using a laboratory-scale batch test, in which the material completely biodegrades under controlled anaerobic conditions. Some of the agro-industrial organic wastes are: agricultural waste from cooperatives (surplus, low-quality, etc.); livestock waste (pig slurry, cattle manure, chicken manure, etc.); food waste of animal origin (slaughterhouses and meat industries, dairy industry waste, fish and seafood processing waste, etc.); food waste of plant origin (surplus and waste from fruit and vegetable production, juice industry bagasse, canning waste, used oils, vinasse, etc.); fatty sludge from industrial food treatment plants; food distribution waste (expired, returned, or out of specification); waste from biofuel plants (glycerin and other residues from bioethanol or biodiesel plants). The advantages are: knowing the actual maximum biogas potential of a specific substrate; performing the specific test to assess its possible use in industrial plants; and comparing the results obtained with existing, published results. Substrate composition is the main factor in determining methane yield and potential. Literature sources report that differences in methane kinetics, potential, and yield depend on the type of substrate used (Forster-Carneiro et al, 2012). Substrate pretreatment methods aim to improve anaerobic digestion qualities by altering their physical, chemical, and biological properties, optimizing the availability of substrate components, and thus increasing the hydrolysis process during anaerobic digestion.

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There are different types of substrate pretreatments; they can be classified as basic or special. Among the basic ones, there are those that have the purpose of reducing the particle size (crushing, milling, sieving). Among the special treatments are thermal, chemical, ultrasound, microwave radiation, and biological treatments (enzymes, fungi, and bacteria).

Pretreatments (basic and special) exhibit certain peculiarities such as increased handling costs, increased legislative requirements for the stabilization and removal of potential pathogens, a tendency toward lower nitrogen levels, which allows for age management of these substrates, and a decrease in the biodegradability of activated substrates (Zhong *et al.*, 2011). However, an analysis of the pretreatment to be used based on the type, performance, and cost is necessary.

The use of different pretreatments for agricultural and animal substrates has been reported in the literature by various authors such as: Kurakake *et al.* (2007); Taherzadeh & Karimi (2008); Vintiloiu *et al.* (2009); Brulé (2014); (Martinez *et al.*, 2014); Martinez et al. (2015); Martínez & García (2016) This research had its genesis in a project proposal submitted simultaneously in Russia and Cuba by the respective Ministries of Science, Technology, and Environment. Its planned objectives were the pyrolysis of Cuban biomass and its evaluation for methane generation potential. Hence the interest in evaluating cattle, pig, and poultry substrates (excreta) in mono-fermentation to assess their biogas generation potential.

Biogas production from excreta varies among cattle, pigs, and poultry farms due to the composition and quantity of manure. In cattle, daily excreta production ranges between 30 and 79 kg per day. In pigs, this is around 3.5 kg per day, while in poultry, both excrement generation and biogas production are lower per animal, and biodigesters must be previously adapted for this type of waste. In summary, cattle manure has the greatest biogas production potential, due to its greater quantity and organic matter content; pigs produce less, but with good relative efficiency; and poultry contributes biogas, but on a smaller scale due to less material and waste volume. Optimal management and mixing (co-digestion) greatly influence the final biogas production and efficiency of each type of manure. In summary, the literature on the subject expresses methane and biogas yields in different units such as: m3 CH4/kg VS*; mL CH4/kg VS; mL CH4/g VS; L_N/kg_{FM}; L_N/kg_{oTS}. Some examples of these values in animal excreta are shown below: cattle (0.15-0.23 m3 CH4/kg VS); pigs (0.10-0.40 m3 CH4/kg VS); poultry (127-288 mL CH4/g VS). Renewable energy production is crucial for Cuba due to the scarcity of fossil fuels. Despite investments in photovoltaic and wind energy, the potential of biomass, especially from agro-industrial waste, remains underutilized. There is a lack of information on the potential of different types of animal excreta for biogas production in Cuba. This study aims to assess the biogas potential of cattle, pig, and poultry excreta for future use in pyrolysis in Cuba.

$$VS^* = oTS - \text{volatile solids}$$

MATERIALS AND METHODS

This study was conducted at the Universidad Central "Marta Abreu" in Las Villas between March and April 2025. Feces samples (cattle, pigs, and poultry) were collected from two livestock facilities of each type, located in four municipalities in the province of Villa Clara. Based on two poultry farms (Ranchuelo (Platinical) and Santa Clara (Yacusey), two pig farms (Manicaragua (El Negrito) and Remedio Buena Vista) and two cattle farms (Remedio (CPA 26 de Julio) and (Buena Vista), Cuba. The test protocol applied was based on the VDI 4630 standard. This standard is frequently used in other European countries. Its application facilitates comparison with previous results on the same or similar substrates. The test also allows to highlight fermentation problems due to inhibitory substances naturally present in the waste (e.g. polyphenols) or incorporated into it during its generation (e.g. pesticides or other xenobiotic substances). Also incompatibilities between wastes in a mixture: Using the VDI 4630 standard the following results can be obtained: Composition of the waste or mixture of wastes: humidity, C/N ratio, toxins, etc. (as needed); biodegradability rate; maximum biogas potential (litres of biogas/kg VS); biogas composition (CH4, CO2, H2S).

Samples were collected in sterilized 1.5 L containers at the beginning, middle, and end of the analyzed facilities, at ground level and equidistant from each other by 10 meters. The samples were homogenized and refrigerated in the Food Science Laboratory for subsequent analysis. The substrates were characterized according to the VDI (2006) standard in our University's Food Science Laboratory, following the protocol established by the VDI (2006) standard. The following were determined for each substrate: fresh matter, dry matter, ash, and moisture content in triplicate. Using German software specialized in substrate calculations called EinwageBatch (Version 1), the following were determined: the quantity of material to be digested or placed per substrate and inoculum, and the quantity of water to be added to each substrate to meet the (excreta/water) ratio required for its fermentation in The experimental syringes, which act as small-scale biodigesters. To assemble them in the syringes, the substrates were homogenized, filtered, and placed in the respective experimental syringes by treatment and replicate. Using this methodology, the biogas potential generated by each treatment and its respective replicates was determined; 35 values were obtained for each. The results obtained included the mean, standard deviation, and coefficient of variation. This methodology, which is internationally known as the Hohenheim Yield Test (HBT), is described in Martínez et al. (2014).

No pretreatment was applied to the experimental samples. Porcine inoculum (6 mL of porcine effluent from a biodigester) was added to the cattle and poultry substrates, due to its greater availability. The porcine substrates were evaluated as a control. The substrates were then introduced into 100 mL experimental syringes. The experiment lasted 35 days, to observe the behavior of anaerobic digestion during this cycle. The experimental syringes were placed in a device called the Hohenheim Yield Test (HBT), at a rate of three replicates per substrate evaluated under field conditions; as well as one replicate in a plastic container (plastic bottle), to investigate the pH evolution during the anaerobic digestion process under field conditions. The following parameters were studied:

- Moisture and dry matter content according to NC 74-22:85 (1985);
- Ash content according NC 74-30:85 (1985);
- Determination of the carbon/nitrogen ratio
- Evolution of pH during biodigestion
- Evaluation of specific biogas yield
- Biodegradability rate
- Maximum biogas potential (L/kg VS).

The biogas yields for the substrates investigated were obtained after the end of the cycle. The biodigestion cycle was carried out by entering the measurements or readings of the volume of biogas produced in each treatment and their respective replicates into a software program called Gärtest nach VDI 4630. This software allowed the results to be graphed and the mean, standard deviation, and coefficient of variation determined.

RESULTS AND DISCUSSION

Figure 1 shows the specific biogas yield of cattle and poultry substrates. The cattle substrate had a significantly higher yield (1457.15 LN/kgFM) than the poultry substrate (131.09 LN/kgFM) ($p < 0.05$). This difference could be due to factors such as the carbon/nitrogen (C/N) ratio, which presents notable differences in each of the substrates evaluated. For example, in cattle manure (16:1 to 25:1); in pig manure (10:1 to 16:1); in poultry manure (6:1 to 7:1). This ratio can vary depending on the animal's diet and the type of manure (solid or liquid). On the other hand, it is proposed that the ideal ratio for the anaerobic digestion process of substrates is 20:1 to 30:1, a high C/N ratio slows the decomposition of substrates due to lack of nitrogen, which limits biogas production; while a low ratio can cause nitrogen losses in the form of ammonia, which is toxic to bacteria that produce methane and can inhibit their activity. Taking this indicator into account, it could be seen that the substrate that closest to the ideal indicator was the one composed of cattle excrement, which was reflected in the yield obtained with this substrate. It could also be seen that biogas production in the different replicates presented drops in its potential during the biodigestion cycle, which corresponds to a diauxia-type behavior. These results partially coincide with those of Barreda *et al*, (2022), who also found a higher biogas yield in cattle excrement, but differ from those of Martínez et al. (2014), who used pretreatments on the substrates evaluated in co-fermentation. Therefore, although this research provides new knowledge, it would be prudent not to consider it conclusive.

Figure 2 shows the evolution of the specific biogas production yields of the substrates (poultry and pork). Significant differences were observed between these two substrates. In this case, the best performance was obtained with the pork substrate (906.23 L_N/kg_{FM}), while the poultry substrate had a low biogas production yield (131.09 L_N/kg_{FM}). In both Fig. 1 and Fig. 2, the behavior of the curves describing biogas production was of the diauxia type, which explains a non-uniform production during the biodigestion cycle (drops in production) in accordance with the VDI 4630 standard. According to these results, it would be pertinent to continue the study of these substrates as candidates to be used in special pre-treatments (pyrolysis) to explore their methane potential under these new conditions

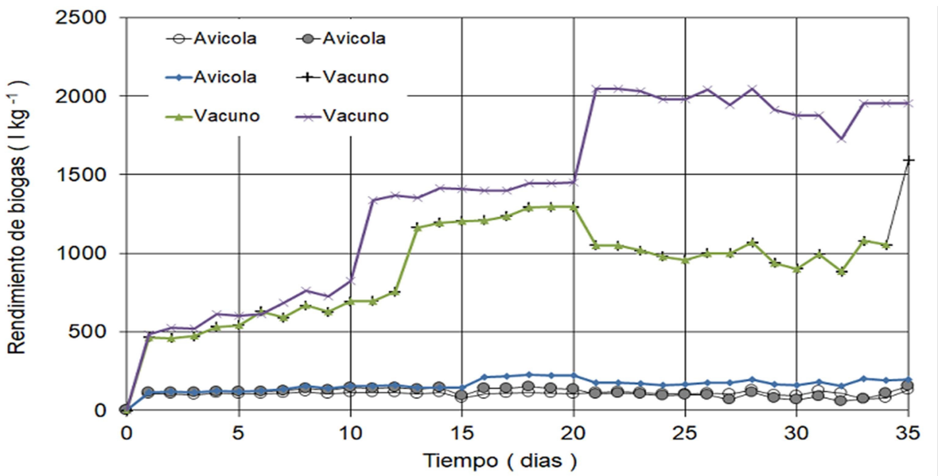

Figure 1. Average specific biogas yield values for cattle and poultry substrates using syringe-scale pig inoculum.

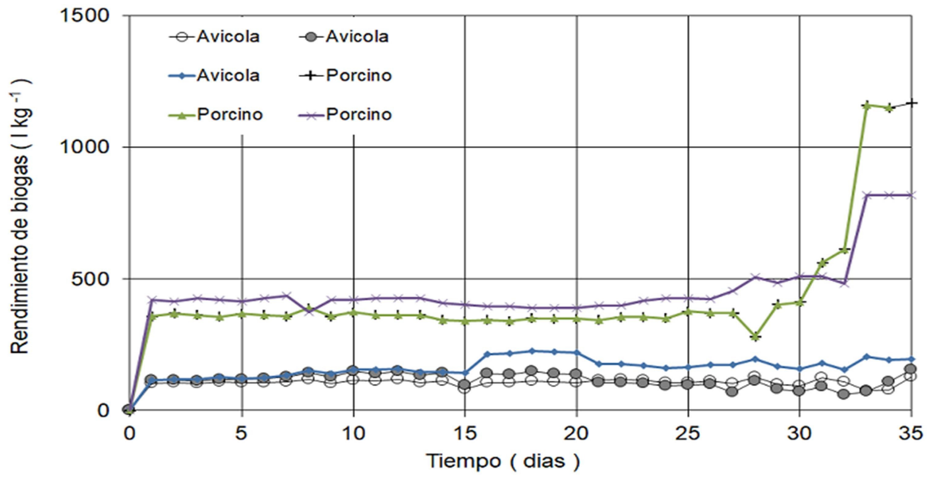

Figure 2. Average specific biogas yield values for pig and poultry substrates using syringe-scale pig inoculum.

Table 1 presents the results obtained with the tested substrates.

From the analysis of Table 1, the behavior of biogas production could be observed with respect to fresh mass (L_N/kg_{FM}) and volatile solids (L_N/kg_{TS}). The average specific biogas yield (L_N/kg_{FM} and coefficient of variation (%) of the different treatments and their replicates were also obtained. The great variability between the replicates of the different treatments is highlighted, with the poultry substrate showing the greatest variability (41%), followed by the beef substrate (31%), and finally the pork substrate (24%). This was interesting and could be the subject of future research.

Regarding the evolution of pH, the results obtained are shown in Figure 3.

In the biomasses evaluated (pork, poultry, and beef substrates), differences could be observed between the substrates evaluated; however, all substrates presented pH values above 7 at the end of the biodigestion cycle. This demonstrates the favorable action of porcine inoculum, which guarantees a buffer effect that allows maintaining adequate conditions for good substrate degrading activity in the pH ranges (between 6 and 8), which agrees with what was proposed by Vintiloiu *et al.* (2009).

CONCLUSIONS

- The bovine substrate presented the highest biogas yield (1457.15 L_N/kg_{FM}), followed by porcine (906.23 L_N/kg_{FM}) and poultry (131.09 L_N/kg_{FM}), suggesting that bovine manure is the most promising biomass for biogas production under the conditions evaluated.
- The low yield of the poultry substrate, with a C/N ratio of 6/1, suggests the presence of anaerobic digestion inhibitors, which requires further investigation.
- It is recommended to investigate the cause of the variability observed between replicates.
- This study was limited to the evaluation of manure in monofermentation; future research could explore the co-digestion of different types of manure and the use of pretreatments to improve biogas yield.
- The pH evolution of the substrates evaluated behaved similarly in all cases, remaining within the optimal biodigestion range.

Table 1. Specific biogas yield per tested substrate

Substrates evaluated	Biogas yield (L_N/kg_{FM})*	Biogas yield (L_N/kg_{oTS})**	Average specific biogas yield (L_N/kg_{FM})	Coefficient of variation (%)
Pig substrate. a	179.76	1150.19	906.23	24
Pig substrate. b	128.07	819.48		
Pig substrate. c	117.06	749.02		
Poultry substrate. a	58.70	92.70	131.09	41
Poultry substrate. b	68.61	108.35		
Poultry substrate. c	121.7	192.2		
Cattle substrate. a	164.52	1052.68	1457.15	31
Cattle substrate. b	305.43	1954.32		
Cattle substrate. c	213.24	1364.45		

* L_N/kg_{FM} -normalized liters of biogas per kg of fresh matter; ** L_N/kg_{oTS} - normalized liters of biogas per kg of total organic solids.

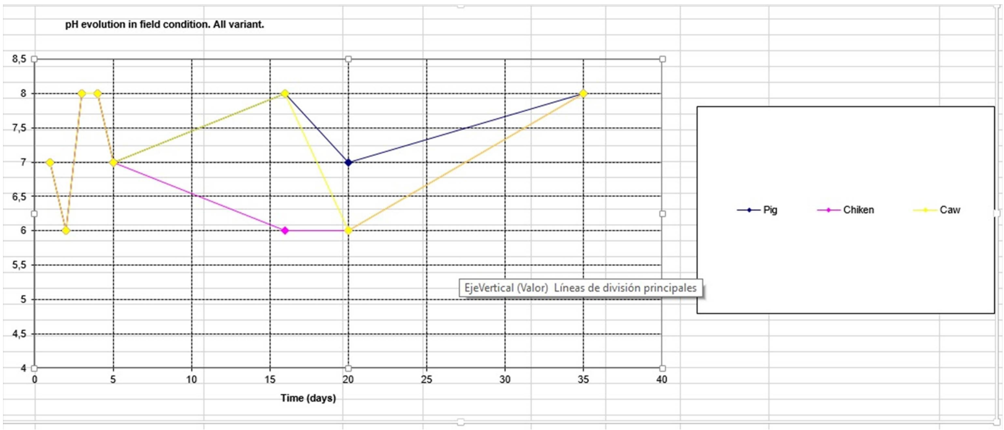

Figure 3. pH evolution in the substrates evaluated during the biodigestion cycle.

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