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Biogas production and electricity generation from a quail manure wastewater treatment system per water depth

Produção de biogás e geração de energia elétrica de um sistema de tratamento de dejeto de codorna por lâmina d'água

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ABSTRACT

Coturniculture, as an activity which demands low investment and quick return, is shown to be a possibility for the rural family producer. Concomitant to this, we highlight the fact that the use of liquid quail farming waste, aimed at generating energy by anaerobic digestion, can mean a viable and promising technology for obtaining biogas from confined animal production systems. The growing demand for energy establishes that new energy sources are better used, and a great opportunity for their growth may be the use of biomass in anaerobic digestion systems, in which the organic substrate is degraded and transformed into energy and biofertilizer. The method applied was Biochemical Potential of Methane, through benchtop bioreactors with a volume of 250 mL, and in mesophilic conditions. Waste was used as inoculum from the manure tank of the quail egg production farm. The substrates used to compose the treatments were liquid quail farming waste from the water depth treatment system, with 15, 30 and 45 days of deposition. In the results obtained, it was verified that the best mono digestion used was inoculum+substrate of 30 days of deposition, with water retention time of 45 days, showing a higher production accumulated in biogas (0.00078476 Nm^3) and CH_4 (0.000575 Nm^3) as well as the highest biogas potential of 0.0043 Nm^3 (kg substrate)$^{-1}$. When converted into electrical energy, by means of a motor generator, using as fuel the biogas produced by the liquid quail farming waste, the value of 104.64 kwh (45 days)$^{-1}$ was obtained.

Keywords: biodigester; energy potential; anaerobic digestion; BMP; coturniculture.

RESUMO

A coturnicultura, enquanto atividade que demanda baixo investimento e tem rápido retorno, mostra-se como possibilidade para o produtor rural familiar. Concomitantemente a isso, destaca-se o fato de que a utilização dos dejetos líquidos da coturnicultura, visando à geração de energia por digestão anaeróbia, pode significar uma tecnologia viável e promissora para a obtenção de biogás originado dos sistemas de produção de animais confinados. A crescente demanda por energia estabelece que novas fontes energéticas sejam mais aproveitadas, e uma grande oportunidade para o crescimento destas pode ser o uso da biomassa em sistemas de digestão anaeróbia, em que o substrato orgânico é degradado e transformado em energia e biofertilizante. O método aplicado foi o Potencial Bioquímico de Metano, por meio de biorreatores em bancada com volume de 250 mL, e em condições mesófilas se utilizou como inóculo o dejeto do tanque da esterqueira da granja de produção de ovos de codornas, os substratos utilizados para compor os tratamentos foram dejetos líquidos da coturnicultura do sistema de tratamento por lâmina d'água, com 15, 30 e 45 dias de deposição. Nos resultados obtidos, constatou-se que a melhor monodigestão utilizada foi inóculo+substrato de 30 dias de deposição, com tempo de retenção hídrica de 45 dias, apresentando maior produção acumulada de biogás (0,00078476 Nm^3) e CH_4 (0,000575 Nm^3), bem como o maior potencial de biogás 0,0043 Nm^3 (kg substrato)$^{-1}$; e, quando convertido em energia elétrica, por meio de motogerador, utilizando como combustível o biogás produzido pelo dejetos líquidos da coturnicultura, obteve-se o valor 104,64 kwh (45 dias)$^{-1}$.

Palavras-chave: biodigestor; potencial energético; digestão anaeróbia; PBM; coturnicultura.

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Introduction

Coturniculture (quail breeding) is an activity that demands low investment and rapid return, for presenting a high production of eggs, the main products on an industrial scale, since the meat of these birds is still considered exotic by consumers. In Brazil, some factors have favored the development of coturniculture, such as the rapid growth of birds, the precocity in the production and sexual maturity of these birds (35 to 42 days), the high productivity (average of 300 eggs per year^{-1}), the use of a small space for large bird populations, the longevity in high production (14 to 18 months), the low investment in the activity and, consequently, the rapid financial return (Pastore et al., 2012). Still in Brazil, in terms of quantity related to coturniculture, in 2020, 16.7 million quails were registered, the state with the greatest flock being Espírito Santo, followed, respectively, by the states of São Paulo, Minas Gerais, Santa Catarina and Ceará (IBGE, 2020).

If, on the one hand, the factors and numbers presented earlier show economic motivation, on the other hand, they become worrying in environmental terms, in view of the consequent increase in the disposal of the quail waste resulting from the expansion of the coturniculture (Pinheiro et al., 2022), since, according to De Bona et al. (2017), the intensive poultry production generates the waste from the activities, which should be treated in such a way as to minimize environmental impacts. For this reason, as impacts on the environment grow dramatically, there is a need to adopt mitigation measures and new technologies aimed at transforming waste into compounds to be absorbed by the biosphere, that is, going beyond sustainability. In this sense Delgado et al. (2016) point to a re-study of the destination of the waste produced, and cite biodigestion as a possibility for the waste disposal. Besides, Marchioro et al. (2018) emphasize that waste from coturniculture has high energy and economic potential to be used as a source of biomass for anaerobic digestion to generate biogas, as well as mitigating impacts and increasing financial profit.

In addition, the use of anaerobic digestion for the treatment of animal waste has been a viable and promising technology for biogas from confined animal production systems. In this perspective, Pinheiro et al. (2022) point out that the treatment of laying bird waste in a rational, environmental and economic way, with the aim of achieving energy potential and reducing environmental impact, can be achieved through anaerobic digestion. In this sense, Capson-Tojo et al. (2016) emphasize that anaerobic digestion can be understood as a biological process that happens in several stages of organic matter degradation, with the intention of producing biogas and digestate in environments without oxygen. The process usually occurs in four steps: hydrolysis, acidogenesis, acetogenesis and methanogenesis.

For the use of anaerobic digestion to produce energy, it is necessary to know the biogas production potential of the substrates, and this potential can be detected by the PBM test, which represents methane production (CH_4), total anaerobic digestion, and also demonstrates the biological degradation of organic substrates (Silva et al., 2016; Rodrigues et al., 2019). In addition to making it possible to know the biodegradability potential of a substrate, the PBM allows to estimate the possibility of inhibition of anaerobic digestion for different conditions, improves inoculum relations and substrates and also gives the retention time necessary to complete the anaerobic digestion of a complex substrate (Angelidaki et al., 2009; Blasius, 2019). In a holistic view of the anaerobic digestion process, considering an energy production technology and also a rapid generation of biofertilizer, the anaerobic digestion process will probably be the dominant technique in the waste treatment (Jurgutis et al., 2020). Thus, anaerobic digestion can be an alternative for the use of coturniculture waste, with the potential results of energy generation and improvement of the energy efficiency of the production system, the environmental sanitation of rural property and the making of biofertilizers through the implementation of biodigesters, results that represent economic, social and environmental advantages.

In the literature, studies can be found with the purpose of verifying the potential of biogas production through the most varied types of substrates using anaerobic digestion. In the work of Silva et al. (2021), the authors analyzed the maximum potential for biogas generation and CH_4 from the combinations of quail bed (substrate)+granulated sludge (inoculum), which presented potential for biogas (0.000220 $Nm^3.g^{-1}VS$) and CH_4 (0.000086 $Nm^3.g^{-1}VS$). Lucas Jr. et al. (1997) *apud* Lucas Jr. and Santos (2000) studied the anaerobic digestion of the coturniculture waste in continuous biodigesters, under four time periods of water retention (HRT) of 30, 20, 15 and 10 days, and obtained significant potential for biogas production of 2.47, 1.90, 1.29, 1.11 m^3, per m^3 biodigester, respectively, to the THR.

Considering the possibility of biogas production and energy generation from the anaerobic digestion of liquid waste from coconut culture (DLC), the main goal of the present study was to investigate the use of DLC with a blade of water treatment system and its potential for biogas production and electric power generation in batch anaerobic bioreactors. To this end, the following specific objectives were set: to analyze the physico-chemical characteristics of inoculum and samples for a better understanding of the anaerobic digestion process and of the generation of biogas and methane; to conduct an experimental analysis with different deposition times of waste and water retention in anaerobic biodigesters, with the aim of evaluating the effect on biogas and methane production; and to verify the potential for energy generation by using biogas produced in coturniculture with a system of treating waste per blade of water.

Meteorological procedures

This study is characterized as experimental and quali-quantitative, and used the PBM test (biochemical methane potential), adopting the construction and monitoring of bench bioreactors under mesophytic conditions. For the performance of the PBM test, 16 bioreactors were made, consisting of borosilicate vials with volumetric capacity of

250 mL, high-strength plastic cap and reinforced buffer system to ensure sealing (Figure 1).

The bioreactors were coupled with relief valves and a pressure gauge of 1 kgf cm^{-2} with a scale of 0.1 kgf cm^{-2}, and the pressure gauges were duly calibrated in a certified laboratory. The samples of the DLC were collected in a farm producing quails eggs equipped with a system of treatment of droppings per blade of water, with a plant of 32,000 laying birds raised in suspended cages, located in the municipality of Massaranduba, State of Santa Catarina.

The treatment system operates in a 45-day cycle, in which on the first day the tank is filled with clean water to start receiving the waste from the quails. Samples were collected every 15 days during a deposition cycle in the water slide tank, totaling 3 (three) samples in total, the first on the 15th day, the second on the 30th day, and the last on the 45th day. The inoculum digested with the samples, in the PBM assay, was the manure pit tank of the farm, that is, the tank that receives the DLC after the end of the cycle. This inoculum was selected because of its availability on the farm and also because there is an additional population of microorganisms already used in the environment, as indicated by Xavier and Lucas (2010), which show that the insertion of inoculum in the anaerobic digestion process represents the supply of an additional population of microorganisms adapted to the new substrate.

The samples were stored in a 5-L polyethylene container and stored at a temperature of 4°C. During the study, the physical and chemical characterization of inoculum and samples was performed and inoculum and different samples were tested with 15, 30 and 45 days of deposition. During 90 days, PBM tests were carried out to evaluate biodegradation and biogas and CH_4. The experiment was installed in bench bioreactors at the Chemical Laboratory of a public teaching institution.

Figure 1 – External aspect of the posture quail breeding aviary (A); Characteristics of the suspended housing cages (B); Treatment system of droppings per blade of water (C); Sample collection of the quail liquid waste (D); Details of bioreactors (E and F).

The reactor fills were performed during a 45-day cycle of DLC deposition, and were established by four treatments, namely: T1=waste from the manure pit tank of the farm (inoculum); T2=liquid deposition of the coturniculture with a 15-day deposition+inoculum; T3=a 30-day liquid deposition+inoculum; and T4=a 45-day liquid deposition+inoculum, all in triplicate, resulting in 16 experimental units with a completely randomized design (IHD).

For the study of DLC mono digestion, the methodology described by Hansen et al. (2004) was adopted for the analysis of biogas generation and production and CH_4 and adapted by Firmo (2013). After assembling the bioreactors, the PBM test was started, namely: the sealing test and filling of the reactors, with the proportions of inoculum and substrates of 16.6% inoculum for three treatments (T2, T3 and T4). T1 was filled with the same proportions of inoculum and inert material in place of substrate. It was verified that the literature does not seem to agree with an optimal proportion, however, the substrate/inoculum ratio (S/I) was adopted (5:1,v:v), which aims to analyze the influence of inoculum on the process.

In the experimental composition, DLC samples of three deposition concentrations were used, 15, 30 and 45 days, with the addition of inoculum, and four treatments were set up in triplicate. Data on biogas generation and production and CH_4 were analyzed after 15, 30 and 45 days, with pressure reading and gas chromatographic analysis. It should be noted that the chromatographic analysis was carried out on the same day as the biogas collection, in order to minimize the risk of contamination of the sample.

After filling with pre-defined volumes of substrates (150 mL), inocula (30 mL) and headspace (70 mL), initial weighing, hydrogen potential (pH) measurement and electrical conductivity were performed. In this experiment, there was no pre-treatment or pH and alkalinity adjustment, since the proposal was to verify the behavior of the process, without any chemical interference.

The methodology used suggests the performance of nitrogen circulation in reactors to remove oxygen from the interior and to ensure anaerobic condition. However, there was a choice for not performing this procedure due to the small amount of oxygen present in the headspace, which would be consumed quickly by the organisms present in the samples.

Once bioreactors with inoculum and substrates were ready, they were identified and covered with aluminum paper to prevent proliferation of algae stimulated by the incidence of light. The bioreactors were then incubated in the bacteriological greenhouse at 37±2°C throughout the experiment, which is a great temperature in the mesophilic band, according to the literatures.

The gas analyses were carried out during the 45 days of incubation, which was established as appropriate considering the need to remove the DLC from the farm, because there is an increase in the ammonia generation inside it. The concentrations of CH_4 in biogas were performed by chromatographic analysis in the chromatography laboratory (CSF). The bioreactors biogas collection was performed with 10 mL triple syringes.

The Shimadzu gas chromatograph (GC-17A model) was used with Shimadzu methanator, model MTN-1 (375 C), using the 60/80 Carboxen 1000 column (5m x 2mm in a stainless steel tube) with flame ionization detectors (FID) and thermal conductivity (TCD). The injector temperature was 220°C with a non-spitting injection with a gastight-type syringe. The temperatures of the methanator, TCD and IDF were 375, 200 and 250°C, respectively. The carrier gas used was argon and the current was 40mA. The initial temperature of the oven was 40°C, for 6 minutes, and the temperature was increased to 220°C, with a rate of 20°C min^{-1}, remaining at this temperature for 20 minutes. Prior to the injection of the sample into the gas chromatography equipment, an analytical curve of the components CO_2 and CH_4, with an R^2 greater than 0.99, was required to determine the composition of the biogas. In the analytical curve, the gas patterns acquired with White Martins were used in a cylinder containing a mixture of gases: 10% methane, 10% ethane, 10% ethylene, 10% propane, 10% propene, 10% butane, 10% butene, 15% carbon dioxide and 15% nitrogen.

The experiments were completed when the 45th day of incubation of the treatments was reached. Then, the last collection of biogas was performed, followed by the gas chromatography. Further on, the existing biogas was completely relieved and, later, the bioreactors were weighed, and the pH and the final conductivity of the digestate were measured.

For the calculation of biogas generation with the intervention of the PBM test, atmospheric pressure data were needed from the site of the experiment. The temperatures and atmospheric pressure, as well as the daily pressure and temperature readings of each bottle, allowed the recording of the volume of biogas produced in the PBM test bottles, calculated according to Equation 1 (Biogas volume generated between T and T+1), Equation 2 (accumulated biogas volume [mL]) and Equation 3 (accumulated biogas volume of the previous day in mL) (Harries et al., 2001):

$$\text{Generated between} \quad T + (T = 1) = \left[\frac{\text{PF(mbar)x VUF(L)x 22,41}}{\text{83,14 xTF(K)}}\right] \text{x1000} \qquad (1)$$

where:
T: time (days);
PF (mbar): bottle pressure in millibars;
VUF (L): useful volume of the bottle in L;
TF (K): bottle temperature in Kelvin.

$$\text{Accumulated volume (mL)=} \\ \text{[generated between T and (T+1)]+VGA (mL)} \qquad (2)$$

where:
T: time (days);
VGA (mL): accumulated biogas volume of the previous day in mL.

$$\text{Accumulated biogas vol. CNTP=} \\ [Vol\ Accumulate\ (ml)] \times \left[\frac{273}{TF(K)}\right] \times \left[\frac{\text{Patm(mbar)}}{760}\right] \qquad (3)$$

where:
TF(K): bottle temperature in Kelvin;
PATM (mbar): atmospheric pressure in millibars.

After measuring the total biogas production, the study considered the use of the biodigester coupled to the generator for converting biogas into electrical energy, which was carried out according to the methodology of the Center for Energy Convention (CCE, 2000) adapted by Marques (2012). By accommodating the diesel-driven generator for the use of biogas as a fuel, the equivalence result was 25% when transforming biogas into electrical energy.

Results and Discussion

The physical-chemical characterization of inoculum and samples was performed before the beginning of the experiment, and is shown in Table 1. It is observed that the carbon and nitrogen ratio (C:N) present in the DLC was 2.8:1, close to the values indicated by Alves (2018), who found in the analyses, during waste research, the values of 5.8:1 in quail waste.

The low C:N ratio found in the DLC was also verified by Steil (2001) in his study, where he identified that the bird waste presents a low C/N ratio, indicating that the nitrogen will not be limiting, but also alerting that the reason is between 10 and 15, which suggests the presence of nitrogen in quantities greater than necessary, and may lead to an increase in ammonia production. And ammonia, in turn, is incorporated into the liquid medium, causing toxic effects to the process.

In relation to total solids (ST), mean contents of 39.000 mg L^{-1} and volatile solids (SV) were found to be close to 25,000 mg L^{-1} for both inocula and the samples evaluated, results of concentrations in the DLC which favor biogas production, since Zhang et al. (2007) sustain that the biodegradability of the waste and biogas production is related to the total and volatile solids content of the sample.

According to Chen et al. (2008), the production of biogas with a high percentage of CH_4 depends on numerous factors, such as the presence of substances that inhibit the anaerobic digestion process, e.g., ammonia, sulfide, organic compounds, heavy metals (chromium, cobalt, zinc, cathode, nickel) and metal ions (sodium, potassium, magnesium, calcium, aluminum). In the analyses performed, in relation to the metal ions, Table 1 shows that they rose according to the time of deposition, but were reduced after 30 days of deposition, except for the potassium, which was accumulated. Appels et al. (2008), in their study, present some concentration ranges of moderately inhibitory substances of the anaerobic process, such as potassium, from 0.25 to 0.45%, calcium, from 0.25 to 0.4%, and magnesium, from 0.1 to 0.15%; below these values, the author also presents some stimulating concentration ranges, such as potassium, from 0.02 to 0.04%, calcium, from 0.01 to 0.02%, and magnesium, from 0.0075 to 0.015%. In the analyses, it was observed that the potassium and calcium substances remained within the moderately inhibitory range, while the magnesium was closer to the stimulating range of the anaerobic process.

Specifically, as for aluminum metal ion, with 97.76 ppm, it was identified only in the 15-day deposition sample. According to Cabirol et al. (2003), the aluminum inhibition mechanism is associated with competition with iron and magnesium or with its adherence to the cell wall, which affects microbial growth. In this experiment, the presence of aluminum was caused by the use of wastewater in the blade of water. After the 30-day sample collection, aluminum was no longer identified, thus not affecting the microbial growth.

Regarding the hydrogen ionic potential (pH), this is a parameter of great importance for biogas and CH 4 production, since the microorganisms responsible for anaerobic digestion have optimal growth and metabolic activity ranges, specific to each group. In this study, the initial and final pH of the PBM experiment were measured.

In Table 2, the means of the initial and final pH and electrical conductivity values are expressed for each experimental condition.

Table 2 shows that the pH values observed were stable at the initial and final time of the experiment. The mean values of the assays are in the range of 7.17 to 8.17, values that are close to the ideal range for microbial development, ranging from 6.0 to 8.0. According to Quadros et al. (2010) and Sánchez-Hernández et al. (2013), a pH of 7.0 can be considered ideal. These aspects reinforce the capacity of the biodigester to develop a buffer effect (Kunz, 2011), so that, under these conditions, the digesters are able to keep treating the DLC.

With regard to electrical conductivity, Rocha et al. (2009) states that the increase in conductivity means that organic matter has been degraded anaerobically by microorganisms, releasing ions to the medium and thus increasing the conductivity of the reactive medium. Silva et al. (2012) reinforces that electrical conductivity has a correlation with the amount of ions dissolved during the liquid phase, so the increase in electrical conductivity would be explained by digesting a more complex matter in a simpler one.

Table 1 – Physico-chemical characteristics of inoculum and of the quail liquid waste samples used in the bio digestion process.

Parameter	Inoculum	Quail liquid waste deposition time		
		-------------- days --------------		
		15	30	45
Total alkalinity	22,180.55 mg L^{-1}	-	-	22,180.55 mg L^{-1}
pH	7.70	7.70	7.90	7.70
Total Organic Carbon	9,980.00 mg L^{-1}	-	-	9,980.00 mg L^{-1}
DBO	25,789.32 mg L^{-1}	-	-	25,789.32 mg L^{-1}
DQO	62,800.00 mg L^{-1}	-	-	62,800.00 mg L^{-1}
Total nitrogen	3,615.70 mg/LN 0.6%	0.57%	0.64%	3,615.70 mg/LN 0.6%
ST	38,920.00 mg L^{-1}	-	-	38,920.00 mg L^{-1}
SV	24,952.00 mg L^{-1}	-	-	24,952.00 mg L^{-1}
Total phosphorus	0.16%	0.96%	0.48%	0.16%
Potassium	0.41%	0.18%	0.20%	0.41%
Calcium	0.03%	0.15%	0.39%	0.03%
Magnesium	0.01%	0.04%	0.06%	0.01%
Zinc	35.68 ppm	6.62 ppm	13.26 ppm	35.68 ppm
Aluminum	0.00 ppm	97.76 ppm	0.00 ppm	0.00 ppm
Sodium	0.02%	0.02%	0.02%	0.02%
Organic matter	71.43%	33.33%	-	71.43%

Source: IBRA – Brazilian Institute of Analysis; LABB – Environmental Analysis (2022).

Table 2 – Initial and final mean pH values and electrical conductivity of the quail liquid waste samples in the different configurations.

Settings	Initial pH	Final pH	Initial conductivity	Final conductivity
			-------------- µs cm^{-1} ------------	
Inoculum	7.40	8.17	26.45	30.65
Inoculum + 15 days deposition	7.17	7.85	18.87	23.23
Inoculum + 30 days deposition	7.75	7.95	25.93	30.51
Inoculum + 45 days deposition	7.57	8.15	27.05	34.20

Table 2 shows that electrical conductivity increased in all deposition times, being higher after 45 days, with a 26% increase.

The experimental analysis with different times of DLC deposition and water retention in the anaerobic biodigesters was performed considering the results obtained in the daily average biogas production evaluation; the accumulated percentage of biogas produced; and the evaluation of biogas production by DLC biomass per m^3.

Figure 2 shows the daily average production of DLC biogas in the 45 days of the process. In the first days of the process, bioreactors, with treatments 2 and 3, presented higher production than treatments 4 and 1. T1 had an initial production of 10 NmL of daily biogas, this being the largest peak of production throughout the process. T2 had an initial production of 15 NmL of daily biogas, reaching its peak production of 43 NmL on the fourth day of the process. T3 had an initial production of 39 NmL of daily biogas and reached its production peak of 48 NmL on the thirtieth day. On the other hand, T4 had an initial production of 13 NmL of daily biogas, with its peak production reaching 28 NmL on the thirtieth day.

Figure 3 shows the experimental analysis of the accumulated percentage of biogas produced for each treatment used. As can be seen, the effect of inoculum use in the anaerobic digestion process of the DLC with a 15-day deposition (T2) is accentuated, reaching 73% of total biogas production at 15 days of TRH in the bioreactor, while with treatments T1 and T3 the same rate occurred at 33 days, and 41 days with T4.

The anticipation of the peak biogas production becomes more evident when T1, T2 and T3 remained with a constant average production, T4 treatment had a late production peak and remained with an average production of 24 NmL day^{-1} until the 45th day of HRT.

The composition of biogas and the results of biogas and CH_4 generation obtained in the mono digestion test through inoculum and DLC with deposition at 15, 30 and 45 days are described in Table 3 according to accumulated volume (Nm^3) and energy potential in m^3 (kg substrate)$^{-1}$ and m^3 (kg ST)$^{-1}$, after 15 days of monitoring.

According to Table 3, there is an increase in biogas and CH_4 production in treatments T2, T3 and T4 after 15 days of retention, when compared to accumulated volume (Nm^3), production of m^3 (kg substrate)$^{-1}$ and m^3 (kg ST)$^{-1}$, with control treatment T1.

In relation to biogas, treatments with the addition of deposition at 15, 30 and 45 days increased the accumulated volume (Nm^3) by 697, 492, 364%, respectively, when compared to control treatment T1. The increase in the percentage of CH_4 was also identified in treatments T2, T3 and T4, which obtained more than 43.94, 32.72 and 27.6%, respectively, when compared to control treatment T1.

Although all treatments with DLC addition showed an increase in accumulated volume (Nm^3), the treatment with a 15-day deposition addition (T2) obtained the highest biogas production (0.000335 m^3) and CH_4 (0.000248 m^3), having a higher energy potential expressed as m^3 of biogas production per kg of substrate (0.0018 m^3 kg^{-1}) and total solids (ST) (0.048 m^3 kg^{-1}). However, it was observed that treatment T2 should be used when the retention time is 15 days inside the bioreactor, because it will have the highest biogas generation and the best percentage of CH_4 (73.86%), as shown in Table 3 and Figure 4.

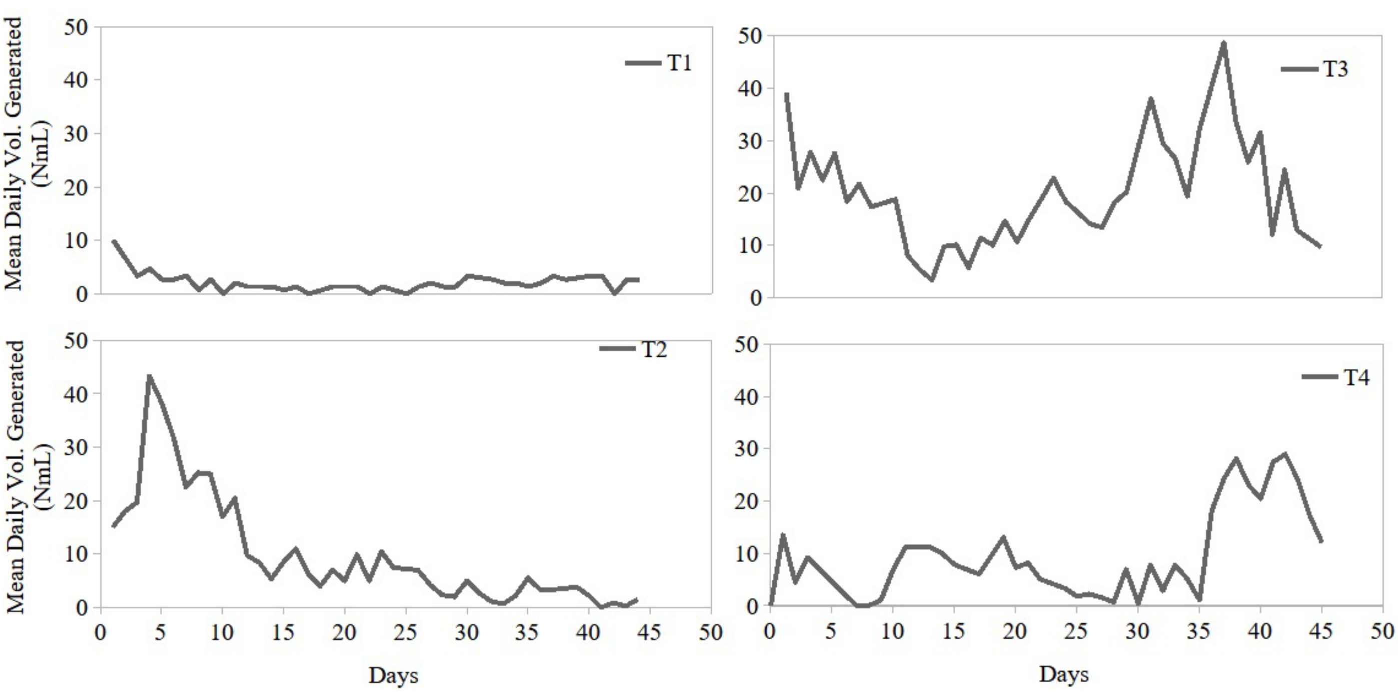

Figure 2 – Daily average biogas production for bioreactors with liquid quails waste in different deposition conditions.

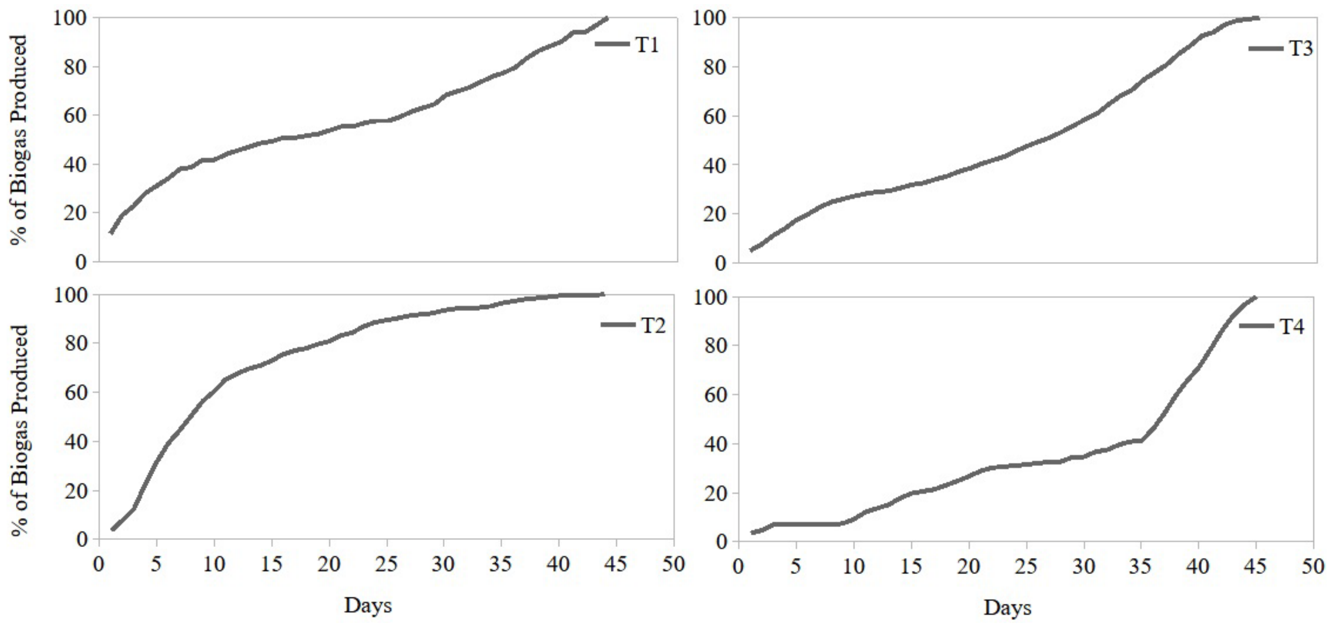

Figure 3 – Percentage accumulation of biogas produced from the biodigestion of quail liquid waste in different deposition conditions.

Table 3 – Results of biogas and CH_4 generation, in the PBM assay of quail waste after 15, 30 and 45 days.

Deposition	Treatment	CH_4	CO_2	Other gases	Volume biogass accumulated CNTP m^3	Volume CH_4 accumulated CNTP m^3	m^3 Biogas (kg substrate)$^{-1}$	m^3 Biogas (kg ST)$^{-1}$	m^3 Biogas (m^3 biomass)$^{-1}$
		---------- % ----------			-------------- m^3 ------------				
Results of biogas and CH4 generation in the BMP test after 15 days									
Inoculum	T1	29.92Cc	30.42Aa	39.650Aa	0.000042Cc	0.000012Dc	0.000200Cc	0.006000Cc	0.23Cc
15 days	T2	73.86Aa	19.36Bb	6.770Bb	0.000335Aa	0.000248Aa	0.001800Aa	0.048000Aa	1.86Aa
30 days	T3	62.64Bb	30.14Aa	7.210Bb	0.000249Bab	0.000157Bab	0.001366Bab	0.03500Bab	1.38Bab
45 days	T4	57.52Bb	34.13Aa	8.340Bb	0.000195Bb	0.000113Cb	0.001066Bb	0.028000Bb	1.08Bb
Results of biogas and CH_4 generation in the BMP test after 30 days									
Inoculum	T1	34.51Bb	21.50Bb	43.980Aa	0.000061Cc	0.000021Cc	0.000300C	0.00800Cc	0.34 C
15 days	T2	65.43Aa	19.80Bb	14.760Bb	0.000416Aab	0.000272Bab	0.00230Aab	0.0590Aab	2.31Aab
30 days	T3	72.20Aa	24.89Aab	2.900Bb	0.000478Aa	0.000346Aa	0.002600Aa	0.06800Aa	2.66Aa
45 days	T4	66.71Aa	27.77Aa	5.880Bb	0.000325Bb	0.000216Bb	0.001800Bb	0.04600Bb	1.81Bb
Results of biogas and CH_4 generation in the BMP test after 45 days									
Inoculum	T1	36.50Cc	17.98Ab	45.510Aa	0.000090Cc	0.000032Dc	0.000500Cc	0.01300Cc	0.5Cc
15 days	T2	74.41Aa	23.17Aab	3.620Bb	0.000478Bb	0.000356Bb	0.002600Bb	0.06800Bb	2.65Bb
30 days	T3	73.59Aa	22.39Aab	4.020Bb	0.000784Aa	0.000575Aa	0.004300Aa	0.11200Aa	4.36Aa
45 days	T4	56.61Bb	29.16Aa	14.220Bb	0.000372Bb	0.000214Cb	0.002033Bb	0.05300Bb	2.07Bb

Note: Upper case letters indicate Scott-Knott test and lower case letters indicate Tukey test at 5% probability level.

The percentage values of CH_4 at 15 days (Figure 4) corroborate the results obtained in studies by Fukayama (2008) and also by Costa (2012), which obtained mean values of methane percentage ranging from 67 to 82%, when they promoted the biodigestion of chicken litter waste with added water.

The results of biogas and CH_4 generation obtained in the same previous mono digestion assay, but now analyzed with 30 days of monitoring, are described in Table 3. In this, there is also an increase in biogas and CH_4 production of treatments T2, T3 and T4 after 30 days of retention, when compared to accumulated volume (Nm^3), production of m^3 (kg substrate)$^{-1}$ and m^3 (kg ST)$^{-1}$, in control treatment T1.

In relation to biogas, treatments with the addition of deposition at 15, 30 and 45 days increased the accumulated volume (Nm^3) by 582, 683, 432%, respectively, when compared to control treatment T1. The increase in the percentage of CH_4 was also identified in treatments T2, T3 and T4, which obtained more than 30.92, 37.69 and 32.2%, respectively, when compared to control treatment T1.

All the treatments with the addition of DLC showed an increase in the accumulated volume (Nm^3). The treatment with the addition of a 30-day deposition (T3) obtained the highest biogas production (0.000478 m^3) and CH_4 (0.000346 m^3), with the highest energy potential expressed as m^3 of biogas production per kg of substrate (0.0026 m^3 kg^{-1}) and total solids (0.068 m^3 kg^{-1}). However, it was observed that treatment T3 should be used when retention time is 30 days within the bioreactor, since it will have the highest biogas generation and the best percentage of CH_4 (72.2%), as shown in Table 3 and Figure 4.

The percentage values of CH_4 at 30 days were higher than those found in the study by Silva et al. (2021), which obtained a CH_4 average percentage of 57% when promoting the biodigestion of quail waste+granular sludge.

On the other hand, the results of biogas and CH_4 generation, with 45 days of monitoring, are described in Table 3. In this, there is also an increase in biogas and CH_4 production in treatments T2, T3 and T4 after 45 days of retention, when compared to accumulated volume (Nm^3), production of m^3 (kg substrate)$^{-1}$ and m^3 (kg ST)$^{-1}$, in control treatment T1.

In relation to biogas, treatments with the addition of deposition at 15, 30 and 45 days, increased the accumulated volume (Nm^3) by 431, 771, 413%, respectively, when compared to control treatment T1. The increase in the percentage of CH_4 was also identified in treatments T2, T3 and T4, which obtained more than 37.91, 37.09 and 20.11%, respectively, when compared to control treatment T1.

Even if all treatments with the DLC addition showed an increase in accumulated volume (Nm^3), the treatment with a 30-day deposition addition (T3) also obtained the highest biogas production (0.000784 m^3) and CH_4 (0.000575 m^3), having a higher energy potential expressed as m^3 of biogas production per kg of substrate (0.0043 m^3 kg^{-1}) and total solids (0.0112 m^3 kg^{-1}). However, it was noted that treatment T3 should also be used in the 45-day retention time within the bioreactor, since it will have the largest biogas and CH_4 generation.

The percentage values of CH_4 at 45 days (Figure 4) show that the results achieved were close to the study carried out by Teles (2019), which found an average percentage of 69% of CH_4, when using mixed pig and poultry biodigestion and pig slurry, resulting in 72% of CH_4.

In view of the data obtained, it is inferred that T1 (inoculum) obtained the lowest biogas generation when isolated. However, the largest generations of biogas occurred when the inoculum mono digestion was carried out with the DLC, with deposition at 15, 30 and 45 days.

The increase in biogas generation is related to the increase in the organic matter available in the anaerobic digestion process, as seen in the physico-chemical analyses carried out in the samples used.

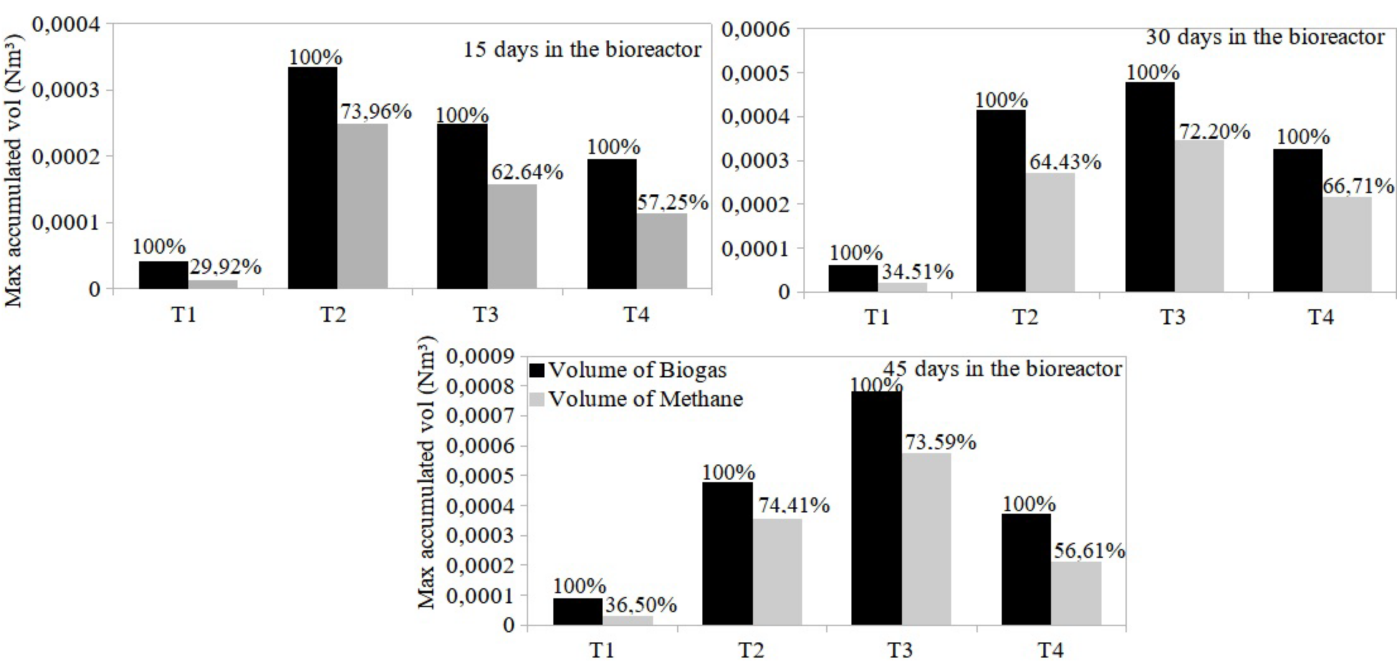

Figure 4 – Cumulative maximum volume of biogas and methane generated from the biodigestion of liquid quail waste at 15, 30, and 45 days of retention in the bioreactor.

In the experimental analysis of biogas production by DLC biomass m^3, (Table 3) there is an increase in biogas and CH_4 production of treatments T2, T3 and T4 at all retention times, when compared to the accumulated volume (Nm^3) and m^3 of biogas (biomass m^3)$^{-1}$, with control treatment T1. Although all treatments with the addition of DLC showed an increase in the accumulated volume (Nm^3), the treatment with the 30-day deposition addition (T3) and with 45-day water retention time obtained the highest biogas production (0.000784 m^3) and CH_4 (0.000575 m^3), with a higher energy potential expressed as m^3 of biogas production by biomass per m^3 (4.36 m^3). However, it can be seen that treatment T3 with retention in the 45-day bioreactor will have the largest biogas and CH 4 generation.

Lucas Jr. et al. (1997) *apud* Lucas Jr. and Santos (2000) studied the anaerobic digestion of coturniculture waste in continuous biodigesters, under four times of water retention (HRT) at 30, 20, 15 and 10 days, and obtained a significant potential for biogas production of 2.47, 1.90, 1.29, 1.11 m^3, per m^3 of biodigester, respectively, to the THR. Thus, it can be deduced that the results obtained in this study are close to those found by Lucas Jr. et al. (1997) when compared to the time of water retention.

The results demonstrate the potential for energy generation by using biogas produced in the coturniculture with a blade of water treatment system, since the amount of m^3 produced is currently 96 m^3 every 45 days. In a simulation, if a biodigester was installed in the quail farm studied, the system could produce 4.36 m^3 of biogas per m^3 of biomass, according to the results obtained in the PBM test, totaling 418.56 m^3 of biogas produced every 45 days. With this volume of biogas produced with the DLC, and being converted into electric energy through a generator using biogas as fuel, it would potentially reach the generation of 9.30 kwh day^{-1} or 104.64 kwh (45 days)$^{-1}$.

Analyzing the electric energy bill made available by the farm, it was possible to identify the average consumption of 23.20 kwh day^{-1} and the average consumption invoiced per month of 571 kwh (30 days)$^{-1}$. By comparing the actual consumption of electricity with the possible volume of electricity from biogas production, a production potential of 12.21% of the electrical energy currently consumed on the entire farm is observed, presumably all the electrical energy consumed by the quail production system.

Conclusions

Based on the results obtained in the experiment on biogas and methane generation, it is recommended to use different treatments when choosing a different water retention time in the bioreactor.

For water retention time of 15 days the best treatment is the mono digestion of Inoculum+a 15-day deposition (T2), with accumulated 0,000335 Nm^3 biogas generation and with a biogas potential of 0.0018 m^3 (kg substrate)$^{-1}$ and a CH 4 percentage of 73.86%.

For the 30-day water retention time, the best treatment is the mono digestion of the Inoculum+a 30-day-deposition (T3), with accumulated biogas generation of 0.000478 Nm^3 and with a biogas potential of 0.0026 m^3 (kg substrate)$^{-1}$ and a CH_4 percentage of 72.2%.

For the 45-day water retention time, the best treatment is treatment 3, as it will have the highest biogas generation (0.000784 Nm^3), with a biogas potential of 0.0043 m^3 (kg substrate)$^{-1}$ and a better percentage of CH_4 (73.59%). It is worth noting that this potential may indicate that 1 m^3 of DLC biomass produces 4.36 m^3 of biogas every 45 days after retention in the biodigester and, when converted to electric energy through a generator using biogas as fuel, the value of 9.30 kwh day^{-1} or 104.64 kwh/(45 days)$^{-1}$ is obtained.

The conclusion is that, through the anaerobic biodigestion of the quail liquid waste, it is possible to produce biogas, with the liquid waste of the coturniculture (DLC), under a blade of water treatment system, having the potential to produce biogas in batch anaerobically-treated bioreactors, which help to reduce the environmental impacts produced, in other words, generating organic fertilizers (bioreactor effluents) for agriculture, without any loss of egg production, and also allowing the reduction of operational costs in the poultry activity.

The results contribute to future economic feasibility studies for the implantation of energy generators for their own consumption, as well as to the realization of new experiments with different inocula from those used in this research.

Contribution of authors:

DUARTE JUNIOR, R.: conceptualization; data curation; formal analysis; investigation; project administration; visualization; writing – original draft; writing – proofreading and editing. ROSSA, U. R.: conceptualization; methodology; project administration; supervision. CHIARELLO, L. M.: formal analysis; resources. SCHARF, D. R: formal analysis; resources. SOMENSI, C. A.: formal analysis; resources. VISCHETTI, C.: formal analysis. GONÇALVES, L. F. S.: formal analysis.

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