Revista Ibero- Americana de Humanidades, Ciências e Educação- REASE

doi.org/10.51891/rease.v10i4.13437

# BIOGAS PRODUCTION FROM SWEET SORGHUM SILAGE AND ANIMAL WASTE

**Neiton Silva Machado**[1]
**Ediclésio de Souza Silva**[2]
**Amanda Aparecida Martins Freire**[3]
**Karla dos Santos Melo de Sousa**[4]
**Daniel Mariano Leite**[5]
**Cristina Akemi Mogami**[6]

ABSTRACT: The objective of this work is to quantify the biogas produced in batch-type benchtop biodigesters, from the anaerobic fermentation of sweet sorghum, stored in silos for 12 months, associated with goat and cattle waste, respectively. The input and output waste (biofertilizer) from the biodigesters was analyzed for physical (solid) and physical-chemical parameters (pH and electrical conductivity). The yield ($L_{biogas}.kg^{-1}{}_{SVad}$), biogas productivity ($L_{biogas}.L^{-1}{}_{reator}.d^{-1}$) and the added volumetric organic load - VOLad ($kg_{SV}.L^{-1}{}_{reator}.d^{-1}$) were calculated. The work was conducted at the Rural Construction Laboratory of the Federal University of Vale do São Francisco located on the Agricultural Sciences Campus. The hydraulic retention time was 30 days in the randomized block experimental design. The constructed biodigesters performed well in quantifying the production of biogas from organic substrate, promoting ideal conditions for the anaerobic digestion process to occur without oxygen contamination. However, there was no significant difference in biogas production between treatments. Treatment T2 (cattle manure) showed the highest yield (240 $L_{biogas}.kg^{-1}{}_{SVad}$) with an average added volumetric organic load of 8 $kg_{SV}.L^{-1}{}_{reactor}.d^{-1}$. Treatment T5 (sorghum 50% + beef 50%) presented a higher numerical value of biogas productivity (0.0703 $L_{biogas}.L^{-1}{}_{reator}.d^{-1}$) in relation to the other treatments, however this difference was not significant at 5% probability using the Tukey test.



**Keywords:** Biofuel. Cattle manure. Goat waste. Sweet sorghum.

[1]Doutor em engenharia agrícola pela Universidade Federal de Viçosa - UFV. Docente efetivo da Universidade Federal do Vale do São Francisco – Univasf, BR. Orcid: https://orcid.org/0000-0001-6049-2279.

[2]Bacharel em Engenharia agronômica pela Universidade Federal do Vale do São Francisco – Univasf, BR.

[3]Bacharela em Engenharia agronômica pela Universidade Federal do Vale do São Francisco Univasf, BR. https://orcid.org/0000-0002-9764-0498.

[4]Doutora em engenharia agrícola pela Universidade Federal de Campina Grande – UFCG Docente efetiva da Universidade Federal do Vale do São Francisco – Univasf, BR.Orcid: https://orcid.org/0000-0001-5000-0330.

[5]Doutor em engenharia agrícola pela Universidade Federal de Viçosa - UFV. Docente efetivo da Universidade Federal do Vale do São Francisco – Univasf, BR. https://orcid.org/0000-0002-6174-1190.

[6]Doutora em engenharia agrícola pela Universidade Federal de Viçosa - UFV. Docente efetiva do Instituto Federal do Sertão Pernambucano – Campus Zona Rural. Orcid: https://orcid.org/0009-0006-8584-9880.

RESUMO: Objetivou-se com este trabalho quantificar o biogás produzido em biodigestores de bancada, tipo batelada, a partir da fermentação anaeróbia de sorgo sacarino, armazenado em silos, por 12 meses, associado com dejetos de caprinos e bovinos, respectivamente. Analisou-se os dejetos de entrada e saída (biofertilizante) dos biodigestores quanto aos parâmetros físicos (sólidos) e físico-químicos (pH e condutividade elétrica). Foram calculados o rendimento ($L_{biogás}.kg^{-1}{}_{SVad}$), a produtividade de biogás ($L_{biogás}.L^{-1}{}_{reator}.d^{-1}$) e a carga orgânica volumétrica adicionada - $COV_{ad}$($kg_{SV}.L^{-1}{}_{reator}.d^{-1}$). O trabalho foi conduzido no Laboratório de Construções Rurais da Universidade Federal do Vale do São Francisco localizado no Campus de Ciências Agrárias. O tempo de retenção hidráulica foi de 30 dias no delineamento experimental blocos casualizados. Os biodigestores construídos apresentaram bom desempenho para quantificar a produção de biogás a partir de substrato orgânico, promovendo condições ideais para ocorrer o processo de digestão anaeróbica sem contaminação por oxigênio. Entretanto não houve diferença significativa na produção de biogás entre os tratamentos. O tratamento T2 (dejeto bovino) apresentou maior rendimento (240 $L_{biogás}.kg^{-1}{}_{SVad}$) com uma carga orgânica volumétrica adicionada média de 8 $kg_{SV}.L^{-1}{}_{reator}.d^{-1}$. O tratamento T5 (sorgo 50% + bovino 50%) apresentou maior valor numérico de produtividade de biogás (0,0703 $L_{biogás}.L^{-1}{}_{reator}.d^{-1}$) em relação aos demais tratamentos, no entanto esta diferença não foi significativa a 5% de probabilidade pelo teste de Tukey.

**Palavras-Chave:** Biocombustível. Dejeto bovino. Dejeto caprino. Sorgo sacarino.

RESUMEN: El objetivo de este trabajo es cuantificar el biogás producido en biodigestores de mesa tipo discontinuo, a partir de la fermentación anaeróbica de sorgo dulce, almacenado en silos durante 12 meses, asociado a desechos caprinos y bovinos, respectivamente. A los residuos de entrada y salida (biofertilizante) de los biodigestores se les analizó parámetros físicos (sólidos) y físico-químicos (pH y conductividad eléctrica). Se calculó el rendimiento ($L_{biogas}.kg^{-1}{}_{SVad}$), la productividad del biogás ($L_{biogas}.L^{-1}{}_{reator}.d^{-1}$) y la carga orgánica volumétrica agregada - COVad ($kg_{SV}.L^{-1}{}_{reator}.d^{-1}$). El trabajo se realizó en el Laboratorio de Construcción Rural de la Universidad Federal de Vale do São Francisco, ubicado en el Campus de Ciencias Agrícolas. El tiempo de retención hidráulica fue de 30 días en el diseño experimental de bloques al azar. Los biodigestores construidos tuvieron un buen desempeño en la cuantificación de la producción de biogás a partir de sustrato orgánico, promoviendo condiciones ideales para que el proceso de digestión anaeróbica ocurra sin contaminación por oxígeno. Sin embargo, no hubo diferencias significativas en la producción de biogás entre tratamientos. El tratamiento T2 (estiércol de ganado vacuno) mostró el mayor rendimiento (240 $L_{biogás}.kg^{-1}{}_{SVad}$) con una carga orgánica volumétrica agregada promedio de 8 $kg_{SV}.L^{-1}{}_{reactor}.d^{-1}$. El tratamiento T5 (sorgo 50% + carne 50%) presentó un mayor valor numérico de productividad de biogás (0.0703 $L_{biogas}.L^{-1}{}_{reator}.d^{-1}$) en relación a los demás tratamientos, sin embargo esta diferencia no fue significativa al 5% de probabilidad utilizando el Prueba de Tukey.



**Palabras Clave:** Biocombustible. Estiércol de ganado. Desperdicios de cabra. Sorgo dulce.

## INTRODUCTION

Population growth triggers numerous problems related to sustainability. The demand for physical space and food, associated with the increasing production of waste, combined with the lack of effective public policies that enable technologies capable of suppressing these impacts at low cost, has generated concerns among scientists and environmentalists around the world. According to Cohen (2005), world population growth is expected to continue to evolve until the year 2050, when the projection is that the world population will reach the mark of 11 billion inhabitants.

Brazil is among the 10 countries that waste the most food in the world, approximately 35% of all agricultural production is discarded (UGALDE and NESPOLO, 2015). Waste from agricultural production is obtained through significant losses throughout the production chain totaling 20% to 50% (KADER, 2002). These losses begin at planting, through harvesting, marketing and reaching the consumer's table, whether the product is fresh or processed. It is estimated that the disposal rate of urban solid waste is growing faster than the population growth rate (REIS; CONTI; CORREA, 2015). This fact has contributed greatly to the worsening of environmental problems that compromise the health and quality of life of the population. Therefore, in 2015, the United Nations published the sustainable development goals (SDGs), with the food system being one of its main axes, with directly related objectives, such as Goal 2 – Zero Hunger and Sustainable Agriculture, Goal 3 – Health and Wellbeing and Goal 12 – Responsible Consumption and Production (UNITED NATIONS BRAZIL, 2023).

According to Pistorello; Tale; Zaro (2015), information has an influence on people's behavior regarding the management of food waste. It is extremely important that the information passed on is of high quality and made available continuously to the community, through technology proposals that allow better coexistence with nature, in order to minimize environmental impacts and assist in people's environmental education.



There is global interest in increasing the production of renewable energy to mitigate dependence on fossil fuels and their negative effects on the environment (PÄÄKKÖNEN, TOLVANEN and RINTALA, 2018). Biomass is a promising alternative to boost the Green economy and create new opportunities for sustainable business (HAGOS *et al*., 2017)

The use of agricultural, forestry, industrial and urban residues as a source of biomass for the production of biogas has been widely studied (EVANS, STREZOV, and EVANS, 2010) however, biomass from energy crops also has high potential (SURENDRA *et al* ., 2014). The use of energy crops in anaerobic co-digestion systems has gained increasing interest due to their high biogas yield per ton.

New alternatives are already being tested in academic environments to quantify affordable biogas production. The batch-type biodigester is a simple system that requires little operational labor. It can be just one or several anaerobic tanks. This biodigester is fed once, keeping the container airtight for a fixed time until the end of anaerobic fermentation, and then it is unloaded. However, this model does not continuously feed organic matter (FURMAN *et al*., 2020 ).

The main factors that interfere with biodigestion are: substrate (water concentration and nutrient concentration), temperature, load, hydraulic retention time, agitation, degradability, alkalinity and pH, factors that are closely associated with the development of prokaryotes that produce methane gas (TOMMY*et al*., 2014, MACHADO *et al*., 2023a). Through various microorganisms, organic matter is converted almost completely into biogas. Furthermore, certain amounts of energy (heat) and new biomass are produced (FRIEHE; WEILAND; SCHATTAUER, 2010). Biogas has in its composition average rates of: Methane ($CH_4$) 60%v/v, Carbon dioxide ($CO_2$) 38%v/v, in addition to nitrogen, hydrogen and hydrogen sulfide gas contents (FERRAZ et., al 1980).

According to Souza et.al., (2012), biogas generation plants have great potential and can be used as treatment stations and waste sorting. The use of waste is a viable option for the coherent use of natural resources, so that they are inexhaustible. The problems caused by environmental degradation, especially organic waste, need to be rethought and used. The biodigestion technique brings numerous benefits for reducing environmental impacts, energy production, biofertilizers, among others not mentioned (GOMES *et al*., 2014).



In rural areas, biointegrated systems specifically using biomass for energy purposes can be a facilitating means to achieve production sustainability due to the availability of biomass on agricultural properties, as they present a low opportunity cost of production waste, great potential of energy generation, reduction in the polluting potential of waste, reduction in pressure on natural resources and saving of energy resources (ANGONESE *et al*., 2006). In this way, the manufacture of this equipment allows obtaining information about the production potential of biogas from organic materials originating from various waste generated in production chains, which can even assist in projects to generate carbon credits, a current demand for agro-sustainable systems.

In this sense, the objective of this work was to build and validate 24 batch-type benchtop biodigesters to quantify the biogas produced from the anaerobic fermentation of agro-industrial and animal waste. Furthermore, physically and chemically characterize the input waste and biofertilizers output from the biodigesters.

## Material and Methods

The experiment was carried out at the Rural Construction Laboratory of the Federal University of Vale do São Francisco (Univasf), located on the Agricultural Sciences Campus (CCA), in the municipality of Petrolina, Pernambuco, Brazil, (latitude: 09° 23' 55'' S longitude: 40° 30' 03'' W), in the months of November and December 2021.

The system consisted of a fermentation chamber, gasometer and manometer. The fermentation chambers were constructed from plastic gallons of 13 L each. The gasometers were produced with 4 units of galvanized tubes measuring 6 meters each, 2 units with a diameter of 50 mm and 2 units with a diameter of 75 mm. These tubes were cut into 6 equal parts of 1 meter each, thus forming two groups of 12 gasometers each. The volumes of the gasometers were 2.88 liters and 4.31 liters, for the smallest and largest diameters respectively.

One end of the tubes was closed with a piece of metal sheet using electric welding. Subsequently, a layer of tartar (Lead tetroxide) was applied to protect against oxidation of the material (rust).

The fermentation chambers were coupled to the gasometers using 20 mm diameter PVC guide tubes connected through adapters and blue PVC LR sleeves of the same diameter.



The connection of the gasometer to the PVC guide tube was carried out by simply placing the metal gasometers poured upside down over them. In Figure 1, you can see the two sizes of gasometers made and the gallon model used as a fermentation chamber, in addition to the insertion of the guide tube in the cover of the fermentation chamber as proposed by Machado *et al.* (2023b; 2023c).

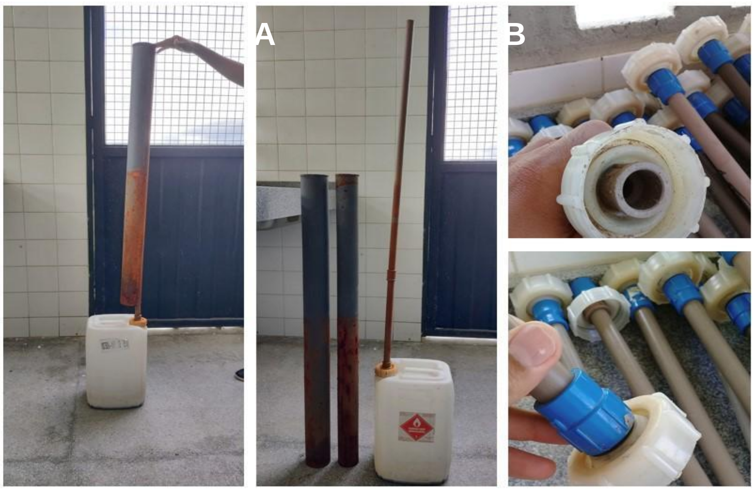


Figure 1 - Gasometers (A), fermentation chamber (B), guide tube (C) and guide tube fixation (D)
Source: Authors' personal archive

An open "U" tube manometer was installed on the outside of each gasometer. This was produced with a school ruler, graduated at 40 cm and an acrylic hose measuring ¼ inch in diameter, secured using a nylon clip (cat hanger). The acrylic hose was divided into two parts. The first part of the hoses reproduced a "U" shape so that one end of the hose was attached to the upper part of the ruler, while the other end was attached to the second half of the hose that was attached to the PVC guide tube installed inside the gas meter. . Through the junction between the parts of the hose, the gas produced daily was released after recording the values, by the simple process of uncoupling the "U" tube. In this way, in addition to emptying the gasometers, it was possible, at the same time, to reset the water column in the manometer. Figure 2 illustrates the experimental model of the biodigesters developed for this work.

The experimental design was in randomized blocks (DBC) with six treatments (T1: goat manure; T2: cattle manure; T3: sorghum 25% + goat 75%; T4: sorghum 25% + cattle 75%; T5: sorghum 50% + beef 50% and T6: sorghum 50% + goat 50%) and four blocks (two blocks per box), as illustrated in Figure 2.

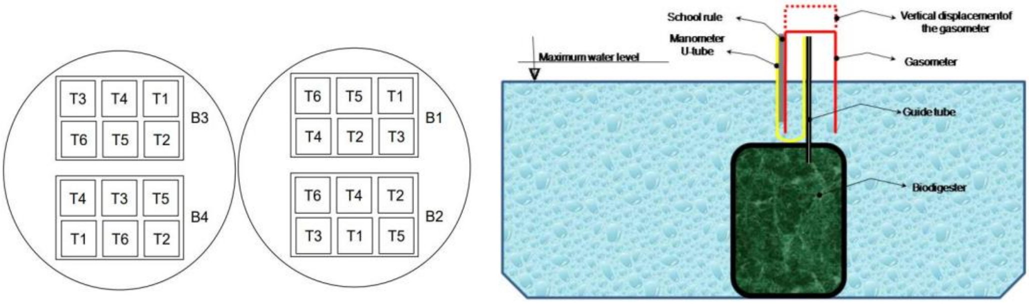


Figure 2 – Experimental design and parts of the anaerobic digestion system.
Source: Authors' personal archive



To produce the treatments, fresh sweet sorghum was collected from the experimental area of the study group in Biosystems Engineering and Coexistence with the Semi-Arid (EngBICS) at Univasf - CCA. The material was then crushed and ensiled in 50-liter barrels for a period of 12 months.

Cattle and goat waste were obtained from the animal production sector of the respective institution.

The sweet sorghum silage, after a storage period of one year, and the goat manure before being inserted into the biodigesters were previously fragmented in a Trapp brand forage crusher, model TRF 70, 1.5CV, 220V single-phase, equipped with the 12mm sieve opening, thus reducing particle size as can be seen in Figure 3. The cattle manure did not need to be crushed.

Figure 3 – Fragmentation of the material (A); Crushed sweet sorghum (B); Biodigesters loading process (C); Measurement of the mass of the material to be added to the biodigester (D).
Source: Authors' personal archive

Samples were taken from both materials to determine humidity. Initially, these were weighed on a semi-analytical scale where the wet mass was obtained and then taken to a forced air circulation oven at 70° C for 48 hours to determine the dry mass. The moisture content of each sample was calculated using Equation 1.



$$H\% = \frac{m_w - m_d}{m_w} \cdot 100 \qquad \text{Equation (1)}$$

On what:
H = Humidity (%);
md = Mass of dry sample (lg)
mw = Wet sample mass (g).'

After determining the initial moisture content of the material that would compose the treatments, it was estimated how much wet mass was necessary to provide 1 kg of dry mass for each of the respective treatments. Then, the mass calculated based on the initial moisture content was transferred to the 24 containers and the biodigesters were filled with water, until 10 kg of waste was obtained for each repetition (Figure 3). The system remained for 10 days in an acclimatization period called start-up phase.

When loading the biodigesters, the inoculum was added, consisting of the same fresh cattle manure in a quantity of 100g per container, providing microbial colonization. After the period of acclimatization and addition of the inoculum, a guide tube was added to each fermentation chamber, connecting the fermentation chamber to the gasometer. Next to the guide tube, the biogas outlet hoses were fixed, used to measure the pressure and empty the gasometer as illustrated in Figure 2.

The biodigesters were maintained in a system to control daily thermal fluctuations. This system was built using two 3000-liter water tanks renovated with fiberglass, resin and a specific catalyst. The two boxes were filled with chlorine-free water (raw water from the São Francisco River) so that the boxes had the maximum water level as illustrated in Figure 2. Above each set of 6 biodigesters, a concrete slab was supported to prevent the fluctuation of them and consequently bubbling of biogas, thus causing losses.

Before the acclimatization period and after the end of the experiment, material was removed from each of the 24 biodigesters for physical and physicochemical analyzes (total solids, volatile solids, fixed solids, pH and electrical conductivity).

Data collection was carried out every 48 hours for a period of 30 days. The displacement of the gasometer, displacement of the manometer meniscus, air temperature and relative humidity, gas temperature and tank water temperature were measured.

The displacement of the gasometer was checked by the difference between the initial reading (height of the gasometer without displacement to the water level) and the final height of the gasometer after displacement to the water line of the Box, these heights were measured with the aid of a tape measure.



Pressure variations were recorded through direct readings on the manometer, by the displacement of the water column, performing the initial and final reading of the position of the meniscus on the graduated ruler.

The temperature and relative humidity of the air were measured using a digital psychrometer from Politerm, model POL-31D.

The gas temperature was measured using a Homis model 438A portable infrared thermometer directed orthogonally to the upper part of the gasometer at a distance of 20 cm.

The temperature of the water in the tank (temperature of the waste) was measured using an analog mercury thermometer submerged inside each water tank.

To quantify the volume of biogas produced, standardization was carried out in accordance with the general gas law or combined gas law (Boiler's Law; Charles' Law and Gay-Lussac's Law) as proposed by Caetano (1985), Eckert (2015 ), Matos (2017) using the equations described in the methodology of the work of Machado *et al* (2023b).

To determine the physical parameters (total solids, fixed solids, and volatile solids) and physical-chemical parameters (pH, and electrical conductivity) of the feed waste from the biodigesters (input) and the biofertilizers produced (output), equipment and procedures were used. analytical methods described in the methodology of the work by Machado *et al.* (2023b).

After the end of the experiment, the normality of data and residuals was verified using the Shapiro Wilk test. The homogeneity of variance was also verified using the Levenee test and then ANOVA (analysis of variance) was performed, and the means were compared using the Tukey test at 5% probability or Student's t. The Box-Cox (logarithmic) transformation was performed for variables that did not show normality of residuals. The variables that did not present homogeneity of variances were performed using the non-parametric Man-White test. All analyzes were performed using SigmaPlot 11 software.

## Results and Discussion

Figures 4 and 5 show the variation in temperature, relative humidity, temperature of waste and biogas on the reading days, in addition to the average volume of biogas produced and the accumulated volume. The temperature of the waste was below the ideal range, recommended by several authors (SINGH 1994, ISOLDI *et al.*, 2001, BOUALLAGUI *et al.* 2004, CHERNICHARO 2007). This is due to the fact that the biodigesters are in thermal oscillation control systems, where the average temperature was close to 26°C, presenting similar values in all treatments. Regarding the biodigestion process, all treatments produced significant quantities from the beginning to the end of the experiment, demonstrating the expected functioning of the manufactured equipment.



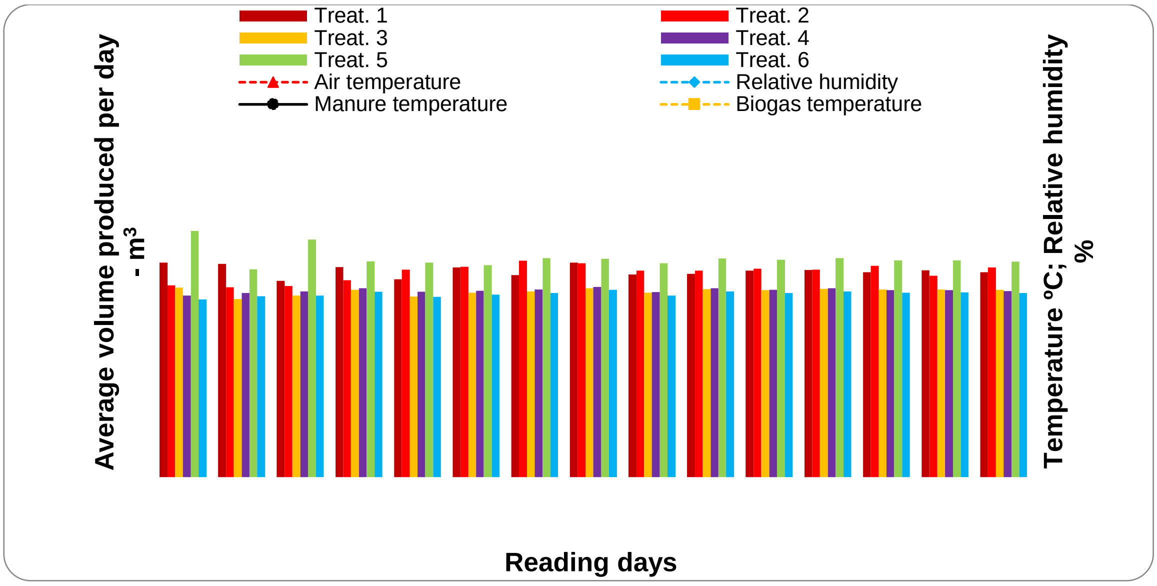


Figure 4 - Average volume produced, temperature and relative humidity on reading days. (Trat1: goat manure; Trat2: bovine manure; Trat3: sorghum 25% goat 75%; Trat4: sorghum 25% cattle 75%; Trat5: sorghum 50% cattle 50% and Trat6: sorghum 50% goat 50%)
Source: Authors' personal archive

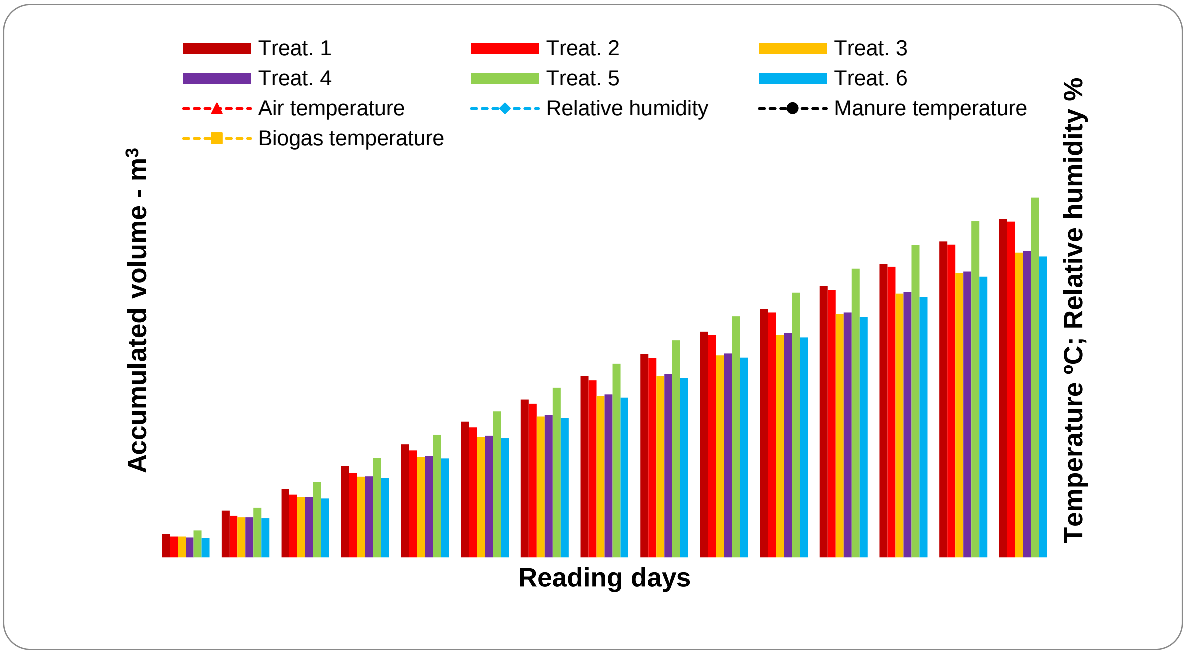


Figure 5 - Accumulated volume, temperature and relative humidity. (Trat1: goat manure; Trat2: bovine manure; Trat3: sorghum 25% goat 75%; Trat4: sorghum 25% cattle 75%; Trat5: sorghum 50% cattle 50% and Trat6: sorghum 50% goat 50%)
Source: Authors' personal archive

Table 1 and Figure 6 detail the values obtained in the determination of solids, which are: Total Solids (TS), Total Volatile Solids (TVS), Total Fixed Solids (TFS) in the waste to feed the biodigester (input) and biofertilizers (output ). According to the Tukey test, there was no significant difference at 5% probability for entry and exit in determining TS, TVS and TFS, maintaining similar proportions at the end of the experiment.



Among the treatments used, (T5) 50% sorghum + 50% cattle manure showed a greater difference in total solids at the input and output, but statistically there was no difference, this effect is explained by the greater consumption of volatile solids, causing a decrease in total solids. Some treatments presented higher ST values at the exit, this can be explained because the samples collected at the end of the hydraulic retention period presented greater homogeneity after anaerobic digestion, that is, it minimized the collection error. At the entrance, we can notice that the treatments containing goat manure (T1, T3 and T6) presented the highest ST means, with no significant difference between them. The treatments containing bovine manure (T2, T4 and T5) had the lowest mean ST and did not show a significant difference between them. At the exit, treatments containing cattle manure (T2, T4 and T5) presented the lowest averages, significantly differentiating from treatments containing goat manure (T1, T3 and T6).

Almeida (2016), working with benchtop biodigesters using 2% to 10% of total solids, states that these ranges of values facilitate the degradation of organic matter in the biodigester. He further reports that the challenge in biogas production is the use of substrates in the appropriate range of total solids. This fact may have influenced the volume of biogas produced by treatments T2 and T4, due to the total solids content being below that recommended in the literature.

Table 1 - Physical parameters (total solids; total volatile solids and total fixed solids) of residues and manure at the entrance and exit of biodigesters

| TREATMENT | ENTRANCE | | | EXIT | | |
|---|---|---|---|---|---|---|
| | %ST | %SVT | %SFT | %ST | %SVT | %SFT |
| Goat Manure (T1) | 8,61 aA | 77,96 aA | 22,04 aA | 6,10 aA | 83,24 aA | 16,76 aA |
| Beef Desire (T2) | 1,31 cA | 81,76 aA | 18,24 aA | 1,49 bA | 72,20 aA | 27,80 aA |
| Sorghum 25% + Goat 75% (T3) | 9,34 aA | 86,04 aA | 13,96 aA | 7,17 aA | 86,72 aA | 13,28 aA |
| Sorghum 25% + Beef 75% (T4) | 1,60 cA | 85,66 aA | 14,34 aA | 2,03 bA | 89,02 aA | 10,98 aA |
| Sorghum 50% + Beef 50% (T5) | 4,23 bcA | 63,31 aA | 36,69 aA | 1,50 bA | 67,26 aA | 32,74 aA |
| Sorghum 50% + Goat 50% (T6) | 6,50 abA | 88,46 aA | 31,16 aA | 7,72 aA | 78,97 aA | 21,03 aA |
| Mean standard error | 1,408 | 3,759 | 3,802 | 1,213 | 3,465 | 3,465 |

Where: ST = Total Solids; SVT = Total Volatile Solids; SFT = Total Fixed Solids

Means followed by the same lowercase letters in the column do not differ statistically by the Tukey test at 5% probability.

Means followed by the same capital letters in the line do not differ statistically by Student's t-test at 5% probability or by the Mann-Whitney test (*)



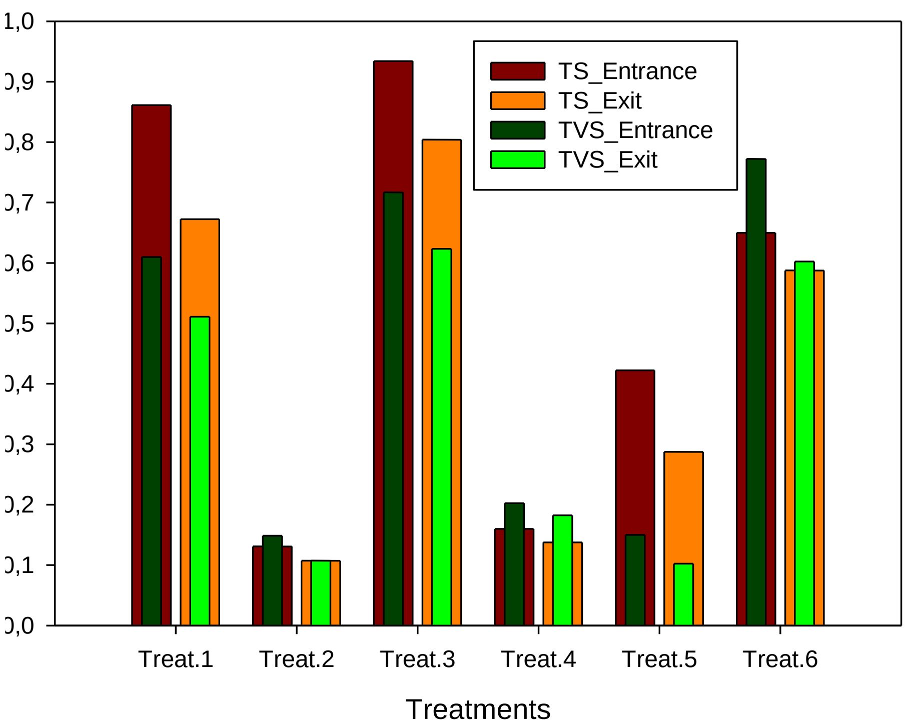


Figure 6 – Mass of total solids and total volatile solids at the entrance and exit of the biodigesters for their respective treatments. (Trat 1: goat manure; Trat 2: bovine manure; Trat 3: sorghum 25% caprine 75%; Trat 4: sorghum 25% bovine 75%; Trat 5: sorghum 50% bovine 50% and Trat 6: sorghum 50% caprine 50%)

The physicochemical attributes, measured at the entry and exit of the biodigestion process, are presented in Table 2.

Treatments T2 and T6 were the only ones to be close to the ideal pH range, which tends to neutrality (pH 7). T2 was the only treatment that did not show a significant difference in relation to input and output, remaining with values very close to the ideal both at the beginning and end of the experiment.

Treatments T5 and T2 suffered an alkalinization reaction during the hydraulic retention time, however only T5 showed a significant difference compared to its input and output. Although, acidification of the treatments, except for the T1 and T2 treatments, was expected, as they are a product of animal digestion, however, only the T2 treatment remained in the same pH range.

In treatments T1, T3, T4 and T6 the results indicate the predominance of acidogenic bacteria. Methanogenic bacteria require a pH tending to neutrality, a result that was not observed in the experimental treatments, except for T5 and T6, which in turn favor the growth of these prokaryotes and consequently the hydrolysis of organic matter to produce gas.

Regarding electrical conductivity, it can be observed that treatments T2, T4, T5 and T6 did not show a significant difference during the experiment, resulting in lower mean values. Treatments T1 and T3 presented the highest averages for conductivity at the entrance, differing significantly at the exit where they had lower values.



Table 2 - Physical chemical parameters (Hydrogenionic Potential and Electrical Conductivity) of residues and waste at the entrance and exit of biodigesters

| TREATMENT | ENTRANCE | | EXIT | |
|---|---|---|---|---|
| | pH | C.E. mS.cm$^{-1}$ | pH | C.E. mS.cm$^{-1}$ |
| Goat Manure (T1) | 8,23 aA | 12,70 aA | 5,60 bB | 9,21 aB |
| Beef Desire (T2) | 7,70 bA | 1,66 dA | 7,71 aA | 1,74 cA |
| Sorghum 25% + Goat 75% (T3) | 8,18 aA | 10,43 bA | 5,06 bB | 8,22 aB |
| Sorghum 25% + Beef 75% (T4) | 5,50 bA | 2,53 dA | 4,52 bB | 2,41 cA |
| Sorghum 50% + Beef 50% (T5) | 4,25 bB | 2,20 dA | 4,47 bA | 1,82 cA |
| Sorghum 50% + Goat 50% (T6) | 6,15 bA | 5,80 cA | 5,26 bB | 5,91 bA |
| mean standard error | 0,65683 | 1,91460 | 0,49994 | 1,35656 |

Where: pH = Hydrogenionic Potential; C.E = Electrical Conductivity.

Means followed by the same lowercase letters in the column do not differ statistically by the Tukey test at 5% probability. Means followed by the same capital letters in the row do not differ statistically by Student's t test at 5% probability

There was no significant difference in the productivity of the treatments. However, we can see in figure 6 that treatment T4 presented average productivity values well below those of the other treatments.

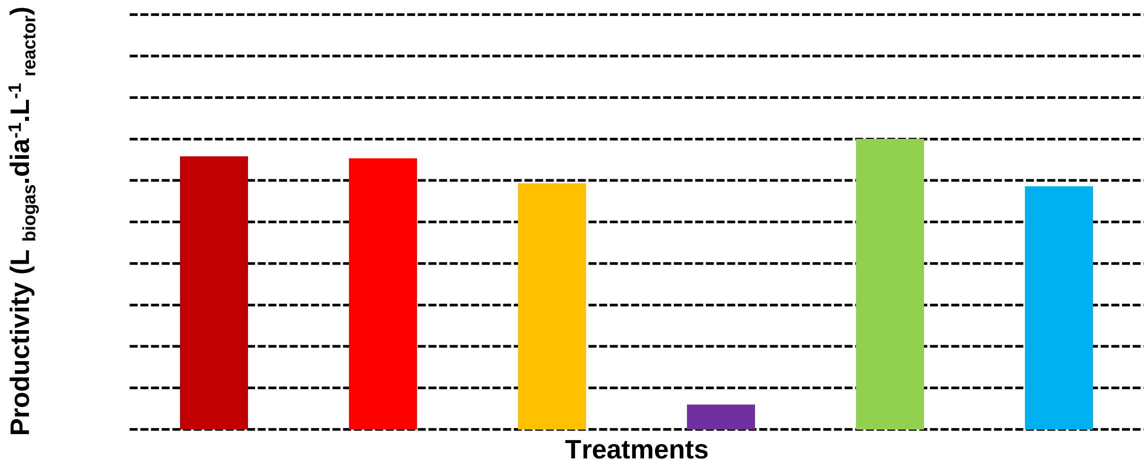


Figure 6 - Productivity of the evaluated treatments. (Trat 1: goat manure; Trat 2: bovine manure; Trat 3: sorghum 25% goat 75%; Trat 4: sorghum 25% bovine 75%; Trat 5: sorghum 50% bovine 50% and Treat 6: 50% goat 50% sorghum).

Treatment T2 presented the highest average in relation to yield, significantly differentiating from the other treatments, followed by treatments T4 and T5, which also contained 75% and 50% bovine manure with the addition of 25% and 50% sorghum respectively, presenting averages higher than those other treatments composed of goat manure and sorghum. Treatments T1, T3 and T6 presented the lowest means and did not differ statistically (Figure 7).



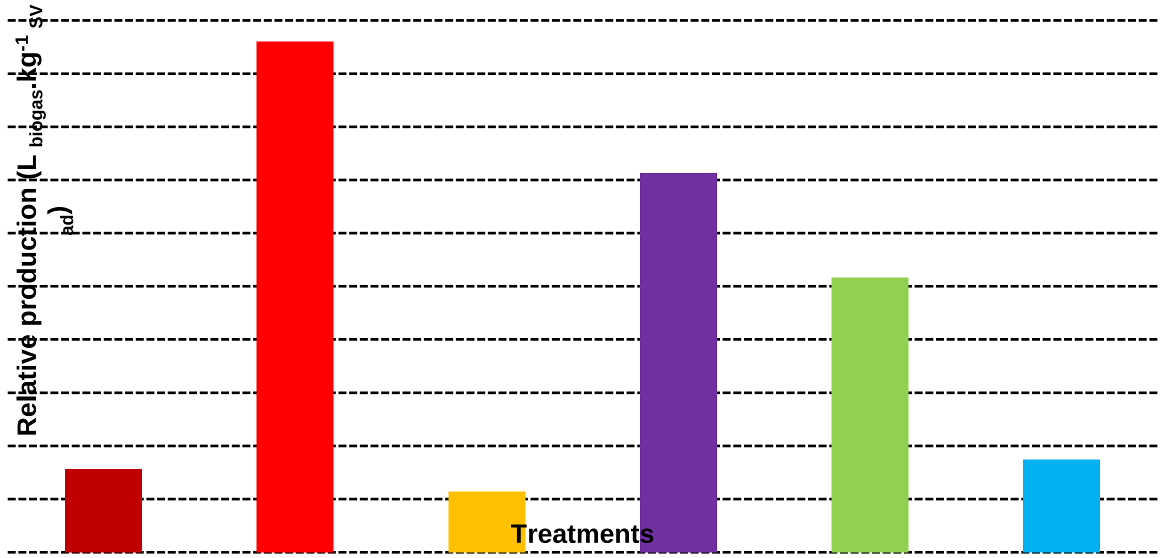


Figure 7 - Relative production (yield) of the evaluated treatments (Trat 1: goat manure; Trat 2: bovine manure; Trat 3: sorghum 25% goat 75%; Trat 4: sorghum 25% bovine 75%; Trat 5: sorghum 50% bovine 50% and Treat 6: sorghum 50% goat 50%).

Treatment T2 also presented the highest value for volumetric organic load (VOL), differing statically from the other treatments. As for yield, treatments T4 and T5 did not show significant differences between them, and obtained higher averages than treatments containing goat manure. Treatments T1, T3 and T6 presented the lowest averages and did not statistically differ from each other. Figure 8 illustrates the VOL values obtained.

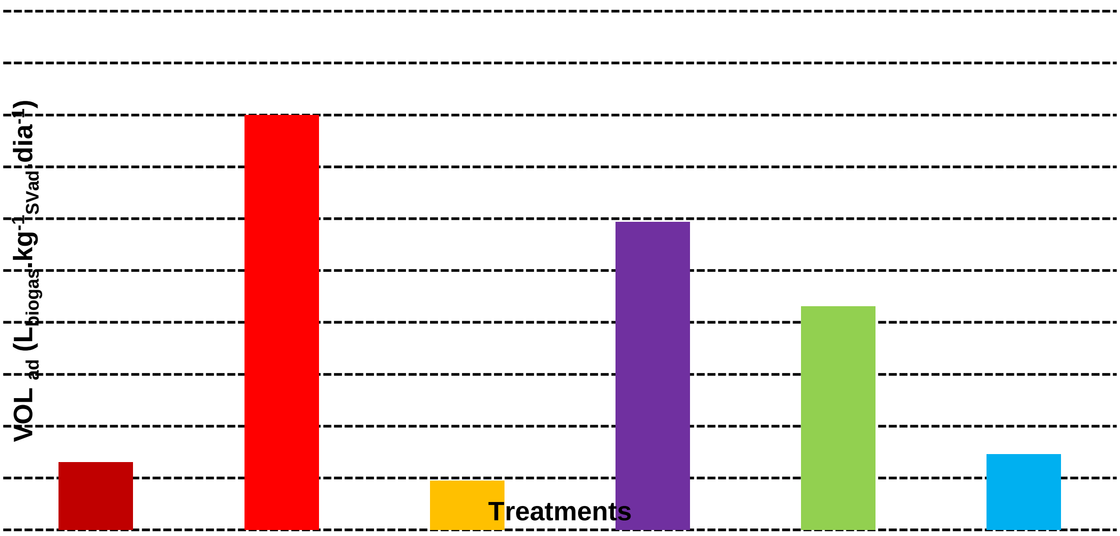


Figure 8 - Volumetric organic load (VOL) of the evaluated treatments. (Trat 1: goat manure; Trat 2: bovine manure; Trat 3: sorghum 25% caprine 75%; Trat 4: sorghum 25% bovine 75%; Trat 5: sorghum 50% bovine 50% and Trat 6: sorghum 50% caprine 50%).

An excellent VOL provides adequate conditions for the development of microorganisms and consequently greater stability in the process (KUNZ; STEINMETZ; AMARAL, 2019). VOL directly influences the anaerobic digestion process, as it is necessary to have adequate quantities, if the microorganisms present are not enough to degrade this material, it can cause the formation of fatty acids, damaging the process.



All treatments presented similar volume averages, treatment T5 presented the highest volume of biogas, but there was no significant difference in the corrected volume of biogas between treatments.

Figure 9 highlights the productive potential of all treatments analyzed in relation to the measurement period, establishing the quantitative qualities for cattle and goat manure, producing volumes above 90 liters in all treatments. This demonstrates the ability to quantify the volume of biogas produced in the manufactured biodigesters. Furthermore, the biogas production values found in this work corroborate those found in tests carried out by ORRICO JÚNIOR *et al.* (2012), who, when evaluating the anaerobic biodigestion of cattle waste, when used as the only component of the substrates, found values of up to 370 liters of biogas and 250 liters of methane per kg of SV added. These values can be increased when lipid waste acts together with cattle waste, increasing biogas and methane yields by up to 41.1% (ZHANG *et al.*, 2013).

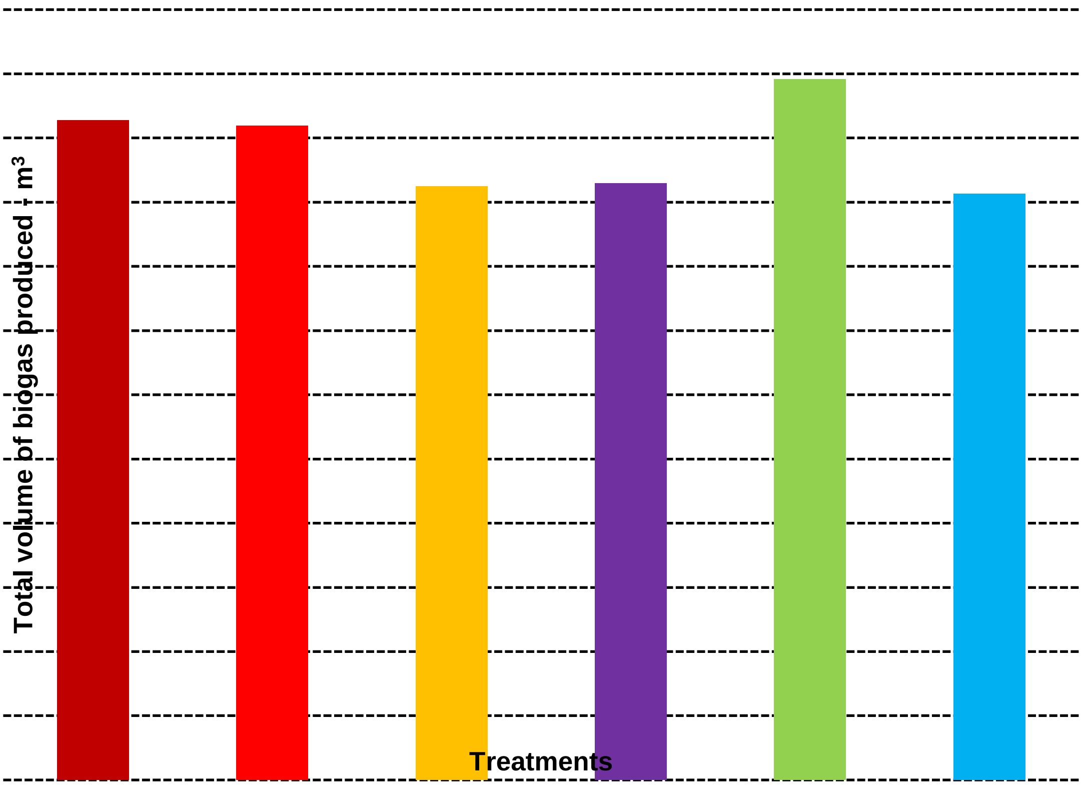


Figure 8 - Total corrected volume of produced biogas. (Trat 1: goat manure; Trat 2: bovine manure; Trat 3: sorghum 25% caprine 75%; Trat 4: sorghum 25% bovine 75%; Trat 5: sorghum 50% bovine 50% and Trat 6: sorghum 50% caprine 50%).



Table 3 - Productivity, yield, volumetric organic load (VOL) and normalized volume of biogas produced at 20°C and 1 atm

| Treatment | Productivity | Performance | VOL | Volume* |
|---|---|---|---|---|
| | $L_{biogas}.L^{-1}_{reator}.d^{-1}$ | $L._{biogas}.kg^{-1}_{SVad}$ | $kg_{SV}.L^{-1}_{reator}.d^{-1}$ | L |
| Goat manure | 0,0660 a | 39,17 c | 1,30 c | 25,68 a |
| Bovine Desire | 0,0653 a | 240,04 a | 8,00 a | 25,47 a |
| Sorghum 25% + Goat 75% | 0,0590 a | 28,54 c | 0,95 c | 23,12 a |
| Sorghum 25% + Beef 75% | 0,0598 a | 178,22 ab | 5,94 ab | 23,24 a |
| Sorghum 50% + Beef 50% | 0,0703 a | 129,23 bc | 4,31 bc | 27,29 a |
| Sorghum 50% + Goat 50% | 0,0588 a | 43,68 c | 1,46 c | 22,82 a |
| mean standard error | 0,00335 | 35,585 | 1,186 | 1,309 |

Means followed by the same lowercase letters in the column do not differ statistically by the Tukey test at 5% probability

## Final Considerations

The constructed biodigesters performed well in quantifying the production of biogas from organic substrates, promoting ideal conditions for the anaerobic digestion process to occur without oxygen contamination.

There was no significant difference in biogas production from anaerobic fermentation between treatments.

The physical parameters (Total Solids - TS, Total Fixed Solids - TFS and Total Volatile Solids - TVS) of most waste to feed the biodigester (input) and biofertilizers from the biodigesters (output) presented values close to those found in the literature, except for treatments T2 and T4 which presented percentages below the recommended level, which is 2% to 10% of ST.

The physical-chemical parameters (pH and Electrical Conductivity) of most of the waste to feed the biodigester (input) and biofertilizers from the biodigesters (output) were not within the ideal range described in the literature for biogas production, except for treatments T2 and T6.

The T2 treatment composed of cattle manure showed a higher yield (240.0365 $L_{biogas}.kg^{-1}{}_{SVad}$) and an average added Volumetric Organic Load of 8.0015 $kg_{SV}.L^{-1}{}_{reactor}.d^{-1}$.

Treatment T5 presented a higher numerical productivity value (0.0703 $L_{biogas}.L^{-1}{}_{reactor}.d^{-1}$) of biogas in relation to the other treatments, however this difference was not significant at 5% probability using the Tukey test.

## BIBLIOGRAPHIC REFERENCES



ALMEIDA, C. *et al*. Potencial de Produção de Biogás a Partir de Biomassa de Suinocultura com Culturas. Dissertação (Mestrado Em Engenharia Energética na Agricultura) Faculdade Estadual do Oeste do Paraná, 2016.

ANGONESE, A.; CAMPOS, A. T.; ZACARKIM, C. E. Eficiência energética de sistema de produção de suínos com tratamento dos resíduos em biodigestor. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v.10, n.3, p.745-750, jul./set. 2006.

https://doi.org/10.1590/S1415-43662006000300030

CAETANO, L. Proposição De Um Sistema Modificado Para Quantificação De Biogás. 1985. 75 f. Dissertação (Mestrado Em Agronomia - Área De Concentração De Energia Na Agricultura). Faculdade De Ciência Agronômicas, Universidade Estadual Paulista, Botucatu, 1985.

COHEN, J. E. A maturidade da população. Scientific American. Edição Especial para o Brasil, São Paulo. n. 41, p. 40-47, out. 2005.

EVANS, A.; STREZOV, V.; EVANS, T.J. Sustainability considerations for electricity generation from biomass, Renew. Sustain. **Energy Rev.** 14 (2010) 1419 - 1427,

https://doi.org/10.1016/j.rser.2010.01.010

FERRAZ, J. M. G.; MARRIEL, I. E. Biogás: uma fonte alternativa de energia. Circular técnica n. 3. Embrapa-CNPMS, Sete Lagoas, p. 27, out. 1980.

FRIEHE, J.; WEILAND, P.; SCHATTAUER, A. Fundamentos da fermentação anaeróbia In: FachagenturNachwachsendeRohstoffe. Guia prático do biogás. Gülzow-Alemanha DeutschesBiomasseForschungsZentrum. 5. ed.p. 20- 27, 2010.

FURMAN, L. *et al*. Construção e operação de um biodigestor em batelada.Anais do Salão Internacional de Ensino, Pesquisa e Extensão, v. 8, n. 2, 28 fev. 2020.

GOMES, William *et al*. Benefícios da biodigestão: uma técnica sustentável. IX Simpósio Internacional de Qualidade Ambiental. Porto Alegre, 2014.

HAGOS, K.; ZONG, J.; LI, D.; LIU, C.; LU, X. Anaerobicco-digestionprocess for biogás production: progress, challengesand perspectives, Renew. Sustain. **Energy Rev**. 76 (2017) 1485e1496, https://doi.org/10.1016/j.rser.2016.11.184.

KADER, A. (ed.) Postharvest Technology ofHorticulturalCrops. 3 ed. UniversityofCalifornia, Agricultureand Natural Resources, Publication 3311. 2002. 535 p.

KUNZ, A. ; STEINMETZ, R. L. R. ; AMARAL, A. C. Fundamentos da digestão anaerobia, purificação de biogás, uso e tratamento do digestato. 1ª edição. Concórdia: EmbrapaSuínos e Aves, 2019.

MACHADO,N.S.; MOGAMI, C.M.; SILVA, K.A.; OLIVEIRA, F.F. Review of alternatives for removing hydrogen sulfide ($H_2S$) from biogas from anaerobic fermentation of agricultural waste and its uses, benefits and economic viability from 1969 to 2010 – 40 years of research. **Revista Ibero-Americana de Humanidades, Ciências e Educação**. São Paulo, v.9.n.03. mar. 2023a.



https://doi.org/10.51891/rease.v9i3.8879

MACHADO, N. S., ALVES, D. J. DA S., OTSUKA, M. Y. F., FREIRE, A. A. M., DA SILVA, K. A., LESSA, B. F. DA T., FELIX, W. P., & DE OLIVEIRA, F. F. Productionofbiogasfromthefermentationofgreensweetsorghum, fruitresiduesand animal waste. **Brazilian Journal of Animal and Environmental Research**, 6(1), 612–631. 2023b.

https://doi.org/10.34188/bjaerv6n1-055

MACHADO, N.S.; SANTANA, M.C.; NASCIMENTO, P.V.P.; SILVA, K.A.; GALHARDO, C.X.; LESSA, B.F.T.; LEITE, D.M. Produção de biogás a partir de restos alimentares, resíduos de cebola e dejetos bovinos. **Revistaft** - V27 - Ed 122 - P 43. 2023c

https://www.doi.org/10.5281/zenodo.7924643

NAÇÕES UNIDAS BRASIL. Os objetivos do desenvolvimento sustentável, 2023. https://brasil.un.org/pt-br/sdgs

ORRICO JÚNIOR, M.A.P.; ORRICO, A.C.A.; LUCAS JÚNIOR, J. *et al*. Biodigestão anaeróbia dos

dejetos da bovinocultuta de corte: influência do período, do genótipo e da dieta. **Revista Brasileira de Zootecnia**, Viçosa, MG, v.41, n.6, p.1533-1538, 2012.

https://www.scielo.br/j/rbz/a/t9RmpgPQP9VVcYgTQ5zjszS/?format=pdf&lang=pt

PÄÄKKÖNEN, A.; TOLVANEN, H.; RINTALA, J. Techno-economic analysis of a power to biogas system operated based on fluctuating electricity price, Renew. **Energy**117 (2018). https://doi.org/10.1016/j.renene.2017.10.031.

PISTORELLO, J.; CONTO, S.M.; ZARO, M. Geração de resíduos sólidos em um restaurante de um Hotel da Serra Gaúcha. Eng. Sanitária e Ambiental, vol. 20, n.3, p. 337-346, Porto alegre-RS, 2015. http://dx.doi.org/10.1590/S1413-41522015020000133231

REIS, M. F.; CONTI, M. D.; CORREA, M. R. M. Gestão de Resíduos Sólidos: Desafios e Oportunidades para a Cidade de São Paulo, RISUS. JournalonInnovationandSustainability, 6 (3): p. 77-96. 2015. https://doi.org/10.24212/2179-3565.2015v6i3p77-96

SOUZA, J. *et al*. Tecnologia para Dimensionamento e Projeto de Reatores Anaeróbicos. VIII Simpósio Internacional de Qualidade Ambiental, Porto Alegre, 2012.

SURENDRA, K.C.; TAKARA, D.; HASHIMOTO, A.G.; KHANAL, S.K.;Biogas as a sustainableenergysource for developing countries: opportunitiesandchallenges, Renew.Sustain. **Energy Rev**. 31 (2014) 846 – 859.https://doi.org/10.1016/j.rser.2013.12.015.

TOMY. *et al* 2014. Manual básico de biogás. 1ª edição. Lajeado: Editora Univates, 2014. 69 p.UGALDE, F.Z.; NESPOLO C.R. Desperdício de alimentos no Brasil. 154 ed. Rio Grande do Sul: SB RURAL. Ano 7, maio, 2015.

ZHANG, C.; XIAO, G.; PENG, L. SU, H.; TAN, T. The anaerobic co-digestion of food waste and cattle manure. **Bioresource Technology**, New York, v.129, p. 170-176, 2013. https://doi.org/10.1016/j.biortech.2012.10.138