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Full Length Research Paper

Comparative Analysis of Pig Faeces Digestion Versus Anaerobic Co-Digestion with Wastewater Sludge and Bovine Ruminal Contents

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Anaerobic co-digestion improves the pig faeces digestion process. This work presents anaerobic digestion of pig faeces (C) as compared to 2 co-substrates: Sludge (L) from waste waters and bovine ruminal gastric content (R). Pig faeces used were generated in a local farm at the Juarez Autonomous University of Tabasco (UJAT), with a total population of 148 animals. Analytical determinations were made on the substrate and co-substrates. Each treatment was performed in triplicate (9 experimental units), for 18 weeks. C+R co-digestion had the highest removal of chemical oxygen demand (COD) with 90%. Biogas production (0.012 L day^{-1}) was quantified for C and C+R, with concentrations of 70.87±8.65 and 71.89 ± 7.60% of methane (CH_4), respectively. For C+L, it was 0.009 L day^{-1}, with 77.89±6.74% of CH_4. Results obtained showed that co-digestion of C+L was better with regards to the quality of biogas from low hydrogen sulfide (H_2S) concentrations (70.33±6.36 ppm). The use of anaerobic co-digestion systems represents an alternative treatment for faeces generated in pig farms and other kinds of wastes to reduce the potential source of infection produced by these types of waste.

Key words: Biogas, digester, manure, pig faeces, rumen.

INTRODUCTION

Breeding of pig is an important and constantly growing activity in rural areas, which represents an option of food and economical resource. In a higher scale, pig activity is carried out in farms with the purpose of reproduction and sale of livestock. However, these activities generate water from washouts, food wastes, faeces and urine, with a high organic load, mostly disposed in natural aquatic environments in open landfill, without any treatment. Productions of pig worldwide generate 9% of the greenhouse gas (GHG) emissions in the livestock sector. In Mexico, 66,708.27 tons of faeces are produced per year with contribution of 27.80% (18.547 tons per year) from the pig sector (Gerber et al., 2013). In Tabasco, particularly in year 2015, 265,214 heads in 45,828

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commercial production units was reported (SIAP, 2015). Montejo et al. (2015) reported that the average faeces generation on a daily basis in five different animal development stages (fattening, weaning, breeding, reproduction and maternity) is 100.96 kg; data was obtained in a survey made in pig farm at the Agriculture and Livestock Academic Division (DACA), Juarez Autonomous University of Tabasco (UJAT). Different alternatives have been given to solve these problems. Garzón and Buelna (2014) mentioned that pig exploitation requires a treatment system such as anaerobic digestion, considering wastes as useful resources in livestock production. Holm-Nielsen et al. (2009) pointed out that anaerobic digestion of animal wastes converts organic waste into two valuable products: biogas and digestate, which may be used as fuel in the generation of energy (heating and electricity), and as organic fertilizer, respectively. Chen et al. (2008) mentioned that anaerobic digestion offers the benefit of reducing the volume of wastes and the deactivation of pathogens. This technology has been successfully applied in the treatment of livestock food wastes, residual waters, and residuals sludge due to their capacity to reduce chemical oxygen demand (COD) and biochemical oxygen demand (BOD). Shah et al. (2015) defined co-digestion as a process where two substrates are anaerobically digested for biogas production. Chen et al. (2008) highlighted that the anaerobic co-digestion process, significantly improves the efficiency of waste treatment promoting the adaptation of the microorganisms to the inhibitor condition. Biogas production is largely supported by the substrate physical and chemical features, by total solid (TS) content, total volatile solids (TVS), fixed solids (FS) and ashes. Zhang et al. (2014), reported values of 29.96±0.26% of TS and 20.89±0.23% of TVS (dry base) for pig feces, while Chen et al. (2015) reported the use of pig faeces in anaerobic digestion, with total solids (TS) values of 20 and 35%, with a production of 2.40 L day^{-1} of biogas and a degradation of 56% of TS. Ye et al. (2013) reported rice straw co-digestion, kitchen wastes and pig manure in a concentration of 54 g TVS L^{-1}, with a yield of 383.9 L CH_4 kg^{-1} TVS. Kaparaju and Rintala (2005) used potato peelings in the co-digestion of pig manure with a ratio of 20 and 80%, respectively, reaching yields of 0.28 to 0.30 m^3 CH_4 kg^{-1} TVS. Borowski et al. (2014) evaluated the co-digestion of sludges in a wastewater treatment plant, pig faeces and bird manure (ratio of 70:20:10), reporting a performance of 336 L CH_4 kg^{-1} TVS, with 67% in volume of CH_4 and 29% in volume of carbon dioxide (CO_2). The purpose of this study was to evaluate the digestion eficiency of pig faeces generated in DACA with two different anaerobic co-digestion treatments using sludge from wastewater treatment plant or ruminal bovine stomach contents from a municipal slaughter house as co-substrates.

METHODOLOGY

Substrate and co-substrates acquisition

Pig faeces (C) were obtained from pig farm at the DACA UJAT (Figure 1a). Bovine ruminal gastric content (R) was obtained from the municipal slaughter house located in Cunduacán, Tabasco (Figure 1b). The sludge (L) was obtained from an Imhoff cone type wastewater treatment plant, located also in Cunduacán (Figure 1c). Composite samples were taken using the quarter method (SCFI, 1985a).

Physicochemical analyses

Each of the substrate samples and co-substrates were analyzed in triplicate for moisture percentage (SCFI, 1985b), TVS percentage (SCFI, 2015), FS and ash percentage (SCFI, 1984). TS determination was determined by the difference of 100% - % humidity according to Bux et al. (2012).

Experimental design

Three experimental units containing pig faeces, three pig faeces - sludges and three pig faeces-rumen units were displayed following a randomized design. Each experimental unit (EU) consisted of a 1 L reaction bottle connected to a 1 L Tedlar bag (Figure 2). Each reaction bottle was mixed at a rate of 500 rpm for 20 min using a Thermo Scientific grill 135935Q ® SP. Treatment were performed in triplicate. Each experimental unit was filled up to 80% (800 mL) in a ratio of 9:1 (Water: TVS), according to Gallardo et al. (2013). Each treatment design is described in Table 1, considering 10% of TVS on a dry basis.

Experimental monitoring

Biogas production was analyzed for 18 weeks. Different physicochemical parameters, like pH, oxide reduction potential (mV), dissolved oxygen (%) and chemical oxygen demand (mgL^{-1}) were measured during the experiment using Multiparametric Hanna® 9828 brand equipment, biogas characterization (% v/v), employing Dräger X-am model 7000 model Gas detection equipment and nutrients using Hanna® 83225 Multiparameter meter.

Statistical analysis

Analysis of variance (ANOVA) was performed with 95% confidence interval to determine differences in the three treatments tested (C, C + L and C + R), in the production of CH_4, CO_2 and H_2S. In the same way, Tukey multiple contrasts test was applied to find differences among treatment. STATGRAPHICS® Centurion XV package was used for the statistical analysis.

RESULTS AND DISCUSSION

Substrates and co-substrates analyses

Table 2 shows the substrate and co-substrates features.

Figure 1. Collection of substrates and co-substrates. (a) Swine Farm. (b) Municipal slaughter house. (c) Waste water treatment.

Figure 2. Reaction bottle connected to Tedlar bag.

pH behavior

C + L treatment started with a neutral pH, while C and C + R treatment started with a more basic pH (above 8, hydrolytic phase). After three weeks, pH values in all 3 treatments reduced to less than 7, remaining in this condition during a week (acidogenic phase), and increased gradually until pH was stabilized at week 12. At the end of the experiment, the pH values remained stable in a range below 8 (methanogenic phase), as shown in Figure 3. This behavior is in good agreement with Kaparaju and Rintala (2005), who suggested that the co-digestion process should have a pH between 7.1 and 8.1. The effect of pH during the 3 weeks, showed less inhibition in the activity of microorganisms resulting in a stable and undisturbed digestion and co-digestion (Chen et al., 2008; Rajagopal et al., 2013).

Oxide-reduction potential (ORP)

After three weeks, ORP values showed an average of -300 mV, highlighting the redox condition (Figure 4). This result is closely related to the recommended value suggested by Flotats et al. (2001), Liu et al. (2011) and Su et al. (2016), who considered that the ORP optimum for an anaerobic process should be less than -270 mV; however, a high redox potential (10.56 V) is a direct inhibition value (Chen et al., 2014).

Chemical oxygen demand (COD)

Treatment C had the lowest efficiency in COD removal values (Table 3) up to the end of the process, which is different from the report of Pazuch et al. (2017), with a value of 68%, but in a anaerobic-digestion process where cattle manure and crude glycerin were used. However, these results are similar to those shown by Nuchdang and Phalakornkule (2012) with values >80% that used anaerobic digestion and co-digestion of glycerol and pig manure.

Table 1. Types of treatments.

Treatments	Substrate (g)	Co-substrate (g)	Total	Treatments
C	125.62	-	125.62	(125.62)(0.6368)= 80.00
C+L	113.06	71.43	184.49	(113.06)(0.6368)+(71.43)(0.112)=79.99
C+R	113.06	9.89	122.95	(113.06)(0.6368)+(9.89)(0.8089)=79.99

C, Pig feces; L, sludge; R, bovine ruminal gastric content waste.

Table 2. Pig feces (C), sludge (L) and bovine ruminal gastric content (R) waste characteristics.

Analytical characteristics (%)	Substrate	Co-substrate	
	C	L	R
H	65.90±0.15	72.81±4.55	83.66±0.37
TS	34.10±0.15	27.19±4.55	16.34±0.37
TVS	63.68±1.07	11.2±0.88	80.89±1.22
FS	6.53±0.30	88.8±0.15	19.11±1.22
Ash	29.79±0.78	85.62±0.88	13.73±0.24

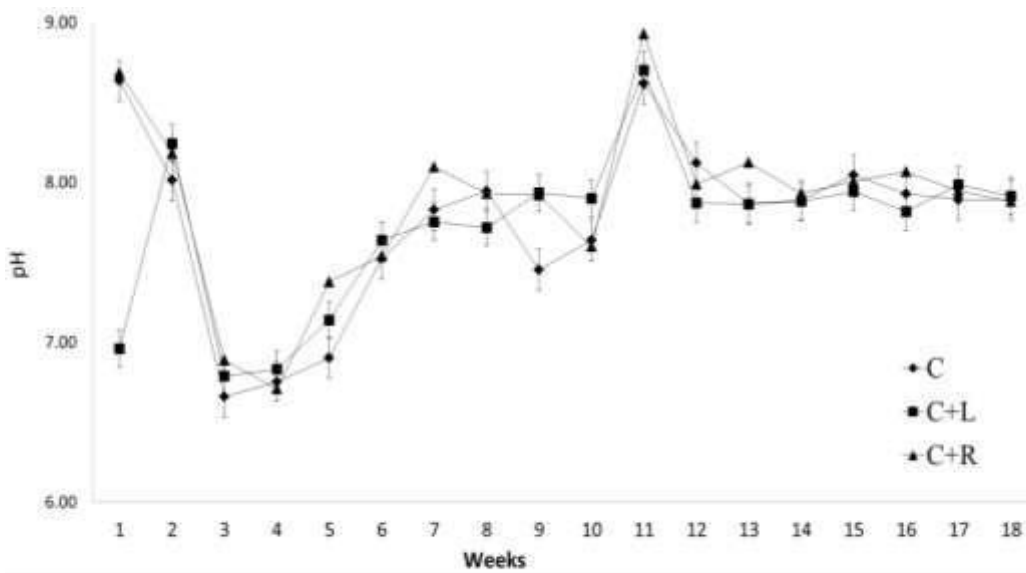

Figure 3. pH behavior for eighteen weeks.

Biogas characterization

The three main gas compounds in a biogas mixture are shown in Table 4. The proportion obtained (% v/v) highlighted high presence of H_2S in treatment C.

Biogas recovering

The biogas produced during this study was 0.012 L day^{-1} in C and C+R treatments, while in C+L, it was 0.009 L day^{-1}. In the C+L treatment, CH_4 and CO_2 content was greater than the values reported by Chen et al. (2015), Nuchdang and Phalakornkule (2012) and Sebola et al. (2015), where 65, 62 and 58% CH_4 was produced, respectively.

Nutrients

In Table 5, the nutritionals characteristics of the digestate, either at the beginning or end of the anaerobic co-

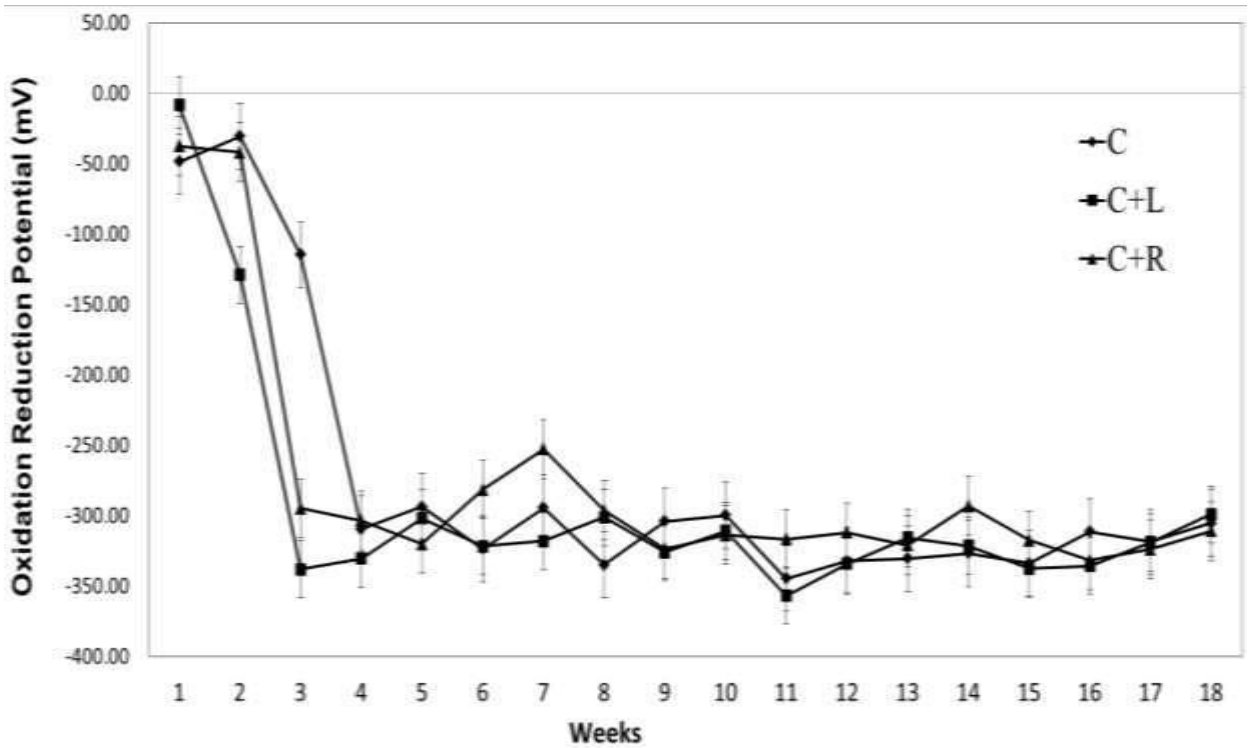

Figure 4. Oxide reduction potential values during the eighteen weeks.

Table 3. COD removal in the three treatments.

Treatments	COD (mg L^{-1})		COD removal (%)
	Initial	Final	
C	28000.0	5600.0	80.00
C+L	26433..3	3333.3	87.39
C+R	20266.7	2000.0	90.13

Table 4. Volumes of gas generated in the biogas.

Treatments	CH_4 (%)	CO_2 (%)	H_2S (ppm)
C	70.87 ± 8.65	29.12 ± 8.65	164.75±16.01
C+L	77.89 ± 6.74	22.11 ± 6.48	70.33±6.36
C+R	71.89 ± 7.60	28.11 ± 7.60	124.67±6.66

Table 5. Nutrient features of co digestion per treatment.

Nutrient	C			C+L			C+R		
(mg/L)	Start	End	%	Start	End	%	Start	End	%
(NO_3^-)	5106	2666	0.26	0	4000	0.40	0	0	0.00
(P_2O_5)	6693	4613	0.46	7440	4160	0.41	6000	3520	0.35
(K_2O)	2800	2533	0.25	3733	2400	0.24	2026	1866	0.18

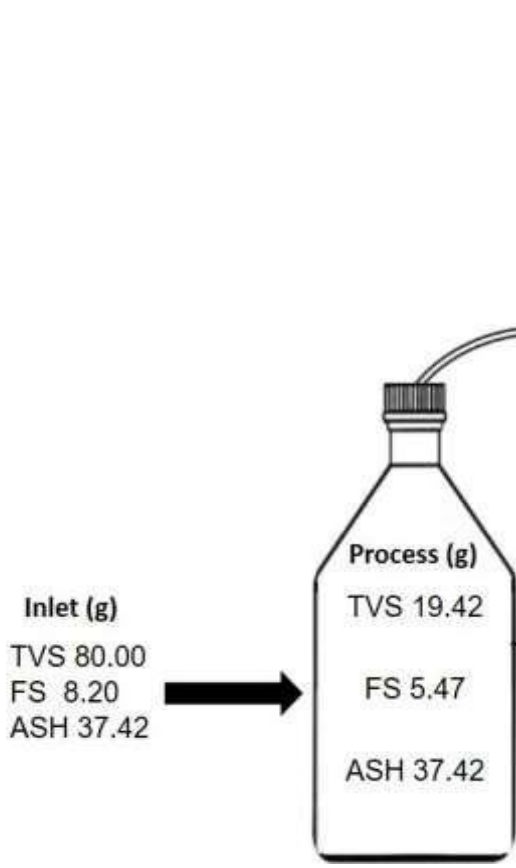

Figure 5. Mass balance of pig manure.

digestion experiment, are showed.

Mass balance for treatment

Treatment C contained 80 g of TVS, 8.20 g FS and 37.42 g ashes, giving a total of 125.62 g. The efficiency of the process showed 63.21 g (60.58 +2.63 g) as biogas production, with 62.31 g of biogas or digestate remaining inside the reactor. During this process, an amount of 71.66% of degradable solid (Figure 5) was removed.

For C+L treatment, 79.99 g TVS, 9.65 g of FS and 94.83 g of ashes were used, giving a total of 184.49 gas original substrate. The efficiency of the process showed 70.03 g (61.84 + 8.19 g) as biogas production, with 114.46 g of biogas or digestate remaining inside the reactor. During this process, 78.12% of degradable solids (Figure 6) were removed.

Finally, for C+R treatment, it was 79.99 g TVS, 7.91 g FS and 35.05 g ashes, giving a total of 122.95 g. The efficiency of the process showed 69.85 g (63.88 + 5.97 g) biogas production, with 53.1 g of biogas or digestate remaining inside the reactor. As a result, 79.46% of degradable solids (Figure 7) were removed.

Statistical analysis of CH_4 and CO_2 production

The analysis of one-way variance shows that there are no significant differences (P = 0.38) among CH_4 production in the three treatments (Figure 8). However, treatment of C + L had a greater CH_4 production, as compared to the other two treatments (C and C + R, respectively) tested. With regards to CO_2 production, one way analysis of variance showed no significant differences (P = 0.38) among treatments. C + L treatment had less CO_2 production (Figure 9).

Statistical analysis of H_2S production

ANOVA showed significant statistical differences (P < 0.01) among the three treatments evaluated (Figure 10). Tukey multiple contrast test showed significant differences among the three treatments evaluated in terms of the production of hydrogen sulfide. It was observed that the

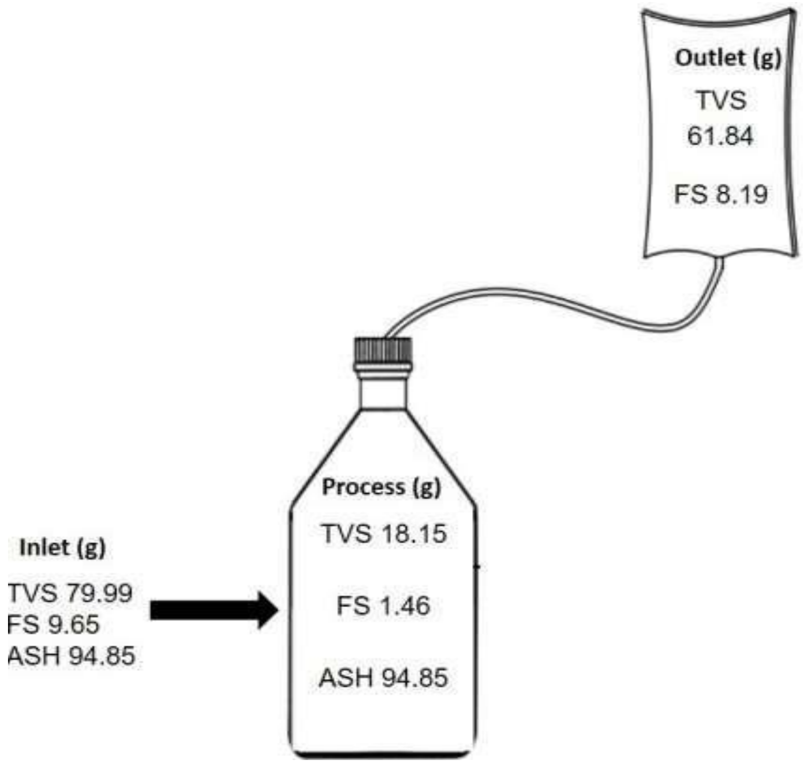

Figure 6. Mass balance of pig manure plus sludge.

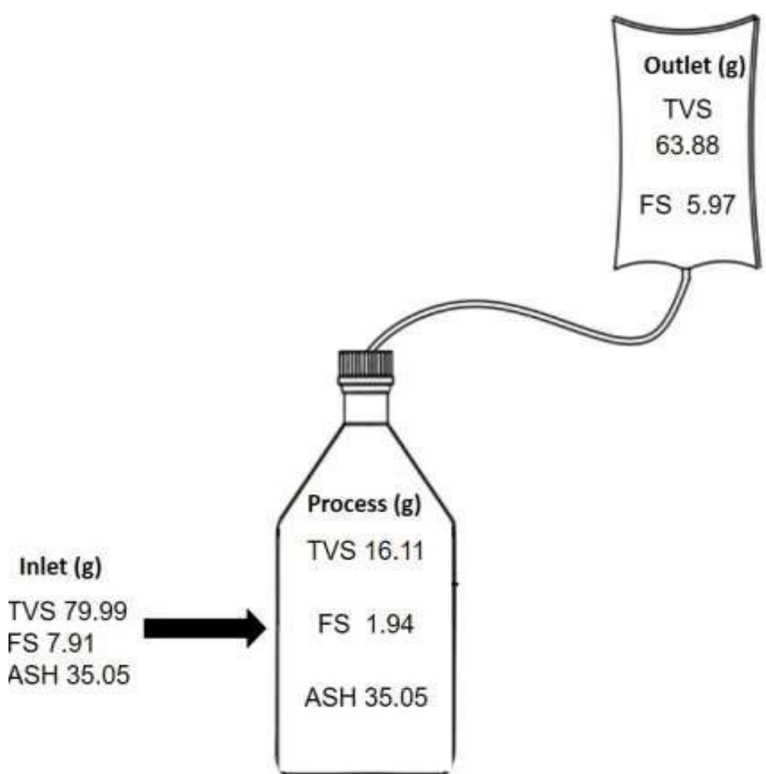

Figure 7. Mass balance of pig manure plus rumen.

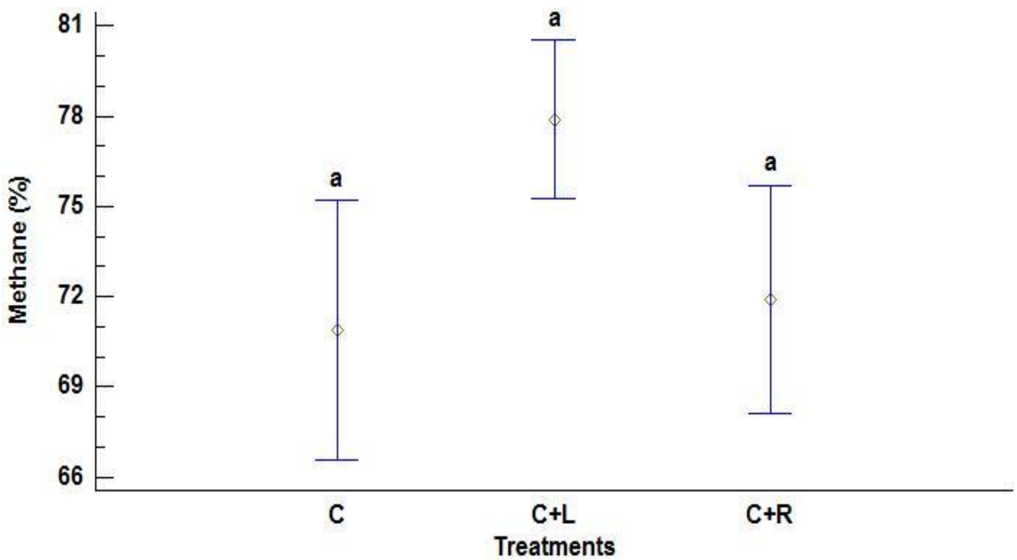

Figure 8. Treatment average values evaluated in the production of CH_4 ± standard error.

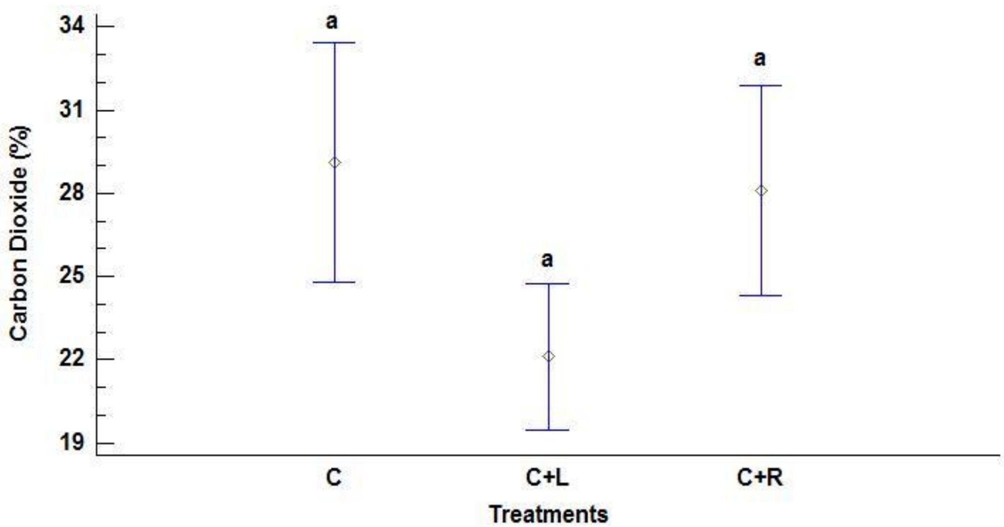

Figure 9. Average values of the treatments evaluated in the production of CO_2 ± standard error.

C + L treatment generated the lowest concentration of H_2S, followed by the C + R. The highest value of H_2S was obtained in treatment C.

Conclusions

The digestion eficiency of pig faeces by two different anaerobic co-digestion treatments using sludge from wastewater treatment plant or ruminal bovine stomach contents as co-substrates showed that the best treatment was C+L, resulting in higher CH_4 production, lower CO_2 and lowest H_2S production, respectively. Therefore, the use of wastewater sludge in anaerobic co-digestion processes promotes more suitable biogas production with pig faeces substrates. C+R treatment had less COD values, reaching 90% efficiency. According to these results, anaerobic digestion and co-digestion are suitable options in agricultural and livestock waste management, reducing waste production and volumes, allowing higher

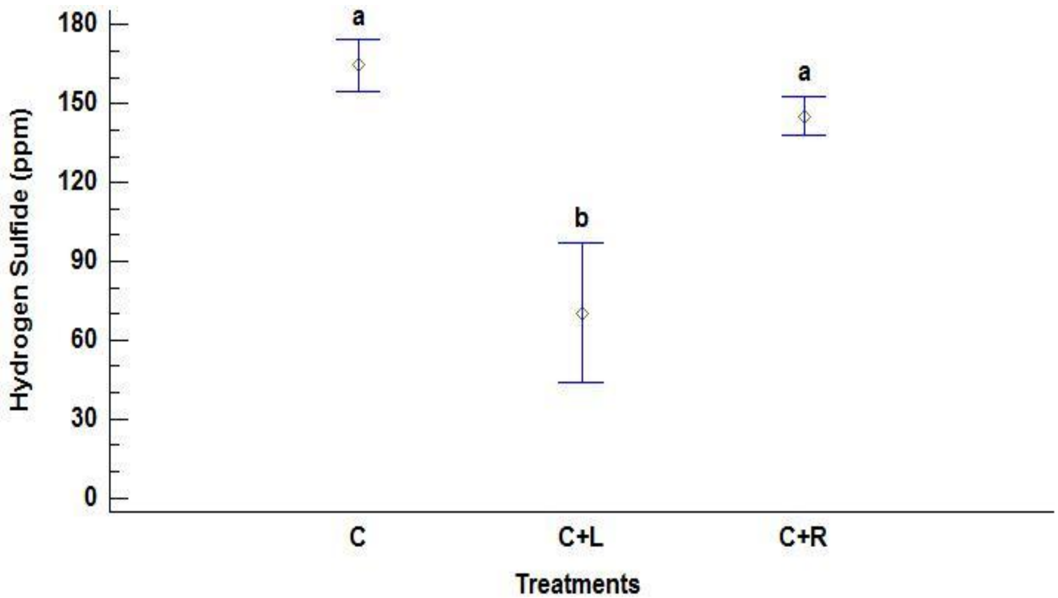

Figure 10. Average values of the treatments evaluated for the production of H_2S ± standard error.

recovery values and maximizing recycling with high calorific or energetic products, such as biogas.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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