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BIOGAS PRODUCTION BY ANAEROBIC DIGESTION OF COFFEE HUSKS AND CATTLE MANURE

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KEYWORDS

anaerobic co-digestion, dry digestion, wet digestion, production potential, mathematical modeling.

ABSTRACT

The use of agricultural residues in anaerobic digestion (AD) for biogas production promotes environmental and socioeconomic benefits. This study aimed to evaluate the biogas production from dry coffee husks (DCH), wet coffee husks (WCH), and cattle manure (CM) in AD. Prototypes of Indian anaerobic benchtop digesters with a batch feeding system supplied with 100 CM, 100 DCH, and 100 WCH for anaerobic mono-digestion (AMoD) and 25:75 DCH:CM and WCH:CM for anaerobic co-digestion (ACoD) were used in the experiment. The dry husk was mechanically pre-treated with grinding in a manual mill. Moisture and total solid presented no statistically significant difference between the studied relationships but the coffee husk as a co-digestant acidified the medium to be digested. The 25:75 DCH:CM ratio anticipated biogas production (7th week) and showed higher potential for weekly and accumulated biogas production. The Gompertz model showed the best fit considering the coefficient of determination, mean relative error, standard deviation of the estimate, and mean squared deviation. Therefore, the coffee husk as a co-digestant of cattle manure is a potential lignocellulosic biomass for biogas production provided that the process is conducted under pre-treatment.

INTRODUCTION

Biogas is a competitive, non-intermittent, and environmentally and economically viable energy source, which can be converted into thermal energy for heating rural facilities, drying grains and cooking food, and using as electricity and biofuel to drive automotive vehicles (Tsapekos et al., 2017; Nadaleti, 2019; Zavarise et al., 2021; Abanades et al., 2022).

In addition to generating different energy sources, one can mention the benefit of converting an environmental liability into an environmental asset, adding value to residues that are usually incorrectly wasted, and, depending on how they are used, inserting them into the context of the circular economy (Nadaleti, 2019; Garcia et al., 2019; Paranhos et al., 2020). Studies have indicated that biogas recovery in production systems is one of the ways of adopting a circular economy, which can contemplate Sustainable Development Goals 2, 3, 5, 6, 7, 9, 13, and 15 (Obaideena et al., 2022; Szyba & Mikulik, 2022; Dhungana et al., 2022). This alternative and renewable source, as it is produced in loco, promote energy security in places with limited access, enabling the compensation system for the injection of excess energy into the electric utility network (Nadaleti, 2019; Zavarise et al., 2021; Abanades et al., 2022).

Agricultural residues can be considered energy resources with great potential for biogas production via anaerobic digestion (AD), which includes anaerobic mono-

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digestion (AMoD) and anaerobic co-digestion (ACoD). The efficiency of biogas production through AMoD of cattle manure has been reported by several authors (Barzallo-Bravo et al., 2019; Garcia et al., 2019; Paes et al., 2020). However, studies have become necessary due to the range of agricultural residues without proper disposal associated with increased energy demand and the adoption of sustainable systems in the productive sector (Garcia et al., 2019). ACoD of cattle manure with lignocellulosic residues has been an alternative to AMoD (Latinwo & Agarry, 2015; Neshat et al., 2017; Tsapekos et al., 2017; Dahunsi, 2019; Andrade et al., 2020; Franqueto et al., 2020; Paranhos et al., 2020). The synergism of these energy resources enhances biogas production and the digestate quality, favoring its use as an organic fertilizer (Neshat et al., 2017; Garcia et al., 2019; Franqueto et al., 2020; Paranhos et al., 2020).

Coffee husk stands out among the possible existing lignocellulosic agricultural residues to be used as a co-digestant with cattle manure. According to CONAB (2022), a production of 53,428.3 thousand bags of processed coffee is estimated in the 2022 harvest, which represents an increase of 12% compared to 2021. The amount of residues (husk) generated by coffee processing can reach approximately 50% of the coffee production (Baqueta et al., 2017), with an estimated coffee husk generation of almost 27 thousand bags, which can be used as biomass for energy generation and a possible introduction of the circular economy on the property.

The different compositions and variability between co-digestants and the proportions of the mixture to be used in the digester need to be evaluated when working with ACoD to favor synergisms and optimize biogas production (Matos et al., 2017; Salehiyoun et al., 2019; Paes et al., 2020; Dhungana et al., 2022). Organic compounds present in coffee husks have the potential to convert energy into biogas. However, stabilizing the pH and biodegradability is supposedly required by adding biomass rich in bacteria, fungi, and protozoa for higher efficiency of anaerobic co-digestion (Widjaja et al., 2019).

Mathematical models are presented as a way to better understand the process due to this dynamism, limiting factors, and a variety of operating conditions, assisting in designing the AD system, the operating conditions, and the most favorable relationships between substrates to allow predicting the efficiency and stability of the system and provide a better evaluation of the system as a whole and ways to improve it (Salehiyoun et al., 2019; Franqueto et al., 2020; Paranhos et al., 2020).

Thus, this study aimed to evaluate the biogas production from the anaerobic digestion of coffee husks and cattle manure, using nonlinear regression models to adjust the observed data of the kinetics of the accumulated biogas production potential.

MATERIAL AND METHODS

The AD system that includes the AMoD and ACoD processes and the physicochemical analyses of the substrate were carried out at the Laboratories of Multi-User Research of the Rural Renewable and Alternative Energies Group (LabGERAR) of the Institute of Technology/Department of Engineering of the Federal Rural University do Rio de Janeiro (UFRRJ), campus of Seropédica, RJ, Brazil, whose geographic coordinates are 22°45′33″ S and 43°41′51″ W. The region has a climate classified as Aw according to the Köppen classification and an annual average temperature of 24.5 °C.

The experiment used an Indian anaerobic benchtop digester, consisting of a "water seal" containment chamber, a fermentation chamber, a gasometer, and a U-bulb manometer with water as the manometric liquid. A spiral-shaped aluminum spring coupled to the gasometer was responsible for the homogenization of the material inside the anaerobic digester (Silva et al., 2021).

The anaerobic digester was supplied with 1.7 kg of a substrate containing only cattle manure (CM), wet coffee husks (WCH), and dry coffee husks (DCH) for AMoD and 25:75 WCH:CM and DCH:CM for ACoD, with tests performed in triplicates.

The pulping of natural coffee batches by the dry and wet methods was carried out manually. The wet method consisted of immersing the coffee fruits in water for 24 h to remove the mucilage and reach a moisture content of 76% wet basis (wb). The dried coffee husks were kept in a dirt yard for one week until they reached 14% wb. The dry husks were subjected to mechanical pre-treatment with grinding in a manual mill. Samples mixed at equal proportions of coffee husk particles with a granulometry of 6 and 12 mesh were used in the experiment.

The supply system occurred in batches, that is, the substrate was placed in the anaerobic digester only at the entrance to the experiment. The period of anaerobic digestion ranged from zero, that is, the feeding time, to 16 weeks. The substrate was supplied to the anaerobic digesters within 12 hours after collection to avoid the loss of biogas generated due to the early fermentation process.

The physicochemical characterization of the anaerobic digester substrate was carried out in terms of moisture (M), total solids (TS), and the potential of hydrogen (pH). Analyses were performed according to the methodology described by APHA (2005), in triplicates. The total solids content was standardized to 11% to obtain higher biogas production efficiency (Franqueto et al., 2020). The data of the physicochemical characteristics of the substrate were subjected to the analysis of variance followed by Tukey's test at a 5% probability level using the free statistical program SISVAR, developed to perform statistical analyses and assist in the planning of experiments through descriptive analysis, analysis of variance, probability calculation, and simple and multiple linear regression, among others (Ferreira, 2011).

The produced biogas volume was calculated as the product of the vertical displacement of the gasometer by its internal cross-sectional area during the period of anaerobic digestion. A 0.6-m graduated ruler was attached to the gasometer to determine the vertical displacement. The biogas volume was corrected for the conditions of 1.0 atm and 20 °C considering the compressibility factor, in which the biogas presents behavior close to the ideal. The expression resulting from the combination of Boyle's and Gay-Lussac's laws was used to correct the biogas volume. The biogas and environmental temperatures were obtained by monitoring them using a thermocouple connected to a millivoltmeter with a ±0.1 °C precision. A thermocouple was inserted into the three-way valve attached to the top of the gasometer to measure the biogas temperature. The average biogas temperature was 26.1 °C for WCH:CM and 26.4 °C for DCH:CM, while the environment reached

26.2 °C. The gasometer was emptied after collecting the temperature and vertical displacement data until reaching zero on the ruler scale attached to it.

The weekly production potential (WPP), in L $kg_{substrate}^{-1}$, was obtained by the ratio between the biogas volume (L) and the amount of substrate added to the anaerobic digesters (1.7 kg) for one week. The accumulated production potential (APP) of biogas (L $kg_{substrate}^{-1}$) was obtained by adding the previous WPP with that obtained in the week of data collection. The APP calculation for each ratio under study considered the data obtained from the confirmation of the existence of methane in the gas generated by the burn test (Silva et al., 2021).

The experimental data of biogas APP as a function of the period of anaerobic digestion were fitted to nonlinear regression models (Silveira et al., 2018), as shown in Table 1.

TABLE 1. Mathematical models fitted to the kinetics of the accumulated biogas production potential.

Model	Equation	
Boltzmann sigmoid	$APP_n = APP_0 + \frac{(APP_{16} - APP_0)}{1 + \exp^{\frac{IP-W}{SC}}} + u_n$	(1)
Gompertz	$APP_n = APP_{16} \times \exp^{-\exp^{(-SC\times(W-IP))}} + u_n$	(2)
Logistic	$APP_n = \frac{APP_{16}}{1 + \exp^{-SC\times(W-IP)}} + u_n$	(3)

In which,

APP_n - accumulated production potential at week n, L $kg_{substrate}^{-1}$;

APP_0 - accumulated production potential at the setup time, L $kg_{substrate}^{-1}$;

APP_{16} - accumulated production potential at week 16, L $kg_{substrate}^{-1}$;

SC - slope of the curve;

IP - inflection point, week;

W - week variable;

u_n - experimental error of the model at week n;

n - 1, …, i,

I - number of measurements of accumulated biogas.

The results of the modeling of biogas APP kinetics and the statistical reports generated by the software allowed obtaining the values of the parameters of the mathematical models Boltzmann sigmoid, Gompertz, and Logistic. The experimental result of the accumulated biogas production potential as a function of the period of anaerobic digestion was fitted to the mathematical models using the R software (R Development Core Team, 2006).

The magnitude of the fitted coefficient of determination (R^2), mean relative error (MRE), standard deviation of the estimate (SE), and mean squared error (MSE) were considered in the selection of the best model that represents the PPP of biogas as a function of the period of anaerobic digestion (Silveira et al., 2018). The R^2 was generated by the R software, while MRE, SE, and MSE were calculated as described in eqs (4), (5) and (6), respectively.

$$MRE = \frac{100}{n} \sum \frac{|Y - \hat{Y}|}{Y} \tag{4}$$

$$SE = \sqrt{\frac{\sum (Y - \hat{Y})^2}{RDF}} \tag{5}$$

$$MSE = \sqrt{\frac{\sum (Y - \hat{Y})^2}{n}} \tag{6}$$

In which,

MRE - mean relative error, %;

SE - standard deviation of the estimate, decimal;

MSE - mean squared error, decimal;

n - number of observed data;

Y - value observed experimentally;

$\hat{Y}$ - value estimated by the models, and

RDF - residual degrees of freedom (n – number of model parameters).

RESULTS AND DISCUSSION

Substrate characterization

As expected, the parameters moisture and total solid between the studied coffee husks and cattle manure ratios showed no statistically significant difference ($p > 0.05$) due to the standardization of TS to 11%. However, the parameter pH differed statistically between coffee husks and cattle manure ratios (Table 2).

TABLE 2. Average values of moisture (M), total solids (TS), and potential of hydrogen (pH) of the substrates.

Parameters	100 CM	100 WCH	25:75 WCH:CM	100 DCH	25:75 DCH:CM	CV (%)	p-value
M (%)	90.07a	88.86a	89.09[a]	88.49 a	89.25 a	0.87	0.2167
TS (%)	11.28a	11.14a	11.42 a	10.77 a	10.61 a	4.86	0.3615
pH	7.04a	5.23b	5.35b	4.58c	5.20b	2.07	0.0000

Means followed by different uppercase letters in the same row differ statistically from each other in the comparison between substrates by Tukey's test at a 5% probability of error.

The moisture values obtained with TS standardization at 11% favor the biodegradability of substrates with a polymeric structure composed of cellulose, hemicellulose, and lignin. Therefore, the water present in ideal amounts in the substrate favors the solvent effect and provides the mobility of the mass of microorganisms through the medium. Inadequate moisture associated with TS higher than 15% results in a rapid accumulation of fatty acids, especially for easily digestible substrates, which impede the activity of methanogenic bacteria, leading to low biogas production. Furthermore, the high biodegradability of cattle manure due to its load of organic and microbial matter makes it very useful for anaerobic co-digestion with recalcitrant substances to improve methane production (Espinal-Arellano et al., 2016; Andriamanohiarisoamanana et al., 2017; Widjaja et al., 2017; Widjaja et al., 2019; Salehiyoun et al., 2019; Franqueto et al., 2020). Andrade et al. (2020) and Franqueto et al. (2020) cited similar TS and M values for AMoD of cattle manure and ACoD of different proportions of food residues and fresh cattle manure.

The average pH value obtained from the AMoD of cattle manure was within the ideal range for the methanogenesis process, with values between 6.0 and 8.0 (Salehiyoun et al., 2019; Andrade et al., 2020; Franqueto et al., 2020). However, the ACoD of bovine manure and coffee husks obtained through dry and wet processes showed low average pH values (Table 2). Probably, the medium acidification may be related to the acidic pH of WCH and DCH as a co-digestant, which can lead to system imbalance, culminating in the inhibition of methanogenic bacteria.

Profile of weekly production potential

The beginning of biogas production occurred from the 8th, 9th, and 7th week for the 100 CM, 25:75 WCH:CM, and 25:75 DCH:CM ratios, respectively. In previous weeks, both AMoD and ACoD produced only gas, with high peaks for the 100 CM and 25:75 DCH:CM ratios (Figure 1). The AMoD from wet coffee husks showed no gas and biogas production over 16 weeks of anaerobic digestion. The absence of methane in the gas produced in the first weeks of the period of anaerobic digestion may be related to the fact that methanogenic bacteria are still inefficient due to the existence of oxygen available in the medium, favoring the action of aerobic and facultative bacteria. It can be attributed to the lag phase, in which bacteria adapt to a new environment (Dahunsi, 2019, Paranhos et al., 2020; Sumardiono et al., 2021).

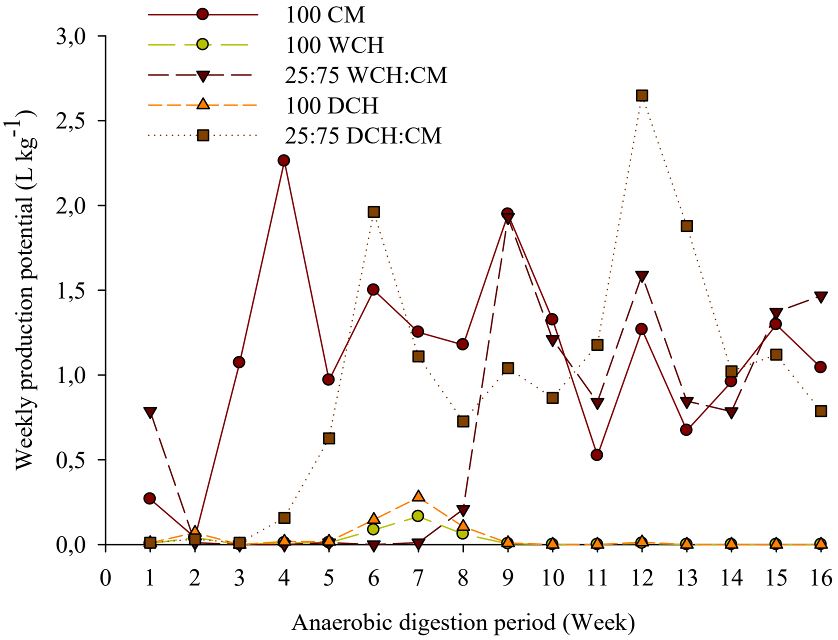

FIGURE 1. Weekly production potential as a function of the period of anaerobic digestion.

Silva et al. (2021) reported initial gas production when assessing the ACoD of fish farming sludge (FFS) and cattle manure (CM). According to these authors, biogas production was detected by the burning test from the third week onwards for all the studied ratios, except for AMoD of fish farming sludge, which presented zero production. Galbiatti et al. (2010) reported the same behavior at the initial stage (up to 71 days) for AMoD of cattle and swine manure (SM) and ACoD of cattle manure and sugarcane bagasse and poultry manure and litter of Napier grass. These results lead to the need to verify whether there is indeed biogas production at the beginning of the anaerobic digestion period to avoid false efficiency results.

ACoD of dried coffee husks and cattle manure presented not only anticipation in biogas production (7th week) but also showed a higher WPP of biogas (2.65 L $kg_{substrate}^{-1}$) in the 12th week. The WPP peak of 1.93 L $kg_{substrate}^{-1}$ for 100 CM and 1.95 L $kg_{substrate}^{-1}$ for 25:75 WCH:CM occurred in the 9th week but was 27% lower than DCH:CM.

The 25:75 DCH:CM ratio also presented the highest APP observed in the 16th week of anaerobic digestion (12.37 L $kg_{substrate}^{-1}$), followed by 100 CM (10.18 L $kg_{substrate}^{-1}$) and 25:75 WCH:CM (10.04 L $kg_{substrate}^{-1}$). In general, the cumulative production potentials for ACoD in this study showed higher values than those reported by Albuquerque & Araújo (2016) for the 50:50 DCH:CM ratio (0.0108 L $kg_{substrate}^{-1}$) and Espinal-Arellano et al. (2016) for 50:50 CM:DS (5.0 L $kg_{substrate}^{-1}$) and 100 CM (11.3 L $kg_{substrate}^{-1}$).

Lignin, the main component of coffee husks, gives lignocellulosic biomass a recalcitrant structure, that is, it creates a protective barrier around carbohydrates (cellulose and hemicellulose), favoring biogas production when digested. In addition, coffee husks have toxic compounds such as caffeine and tannin, which inhibit the action of microorganisms and enzymes, reducing their bio-degradability (Latinwo & Agarry, 2015; Tsapekos et al., 2017; Dahunsi, 2019).

Cattle manure assists in the dilution of some concentrated organic components of the lignocellulosic biomass (Neshat et al., 2017). Also, cattle manure has a high amount of microorganisms favorable to biogas production, but a low amount of cellulose, lignocellulose, and other important organic compounds for microbial growth and, consequently, methane production. The importance of achieving synergy between different co-digestants consists of researching the addition of lignocellulosic biomass in an ideal amount to increase production yield and biogas in the ACoD process. According to Widjaja et al. (2017), sugarcane, rice straw, and corn are potential lignocellulosic biomasses to increase methane production during ACoD with animal manure. According to Franqueto et al. (2020), the importance of adding banana peel as a co-digestant of cattle manure consists of providing sugar and digestible compounds, favoring the reduction of the lag phase and the period of anaerobic digestion. Furthermore, Tsapekos et al. (2017) demonstrated that anaerobic co-digestion of lignocellulosic biomass and animal manure can increase the bioenergy production of a full-scale biogas plant in a range of 12 to 23%.

The greater potential for biogas production by ACoD from dry coffee husks and cattle manure may be due to the adopted mechanical pre-treatment. Grinding dry coffee husks reduced the size of particles and, consequently, increased their surface area, allowing bacteria and enzymes to access plant structures of interest for anaerobic digestion, thus optimizing biogas production (Neshat et al., 2017). Mechanical pre-treatment leads to the breakdown of structural materials in the lignocellulosic biomass, which reflects in a reduction of the lag phase during the hydrolysis step of anaerobic digestion, increased biodegradability, and, consequently, optimization in biogas production of up to 22% (Dahunsi, 2019) and 20% (Tsapekos et al., 2017).

Anaerobic co-digestion of wet coffee husks and cattle manure without pre-treatment may have limited the anaerobic digestion rate and hence methane production, affecting bacterial growth due to the presence of toxic compounds (Widjaja et al., 2017). There are several pre-treatments available for use in lignocellulosic biomass, reducing the period of anaerobic digestion over the hydrolysis step of the material and optimizing biogas production (Widjaja et al., 2019; Sumardiono et al., 2021).

Thus, evaluating the conditions that favor the synergism between co-digestants is essential to optimize biogas production. In addition, obtaining a quality and stable digestate by studying the most appropriate mixing ratio for the chemical and physical composition of the materials and operating conditions of the reactors that influence the synergistic effect on the co-digested substrates is important (Andriamanohiarisoamanana et al., 2017; Franqueto et al., 2020).

Mathematical modeling of the accumulated biogas production potential

All the mathematical models fitted to the experimental data of APP of biogas presented a coefficient of determination higher than 98% for the studied relations (Table 3). The R^2 values found for the Boltzmann sigmoid (Equation 1), Gompertz (Equation 2), and Logistic (Equation 3) models are within the range reported by Latinwo & Agarry (2015), Franqueto et al. (2020), and Silva et al. (2021). However, only R^2 is not enough to determine the best model that represents the phenomenon. In addition to the parameter coefficient of determination, MRE values lower than 10% and low MSE and SE values indicate satisfactorily fitted models (Table 3). The parameter MRE evaluates the deviation of the curve, which was estimated by the model relative to the observed values, while SE allows evaluating the effectiveness of the adjustment of the observed values and the models so that the lower this value, the more efficient this fitting (Jordan et al., 2020).

TABLE 3. Coefficient of determination (R^2), mean relative error (MRE), standard deviation of the estimate (SE), and mean squared error (MSE) for fitting the kinetic models of the accumulated biogas production potential at the 100 CM, 25:75 DCH:CM, and 25:75 WCH:CM ratios.

Ratio	Model	R^2 (%)	MRE (%)	SE (decimal)	MSE (decimal)
100 CM	Boltzmann sigmoid	0.9839	5.92	0.52	0.45
	Gompertz	0.9895	5.05	0.41	0.37
	Logistic	0.9810	13.92	1.25	1.13
25:75 WCH:CM	Boltzmann sigmoid	0.9861	3.87	0.46	0.40
	Gompertz	0.9911	3.40	0.36	0.33
	Logistic	0.9841	4.33	0.82	0.74
25:75 DCH:CM	Boltzmann sigmoid	0.9952	6.00	0.34	0.31
	Gompertz	0.9965	4.51	0.30	0.26
	Logistic	0.9962	4.42	0.52	0.47

Gompertz (Equation 2) best represented the biogas APP kinetics for all studied relationships among the analyzed models. This model showed an R2 value above 98% and lower MRE, SE, and MSE values (Table 3). Silva et al. (2021) selected the Boltzmann sigmoid model for 75:25 and 0:100 FFS:CM and the Gompertz model for 50:50 and 25:75 FFS:CM to estimate cumulative biogas production kinetics curves based on higher R^2 values, lower than 10% of MRE, and lower than SE and MSE. The Gompertz model was selected to represent the ACoD of cattle manure and banana peel (Franqueto et al., 2020), as well as poultry manure and rice straw, corn cob, peanut shell, sawdust, coffee husk, and sugarcane (Paranhos et al., 2020). Latinwo & Agarry (2015) evaluated the exponential, logistic, and Gompertz models to represent the accumulated biogas production potential as a function of the anaerobic digestion time of AMoD and ACoD of cattle manure and banana peel. These authors reported that the logistic and Gompertz models can be used with good accuracy to simulate biogas production from AMoD of cattle manure and ACoD of banana peel. However, R^2 was the only adopted statistical parameter, demonstrating the importance of selecting the model based on other parameters. The parameter APP_{16} estimated by the Gompertz model (Equation 2) obtained a superior result for 25:75 DCH:CM among the other ratios (Table 4). According to Silveira et al. (2018), this parameter is more relevant in practical terms, as it allows sizing anaerobic digesters and estimating the amount of energy produced and the cost and financial return of the system when evaluating the maximum volume of accumulated biogas.

The parameter IP of the Gompertz model (Equation 2) estimates the time in which the APP of biogas occurs, that is, around 37% of the total produced (Silveira et al., 2018). Thus, the APP of the 100 CM, 25:75 WCH:CM, and 25:75 DCH:CM ratios reached 4.33, 4.59, and 6.22 L $kg_{substrate}^{-1}$ for IPs of 10.4, 11.4, and 11.3 weeks, respectively. The 25:75 DCH:CM ratio showed a higher value of 37% of APP_{16} and a lower value of INC compared to AMoD and ACoD with wet coffee husks. Furthermore, AMoD anticipated IP by one week (Table 4).

TABLE 4. Statistical parameters of biogas production potential at week 16 (APP_{16}), slope of the curve (SC), and inflection point (IP) estimated by the Gompertz model.

Relation	APP_{16} (L $kg_{substrate}^{-1}$)	SC	IP (Week)
100 CM	11.7	0.30	10.4
25:75 WCH:CM	12.4	0.29	11.4
25:75 DCH:CM	16.8	0.26	11.3

Furthermore, the inflection point can be analyzed from the perspective of the change in the concavity of the curve, indicating the moment of change in performance and prediction of a turning point in the potential of accumulated biogas production as a function of the period of anaerobic digestion. This trend can be seen in the inversion of the concavity of the curve (Figure 2). Associated with the inflection point, the higher the magnitude of the slope, the steeper the curve and the higher the rate of change. In other words, the parameter SC refers to the increase in the biogas accumulation rate in IP (Silveira et al., 2018).

The concavity of the curve facing upwards shown in Figure 2 shows an increase in APP up to the respective IP of each ratio under study, followed by a deceleration in biogas production. This moment indicates the trend of APP to reach constant biogas production, being more prominent in AMoD and 25:75 WCH:CM. Linked to this fact, the less steep slope of the curve presented by the 25:75 DCH:CM ratio characterizes slowness in the trend to reach constant biogas production, resulting in longer anaerobic digestion times and, possibly, biogas production (Table 4 and Figure 2).

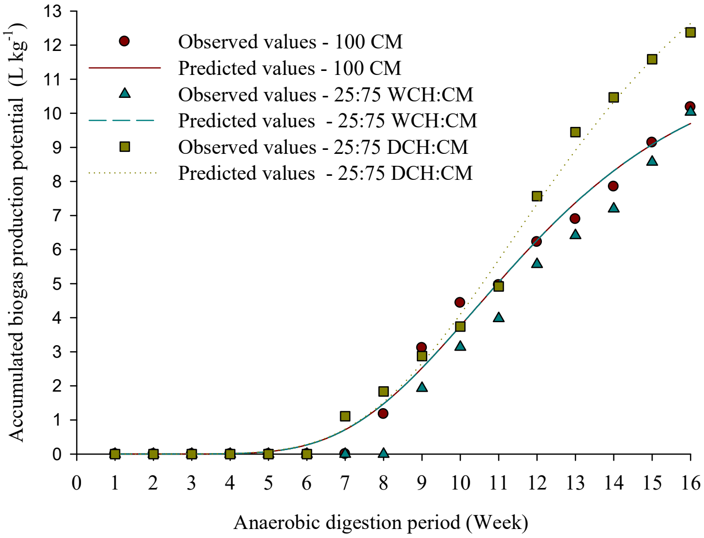

FIGURE 2. Kinetics of the accumulated biogas production potential (L $kg_{substrate}^{-1}$) as a function of the anaerobic digestion period (week) using the Gompertz model.

The accumulated biogas production potential showed no difference in the first five weeks for all the studied relationships (Figure 2). This time interval, considered the lag phase, can confirm what is reported in Figure 1 regarding the absence of biogas production at the beginning of the AD process. Studies aimed at evaluating ACoD between coffee pulp and chicken feathers (Sumardiono et al., 2021) and poultry manure and rice straw, corn cobs, peanut husks, sawdust, coffee husks, and sugarcane bagasse (Paranhos et al., 2020) have shown the same initial behavior.

A satisfactory fit of the Gompertz model was observed in the description of the accumulated biogas production potential as a function of the period of anaerobic digestion, as the observed values are close to those predicted (Figure 3). Likewise, Sumardiono et al. (2021) reported similar values of experimental and estimated accumulated biogas production potential, confirming the accuracy of the referred model.

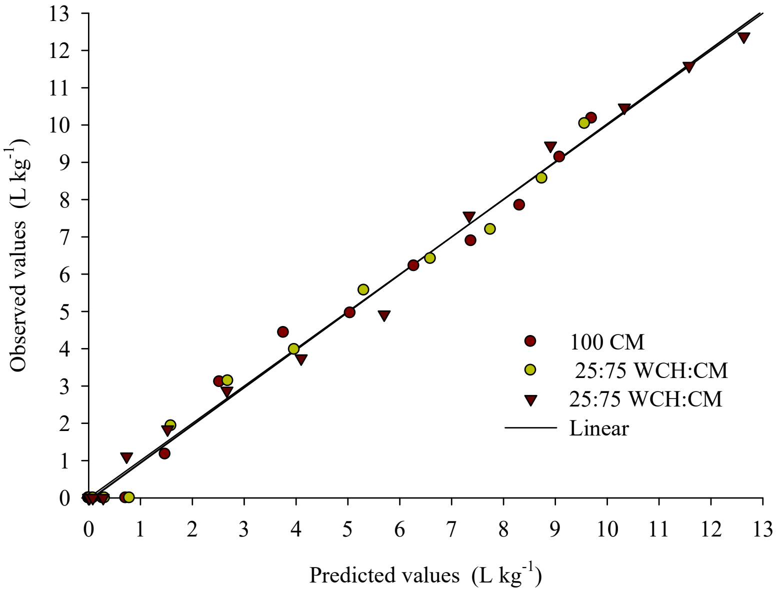

FIGURE 3. Experimental and estimated values of accumulated production potential by the Gompertz model for 100 CM, 25:75 WCH:CM, and 25:75 DCH:CM.

CONCLUSIONS

Coffee husk can be a potential co-digestant with cattle manure to generate biogas, with mechanical pre-treatment being a means of optimizing the process. A better fit of the observed data was obtained by the Gompertz model, with 25:75 DCH:CM showing the highest biogas production potential.

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