

CHARACTERISTICS OF PRODUCTS FROM ANAEROBIC DIGESTION OF CASSAVA WASTE FOR BIOGAS PRODUCTION

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ABSTRACT

This paper examines the characteristics of products from anaerobic digestion of cassava waste with and without starter culture. The anaerobic digestion experiment was conducted using a 20 litre anaerobic digester at mesophilic temperature for 41-day hydraulic retention time. In addition to experimental yields, maximum theoretical biogas yield and biomethane potential were estimated using Buswell and Neave model, while the Hashimoto model was used to determine the kinetic parameters. Digestate specie distribution was assessed using elemental analysis. The result of the study showed biogas yields of 0.1-0.25m³/kgVS_{added} for digester1 (D1), and 0.1-2.5m³/kgVS_{added} for digester2 (D2), with an average yield of ~0.2 and 1.0m³/kgVS_{added} for respective digesters. About 0.8m³/kgVS_{added} was the estimated maximum theoretical biogas yield, and 1.32m³/kgVS_{added} for CH₄. The percentage of CH₄ in produced biogas was approximately 60%. The correlation coefficient (D2) was obtained for the decay constant (k). The elemental composition of digestates substantially reduce when compared with that of initial feedstock. About 40–68% C, 36.57% H₂, 21.4–28.6% S and up to 94% N was distributed to biogas phase, the remnant in the digestate.

Keywords: Agricultural waste, Anaerobic digestion, Biogas, Biomass–Bioenergy, Cassava waste.

INTRODUCTION

With dwindling fossil fuel sources and growing concerns about climate change, effective waste disposal techniques and pollution control, pursuing an alternative and renewable source of energy has become important.

Interestingly, most of these developing tropical countries are highly dependent on agriculture, of which cassava is one of the major food crop, especially in Africa (Kemausuor et al. 2015). Approximately 60% of cassava products are used for human consumption, and also for animal and extraction of starch (Pandey et al. 2000; Veiga et al. 2016). In 2012, cassava product was reported to account for about 260MT globally. However, during processing of cassava from harvesting stage to finished products, large quantities of polluting organic wastes (peel and wastewater) are generated and discharged into the environment. Due to limited supply of energy from national electric grid to the locals in these countries, they are highly dependent on wood and charcoal as form of energy for processing of the harvested cassava.

Apparently, such activities lead to deforestation, erosion, loss of biodiversity and pollution effects such as release of particulate and smoke irritation to eyes and difficulties in breathing (Duku et al. 2011).

Cassava waste could be of great interest as it contains highly exploitable energy, availability, and have relatively low market price incentive for cassava roots (Pattiya, 2011). On dry basis, cassava peel contains 2.20% lignin, 18.47% cellulose, 6% hemicellulose (Tovar et al. 2015). Therefore, organic waste from large areas of cassava field could be a source of renewable energy, and if the investment is economically viable, surplus amount of energy can be sold to improve profits. In last decade, worldwide cassava production had increased by 30% (FAO, 2012), thus bolstering the potentials of producing energy from cassava waste (Veiga et al. 2016). Cassava waste has been reported as one of the most promising agricultural wastes for biogas production (Thomsen et al. 2014).

As a result, there has been increasing research on developing technologies for conversion of the unutilized cassava waste to

produce energy required for either drying and or mechanical press unit during processing of cassava. Anaerobic digestion is one of the techniques for the conversion of organic waste materials. Biodegradation of organic matter through anaerobic digestion is a well-known natural process, which is performed by specific microorganisms, that transform degraded organic matter to produce biogas, and stabilized semi solid residue usually referred to as digestate (Roati et al. 2012). Biogas is an eco-friendly alternative source of energy, which contains 50–70% (v/v) methane (CH₄), 30–40% (v/v) carbon dioxide (CO₂) and trace amounts of hydrogen sulphide (H₂S) and ammonia (NH₃) (Manilalet al. 1990; Kemausuor et al. 2015). The digestate contains essential nutrients for plant growth, hence could be applied as biofertiliser.

A review of the scientific literature showed limited study on anaerobic digestion of cassava waste for biogas production. The few scientific studies were mostly on the feasibility of CH₄ production, either using cassava waste as a single substrate or co-digested with other organic waste. Aso et al. (2019) investigated anaerobic digestion of cassava peel using a batch mode anaerobic digester. They reported biogas yield including percentages of methane and mass balance for processing of cassava peel. However, the study performed individual AD of separated cassava peel of periderm and cortex. It is envisaged additional cost and time would be incurred for separation. Pattiya, (2011) investigation was on the characteristics of cassava residues (stalk and rhizome) using proximate and ultimate analysis. Thomsen et al. (2014) investigated theoretical analysis of biomethane production using the Boswells' formula and the stoichiometry of chemical oxygen demand for varieties of agricultural waste including cassava peel.

In 1992, Cuzin et al. investigated methane potential of cassava peels using a plug flow anaerobic digester. They reported 85% theoretical of biogas yield, and estimates on amount of energy for drying. Other research studies were on biomethane production from codigestion of cassava peel with other organic waste (Ezekoye et al. 2011; Asikong et al. 2012; Oparaku et al. 2013). This aforementioned studies have demonstrated the feasibility of

producing biogas from cassava waste. However, there are limited data on methanogenic pressure build-up inside digesters and elemental species distribution during anaerobic digestion. In addition, there is limited data on the maximum methane yield achievable from AD of cassava waste (Ahou et al. 2019). Therefore, the focus of this study is on the characteristics of products from anaerobic digestion of cassava waste, in addition to elucidation of pressure build-up during digestion. This is necessary to provide additional knowledge for further understanding of biodegradation of cassava waste for biogas production. As such data could be vital to the scientific community and industrialist for setting up a biogas generation plant.

MATERIALS AND METHOD

Materials

Cassava peel used for this study was collected from local farm in Oleh (5.4589°N, 6.2031°E) Delta State, Nigeria. Anaerobic digestion experiment was conducted using 20L fabricated digester. The digester had three openings at the top; one of the openings was used as an inlet for addition of substrate. The second one functioned as an outlet for gas collection, while the third was fitted with pressure gauge. A schematic view of the anaerobic digester parts and its assembly is shown in Figure 1.

Starter culture was prepared using 3kg of cow dung and 9L of water, forming a slurry. The slurry was fed into the digester, sealed, and allowed to stand for 14day HRT. After allowed stand time, the digester was opened to obtain the effluent (wastewater), which was filtered in order to remove particles. The filtrate obtained was used as the starter culture.

Anaerobic digestion procedure

Two digesters were used for the anaerobic digestion experiment. One of the digester “(D1)” was loaded with 2kg of cassava peel (3mm), 3L water and 3L starter culture, while the second digester “(D2)” was fed with 2kg of cassava peel and 6L of water.

The anaerobic digestion experiment was conducted over 41days hydraulic retention time (HRT). The digesters were agitated by manual shaking for about 2minutes daily during the

entire HRT (Labatut et al. 2011). This is in order to facilitate contact between bacteria and substrates, to avoid accumulation of toxic substances, fatty acids, and to enhance digestion (Eboibi et al. 2015). The daily biogas production

was collected on a two-day interval basis using water displacement method. After completion of predefined HRT, the digestion was stopped and the digestate were removed.

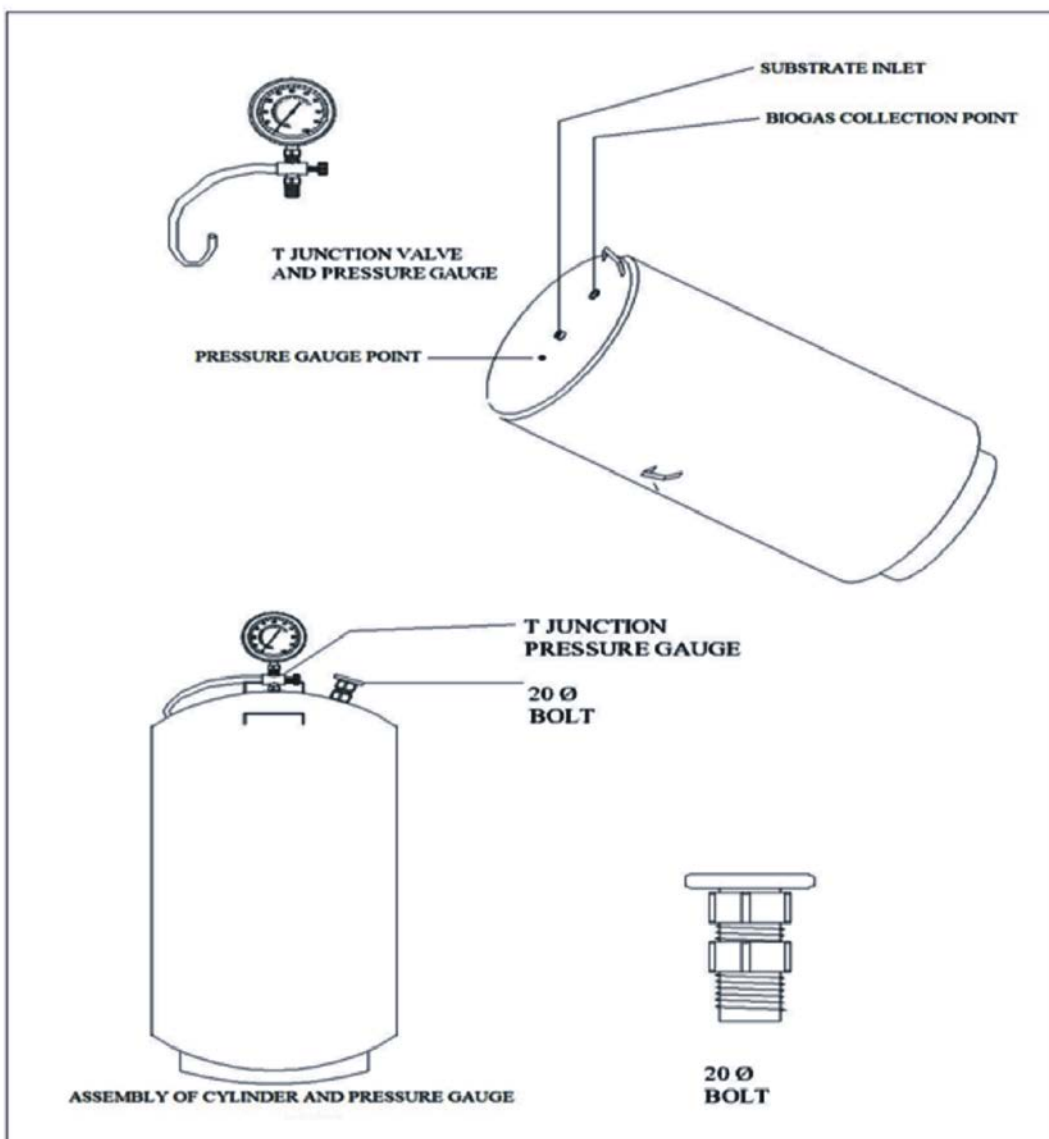


Figure 1: Schematic view of anaerobic digester.

Analytical Methods:

The proximate analysis was determined in accordance to methods as explained in previous studies (Polematidis et al. 2008; Aso et al. 2019).

The composition of elemental carbon (C), hydrogen (H), nitrogen (N), and sulfur (S) of cassava peel, and the anaerobic digestates determined in accordance to the ASTM-D-5239 method using VarioEL III Elemental Analyser system, GmbH. The oxygen (O) content was obtained by difference (100% - sum (CHNS)).

The higher heating values (HHV, MJ/kg) were determined by substituting the CHNSO

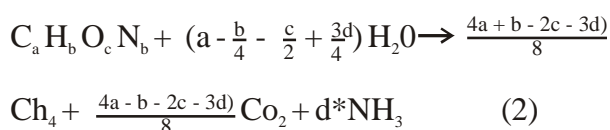
data into a unified correlation equation (Eq. (1)) proposed by Channiwala and Parikh, (2012).

$$HHV \frac{MJ}{kg} = 0.3491C + 1.1783H + 0.1005S + 0.1034O - 0.151N - 0.0211A \quad (1)$$

where: C, H, N, S, and O represents the mass of carbon, hydrogen, nitrogen, Sulphur, and oxygen on a dry weight basis.

Buswell and Neave, (1930) proposed formula (Eq. 2), developed from stoichiometric balance between the amount of organic matter (expressed as C_a H_b O_c N_b) to be biodegraded and

the gaseous product resulting from its anaerobic biodegradation was applied to estimate methane yield.



The maximum theoretical biogas and methane yields (also known as biochemical methane potential) were estimated using Eq. (3) and Eq. (4), respectively, which was obtained from the general balance of Eq. (2) (Roati et al. 2012).

$$Biogas (\frac{m^3}{kgvs}) = \frac{22.415a}{12a + b + 16c + 14d} \quad (3)$$

$$CH_4 (\frac{m^3}{kgvs}) = \frac{4a + b - 2c - 3d}{12a + b + 16c + 14d} * 22.415 \quad (4)$$

The percentage of methane production was obtained using Eq. (5)

$$CH_4 \% = \frac{CH_4 \frac{m^3}{kgvs}}{Biogas \frac{m^3}{kgvs}} \quad (5)$$

The kinetics of the methane yield was determined using a first order kinetic equation (Eq. 6) proposed by (Hashimoto, 1989).

$$B = B_o (1 - \exp^{-kt}) \quad (6)$$

where *B*, *B_o*, *k*, *t*, represents the cumulative methane yield, maximum methane yield, first order decay constant, and hydraulic retention time, respectively.

RESULTS AND DISCUSSION

Feedstock analysis

The proximate and elemental composition of the feedstock (cassava peel) is presented in Table 1. The cassava peel has a moisture content of 6.4%, 89.5% volatile solids, and about 3.2% ash content. Also, it comprises 54.33% carbon, 6.84% hydrogen, 0.90% nitrogen, ~0.1% sulfur content and 37.83% oxygen content, with HHV of 22.92MJ/kg. As shown in Table 1, the elemental and proximate data are within the range of previous research investigations. The carbon content was found to be more than 42.91 to 44.6% carbon content reported by Veiga et al. (2016) but close to 51.59% reported by Pattiya, (2011). The hydrogen content of 6.52% to 6.69%, 0.8% to 1.27% nitrogen and 0.1-0.2 % sulfur content are very well with the range of respective elements found in the present study. Moreover, there was a marginal difference between the oxygen content of present study to those of previous reports, which corresponded with the little variation in HHVs of 22.92MJ/kg of present study. HHV of 21.46MJ/kg was reported by Pattiya, (2011), while Tovar et al. (2015) reported 12.78MJ/kg. About 16.59-23.67MJ/kg HHV was reported by Veiga et al. (2016). The difference in HHV could be due to differences in oxygen content, as the higher the oxygen content, the lower the HHV, vice-versa. The volatile solids of 77.77%, and 85% to 87% were found close to 89.5% of present study. Also, the ash (3.2%) and moisture (6.4%) contents were in within range of those reported in scientific literature, as shown in Table 1.

Table 1. Properties of cassava waste

Analysis	Present study Proximate analysis	Pattiya, (2011)	Tovar et al. (2015)	Veiga et al. (2016)
Moisture content	6.4	8.31%	NR	9.55 to 9.73
Ash	3.2	4.05%	NR	2.13 to 3.3
VS	89.5	77.77	NR	85 to 87
	Elemental analysis			
C	54.33	51.59	39.96	42.91 to 44.6
H	6.84	6.69	3.98	6.52 to 6.58
N	0.90	1.27	0.26	0.8 to 1.01
S	0.1	<0.1	0.12	<0.2
O	37.83	40.45	55.68 [^]	48.08 to 49.97
HHV, MJ/kg	22.92	21.46*	12.78*	16.59 to 23.67

[^]Estimated by difference. *Estimated with Channiwala and Parikh, (2012) unified correlation equation

Biogas yield and pressure build-up

The biogas yield obtained from AD of cassava peel from Digester 1 and Digester 2 (without starter culture) is shown in Figure 2. As shown in Figure 2, there was a wide difference in yield of biogas, despite observing the digestion under same condition except with and without starter culture. Biogas yield from Digester 2 was between 0.1 and 2.52 m³/kgVS_{added} with a maximum yield of 2.52 m³/kgVS_{added} obtained at 17 day HRT, while minimum of 0.025 m³/kgVS_{added} was achieved at 41 day HRT. For D2, biogas yield was in the range of 0.1-0.35 m³/kgVS_{added}, with maximum yield of 0.327 m³/kgVS_{added} at 23 day HRT, and minimum of 0.08 m³/kgVS_{added} at 15 day HRT. The trend in biogas yield depicts microorganisms' growth

phase comprising of lag phase, stationary to dead phase as reported in previous study (Eboibi et al. 2015). During AD, there is increase growth of syntrophic bacteria such as Syntrophomonas and Syntrophorhabdus, which are capable to degrade large range of different types of organics (Usman et al. 2020). The average yield for D1 and D2 were ~0.2 m³/kgVS_{added} and 1.0 m³/kgVS_{added}, respectively. The variation in biogas yields for D1 and D2 suggest the starter culture could have led to inhibitory influence, thereby reducing the biodegradability in D1 compared to D2. Rapid acidification due to high biodegradable sugars and low nitrogen content and release of cyanide has been reported to cause early inhibitory effects and toxic to methanogenic bacteria during anaerobic digestion of cassava peel (Cuzin et al. 1990; Ahuo et al. 2019).

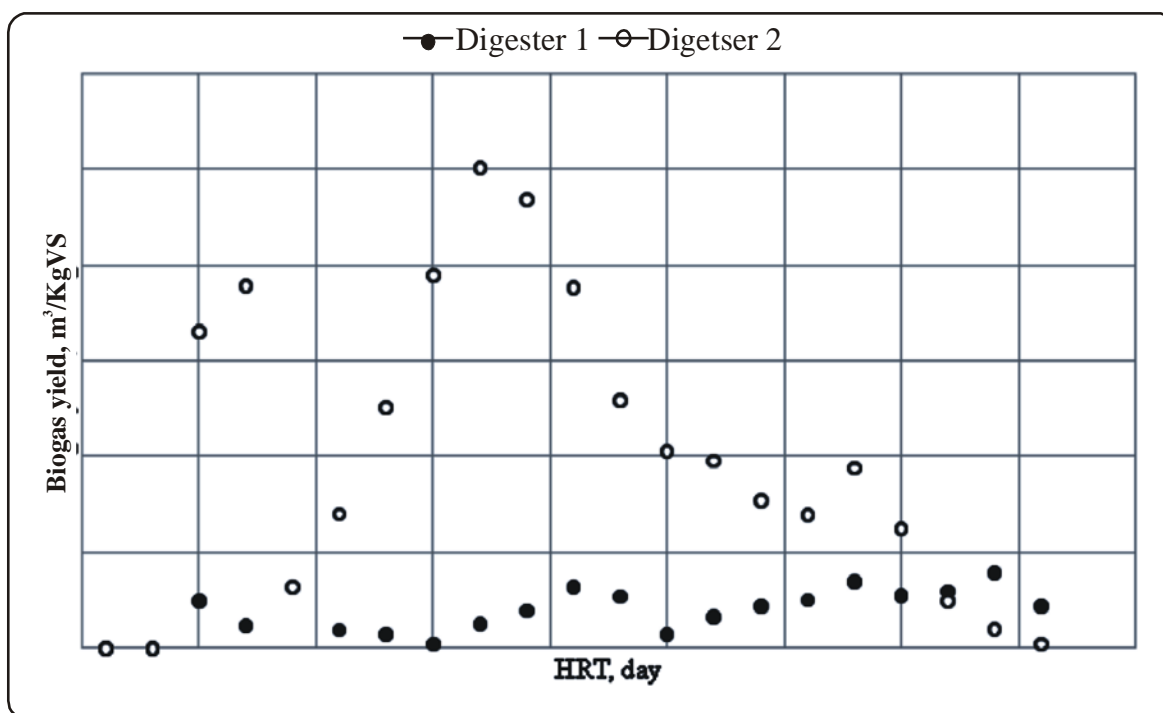


Figure 2: Biogas yield from anaerobic digestion of cassava peel.

Furthermore, the pressure build-up inside the digesters are presented in Figure 3. As illustrated in the figure, pressure build-up in D1 was lower when compared to that of D2. These differences in pressure corresponded with biogas yields as mentioned earlier. Due to perceived inhibitory effects, methanogenic *Archaeobacteria* could also have been suppressed, reducing biological pressure production. About 0.08-0.7Psi and 0.08-3.7Psi pressure build-up was

observed for D1 and D2, respectively. The maximum pressure was obtained at 17 day HRT for D2, while it was at 23 day HRT for D1, which also tallied with the HRT observed for maximum yields in biogas. Also, the pressure build-up inside both digesters were of similar trend as observed for biogas yields. This finding therefore suggests pressure build-up inside digesters could be a function of biogas yield.

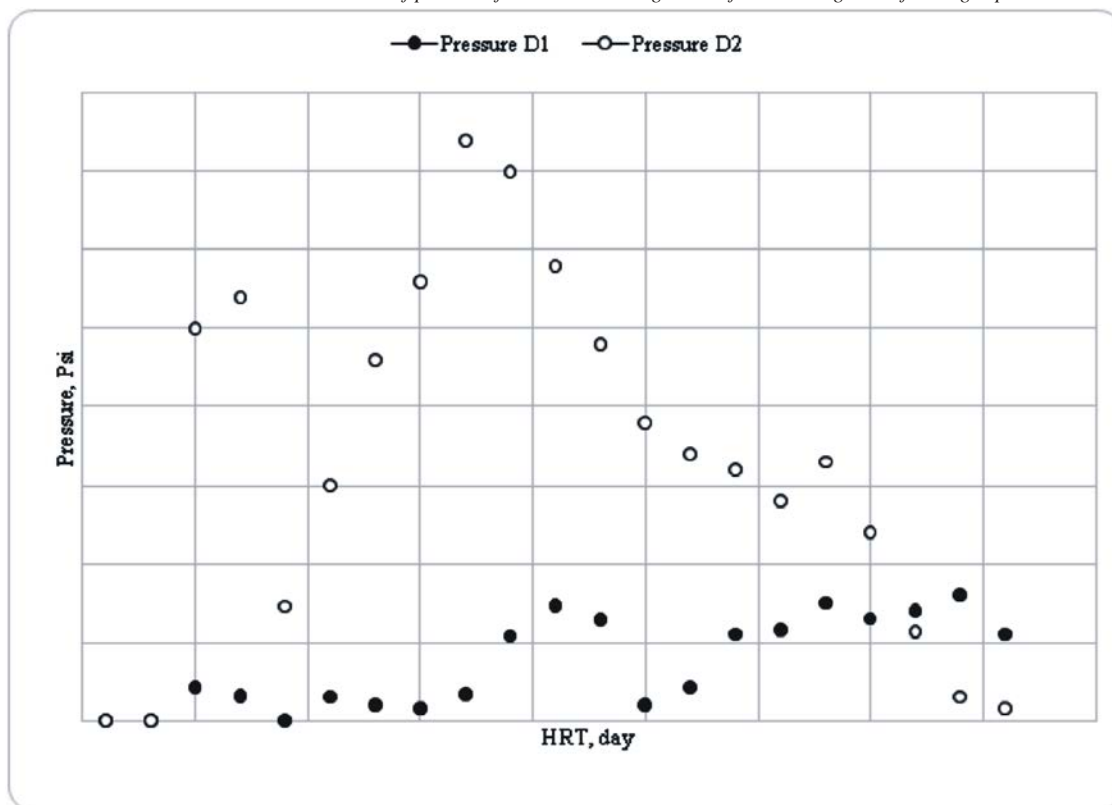


Figure 3: Pressure build-up from anaerobic digestion of cassava peel

Based on the biogas and biochemical methane potential analysis, the maximum methane (CH₄) yield from anaerobic digestion of cassava peel was 60%, which agrees and is within the range of previous reports on anaerobic digestion of cassava waste. Earlier, Aso et al. (2019) reported 54% as mean CH₄ yield from the biogasification of cassava residue, while 58%, 57% and 59% CH₄ was obtained by Cuzin et al. (1990); Ahou et al. (2019) and Manilal et al. (1990), respectively, for anaerobic digestion of cassava waste.

This study has shown that anaerobic digestion of cassava waste produces biogas containing up to 60% CH₄, which is an important energetic potential. This could be of value in improving the economies of farmers involved in cassava processing. Moreover, the amount of methane could be improved up to 90%, reducing CO₂ content, with the use of pressurised batch reactor (Lindeboom et al. 2011; Lemmer et al. 2017).

The biomethane methane potential for AD of cassava peel was found to be 0.8m³/kgVS_{added}, while maximum theoretical yield in biogas yield was 1.32m³/kgVS_{added}. In 2012, Roati *et al.*

reported 0.72-1.61m³/kgVS_{added} biogas potential with 0.42-0.56% CH₄ for processing cassava wastewater. The theoretical biogas yield of 1.32m³/kgVS_{added} was found to be within the range of previous study (Roati et al., 2012) but higher, but close, when compared to the average experimental biogas yield of ~1.0m³/kgVS_{added}. This variation was expected as the Buswell's formula has been previously shown to overestimate yields, which could be majorly due to unaccounted microbial maintenance and biodegradability of substrate. Nevertheless, the application of stoichiometric method and biodegradability data was able to give reasonable estimation of specific methane yields (Labatut et al. 2011).

Kinetic parameters

The cumulative methane yields are presented in Figure 4. As shown in Figure 4, the correlation coefficient (R²) was 0.91 for D1 and 0.96 for D2, while the first order decay constant (*k*) were 0.06 for D1 and 0.36 for D2. There are limited information on the kinetics parameter of cassava peel in scientific literature, however, the obtained data in present study was compared

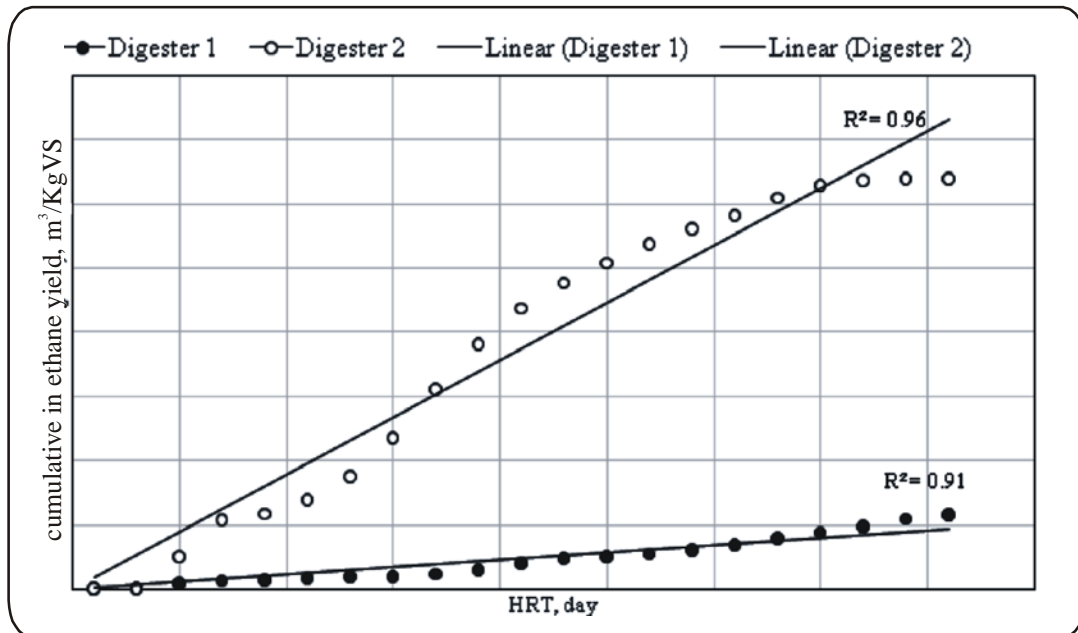


Figure 4: Cumulative methane yield from anaerobic digestion of cassava peel

The obtained R^2 and K values were found in good agreement with previously reported data on AD of organic waste, as shown in Table 2. Labatut et al. (2011) reported R^2 of 0.93 using Buswells' formula and 0.91 for McCarty's model.

Fleck et al. (2017) obtained R^2 of 0.94 and 0.80 for anaerobic digestion of cassava process wastewater. Li et al. (2013) reported R^2 of 0.980 and 0.964, and K of 0.15 and 0.09, respectively, for rice straw and wheat straw.

Table 2: kinetic parameters for anaerobic digestion of cassava peel

Organic waste	R^2		K		Reference
	D1	D2	D1	D2	
Cassava peel	0.91	0.96	0.06	0.36	Present study
Food waste	0.86	-0.99	0.056	-0.364	Browne and Murphy, (2013)
Cassava wastewater	0.94,	0.80	NR		Fleck et al. (2017)
Organic substrates	0.91,	0.93	NR		Labatut et al. (2011)
Rice straw	0.980		0.15		Li et al. (2013)
Wheat straw	0.964		0.09		Li et al. (2013)

Elemental composition of digestates

The elemental composition (CHNSO) of digestates obtained from D1 and D2, and compared with that of feedstock is presented in Figure 5. Figure 5 showed that the carbon content reduced from 54.33%w/w (initial feedstock) to 32.78%w/w and 17.31%w/w for D1 and D2 digestates, respectively. These elements are essential in microbial growth during anaerobic digestion, which led to substantial loss of about 94% nitrogen from the digesters, and 36.5%, and 70.1% hydrogen, 21.4% and 28.6% sulfur for D1 and D2, respectively. Apparently, the oxygen content

would reduce, due to biodegradability of the substrates, which had substantial impact on the digestate HHVs. The HHV of digestate reduced from 22.9MJ/kg to 10.1MJ/kg for D1 and 2.3MJ/kg for D2, which accounted for 56.10% (for D1) and 89.80% (for D2) usage by the substrate. This finding reaffirms the better performance of digester 2 during anaerobic digestion. This study has provided additional information improving the database for anaerobic digestion conversion efficiency of cassava waste, which could be useful in the design and applications for biogas production.

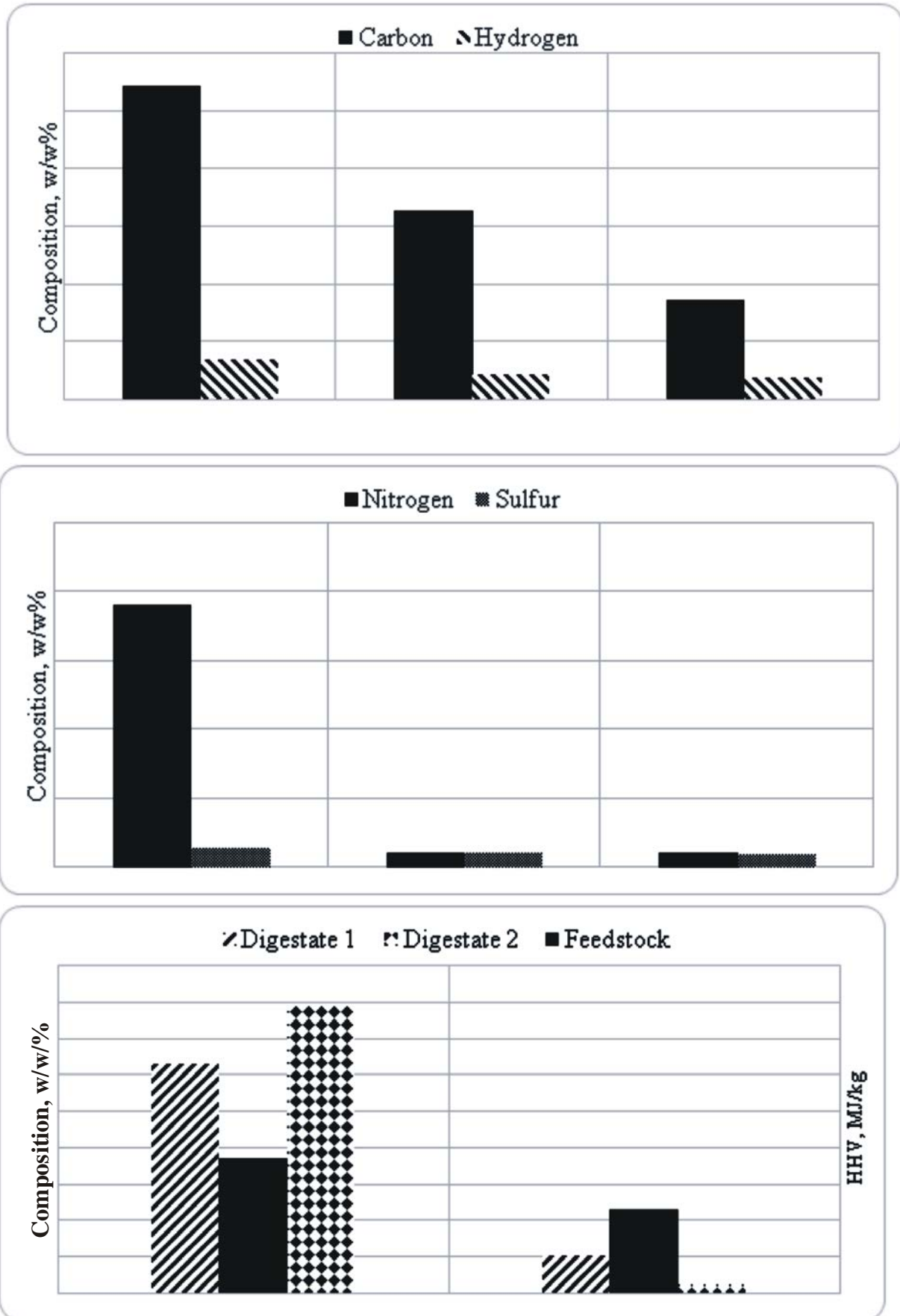


Figure 5: Elemental composition of digestate from anaerobic digestion of cassava peel

CONCLUSION

Characteristics of product from anaerobic digestion of cassava waste were evaluated in this study. Experimental yields and theoretical estimates were also compared. The study showed the feasibility of producing biogas from cassava waste, with substantial impact of starter culture on products yield and properties. An average biogas yield of 0.2 and 1.0m³/kgVS_{added} was produced, while 1.32 m³/kgVS_{added} was estimated maximum theoretical yield, with 60%CH₄ content. A further study on influence of starter culture at different ratios on AD is necessary. The elemental composition of the digestates was found to substantially reduce when compared with that of initial feedstock. About 40–68%C, 36.57%H₂, 21.4–28.6%S and up to 94%N was distributed to biogas phase, the remnant in the digestate.

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