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## Comparative Anaerobic Co-Digestion Effects of Some Agricultural Biomass on Their Digestates Biochemical Properties

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Page | 3929

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### ABSTRACT

The huge agro-industrial biomass wastes had engendered the need for appropriate treatment technology, which could be deployed to sustainably manage and convert them to useful by-products. Consequently, the comparative anaerobic co-digestion effects of some agricultural biomass on their digestates biochemical properties were conducted. Twelve (12) replicates slurries from four mixing ratios of maize cob, poultry droppings and cow dung (1:0, 1:0, 1:0 and 1:1:1) as treatments T<sub>A</sub>, T<sub>B</sub>, T<sub>C</sub> and T<sub>D</sub> respectively, were separately digested in 13.6L locally fabricated batch-digester reactors, for eight weeks. Proximate and amino acids constituents were evaluated by standard procedure prior to and at post anaerobic digestion (AD). The biogas yields followed the sequence of T<sub>D</sub> (2200.7ml/kg) > T<sub>B</sub> (2197.9ml/kg) > T<sub>C</sub> (2079.0ml/kg) > T<sub>A</sub> (1713.2ml/kg), showing co-substrate effects. Proximate assay depicted a decrease in crude lipid across the treatments, with T<sub>C</sub> (86.82%) and T<sub>D</sub> (64.66%) as highest and lowest values. Crude fiber and nitrogen free extract had similar observation, apart from T<sub>B</sub> and T<sub>C</sub> with increased values. Percentage moisture and percentage ash contents increased across treatments. Carbon - Nitrogen ratio reduction (C/N<sub>Reduction</sub>) was in the range of 12.94 - 85.79%. The Percentage chemical oxygen demand reduction (CODR), followed the order of T<sub>A</sub> (46.81%) > T<sub>B</sub> (34.15) > T<sub>C</sub> (25.81%) > T<sub>D</sub> (8.00%). There was increased histidine, glycine, cystine, methionine, total non-essential amino acids (TNEAA) and total aromatic amino acids (TArAA), with decrease in aspartic acids and serine. Percentage arginine, threonine, glutamic acid, proline, alanine, isoleucine, tyrosine, total amino acids (TAA) and total essential amino acid (TEAA) decreased only in T<sub>B</sub>. While, only T<sub>A</sub> had Percentage increased lysine (25.00%), valine (40.98%) and TArAA (6.13%), with phenylalanine unaffected (0.00%), Percentage leucine of T<sub>B</sub> (60.14%) and T<sub>D</sub> (23.08%) were reduced after AD. The process had revealed the alternative waste management, energy options, and useful industrial by-products for agro-allied industries.

**Keywords:** Co-Digestion, Biogas, Maize Cob, Poultry Droppings, cow dung proximate analysis, amino acids Effluents

### Introduction

The increase of physical volume and biomass incidental upon agricultural and biomass wastes from industries was occasioned by exponential rise in population and industrialization. These against the back drop of rising demand for and

fluctuating costs of fossil fuel, have engendered the need for portable, affordable, environmentally friendly and sustainable fuels (Chomini *et al.*, 2019a). Waste management strategies remain major front burning concerns by respective

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regional governments, due to its huge economic chunk. The bio-methanation techniques remain outstanding practicable strategies to effectively manage biodegradable municipal agricultural wastes. This derives from its numerous valued advantages including production of sustainable energy (biogas), nutrient-rich digestates(used as bio-fertilizer), production of CO<sub>2</sub>, CFC etc, and pathogenicity reduction (Babae *et al.*, 2013; Chomini and Joshua, 2019a; Yang *et al.*, 2019), in addition to providing a bioremediation of toxic elements of the resultant digestates(Gupta *et al.*, 2012; Chomini *et al.*, 2019a).

Despite some biomethanation attempts, full exploitation of the huge biomass residues for biomethanogenesis in Nigeria is menial (Ogwus, 2019). Co-substrates anaerobic digestion involves a strategy of enhancing and optimizing biomethanation through degradation of more than one organic substrate simultaneously. It guarantees dilution of harmful substrates (Angeriz-Campoy *et al.*, 2015), increases organic matter blend (Villamil *et al.*, 2018), ensuring synergistic andcomplementary effects, for increased production, and enhance chemical oxygen demand (COD) and volatile solids (VS) removal efficiency, while balancing the C:N fraction thereby enhancing buffering ability (Capson-Tojo *et al.*, 2018). It consequently reflects the metabolic status of microorganism community in digestive medium (Hallaji *et al.*, 2019). Anaerobic mixed substrate digestion also effects process enhancement, through the improvement of carbon to nitrogen (C:N) ratio of the digestive medium. Some workers (Adebayo *et al.*, 2015; Chomini *et al.*, 2015), have codigested different organic wastes ranging from municipal solid wastes, animal wastes and crop residues, for biomethane production. This study therefore focused on comparative anaerobic co-digestion effectsof cow dung, poultry manure and maize cobs on the digestate biochemical properties.

## Materials and Methods

### Substrate preparation

The agricultural wastes (cow dung, poultry manure and maize cobs) collected from research unit of the Federal College Forestry, Jos, Nigeria, from were pretreated (drying, sorted, screened, pulverized and homogenized). Thereafter, mixed (w/w) in selected ratios (Table 1), parked aseptically in black polythene bags and stored below 20°C until use. (Chomini *et al.*, 2015).

**Table 1:** Treatment description

Treatment	Description	Ratio(w/w)
T <sub>A</sub>	Maize Cobs	1:0
T <sub>B</sub>	Poultry droppings	1:0
T <sub>C</sub>	Cow dung	1:0
T <sub>D</sub>	A + B + C	1:1:1

### Anaerobic Digestion and Biogas Evaluation

Separate slurries of each of the treatment substrates were obtained after mixing 1000g of each sample with 3000ml of sterile distilled water (1:3 ratio, w/v) (Grant and Marshalleck, 2008). The resultant slurries (in triplicates) were separately fed to sterilized 13.6L capacity digesters. It was firmly sealed(air-tight), fitted with thermometer and gas delivery pipe, using rubber corks. The twelve (12) experimental units were arranged, using completely randomized design (CRD) under uniform temperature within the experimental chamber. They were manually shaken once daily to ensure uniform substrate condition, and keep for 8weeks digestion period. (Chomini *et al.*, 2015). Weekly observations were made on volume of biogas produced (ml/kg), using the water displacement method, over the trial period (Chomini, 2017).

### Proximate assay of treatment substrates and spent slurries

Triplicate fractions of dried, pulverized treatment samples (digested and undigested) were subjected

to authorized procedures (AOAC, 2005), to assess proximate compositions such as moisture content (MC), crude protein (CP), crude fibre (CF), crude lipid (CL), nitrogen free extract (NFE), total ash (TA), total nitrogen (TN) and total organic carbon (TOC). The chemical oxygen demand (COD) composition of the treatment substrates prior to and at post digestion were determined, using spectrophotometer DR 2800 (APHA, 2005).

### **Assessment of Amino Acid content of Digested Samples**

The AOAC (2005) and Spackman's methods modified by Muhammad and Oloyede (2009) were adopted for analyzing the amino acid contents of both undigested and digested samples. It involved subjecting dried fractions to defatting, hydrolysis and evaporation by rotatory evaporator before loading into a Technicon Sequential Multi-sample (TSM) amino acid analyzer.

### **Statistical analysis**

Data obtained were subjected to analysis of variance to determine their significant difference. Significant means were separated using least significant difference (LSD) approach.

### **Results**

#### **Effects of Anaerobic Digestion of treatment substrates on Biogas Yields and Chemical Oxygen Demand (COD)**

There was significant ( $P < 0.05$ ) progressive rise in average biogas yields within the first six weeks of digestion (WOD). This was interrupted by sudden sharp decrease at the last two weeks of digestion. Treatment B(1:0, poultry droppings) had 93.3ml/kg, 150.7ml/kg and 262.7ml/kg as highest weekly production for week 1-3, while treatment T<sub>D</sub> (1:1:1, maize cob : poultry droppings: cow dung) gave the best yield at weeks 4(328.3 ml/kg), 5(426.0ml/kg), 6(525.7ml/kg) and 7(398.7ml/kg). However, treatments T<sub>C</sub> and T<sub>D</sub> recorded 272.0ml/kg and 128.3ml/kg as the greatest and

least values at 8<sup>th</sup> WOD respectively (Figure 1). Cumulative yield depicted an order of treatment T<sub>D</sub> (2200.7ml/kg) > T<sub>B</sub> (2197.9ml/kg) > T<sub>C</sub> (2079.0ml/kg) > T<sub>A</sub> (1713.2ml/kg) (Table 4).

#### **Proximate content of treatment substrates and spent slurries**

Effects of anaerobic digestion (AD) on proximate composition revealed percentage decrease in crude lipids across the treatments which followed the order of 86.82%(T<sub>C</sub>) > 77.04%(T<sub>A</sub>) > 65.99%(T<sub>B</sub>) > 64.66%(T<sub>D</sub>). Similar observations were made for nitrogen free extract (NFE) and crude fiber (CF), except for treatments T<sub>B</sub> and T<sub>C</sub> which recorded percentage increases in CF (76.03%) and NFE (61.07%) respectively. Conversely, only treatment T<sub>B</sub> had 5.74% as percentage decrease after 8 weeks of digestion. Percentage increases in ash and moisture contents across the treatments, due to AD, with treatments T<sub>A</sub> (763.60%) and T<sub>D</sub> (525.64%), showing the highest percentage increase, while T<sub>B</sub> (48.06%) and T<sub>C</sub> (140.65%) gave the least based on anaerobic digestion respectively (Table 2). All treatments indicated outstanding reductions in carbon: nitrogen (C/N) ratios and chemical oxygen demand (COD) compositions of substrates due to AD. The C/N values extended from 12.94 – 85.79%, with T<sub>B</sub> and T<sub>D</sub> having the least and highest percentage reduction, later showed an order of 46.81%(T<sub>A</sub>) > 34.15%(T<sub>B</sub>) > 25.81% (T<sub>C</sub>) > 8.00%(T<sub>D</sub>) (table 4).

#### **Anaerobic Digestion (AD) Effects on Digestates Amino Acids compositions**

There were percentage increases in histidine, glycine, cysteine, methionine, total non-essential amino acids (TNEAA) and total aromatic amino acids (TArAA) for all digestates, based on effects of AD. These depicted 596.77%(T<sub>A</sub>) and 197.04(T<sub>B</sub>), 163.64%(T<sub>C</sub>) and 89.47%(T<sub>D</sub>), 926.2%(T<sub>A</sub>) and 677.19%(T<sub>B</sub>), 102.78%(T<sub>D</sub>) and 36.96%(T<sub>B</sub>), 48.47%(T<sub>C</sub>) and 10.47%(T<sub>B</sub>), and 554.41%(T<sub>A</sub>) and 391.26%(T<sub>B</sub>), as highest and lowest values respectively. Percentage aspartic

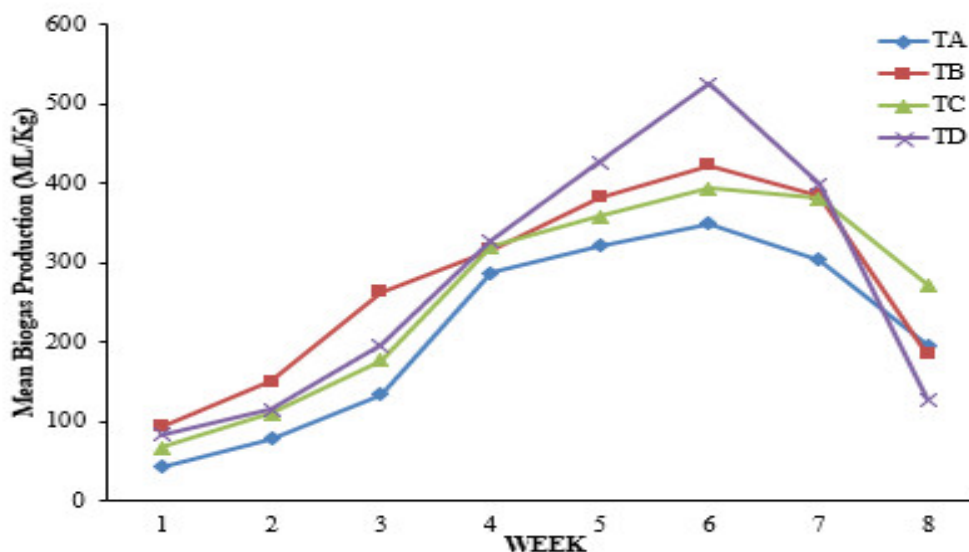
acid and serine were notably reduced across treatments after AD. Only treatment T<sub>B</sub> gave percentage decrease in arginine (25.83%), threonine (6.94%), glutamic acid (21.44%), proline (1.84%), alanine (13.24%), isoleucine (16.89%), tyrosine (19.07%), total amino acids (TAA, 23.38%) and total essential amino acid (TEAA, 24.44%). Conversely, only treatment T<sub>A</sub>

was positively influenced, with lysine (25.00%), valine (40.98%) and total aromatic amino acid (TArAA, 6.13%). While phenylalanine fraction of T<sub>A</sub> was unaffected (0.00%), leucine constituent of T<sub>B</sub> (60.14%) and T<sub>D</sub> (23.08%) were reduced after AD (Table 3)

**Table 2:** Effects of Anaerobic Digestion on Proximate Properties (%) of the Digestates at Eight Weeks of Digestion

Treatment	Condition	AS	TCL	CF	NFE	CP	MC
T <sub>A</sub>	BAD	2.83	9.54	36.98	43.26	3.06	4.33
	AAD	24.44	2.19	22.66	35.42	11.87	10.42
	%EOD	763.60	-77.04	-38.72	-18.12	287.91	140.65
T <sub>B</sub>	BAD	30.69	6.88	10.68	31.31	16.19	4.25
	AAD	45.44	2.34	18.80	25.66	15.26	15.51
	%EOD	48.06	-65.99	76.03	-18.05	-5.74	264.94
T <sub>C</sub>	BAD	23.71	13.81	29.85	15.95	12.13	4.55
	AAD	36.97	1.82	22.16	25.69	19.19	22.17
	%EOD	55.93	-86.82	-25.76	61.07	58.20	387.25
T <sub>D</sub>	BAD	19.40	10.30	25.48	34.01	6.13	4.68
	AAD	39.83	3.64	16.51	29.71	18.04	29.28
	%EOD	105.31	-64.66	-35.20	-12.64	194.29	525.64

BAD = Before Anaerobic Digestion; AAD= After Anaerobic Digestion; %EOD = percentage Effect of Digestion; AS = Ash; TCL=Total Crude Lipid; CF= Crude Fiber; CP =Crude Protein; MC=Moisture Content



**Figure 1:** Mean Biogas Yield (ml/Kg) During Eight Weeks of Anaerobic Digestion

**Table 1:** Effects of Anaerobic Digestion on Amino Acids Composition (%) of the Digestates at Eight Weeks of Digestion

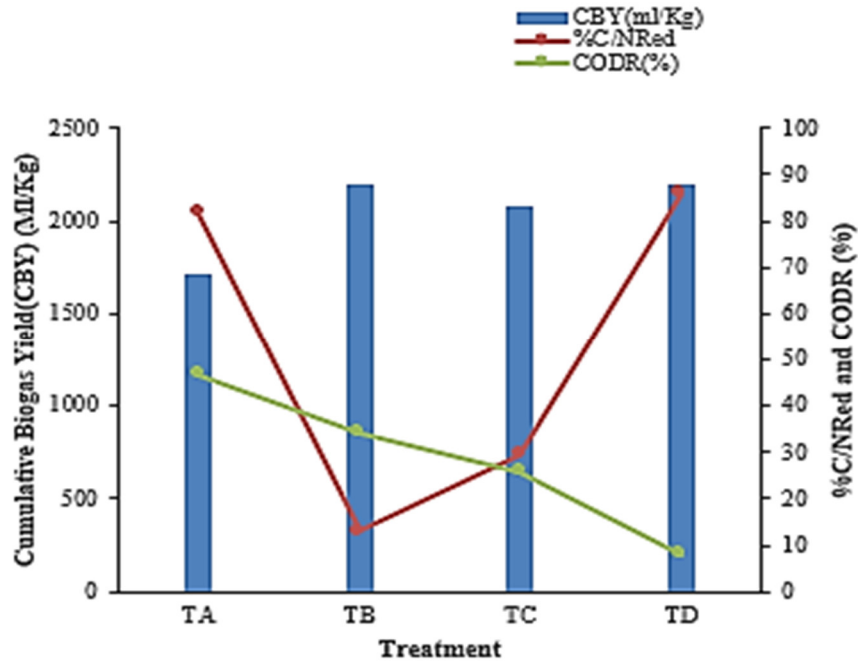
Tmt	T <sub>A</sub>			T <sub>B</sub>			T <sub>C</sub>			T <sub>D</sub>		
AA	BAD	AAD	%Eff	BAD	AAD	%Eff	BAD	AAD	%Eff	BAD	AAD	%Eff
Lys	1.92	2.40	25.00	2.83	2.00	-29.33	3.50	2.03	-42.00	3.50	2.05	-41.43
His	0.62	4.32	596.77	1.35	4.01	197.04	1.09	5.27	383.49	1.06	4.26	301.89
Arg	1.23	1.99	61.79	3.02	2.24	-25.83	1.71	1.90	11.11	2.18	1.90	-12.84
Asp	3.35	2.30	-31.34	4.05	2.26	-44.20	4.02	2.79	-30.60	3.60	2.70	-25.00
Thr	2.02	2.15	6.44	2.16	2.01	-6.94	1.34	2.31	72.39	1.50	2.21	47.33
Ser	1.55	1.09	-29.68	1.93	1.14	-40.93	1.93	1.25	-35.23	1.64	1.60	-2.44
Glu	4.01	6.29	56.86	7.23	5.68	-21.44	6.21	7.57	21.90	5.51	6.97	26.50
Pro	1.20	2.03	69.17	2.18	2.14	-1.83	1.17	2.24	91.45	1.36	2.24	64.71
Gly	2.23	5.60	151.12	3.05	6.89	125.90	2.75	7.25	163.64	2.66	5.04	89.47
Ala	2.13	3.19	49.77	3.55	3.08	-13.24	2.23	3.34	49.78	2.60	3.00	15.38
Cys	0.38	3.90	926.32	0.57	4.43	677.19	0.51	3.97	678.43	0.45	3.57	693.33
Val	1.83	2.58	40.98	3.50	2.35	-32.86	2.60	2.52	-3.08	2.63	2.32	-11.79
Met	0.30	0.55	83.33	0.46	0.63	36.96	0.41	0.63	53.66	0.36	0.73	102.78
Ileu	1.35	1.90	40.74	2.25	1.87	-16.89	1.73	2.00	15.61	1.63	2.12	30.06
Leu	1.95	3.00	53.85	7.25	2.89	-60.14	2.84	3.20	12.68	3.90	3.00	-23.08
Tyr	1.08	1.27	17.59	2.36	1.91	-19.07	1.08	1.27	17.59	1.24	1.59	28.23
Phe	2.02	2.02	0.00	3.90	2.19	-43.85	2.30	1.85	-19.57	2.67	2.19	-17.98
TAA	29.17	46.58	59.68	51.64	47.72	-7.59	37.51	51.39	37.00	38.49	47.49	23.38
TEAA	13.24	22.39	69.11	26.72	20.19	-24.44	17.52	21.71	23.92	19.43	20.78	6.95
TNEAA	15.93	23.58	48.02	24.92	27.53	10.47	19.99	29.68	48.47	19.06	26.71	40.14
TSAA	0.68	4.45	554.41	1.03	5.06	391.26	0.92	4.60	400.00	0.81	4.30	430.86
TArAA	3.10	3.29	6.13	6.26	3.38	-46.01	3.38	3.12	-7.69	3.91	3.78	-3.32

Tmt= Treatment; AA = amino acid; Lys = Lysine; His = Histidine; Arg = Arginine; Asp =Aspartic acid; Thr = Threonine; Ser = Serine; Glu = Glutamic acid; Pro = Proline; Gly = Glucine ; Ala = Alanine ; Cys = Cystine ; Val = Valine; Met = Methionine; Ileu = Isoleucine; Leu =Leucine; Tyr = Tyrosine ; Phe = Phenylalanine ; TAA = Total amino acids; TEAA = Total essential amino acids; TNEAA = Total non-essential amino acids; TSAA = Total sulphur amino acids; TArAA = Total aromatic amino acids.

**Table 4:** Effects of anaerobic digestion on cumulative biogas yield, %CODR and%C.NRed

Treatment	CBY(MI/Kg)	%C/N <sub>Red</sub>	%CODR
T <sub>A</sub>	1713.2	81.80	46.81
T <sub>B</sub>	2197.9	12.94	34.15
T <sub>C</sub>	2079.0	29.35	25.81
T <sub>D</sub>	2200.7	85.79	8.00

CBY = cumulative biogas yield, %CODR = percentage in chemical oxygen demand reduction, %C/N<sub>Red</sub> = percentage carbon to nitrogen ratio reduction



**Figure 2:** Effects of Chemical oxygen demand reduction (CODR) and %Carbon/Nitrogen Reduction(%C/N<sub>Red</sub>) on Cumulative Biogas Yield (CBY)(ml/Kg) after 8 WOD

### Discussion

Biogas yield pattern during the first 6 weeks of digestion (WOD) corroborated reports of Pramanik *et al.*, (2019), indicating an initial increased production during the first 37day, following a decreased through the 75<sup>th</sup> day. Hallaji *et al.* (2019) posited that availability of biodegradable organic matter for better microbial activity, organic loading rates (OLRs) and decreasing hydraulic retention times (HRTs) could enhance the process. Pramanik *et al.* (2019) and Liu *et al.* (2017) also attributed the observation to methanogenic activity inhibition, resulting from reactor acidification due to increased VFA. The nature of co-substrates mixing ratio were viewed to affect biogas yield significantly (Chomini *et al.*, 2019c). The volumetric gas yield recorded its peak for T<sub>D</sub> (1:1:1, maize cob: poultry droppings: cow dung) with maximal weekly and cumulative yield(2200.7ml/kg), depicting the effects of co-

substrates on methanogenesis. These observations were consequent upon positive synergistic effects, more balanced nutrients, increased buffering capacity, increased bacterial due to supply of deficient nutrients during co-digestion (Chomini *et al.*, 2014).

The proximate assay depicted percentage increases in ash and moisture contents across treatments, consequent upon the biomethanation process, with treatments T<sub>A</sub> (763.60%) and T<sub>D</sub> (525.64%), recording the highest percentage increase, while T<sub>B</sub> (48.06%) and T<sub>C</sub> (140.65%) gave the least effects due to AD (Table 3). Effects of biomethanation process gave a percentage decrease in crude lipids across treatments, following the order of 86.82% (T<sub>C</sub>) > 77.04% (T<sub>A</sub>) > 65.99% (T<sub>B</sub>) > 64.66% (T<sub>D</sub>). Similar observations were made for crude fiber (CF) and nitrogen free extract (NFE), apart from treatments T<sub>B</sub> and T<sub>C</sub> with recorded percentage increases in CF (76.03%) and NFE (61.07%)

respectively. Conversely, only treatment T<sub>B</sub> had 5.74% as % decrease after 8 weeks of digestion.

The high moisture contents (MC) were explained to enhance methanogenesis (Eze and Okonkwo, 2013), by dissolving readily degradable organic matter, especially at 60–80% moisture (Hernandez-Berriel *et al.*, 2008). The MC promotes rate-determining hydrolysis stage during biomethanation process (Ma *et al.*, 2013), by enhancing waste pretreatment especially decomposition of heavy lignocellulosic wastes (Kumar and Sharma, 2017). The enhanced percentage crude protein suggested that their initial values were adequately sufficient (Ofoefule and Ibeto, 2010). They also opined release of nitrogenous and non-nitrogenous fractions including microbial single cell protein (Dairo *et al.*, 2011), bioconversion of dissolved carbohydrate fractions of the substrates to bacterial protein (Vijayan *et al.*, 2009), in addition to enzymatic metabolism (Hassan, 2003). The observed decrease of percentage total crude lipid corroborated the reports of Chomini *et al.* (2019b), inclined to its metabolism, as ATP supply for growth of digesting microorganisms, resulting to terminal reduction. The content of cellulolytic microbial enzymes is a function of fungal species types, which determines the resultant percentage crude fiber fraction (Akinfemi *et al.* 2009). The carbohydrate metabolism and the medium energy capacity are other considerations (Adenipekun and Okunlade, 2012).

The general decrease in carbon: nitrogen (C/N) ratios in addition to chemical oxygen demand (COD) across the treatment effluents were discussed (Meegoda *et al.*, 2018). They indicated implication of C/N ratio in improving the activities of hydrolytic enzymes such as protease. This according to them, depends on the type of substrates, as substrates with high ratios, often yielded low methane (Meegoda *et al.*, 2018). But when digested as mixed substrates with reduced

C/N ratio, gave improved biogas yield (Figure 2). This explains current observation, with T<sub>D</sub> (1:1:1), having the greatest yield (Figure 1). Ghasimi *et al.* (2009), reported an excessively high C:N ratio would increase acidity and retards methanogenesis, while the contrary would lead to ammonia poisoning.

The decreased percentage chemical oxygen demand, resulting from AD, demonstrated an inverse relationship with cumulative biogas yields. This corroborated the findings of Hallaji *et al.* (2019). They attributed their findings to the slurries condition. Achma *et al.* (2014), posited that percentage COD removal depended on COD content utilized, substrate richness and digester's microbial load (Sumardiono *et al.*, 2013). They related this as proportional to the yield. This was reinvigorated by present study (Figure 2), suggesting that microbial consortium acclimated very well, and consequently responsible for the degradation of organic fraction (COD and VS) of the substrates.

#### **Biodegradation Effects of Treatment Substrates on Amino Acid Contents**

The profile pattern of amino acids (AA) showed variations in contents due to microbial digestion effects. This was adduced to protease metabolism of protein (Feng *et al.*, 2009). Liu *et al.* (2012), indicated that various AA residues reflect the extent or their metabolism. Some amino acids (isoleucine, glutamic acid lysine etc) are synthesized from their precursors, whose relative abundance determine their resultant concentrations. According to Burkovski (2005), the digestate AA contents depend on specific uptake by digesting microbes, metabolic rate *de novo* or from proteinoic amino acid precursor. This was in addition to mineral element requirements during microbial amino acid biosynthesis. Burkovski (2003), stipulated that availability of N-donor AA such as glutamine, glutamate, serine, alanine and asparagine, were

responsible for specific AA synthesis. Netzer *et al.* (2004), reported that assimilation of N as ammonia, pyruvate or  $\alpha$ -ketoglutarate, necessitated AA synthesis. Furthermore, Burkovski (2005), indicated that degradation of S-amino acids like methionine and cysteine was responsible for AA synthesis. On the other hand, Lee (2005), found deamination of certain polypeptides and fermentation period as major determinant for AA production. Vijayan *et al.* (2009) stressed that dominant microbes in the digestive medium, would determine the resultant AA content. Moreover, fungal and bacterial - rich media would produce high lysine and methionine contents respectively (Safari *et al.*, 2012),

### Conclusion and Recommendations

The effects of biomethanation indicated biogas yields in the order of  $T_D$  (2200.7ml/kg) >  $T_B$  (2197.9ml/kg) >  $T_C$  (2079.0ml/kg) >  $T_A$  (1713.2ml/kg), showing the advantage of co-substrate over the mono-substrates. Proximate analysis gave a decrease in crude lipid across the treatments with  $T_C$  (86.82%) and  $T_D$  (64.66%) as highest and lowest values. Crude fiber and NFE had similar observation, apart from  $T_B$  (76.03%) and  $T_C$  (61.07%) with increased values. All treatments recorded increased %moisture and ash contents. Carbon - nitrogen ratio reduction ( $C/N_{Reduction}$ ) was in the range of 12.94 - 85.79%. The percentage chemical oxygen demand reduction (CODR), followed the order of  $T_A$  (46.81%) >  $T_B$  (34.15) >  $T_C$  (25.81%) >  $T_D$  (8.00%). The AD process engendered increased histidine, glycine, cystine, methione, total non-essential amino acids (TNEAA) and total aromatic amino acids (TArAA), and reduction in aspartic acids and serine for all treatments. Only  $T_B$  gave percentage reductions in arginine, threonine, glutamic acid, proline, alanine, isoleucine, tyrosine, total amino acids (TAA) and total essential amino acid (TEAA). Conversely, only treatment  $T_A$  was positively influenced,

with lysine (25.00%), valine (40.98%) and total aromatic amino acid (TArAA, 6.13%). While phenylalanine composition of  $T_A$  was unaffected (0.00%), percentage leucine was reduced for  $T_B$  (60.14%) and  $T_D$  (23.08%) after AD. Consequently, other levels of the substrates and other organic biomass be investigated, in addition to harnessing the proceeds of the current efforts as a veritable waste management strategy, while providing useful by-products for the agro-allied industries.

### Competing interests

Authors have declared that no competing interests exist.

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