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A COMPARATIVE ASSESSMENT OF BIOGAS PRODUCTION FROM CO-DIGESTION OF COW DUNG AND SELECTED WASTES

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ABSTRACT
Biogas production from 7 batch digesters containing varying Co-substrates of mixture of Cow dung and other organic wastes was studied for a period of 84 days at ambient temperature. Results showed that digestion of Co-substrates increased biogas yield as compared to pure substrate of Cow dung. The highest maximum biogas yield per Kg of Dry solid was attained with the mixtures of Cow dung and Palm fruit waste, followed by the mixture of Cow dung and Poultry droppings. One-Way ANOVA suggested that there was a significant difference ($P < 0.05$) in the pH dynamics, COD dynamics and Microbial population Dynamics of the anaerobic digestion processes. The Polynomial regression model was used to adequately describe the cumulative biogas production from these digesters. The polynomial correlation with $R^2 = 0.99$ seemed to be very reliable in predicting gas production in anaerobic digestion of Cow dung Co-digested with other animal and plant wastes, respectively. This tool is useful in optimizing biogas production from energy materials, and requires further validation and refinement. Hopefully, this study advances this increasingly growing area of bio-energy research.

KEY WORDS: *Cow dung, Co-substrates, anaerobic, Regression, biogas.*

INTRODUCTION

Anaerobic digestion (AD) is a technology widely used for treatment of organic waste for biogas production. Biogas refers to a mixture of gases produced by anaerobic digestion of organic materials. It consists of varying percent of methane, carbon dioxide, nitrogen, hydrogen, ammonia, hydrogen sulphide and water vapour. Biogas is used for direct combustion in cooking or lighting applications, or to power combustion engines for motive power or electricity generation. Biogas can be utilized in all energy consuming applications designed for natural gas (Ross, 1966). It can be directly used for heating. A cubic meter of biogas with 60% methane content can substitute approximately 0.6 cubic meters of natural gas or 0.6 L of fuel oil during electricity generation in a combined heat and power (Kapdi, 2003). This type of energy generation is practically carbon-neutral as the green house gases released during the combustion have been previously consumed by plants (especially when using Agro/animal wastes as the Substrate). As a renewable energy source, Biogas could be a relative means of solving the problems of grossly inadequate energy supply in Nigeria, rising energy prices, waste treatment/management and creating sustainable development. Moreover, the effluent of this process is a residue rich in essential inorganic elements like nitrogen and phosphorus needed for healthy plant growth known as bio-fertilizer which when applied to the soil, enriches it with no detrimental effects on the environment (Bhat *et al*., 2001). Biogas production is a complex biochemical reaction found to take place under the action of delicately pH sensitive microbes mainly bacteria in the presence of little or no oxygen. There are a number of bacteria that are involved in the process of anaerobic digestion including the hydrolytic bacteria group, acidogenic bacteria group, acetogenic bacteria group and the methanogenic archaea group, respectively (Schnurer and Jarvis, 2010). These organisms feed upon the initial feedstock, which undergoes a number of different processes converting it to intermediate molecules including sugars, hydrogen and acetic acid before finally being converted to biogas. Different species of bacteria are able to survive at different temperature ranges. The ones living between 25 - 40°C are called mesophiles and some of the bacteria that can survive at the hotter and more hostile conditions of 55 - 60°C are called thermophiles (Gerardi, 2003). Studies (Igoni *et al*., 2008; Ojolo *et al*., 2008; Patil *et al*., 2011; Li *et al*., 2009; Budiyono *et al*., 2010; Ofoefule *et al*., 2010; Yusuf *et al*., 2011) had been conducted by several researchers in order to optimize biogas yield in Anaerobic digestion. Also, several studies had been conducted by other researchers on biogas production from different Co-Substrates (Uzodinma and Ofoefule, 2009; Nnabuchi *et at*., 2012; Nordberg *et al*., 1997; van Lier *et al*., 2001; Ahring, 2003; Yadvika *et al*., 2004; Alvarez and Lidén, 2008). The main objective of this research is to employ anaerobic digestion process as a sustainable technology for digesting both animal and plant wastes (Cow dung, Poultry dropping, Pig waste, Palm fruit waste, Plantain peels and Orange waste), available in large amounts in poultry farms, Abattoirs and market places respectively, and to provide the renewable source of energy (biogas) that can reduce the potential green house gas emission. The specific objectives are; (i) To compare the rate of biogas production from the Co-digestion of Cow dung with other animal and plant wastes (ii) To optimize the biogas evolution from the Co-substrates (iii)

To determine parameters, such as Total (or Dry) solids (TS), pH dynamics, Chemical oxygen demand (COD) dynamics and Microbial population dynamics (MPD) for the stability of anaerobic digestion systems, (iv) To have an understanding of the anaerobic digestion of the Co-Substrates under ambient temperature conditions.

MATERIALS & METHODS

(a) Sample Collection, Characterization and Preparation

The Cow dung and Pig waste were collected from an abattoir in Aluu Community of Obiapkor Locality in Rivers State, Nigeria. The Poultry droppings were collected from the Poultry farm in the Department of Agriculture Choba Campus, University of Port Harcourt, Rivers State (Nigeria). The Plantain peels, Orange waste and Palm fruit waste were collected from Choba main market in Port Harcourt (Rivers State), Nigeria. After collection, analysis was carried out to determine their respective Dry (or Total) solids using the AOAC (1995) method. The experimental design for the anaerobic digestion of the Co-Substrates was carried out at a Laboratory (ambient) temperature that ranged between 22°C to 35°C in separate batch digesters with 30 litre capacities each. The main experiment apparatus consists of biodigester and biogas measurement. Biodigester were made from seven calibrated plastics container. The biogas formed was measured by the ’liquid displacement method’ (Momoh and Nwaogazie, 2008). The compositions of the feedstock in each digester are presented in table 1.

TABLE 1: Composition of the Feedstock in the anaerobic digesters

Co-Substrate	Dry Solid (Kg)	Water (L)
2.0kg of Cow Dung (CD)	2.00kg	20.22
1kg CD + 1kg Poultry Droppings (PD)	2.00kg	20.22
1kg CD + 1kg Pig Waste (PIW)	2.00kg	20.22
1kg CD + 1kg Palm Fruit Waste (PFW)	2.00kg	20.22
1kg CD + 1kg Plantain Peels (PP)	2.00kg	20.22
1kg CD + 1kg Orange Waste (OW)	2.00kg	20.22
0.33kg of the Substrates (CPPPPO)	2.00kg	20.22

(b) Physicochemical and Biological Analyses

To monitor the anaerobic digestion process of the Co-substrates, the process pH was measured using a digital pH meter (SCT-lilliput, Scichem Tech.). The chemical oxygen demand was determined using the method described by Reaffirmed (2006). Finally, the population of Total viable anaerobic bacteria was determined using the method described by Summanen *et al*., (1993) and Goldstein *et al*., (1992).

(c) Data Analysis

One-Way ANOVA was used to determine whether there was a significant change in the pH dynamics, COD dynamics and Microbial population dynamics during the anaerobic digestion of the Co-substrates. The data generated was analyzed by adopting the Polynomial regression model ($K_T = a + bR_T + cR^2{}_T + dR^3{}_T$) by Samuel (1991). Where K_T can be represented as total biogas yield, R_T as retention time for substrate loadings, and a, b, c are regression constants to be determined using MS Excel (2007) computer software. This model was chosen because according to Nnabuchi *et al*., (2012), the Polynomial regression equation seemed to be more reliable in predicting biogas production in anaerobic digestion of animal wastes.

RESULT & DISCUSSION

From the experiment performed in the laboratory, a set of results were obtained that contain the pH dynamics, COD dynamics, microbial population dynamics and the cumulative biogas yields for the different Co-substrate loadings. The result of pH dynamics for each Co-digestion process is presented in Table 2 and Figure 1. Result from the One-way ANOVA (Table 3) showed that there was a significant ($P < 0.05$) change in the pH dynamics of the anaerobic digestion of the Co-substrates. However, the observed pH lie within the optimum pH range for biogas production in anaerobic digestion processes (Garba, 1996). Low pH value inhibits methanogenic bacteria and methanogenesis (Vicenta, *et al*., 1984). The high pH value recorded in this study could be attributed to large ammonia losses resulting from C/N ratio (Gray *et al*, 1971).

TABLE 2: Average pH of the Anaerobic Digestion Processes

Feedstock	Day 0	Day 14	Day 28	Day 42	Day 56	Day 70	Day 84
CD	7.5	7.9	7.4	7.2	7.6	7.9	7.9
CD+PD	8.3	7.5	6.8	6.9	7.3	7.6	7.7
CD+PIW	8.5	7.8	7.5	7.1	7.3	7.6	7.8
CD+PW	6.8	6.5	6.2	6.3	6.7	6.9	7.2
CD+PP	8.6	8.1	7.6	7.9	7.9	8.1	8.2
CD+OW	7.8	7.5	6.9	6.9	7.3	7.4	7.5
CPPPPO	7.9	7.5	7.2	7.2	7.1	7.4	7.6

Key; CD = Cow dung, PD = Poultry dropping, PIW = Piggery waste
PW = Palm fruit waste, PP = Plantain peels, Orange waste,
CPPPPO = CD + PD + PIW + PW +PP + OW

TABLE 3: Single Factor Analysis of Variance for pH Dynamics (One-Way ANOVA)

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4.146939	6	0.691156	3.171036	0.011736	2.323994
Within Groups	9.154286	42	0.217959			
Total	13.30122	48				

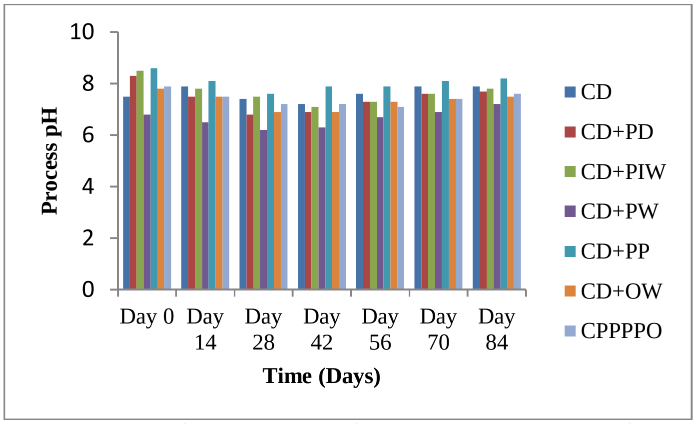

FIGURE 1*:* A Comparison of pH Dynamics of the Anaerobic digestion of the Co-Substrates

The result of COD dynamics and total COD removed from each Co-digestion process is presented in Table 4 and Figure 2. Result from the One-way ANOVA (Table 5) showed that there was a significant ($P < 0.05$) change in the COD dynamics of the anaerobic digestion of the Co-substrates. The COD for the various Processes reduced significantly as shown in Figure 2. This usually correlates with the degree of digestion of the Co-substrates (Schnurer and Jarvis, 2010).

TABLE 4: COD (mg/L) Reduction by the Anaerobic Digestion Processes

Feedstock	Day 0	Day 14	Day 28	Day 42	Day 56	Day 70	Day 84	COD (mg/L) removed
CD	11,824.40	10,946.20	8,374.80	6,104.50	4,376.70	2,142.10	2,054.30	9,770.10
CD+PD	10,937.80	9,832.40	7,436.90	5,096.40	2,142.60	1,097.30	1,025.20	9,912.60
CD+PIW	11,573.10	10,351.10	8,969.60	5,308.70	3,478.60	1,746.30	1,769.80	9,803.30
CD+PW	12,212.30	10,121.70	8,853.60	6,276.50	3,038.40	1,248.10	1,192.20	11,020.10
CD+PP	9,816.75	8,926.20	6,217.10	3,451.30	2,631.90	1,494.50	1,439.40	8,377.35
CD+OW	8,049.60	6,925.70	4,376.10	3,613.80	2,019.20	1,214.50	1,158.70	6,890.90
CPPPPO	10,735.66	9,517.22	7,371.35	4,975.20	2,947.90	1,490.50	1,427.90	9,307.76

TABLE 5: Single Factor Analysis of Variance for COD Dynamics (One-Way ANOVA)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6.05E+08	6	1.01E+08	82.55357	1.23E-21	2.323994
Within Groups	51292014	42	1221238			
Total	6.56E+08	48				

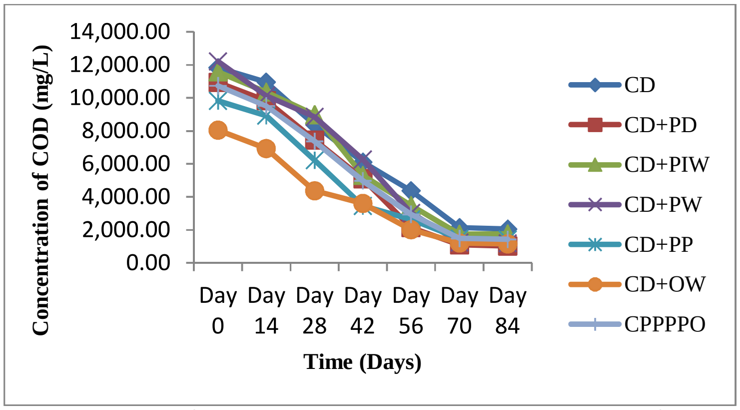

FIGURE 2: A Comparison of COD Removal by the Anaerobic Digestion of the Co-Substrates

The result of microbial population dynamics for each Co-digestion process is presented in Table 6 and Figure 3. Result from the One-way ANOVA (Table 7) showed that there was a significant ($P < 0.05$) change in the population of Total Viable anaerobic bacteria in the anaerobic digestion of the Co-substrates. The growth of the microbes was slow at the start of the digestion processes however, their population increased significantly and picked at between Day 56 to Day 70 before dropping slightly at Day 84. This growth dynamics seemed to correlate with the rate of biogas production from the Co-substrates (Schnurer and Jarvis, 2010).

TABLE 6: Population dynamics of the viable anaerobic bacteria (10^5 CFU/ml) in the anaerobic digestion processes

Feedstock	Day 0	Day 14	Day 28	Day 42	Day 56	Day 70	Day 84
CD	2.2	15.3	35.5	45.2	47.6	47.3	46.8
CD+PD	5.8	28.7	40.9	53.4	54.1	54.5	53.63
CD+PIW	3.96	20.53	36.95	49.31	49.82	50.88	49.48
CD+PW	3.73	19.87	46.1	47.23	47.77	48.51	48.32
CD+PP	1.83	11.34	31.9	42.8	43.45	43.89	42.76
CD+OW	1.45	12.7	38.73	42.64	42.66	43.42	42.29
CPPPPO	3.16	18.1	38.76	43.1	44.45	45.29	44.85

Key; CD = Cow dung, PD = Poultry dropping, PIW = Piggery waste
PW = Palm fruit waste, PP = Plantain peels, Orange waste,
CPPPPO = CD + PD + PIW + PW +PP + OW

TABLE 7: Single Factor Analysis of Variance for Microbial Population Dynamics (One-Way ANOVA)

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	13201.49	6	2200.248	127.7949	2.41E-25	2.323994
Within Groups	723.1148	42	17.21702			
Total	13924.6	48				

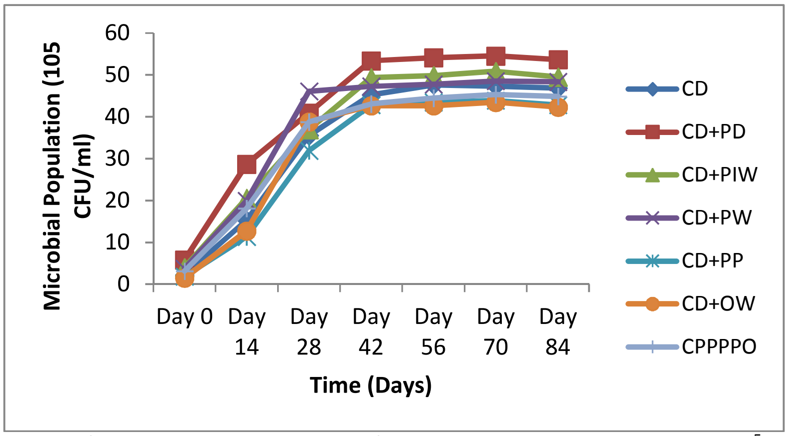

FIGURE 3: A Comparison of the Population Dynamics of Total Viable Anaerobic Bacteria (10^5 CFU/ml) taking part in the Anaerobic Digestion process for the different Co-Substrates.

The results of biogas production from cow dung and the Co-substrates are documented in Table 8 and Figure 4 and the maximum biogas yield was plotted against the Substrates (Figure 5).

TABLE 8: Cumulative Biogas (L) and Maximum Biogas Production (L/Kg TS)

Feedstock	Day 0	Day 14	Day 28	Day 42	Day 56	Day 70	Day 84	TS (Kg)	GasYield (L/Kg TS)
CD	0	0.26	1.14	2.52	4.10	4.44	4.44	2.0	2.22
CD+PD	0	0.60	1.70	3.90	5.40	5.90	5.90	2.0	2.95
CD+PIW	0	0.44	1.42	3.40	4.96	5.51	5.51	2.0	2.75
CD+PW	0	0.62	1.90	4.20	5.70	6.03	6.03	2.0	3.02
CD+PP	0	0.37	1.44	2.94	4.98	5.75	5.75	2.0	2.87
CD+OW	0	0.34	1.30	2.76	4.60	5.33	5.33	2.0	2.67
CPPPPO	0	0.44	1.50	3.30	4.95	5.50	5.50	2.0	2.77

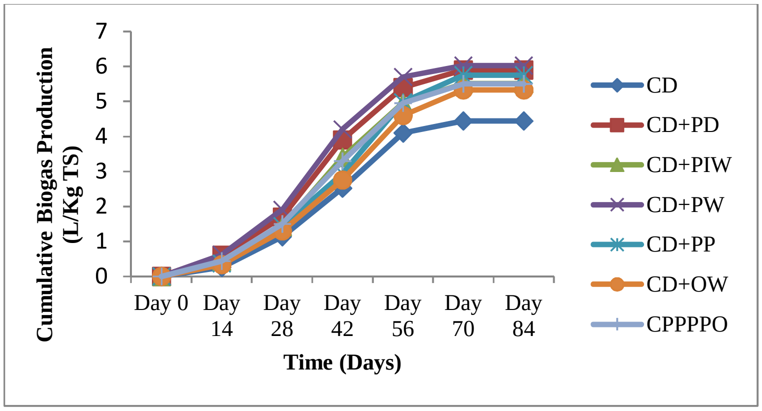

FIGURE 4: A Comparison of Cumulative Biogas Production among the Co-Substrates

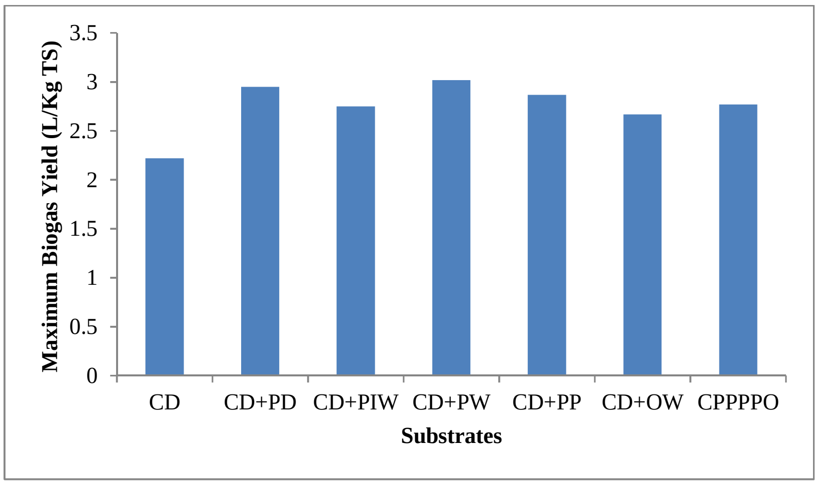

FIGURE 5: A comparison of the Maximum Biogas Yield per Kg of Total (or Dry) solid loaded for each of the Co-substrate

It was observed that Biogas production was slightly slow at the beginning and the end of the observation period. This is predicted because biogas production rate in batch condition is directly proportional to specific growth rate of methanogenic bacteria in the bio-digester (Nordberg and Edstrom, 2005). Result from the One-Way ANOVA (Table 9) showed that there was a significant (P < 0.05) difference in the rate of biogas production from the single and co-substrates, respectively. The Co-substrates generally produced higher biogas yield compared to the pure substrate (Cow dung [CD]). However, the highest maximum biogas yield was attained with the mixture of Cow dung and Palm fruit waste. This concurs with the findings of Uzodinma and Ofoefule (2009), Nnabuchi *et at*.,(2012), Nordberg *et al*., (1997), van Lier *et al*., (2001), Ahring (2003), Yadvika *et al*., (2004) and Alvarez and Lidén, (2008) that Co-substrates usually produce higher biogas than a single substrate. Hobson's (1981) findings attributed the lower production of biogas to low biodegradable material in the cow dung.

TABLE 9: Single Factor Analysis of Variance for Microbial Population Dynamics (One-Way ANOVA)

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	239.4102	6	39.90171	220.0908	4.41E-30	2.323994
Within Groups	7.614457	42	0.181297			
Total	247.0247	48				

The cumulative biogas generation monitored for the different substrates were used for developing predictive models for the generation of biogas for different substrate loading for various retention time. Using the MS Excel (2007) software, the Polynomial regression model was employed for this purpose because the Polynomial regression equation seemed to be more reliable in predicting biogas production in anaerobic digestion of animal wastes (Nnabuchi *et al*., (2012). After carrying out this analysis, the result (Table 10) from the respective polynomial correlations (R^2 = 0.99) showed that the polynomial function is very reliable in predicting gas production in the anaerobic digestion of Co-substrates containing a mixture of animal and plant wastes.

TABLE 6: Result from the Polynomial Regression Model Analyses

Co-Substrate	Regression Equation	R^2
2.0kg of Cow Dung (CD)	$K_T = 0.01 - 0.0259R_T + 0.0032R^2_T - 0.00003R^3_T$	0.99
1kg CD + 1kg Poultry Droppings (PD)	$K_T = -0.00952 – 0.00363R_T + 0.003505R^2_T – 0.000031R^3_T$	0.99
1kg CD + 1kg Pig Waste (PIW)	$K_T = 0.05238 – 0.01947R_T + 0.003639R^2_T + 0.000031R^3_T$	0.99
1kg CD + 1kg Palm Fruit Waste (PW)	$K_T = -0.04 + 0.005468R_T + 0.003482R^2_T – 0.000032R^3_T$	0.99
1kg CD + 1kg Plantain Peels (PP)	$K_T = 0.0457149 – 0.03373R_T + 0.003905R^2_T – 0.000032R^3_T$	0.99
1kg CD + 1kg Orange Waste (OW)	$K_T = 0.041429 – 0.03213R_T + 0.003649R^2_T – 0.00003R^3_T$	0.99
0.33kg of the Substrates (CPPPPO)	$K_T = 0.006429 – 0.01697R_T + 0.003533R^2_T -0.00003R^3_T$	0.99

CONCLUSION

Biogas production from co-digestion of Cow dung (CD) and Poultry droppings (PD), Piggery waste (PIW), Palm fruit waste (PW), Plantain peels (PP), Orange waste (OW) and the combination of all the substrates respectively, was established here to be feasible at ambient temperature. Comparing with the pure CD, the Co-substrates generally increased biogas yield. The maximum biogas yield was attained with mixtures of Cow dung and Palm fruit waste (CD + PW), followed by the Co-substrates of Cow dung and Poultry droppings (CD + PD), etc. Co-digestion of cow dung and other waste materials is therefore, one way of addressing the problem of lack of enough feedstock for biogas production in Nigeria. One-Way ANOVA also suggested that there was a significant difference in the pH dynamics, COD dynamics and Microbial population dynamics of the Co-substrates during the anaerobic digestion processes. Mathematical models derived using the Polynomial regression analysis indicated that biogas production from Co-substrate of animal and other waste materials can be predicted based on digestion time. The polynomial function seemed to be very reliable in predicting gas production in anaerobic digestion of Co-substrates. This tool is useful in optimizing biogas production from energy materials, and requires further validation and refinement. It is our sincere desire that more research work be done in this area of bio-energy to promote environmental sustainability and also fall in line with the transformation agenda of the president of Nigeria, Dr. Goodluck E. Jonathan.

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