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QUANTIFYING CASSAVA WASTE GENERATION AND BIOGAS PRODUCTION IN EHA-ALUMONA GRINDING MILLS

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ABSTRACT

Garri processing is a major agricultural and food related activity which leads to waste generation and this waste in turn constitute environmental problems in terms of stench smells and poor hygienic conditions that allow microbes and germs to thrive. Rural dwellers are normally poor thus the payment of electricity bills impoverishes them further. Inadequate energy supply and environmental pollution are gargantuan problems confronting Nigeria and many other developing nations of the world. In this research we estimated the cassava waste generation rate associated with processing of cassava for garri production activities and estimation of amount of biogas generation from specific mass of the waste. A simple digester is fabricated for sample digestion process. The result was then used in estimation of biogas generation potential of the *garri processing mills. Five different garri processing activities were studied for statistical reliability of results. The results of the five studied garri production activities as described in the methodology were summarized in table 3.1. The quantities* m_1, m_2, m_3 *and* m_{34} *were directly measured as described while the* m_{12} *and* m_{23} *were calculated in each cell of table 3.1 as differences* $m_{12} = m_1 - m_2$ *and* $m_{23} = m_2 - m_3$. *The sum of waste generated in each of the studied activity* M_w *is given in equation (3.1). The counted number of bags for each studied activity was given as* n_p. *The estimation for daily generation of pressed bags of cassava by the community is* $N_{p,total} = 44.35$ *bags.*

Keywords: Biogas, Energy, Cassava, Waste, Garri.

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1. INTRODUCTION

Cassava has the highest yield of carbohydrates per hectare with the exception of sugarcane and sugar beet (Okudoh et al. (2014). It contains large amounts of starch (20–35% fresh and 80.6% dry weight)(Wang, 2002; Jansson et al., 2009; Okudoh, 2014) and total dry matter (38.6%)(Nuwamanya et al., 2012) . Also Gerbens-Leenes et al (2009) stated thatand cassava has the lowest water-footprint (21 m^3/GJ) in comparison to other crops. Cassava waste was reported to be suitable feedstock for bio-fuel production from the 1st Generation, 2nd Generation and integrated processes unlike the other Nigerian crop residues that are mainly suitable for the not-yet-viable 2nd Generation bio-fuel production (Ozoegwu, 2017). Due to these facts, it has gained more attention for the generation of bioenergy (Jansson et al., 2009), mostly in biogas yeild (Panichnumsin, 2010; Adelekan, 2009; Ezekoye, V.A., 2008)

Disposal of garri related cassava waste and cassava waste in general are known to constitute environmental problems in terms of stench smells and poor hygienic conditions that allow microbes and germs to tribe. Rural dwellers are normally poor thus the payment of electricity bills impoverishes them further. Inadequate energy supply and environmental pollution are gargantuan problems confronting Nigeria and many other developing nations of the world (Owamah et al. 2014).

The major threats to the world are Global warming and ozone depletion. Global warming occurs due to incomplete combustion of fossil fuels and the anthropogenic gases released from dumping of organic wastes into open land (Bacenetti, 2013). The continuous use of fossil fuel in Nigeria has contributed immensely to environmental degradation and related health challenges (Okonkwo et al. 2018a; Okonkwo et al. 2015). The rise in the price of fossil fuel coupled with the negative environmental impact of global warming and exhaust emissions has aroused interest of researcher in exploring alternative sources of energy (Osueke et al. 2018; Okonkwo et al. 2018b).

Renewable energy sources appear to be one of the most efficient and effective solution to the problems posed from the use of fossil fuels as an energy source Okonkwo et al. 2018c). Biomass is the biological organic material that is renewable and can be recycled to produce biogas. What is considered as waste many years ago has in recent time become useful, just as the saying goes, nothing is a 'waste' in life.

Biogas is a renewable energy, the energy generated can be use for heating, combined heat and power, or a vehicle fuel instead of the current practice of using fossil fuels (Machunga-Disu and Machunga-Disu, 2012).

Biogas is generated when organic matters undergo decomposition in the absence of oxygen in Anaerobic Digestion (AD) system through the synergistic metabolic activities of consortia of hydrolytic, acidinogenic, acetogenic and methanogenic bacteria on organic materials (Sugumar et al., 2016; Li et al., 2011). AD is equally known to be particularly famous in developing countries where mostly the produced gas is used as fuel for cooking while the digestate is used as fertilizer or soil conditioner (Abudi et al., 2016; Dahunsi and Oranusi, 2013).

The anaerobic digester may be operated as a batch or continuous process and the biogas production could be enhanced effectively through co-digestion process of substrates (Okonkwo et al., 2016; Achebe et al., 2018). The anaerobic digestion process is capable of converting complex organic feedstock into methane, including agricultural by-products, organic wastes as well as animal manure and energy crops (Herrmann et al., 2016).

Organic wastes are mainly treated by composting, stabilization ponds, aerobic digestion, and anaerobic digestion (Ye et al. 2008; Momayez; 2019). The use of 72 combination of pre-treatment methods enhanced the biogas yield in the pre-treated substrates (Dahunsi et al. (2018).

In the recent years the composting practice for anaerobic digestates has been thoroughly studied for many different types of substrate, for co-composting and many different bulk agents (Nakasaki et al., 2009; Himannen et al., 2011).

Achebe et al. (2018) investigated the effects of poultry droppings (PD) on the anaerobic co -digestion of cassava peels (CP) using different mixture ratio. It was deduced that digester with a mixture of 75% PD and 25% CP had the highest biogas production due to better synergy of microorganism in the digester.

Desai et al. (1994) reported that the temperature from anaerobic digestion of cow dung, poultry waste and cheese whey increased from 20 to 40ºC with an increase in methane percentage. Oparaku (2013) investigated the Biogas generation from cassava (Manihot esculentus) peels blended with pig dung under a mesophilic temperature condition. It was reported that the blend had great effect on the yield of biogas.

The low literacy level in the rural areas causes lack of record on biomass availability and biomass energy. Efficient utilization of these biomass resources will solve the problems above by preventing an unfriendly disposal of the waste, providing cheap energy near the point of generation (avoiding transmission and transportation costs) and providing an avenue to systematically quantify biomass resource of the community.

The aim of this research is to generate biogas from co-digestion of cassava waste and cow dung under anaerobic digestion.

2. MATERIALS AND METHODS

Methodology in this work simply revolves around estimation of cassava waste generation rate associated with processing of cassava for garri production activities and estimation of amount of biogas generation from specific mass of the waste. A simple digester is fabricated for sample digestion process. The result was then used in estimation of biogas generation potential of the garri processing mills.

2.1. Estimation of Waste Generation Rate

Five different garri processing activities were studied for statistical reliability of results.

Mass of the harvested cassava designated m_1 is ascertained using a butcher's weighing balance. The harvested cassava is weighed in bits and summed to get m_1 since the overall mass m_1 is greater than the capacity of the balance and also because the harvested cassava is too cumbersome for the holding capacity of the balance. The mass of the cassava remaining after peeling and washing is measured asm_2. The mass of the first stage waste generation of garri production process becomes$m_{12} = m_1 - m_2$. The first stage waste generation of garri production process is composed of the peels (the removed back), the woody head of the tubers and the spoilt tubers. The clean cassava tubers were taken to the grinding mill where they were ground to pulp and pressed in bags through screw pressure. The mass of the pressed cassava is ascertained and designated m_3. The mass of the water and starch content of the cassava (effluent) removed by pressing becomes $m_{23} = m_2 - m_3$. The m_{23} represents the mass of the second stage waste generation of garri production process. The pressed cassava is weighed in bits on the balance after it is removed from the containing bags as precaution against error that could result from the mass of the containing bags. The pressed cassava is sieved to separate the debris that represents the third stage waste generation of garri production process. The debris arises because of clearance between the grinding wheel and the walls of the grinding chamber. The mass of the debris is ascertained with the weighing balance and represented with m_{34} for consistency of notation of masses of wastes of different stages of generation. The sieved cassava is fried on large frying pans to produced garri as the end product. The mass of the arising waste becomes

$$M_w = m_{12} + m_{23} + m_{34} \tag{3.1}$$

The resulting number of bags of pressed cassava is represented as n_p. The mass of cassava waste generated per pressed bag becomes

$$m_w = \frac{M_w}{n_p} \tag{3.2}$$

The results of the five studied garri production activities are summarized in table 3.1. The average mass generated per pressed bag becomes given as

$$m_{w,av} = \frac{1}{n}\sum_{p=1}^{n} m_{w,p} \tag{3.3}$$

Where n is the number of studied activities. The standard deviation which is a measure of dispersion from the averaged value is given as

$$\sigma_w = \left[\frac{1}{n}\sum_{p=1}^{n}\left(m_{w,p} - m_{w,av}\right)^2\right]^{1/2} \tag{3.4}$$

It is necessary to normalize the mass of waste generation per bag of pressed cassava with the mass of pressed cassava per bag to generate the non-dimensional ratio

$$r = \frac{m_w}{m_3} \tag{3.5}$$

This ratio would be useful for estimating waste generation at a mill in other communities once n_p and m_3 values are known. In average terms

$$r_{av} = \frac{m_{w,av}}{m_{3,av}} \tag{3.6}$$

The daily production of pressed cassava bags of the grinding mills (x=3) in the studied community is monitored for forty days for statistical reliability. The number of bags generated per mill per day is designatedN_p. The result of forty days study of the daily production of pressed bags of the mills is summarized in figure 3.1. The average daily generation of pressed bag by the jth mill where j=1, 2, x=3 is given by

$$N_{p,av}^{(j)} = \frac{1}{40}\sum_{i=1}^{40} N_{pi}^{(j)} \quad (3.7)$$

The estimation for daily generation of pressed bags of cassava becomes

$$N_{p,total} = \sum_{j=1}^{x} N_{p,av}^{(j)} \quad (3.8)$$

The estimation for daily generation of cassava waste becomes

$$m_{daily,total} = N_{p,total} m_{w,av} \quad (3.9)$$

If average biogas yield of unit mass of the waste can be estimated and designated as v_{pmass} then the daily biogas potential of the studied location becomes

$$V_{daily\ bg.pot} = m_{daily,total} v_{pmass} \quad (3.10)$$

This is seen from equation (3.7) to become

$$V_{daily\ bg.pot} = N_{p,total} m_{w,av} v_{pmass} \quad (3.11)$$

The methodology for experimental estimation of v_{pmass} is presented in what follows.

2.2. Collection of feedstock and inoculum

8kg of waste was drawn from the three stages of wastes. Mass from each of the mixtures in approximately the obtained ratios given in table 4.1 such that the mass of the first stage waste was 2.7kg, the mass of the second stage waste was 4.81kg and the mass of the third stage waste was 0.5kg. The collected wastes from the three stages were placed in an ice-cold box (cooler) and transported to Awka with geographical coordinates of Latitude 6 ^{o} 12 ^{1} 25 ^{11} N and 7 ^{o} 04 ^{1} 04 ^{11} East, South Eastern Nigeria in a journey of 1.5 hours.

Cow dung was collected from rumen of slaughtered cows in a cow market (Gariki) at Amansea in Awka north of Anambra state. The liquid portion of the cow dung used as inoculum in the anaerobic digestion experiment was separated from the fibrous and insoluble portion by squeezing using cheesecloth. It was stored in an air-tight container and transported to the location slated for the anaerobic digestion experiment within minutes.

2.3. Fabrication of Simple Biogas Digester

A simple biogas digester employed in this study was fabricated from readily accessible materials. The basic requirements are simple; a container for retention of slurry (substrate + inoculum + water), a delivery channel for passage of generated biogas, a calibrated containment for the generated biogas and support for the set-up. A transparent plastic container, flexible rubber tubing, a calibrated burette and a stand were acquired respectively to meet with the listed requirements. These items were purchased from Kevon Scientific Ltd at Eke Awka. The picture of the fabrication is shown in figure 2.1a. A is a side view of the set up while figure 2.1b is the setup viewed from a steep angle of depression. Evostic bond was used to prevent leakage from the retention container between the delivery hose and the stopper cover of the retention container. The bond was also applied round the contact between the retention container and its cover. The volume of produced biogas was determined by upward gas delivery and downward water displacement method. This method entails allowing the produced biogas to rise to the top of the inverted burette and displace a column of water in the burette downwards so that the volume of the produced gas can be measured. This was aided with slight acidification of the water. This acidification with sulphuric acid has a surfactant effect on water thus allowing easier diffusion and passage of the generated gas through the water to the top of the inverted burette. The bond was also applied at the contact between the rubber tubing and the burette.

(a) (b)

Figure 2.1: The picture of the fabricated biogas digester. (a) Side view of the set up. (b) The setup viewed from a steep angle of depression.

2.4. Batch digestion

The Batch anaerobic digestion test was carried out on varying mixtures of cassava peels (CP) and cow dung (CD). The digesters were labeled A, B. The mixture compositions for the digesters are; digester A (40% CP and 60% CD) and digester B (50% CP and 50% CD).The percentages of the biomass (CP and CD) were based on total solid concentration. The reactors were run steadily at mesophilic temperature of 35 ± 3^0 C. The substrates were feed into the reactor through inbuilt peristaltic pumps and flow meters. The experiments were carried out within the period of 15 hours for 35 days.

2.5. Experimental Estimation of Biogas Generation per Mass of Waste

The sample for experimental analysis was collected from the feedstock. The sample was 1kg collected from the three stages of waste generation in the ratio 337.5g (1st stage WG)/ 600g (2nd stage WG)/ 62.5g (3rd stage WG) which reflects the ratio $\frac{0.33688}{0.993762}:\frac{0.59732}{0.993762}:\frac{0.059562}{0.993762}$ where WG is acronym for waste generation. The mixture of the 1st stage waste and 3rd stage waste was pound in a mortar with pestle. Then the 600g of the 2rd stage waste was poured in the pound mixture. 100g of the resulting waste was mixed with hundred ml of inoculums and the mixture poured in the anaerobic digester at 8pm of 6th June. The digestion was allowed to occur in an interval of about one month. In other words the retention time for the anaerobic digestion was about one month.

3. RESULTS AND DISCUSSION

The results of the five studied garri production activities as described in the methodology of section 2.1 were summarized in table 3.1. The quantities m_1, m_2, m_3 and m_{34} were directly measured as described while the m_{12} and m_{23} were calculated in each cell of table 3.1 as differences $m_{12} = m_1 - m_2$ and $m_{23} = m_2 - m_3$. The sum of waste generated in each of the studied activity M_w is given in equation (3.1). The counted number of bags for each studied activity was given as n_p. Fig.3.1a-3.1c show the Daily generation of pressed bags for the studied Mills while total and average pressed bags for the Studied Mills was shown in figure.3.2

Table 3.1: Summary of waste generation of the five studied garri production activities

mass / *activity*	m_1	m_2	m_3	m_{12}	m_{23}	m_{34}	M_w	n_p
1st	237	198	128	39	70	8	117	4
2nd	130	106	63	24	40	3	67	2
3rd	312	256	150	54	101	7	162	5
4th	65	54	34	11	18	2	32	1
5th	350	290	160	60	115	15	190	5

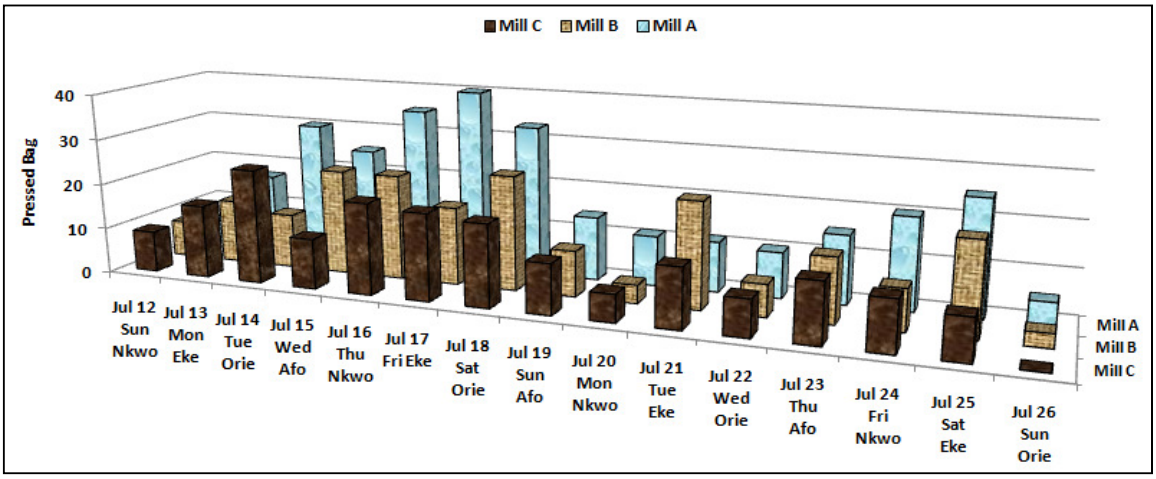

Figure 3.1a: Daily Generation of Pressed Bags for the Studied Mills

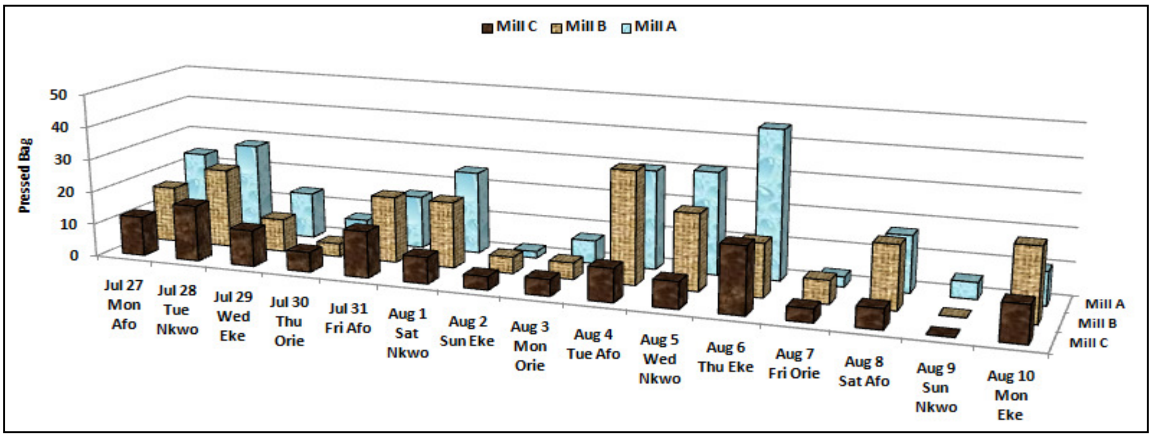

Figure 3.1b: Daily Generation of Pressed Bags for the Studied Mills

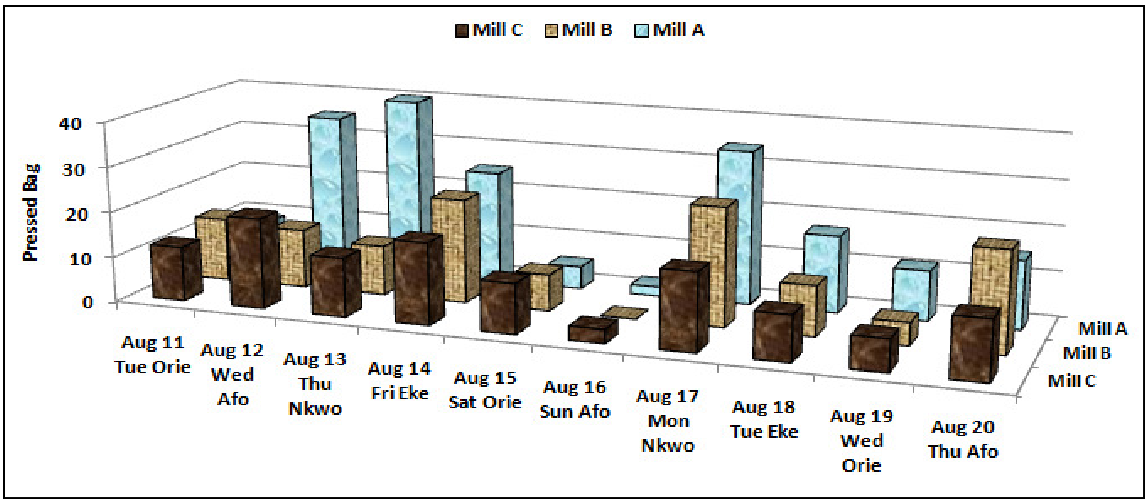

Figure 3.1c: Daily Generation of Pressed Bags for the Studied Mills

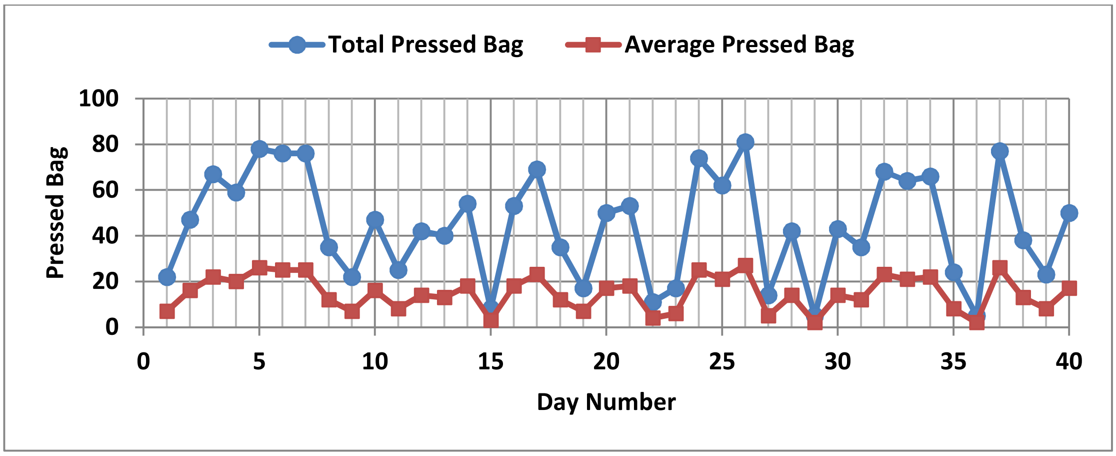

Figure 3.2: Total and Average Pressed Bags for the Studied Mills

From figure 3.3, it can be clearly seen that digester A, with a combination of 40% CP and 60% CD was found to have higher biogas yield than the other digesters. The least biogas production of digester B could be as a result of the high C/N ratio, above the recommended limit of 20-35 Ghasimi, (2009), Ozturk,(2013), and higher lignin content Momoh and Nwaogazie, (2011). According to Ozturk, (2013), a high C/N ratio results in acidification which consequently inhibits methanogenic activities while high lignin content inhibits initial hydrolysis of substrates.

Also for the cumulative biogas production, digester A has the highest cumulative biogas yield compared to digester B. This result shows that the co-digestion agro-wastes such as cassava peels with CD with can enhance its biogas production when mixed optimally as shown in figure.3.4.

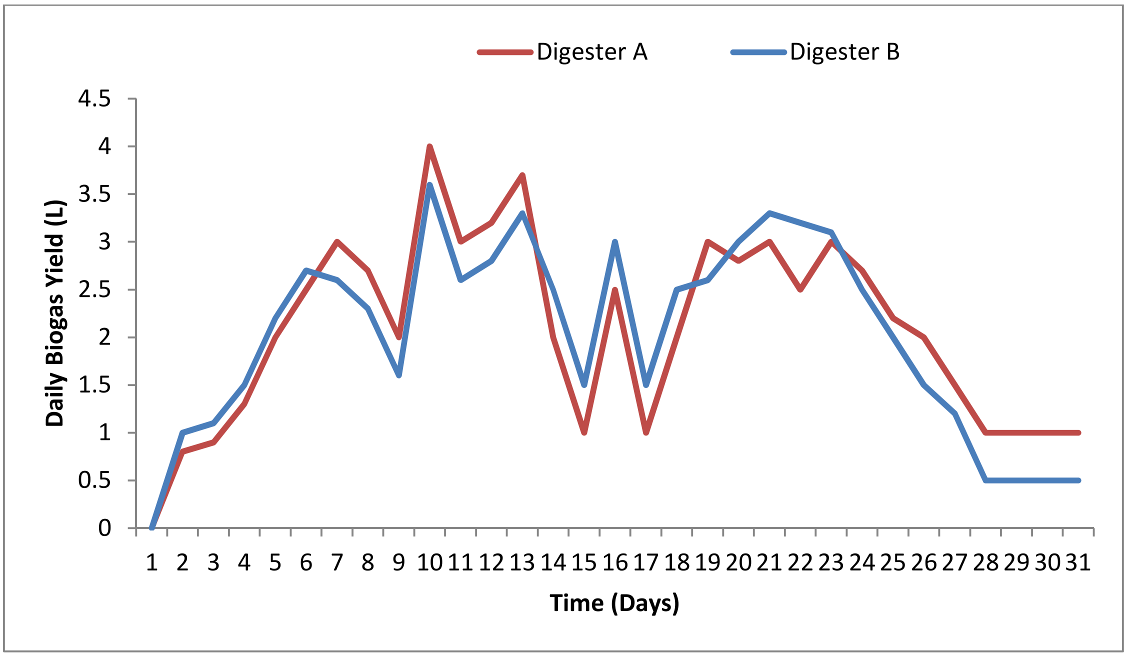

Figure 3.3 Daily Biogas Production

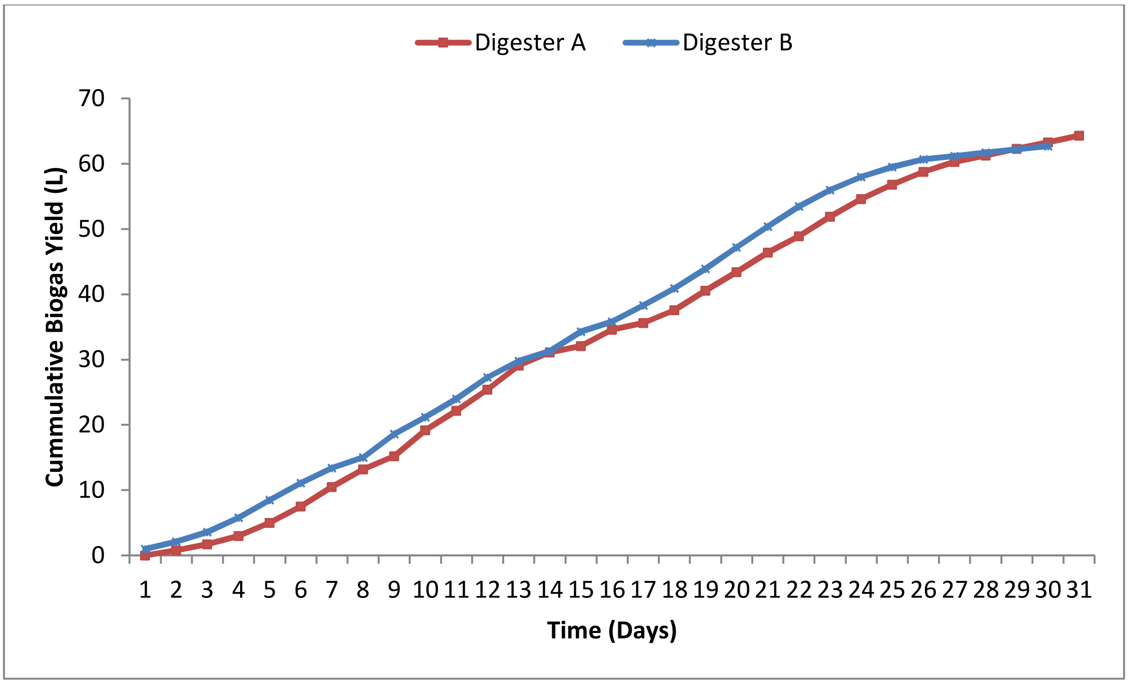

Figure 3.4: Cumulative biogas generation rate from anaerobic digestion of 100g of waste inoculated with 100mL of inoculum.

4. CONCLUSION

The estimation for daily generation of pressed bags of cassava by the community is $N_{p,total} = 44.35$ bags. The estimation for daily generation of cassava waste is $m_{daily,total} = 1465kg$. The cumulative biogas production from 100g of waste was estimated at 131.4ml. The cumulative daily biogas production from garri-associated waste was estimated for the studied rural area which amounted to 1.93m^3. This was translated to mean that the energy potential of the studied village from biogas deriving from garri-related cassava waste is about 50.18MJ of energy. It was stated in quantitative terms that the garri-related cassava waste of the community can be transformed into bioenergy that can warm water 796.51kg from 30ºC to 45ºC for hospital, home etc usage. This bioenergy potential can heat 170.68kg of water from 30ºC to 100ºC for sterilization and cooking applications. This amount of hot water would be more than enough to meet with typical hot warm water demand of rural cottage hospital for sterilization. In conclusion, anaerobic digestion of the garri-related cassava waste as demonstrated in this work will not only alleviate the energy poverty of the rural dwellers in a sustainable manner but will address the associated environmental concerns in terms of aesthetics and hygiene.

RECOMMENDATION

We are recommending that the garri-related cassava waste together with the other agricultural and food wastes of rural communities be transformed into bio energy that can reduce thermal energy need of some established Institutions. It is recommended that biogas potential of other crop wastes should be taken down to the rural levels where majority subsist on small scale farming. It is known in literature that co-digestion of agricultural wastes which are rich in carbohydrates with animal wastes like poultry droppings which are rich in ammonium nitrogen improves carbon/nitrogen ratio and produces nutrient balance that improves biogas production.

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REFERENCES

[1] Abudi, Z. N., Z. Hu, N. Sun, B. Xiao, N. Raja, C. Liu, and D. Guo.2016. Batch anaerobic co-digestion of OFMSW (organic fraction of municipal solid waste), TWAS (thickened waste activated sludge) and RS (rice straw): Influence of TWAS and RS pretreatment and mixing ratio. Energy 107:131–40. doi:10.1016/j.energy.2016.03.141.

[2] Achebe, C. H., Onokwai, A. O., Onokpite, E. (2018). Anaerobic Digestion and Co-digestion of Poultry Dropping (PD) and Cassava Peels (CP): Comparative Study of Optimal Biogas Production. *Journal of Engineering and Applied Science, Nnamdi Azikiwe University, Awka, Anambra State*, (2018)15, Pp. 87-93. https://www.researchgate.net/publication/326560759_Anaerobic_Digestion_and_Co-digestion_of_Poultry_Droppings_PD_and_Cassava_Peels_CP_Comparative_Study_of_Optimal_Biogas_Production .

[3] Adelekan, B.A., Bamgboye, A.L. Comparison of Biogas productivity of cassava peels mixed in selected ratios with major livestocks waste types. Afr J Agric Res, 4: 571-7.

[4] Bacenetti, J., Negri, M., Fiala, M., Gonzalez-Garcia, S.(2013). Anaerobic Digestion of different Feedstock: Impact on Energetic and Environmental Balances of Biogas Process. Sci Total Environ, 463:541-51.

[5] Dahunsi, S. O., and Oranusi. U. S. (2013). Co-digestion of food waste and human excreta for biogas production. British Biotechnology Journal 3 (4):485–99. doi:10.9734/BBJ/2013/4476

[6] Dahunsi, O.S., Oranusi, S.U., Efeovbokhan, V.E., Enyinnaya, M., Zahedi, S., Ojediran, J., Oluyori, P., Izebere, J. (2018). Biochemical Conversion of Fruit Rind of Telfairia Occidentalis (Fluted Pumpkin) and Poultry Manure. Energy Sources, Part A: Recovery, Utilization and Environmental Effects. DOI: 10.1080/15567036.2018.1511651

[7] Dairo, O. U., Olayanju, T.M.A., Ajisegiri, E.S.A., Alamu, O.J., Adeleke, A.E.(2013). Optimization of in-situ Biodiesel Production from Raw Castor Oil-Bean Seed. Journal of Energy Technologies and Policy, 3(13): 15

[8] Desai, M., Patel, V., Madamwar, D. (1994). Effect of Temperature and Retention Time on Biomethanation of Cheese Whey-Poultry Waste-Cattle Dung, Environmental Pollution, 83 (1994): 311-315.

[9] Ezekoye, V.A.(2008). Anaerobic Digestion of cassava peels in batch-operated plastic biodigester and the use of stored biogas for heating. J Home Econ Res, 9: 104-13.

[10] Ghasimi, S.,M.,D.,Idris,A., Chuah, T.,G.,Tey, B.,T. (2009). The Effect of C:N:Pratio, volatile fatty acids and Na^+ levels on the performance of an anaerobic treatment of fresh leachate from municipal solid waste transfer station. *African Journal of Biotechnology*,8(18),pp.4572-4581.

[11] Himanen M., Hänninen K. (2011). Composting of bio-waste, aerobic and anaerobic sludges–Effect of feedstock on the process and quality of compost. Bioresource Technology, 102(3): 2842-2852.

[12] Herrmann, C., Idler, C., Heiermann, M. (2016). Biogas crops grown in energy crop rotations: linking chemical composition and methane production characteristics. Bioresour. Technol. 206: 23-35.

[13] Jansson, C., Westerbergh, A., Zhang, J., Hu, X., Sun, C. (2009). Cassava, a potential biofuel crop in the people's Republic of China. Appl Energy, 86: 595-9.

[14] Li, Y., Stephen, Y., Park, Jiying, Z., (2011). Solid–state anaerobic digestion for methane production from organic waste, Renewable and Sustainable Energy Review, 15: 821-828.

[15] Machuga-Disu, I.I., Machuga-Disu, Z. (2012). Sustainable Managemtent of Natural Resources and the need for Revenue Transparency, Subsidy Reform and Full Deregulation: The Transformation from Fossil Fuel to Green Energy, Green Deal Nigeria. A Publication of Heinrich Boil Stiftung, Nigeria. http://ng.boell.org/downloads/Chapter__6_oil_and_Gas_Technical_Backgroung_Paper.pdf .

[16] Momayez, F., Karimi, K., Taherzadeh, M.J. (2019). Energy recovery from industrial crop wastes by dry anaerobic digestion: A review. Industrial Crops and Products, 129 (2019): 673-687.

[17] Momoh, O.L.Y., Nwaogazie, I.L. (2011). The effect of waste paper on the kinetics of biogas yield from the co-digestion of cow dung and water hyacinth. *Biomass and Bioenergy* , 35:1345-1351.

[18] Nakasaki, K., Tran, L.T.H., Idemoto, Y., Abe, M., Rollon, A.P. (2009). Comparison of organic matter degradation and microbial community during thermophilic composting of two different types of anaerobic sludge. Bioresource Technology, 100(2): 676-682.

[19] Nuwamanya, E., Chiwona-Karitun, I., Kawuki, R.S., Baguma, Y. (2012). Bio-ethano Production from non-food parts of cassaa (Manihot esculenta crantz). AMBIO, 41:262-70.

[20] Okonkwo, U. C. Onokpite, E., Onokwai, A. O. (2016). *Comparative Study of the Optimal Ratio of Biogas Production from various Organic Wastes and Weeds for Digester/Restarted Digester*. Journal of King Saud University-Engineering Science, (2018)30:123-129. https://doi.org/10.1016/j.jksues.2016.02.002.

[21] Okonkwo, U.C., Onokwai, A. O., Okafor, E. O. (2018). *Thermal Performance of a Developed Solar Box Cooker for Awka Metropolis*. Journal of Engineering and Applied Science, NnamdiAzikiwe University, Awka, Anambra State, (2018)12: 64-75.

[22] Okonkwo, U. C., Ijioma, I. N., Onwuamaeze, I. P. (2015). Pollutants Emissions of Filling Stations and Their Impact on the Air Quality.International Journal of Engineering. 28 (6): 949-955.

[23] Okudoh, V., Trois, C., Workneh, T., Schmidt, S. (2014). The Potential of Cassava Biomass and Applicable Technologies for Sustainable Biogas Production in South Afric: A review. Renewable and Sustainable Reviews, 39(2014): 1035-1052.

[24] Oparaku, N.F., Ofomatah, A. C., Okoroigwe, E.C. (2013). Biodigestion of cassava peels blended with pig dung for methane generation. National Center for Energy Research and Development, University of Nigeria, Nsukka, Enugu State, Nigeria.

[25] Osueke, C.O., Onokwai, A. O., Ezugwu, C. A. K., Uzendu, P., Okunola, A.A., Ikpotokin, I. and Ibiwoye, M. (2018). Design and Fabrication of an Anaerobic Digester for Biogas Production, International Journal of Civil Engineering and Technology, 9(11): 2639–2648 http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET &VType=9&IType=11.

[26] Owamah, H.I., Alfa, M.I., Dahunsi, S.O. (2014). Optimization of Biogas from Chicken Droppings with Cymbopogon Citratus. Renewable Energy, 68(2014): 366-371. https://doi.org/10.1016/j.renene.2014.02.006.

[27] Ozoegwu, C.G., Eze, C., Onwosi, C.O., Mgbemene, C.A., Ozor, P.A. (2017). Biomass and bioenergy potential of cassava waste in Nigeria: Estimations based on rural-level garri processing case studies. Renewable and Sustainable Energy Reviews, 72 (2017): 625-638.

[28] *Ozturk, B. (2013).* Evaluation of Biogas Production Yields of Different Waste Materials.*Earth Science Research*, 2, No.1.

[29] Panichnumsin, P., Nopharatana, A., Ahring, B., Chaiprasert, P. (2010). Production of methane by co-digestion of cassava pulp with various concentrations of pig manure. Biomass Bioenergy, 34: 1117-24.

[30] Sugumar S., Shanmuga P and Dinesh S.(2016). A Review on Performance Study of Anaerobic Digestion to Enhance the Biogas Production. International Journal of Civil Engineering and Technology, 7(6), pp.202 – 206. http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET &VType=7&IType=6

[31] Ye, C., Cheng, J.J., Creamer, K.S. (2008). Inhibitation of anaerobic Digestion Process: A Review. Bioresour. Technol. 99: 4044-4064.

[32] S. Sugumar, R. Shanmuga Priyan and S. Dinesh, A Review on Performance Study of Anaerobic Digestion to Enhance the Biogas Production. International Journal of Civil Engineering and Technology, 7(6), 2016, pp.202 – 206.

[33] Chris Sheba Vivian, Premsudha Rangasamy and Uma Rontala Navakoti, Biogas Production Comparison of Vegetable Waste and Fruit Waste from Coimbatore City Market, Codigested with Water Hyacinth. International Journal of Civil Engineering and Technology, 9(8), 2018, pp. 1285-1294.

[34] V. Venugopalan, Dr. N. Balasundaram and S. Hemalatha, Comparative Study on Biogas Production from Cow Dung, Food Waste and Organic Wastes. International Journal of Civil Engineering and Technology, 8(2), 2017, pp. 100–106.

[35] Nathaniel Sawyerr, Cristina Trois, Tilahun Workneh and Vincent Okudoh, Comparison and Modelling of Biogas Production From Unpeeled and Peeled Cassava Tubers at A Mesophilic Temperature, International Journal of Mechanical Engineering and Technology, 9(12), 2018, pp. 338–352