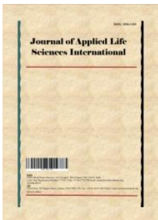

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# Investigation of Factors Affecting Biogas Production from Cassava Peels by Fractional Factorial Design Experimental Methodology

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***Authors' contributions***

*This work was carried out in collaboration among all authors. Author MTN designed the study, wrote the protocol and wrote the first draft of the manuscript. Author MRM performed the statistical analysis. Authors KMT and SJK managed the analyses of the study. Authors GE and MEB managed the literature searches. All authors read and approved the final manuscript.*

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## ABSTRACT

The aim of this study was to investigate parameters affecting biogas production from cassava peels by using fractional factorial design method. The parameters studied were initial pH, organic loading rate, particle size and co-substrate type. Eight biodigesters (TH1, TH2, TH3, TH4, TH5, TH6, TH7 and TH8) in duplicate were performed to produce biogas from cassava peels. The experimental results showed that organic loading rate (X2), particle size (X3) and co-substrate (X4) have significant effect on the yield of biogas. The full mathematical model developed includes two main

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effects (X2 and X3) and three interactions (X1X2, X2X3 and X1X2X3). Reduced model was introduced in the present study. The highest volume of biogas (2252 mL) was obtained in digester TH2 under the following conditions: initial pH 7.8, 5% TS, ≤2 mm of particle and urea as co-substrate, while digester TH8 had slightly low biogas yield (2129.5 mL). Thus, the best conditions to produce biogas from cassava peels are those of TH2.

*Keywords: Biogas production; cassava peels; fractional factorial design; urea.*

## 1. INTRODUCTION

Nowadays waste generation is increasing fast and creating enormous wastes disposal and management problems in the world, especially in developing countries. The main cause is the population growth and cities' expansion [1]. Organic wastes which are a major constituent of waste are considered as low-valued materials [2], indiscriminately discharged into the environment and amassed at waste dumps. The unpleasant odor, leachate and methane generated from disposal wastes enhance the risk of pollution to the environment which is dangerous for the living being and water resources.

A lot of money is spent yearly to manage solid organic wastes around the world, but these efforts are often inefficient in developing countries such as Democratic Republic of the Congo mainly because of poverty. Therefore, governments and industries are constantly searching for technologies to value these wastes [1]. It had been shown that waste accumulated in landfills are source of emissions of pollutants in the atmosphere, soil and water resources [3,4]; incineration and pyrolysis technologies are not adequate solution because they raise also air pollution problems.

Cassava (*Manihot esculenta* Cranz) which is the main food stuff in sub-Saharan Africa, generate in its process, a lot of solid wastes especially peels [5]. Although, a small quantity of peels is used as animal food, a lot of these wastes are amassed on sites where cassava is processed therefore increasing the risk of environmental pollution [6].

There have been several attempts to use cassava peels as substrate for biogas production. Adelekan and Bamgboye [5], compared biogas production of cassava peels mixed with poultry, piggery and cattle wastes as co-substrate, in selected ratios in 220L batch fermenter under mesophilic conditions. The results obtained showed that yields depended on the type of waste and on their ratio.

Nkodi et al. [7] studied co-digestion of cassava peels with different urea concentrations during 14 days under mesophilic conditions; the highest biogas yield obtained (80.79 L/KgTS) was with 0.01% of urea. In the co-digestion of composted mixtures of cassava peels and coffee pulp with or without cow dung, the highest cumulative volume of biogas of 16.50 L/kgTS, was produced when cow dung was associated in the mixture [8].

Sajeena et al. [9] studied the optimal conditions for biogas production from organic fraction of municipal solid waste by response surface methodology (RSM). The experimental results obtained by investigating initial pH, substrate concentration and total organic carbon showed that the linear model terms of initial pH and substrate concentration while the quadratic model terms of the substrate concentration and total organic carbon which had significant individual effect ($p < 0.05$) on biogas yield. However, there was no interactive effect between these variables ($p > 0.05$). The highest level of biogas produced was 53.4 L/kg VS at optimum pH, substrate concentration and total organic carbon of 6.5, 99 gTS/L and 20.32 g/L respectively.

Thus, biogas produced from anaerobic digestion of organic solid wastes is a sustainable energy source currently used in many countries as fuel and for generation of heat for cooking and electricity [10-11].

Following our previous studies on biogas production from cassava peels by co-digestion with manure, coffee pulp or urea, we focus our attention here to investigate thoroughly factors affecting biogas production from cassava peels by using factorial design experimental methodology.

## 2. MATERIALS AND METHODS

### 2.1 Collection and Pretreatment

Cassava peels used as raw matter was collected from the farm of Reserve Stratégique Générale at N'sele/Mbenzale area, in Kinshasa. They were pretreated according Nkodi et al. [7] to enhance sludge digestion and the quantity of biogas [12]. After sun dried and grinded, the powder was sieved into the sieve shaker 2 mm to obtain two kinds of particle size (≤2 mm and >2 mm). Cow dung was obtained from general slaughterhouse of Masina/Kinshasa and was kept in cold until used. Urea was bought at market in Lemba/Kinshasa, D.R Congo. Standard methods were used to assess the proximate composition of materials (pH, moisture, total solids, organic carbon and ash) [11] before their use.

## 2.2 Design of Experiments

To investigate factors affecting biogas production from cassava peels, experiments were carried out based on experimental design methodology which is a structured and organized method used to estimate the effect of several factors on the response of the process. The first order polynomial equation (1) is a predicted equation used to model the response variable Y as a function of the input factors (x) [13].

$$Y = \beta_0 + \sum_{i=1}^{n} \beta_i x_i + \sum_{i}^{n} \sum_{j}^{n} \beta_{ij} e \quad (1)$$

Where

$\beta i$: the overall mean response

$\beta_j$: the main effect for factor (i=1, 2, 3, ….)

$\beta_{ij}$= the two-way interaction between the $i^{th}$ and $j^{th}$ factors.

Table 1 show independent variables used in fractional factorial method with respect of their actual and coded forms.

## 2.3 Biogas Production

Eight plastic digesters bottle of 1 L capacity were performed in duplicate for biogas production from cassava peels in mesophilic conditions. The batch reactors were loaded with 42,62 g (≤2 mm) or with 21,31 g (>2 mm) of cassava peels while cow dung was accurately weighed 83.93g and 167.86 g respectively for 5% TS 10%TS, in different conditions as reported in Table 3. All digesters were labeled as TH1, TH2, TH3, TH4, TH5, TH6, TH7 and TH8 in duplicate (A and B). Urea (0.01%) or cow dung was mixed correctly with peels to obtain a slurry to be digested after charging and sealing tightly the digester with plastic stopper to ensure anaerobic conditions. They were connected on the top with plastic tubes to remove gas to another plastic bottle filled with NaOH 0.1N. The volume of biogas produced and collected over 0.1N NaOH solution was assessed by measuring in a cylinder the quantity of NaOH solution displaced. Digesters were shaken manually twice daily morning and evening to ensure the formation of homogenous mixture until the end of digestion (33 days).

**Table 1. Coded value of independent variables and experimental ranges**

| Factor | Name | Unit | Coded lower limit | Coded higher limit | Real lower limit | Real higher limit |
|---|---|---|---|---|---|---|
| X1 | Initial pH (A) | - | -1 | +1 | 6.8 | 7.8 |
| X2 | Organic Loading rate (B) | (%TS) | -1 | +1 | 5 | 10 |
| X3 | Particle size (C) | Mm | -1 | +1 | ≤ 2 | > 2 |
| X4 | Co-substrate type (D) | - | -1 | +1 | Urea (0.01%) | Cow dung |

*Where, $x_0$: constant $x_1$: initial pH, $x_2$: Organic loading rate, $x_3$: particle size, $x_4$: co-substrate type and $x_1x_2$, $x_1x_3$, $x_2x_3$, $x_1x_2X_3$ and $x_1x_2X_3x_4$ are the interaction between different parameters.*

**Table 2. Physicochemical properties of raw materials**

| Run | Parameter | Cassava peels | Cow dung |
|---|---|---|---|
| 1 | pH | 5.51±0.10 | 7.89±0.03 |
| 2 | Moisture content | 12.17±0.46 | 76.54±0.74 |
| 3 | Total solids | 87.83±0.46 | 23.46±0.74 |
| 4 | Volatile solids | 92.27±0.63 | 86.06±0.68 |
| 5 | Organic Carbon | 54.26±0.37 | 49.46±0.68 |
| 6 | Ash | 7.73±0.63 | 13.94±0.68 |

## 3. RESULTS AND DISCUSSION

### 3.1 Feedstock's Physicochemical Parameters

Before using the materials, their physicochemical properties were determined and the results are shown in Table 2. We noted that cassava peel is a good matter for biomethanization because it has 92.27% of volatile solids matter and 7.73% of ash which make it a good substrate for energy conversion [7,5]. The ash content was higher than in previous study [7]. It is a clear indication that chemical composition of matter depends of various factors such as source, age, period of harvest. Mineral elements into ash are important for survival of methanogen bacteria [14].

### 3.2 Biogas Production

The results obtained from different essays are reported in Table 3 and Fig. 1. The output from fitting a fractional factorial mathematical model was used. Table 3. presents the matrix of effects which enabled the calculation of the mathematical model coefficients from coded values (-1 and +1) of factors (A,B,C and D) and he experimental response average of each essay. All relevant factors were varied simultaneously in a set of planed experiments, then the results obtained were connected by the means of the mathematical model. From the matrix obtained, the effect coefficients were calculated as showed in Table 4.

Fig. 1 gives details about biogas production from cassava peels according to experimental design methodology. Comparing the cumulative biogas yield produced from the eight biodigesters as in Fig. 1, it is evident that the highest biogas production is from digester TH2 followed by TH8 with 2252 and 2129.5 mL respectively. Those experiences have been carried out under the following conditions: pH 7.8, loading rate of 5% TS, particle size ≤2mm and urea as co-substrate (for TH2); and for TH8, pH was 7.8, 10% of loading rate, >2 mm of particle and urea as co-substrate. The highest amount of biogas in digester TH2 is significantly influenced by the particle size. According to the literature, particle size affects biodegradability of lignocellulosic waste by methanogen bacteria [7,15,16]. According to Gashaw [17], the size of feedstock should not be too large otherwise it would obstruct digester and also it would be difficult for microbes to carry out its digestion. Smaller particles provide a large surface area for adsorbing the substrate that would result in increased microbial activity and hence increased gas production. Feedstocks having 1-2 mm of size are easily hydrolyzed and are digested without difficulty by microorganisms [18].

When cow dung is used as co-substrate, digester TH3 produced the highest amount of biogas comparatively to TH4, TH5 and TH6. They have produced 2119, 1163, 545.5 and 332 mL, respectively. It has been noticed that, initial pH had influenced biogas yield for digesters TH3 and TH4. Hence, pH is another important parameter affecting the growth of microbes during anaerobic fermentation. A pH below 6.0 inhibits methane bacteria activity, 6.8 is a favorable pH value to enhance biogas yield from cassava peels and cow dung as a co-substrate. Conversely, when increasing particle size with the same co-substrate, biogas yield decreases.

**Table 3. Experimental effect matrix used and experimental responses (Cumulative volume of biogas) obtained**

| Essay | I | A | B | C | AB | AC | BC | ABC | Experimental replicate | | Responses average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ABCD | BCD | ACD | ABD | CD | BD | AD | D | Y1 | Y2 | |
| 1 | 1 | -1 | -1 | -1 | 1 | 1 | 1 | -1 | 889.5 | 857.5 | 873.5 |
| 2 | 1 | 1 | -1 | -1 | -1 | -1 | 1 | 1 | 2130.5 | 2373.5 | 2252 |
| 3 | 1 | -1 | 1 | -1 | -1 | 1 | -1 | 1 | 1857.5 | 2380.5 | 2119 |
| 4 | 1 | 1 | 1 | -1 | 1 | -1 | -1 | -1 | 1093.5 | 1232.5 | 1163 |
| 5 | 1 | -1 | -1 | 1 | 1 | -1 | -1 | 1 | 595 | 496 | 545.5 |
| 6 | 1 | 1 | -1 | 1 | -1 | 1 | -1 | -1 | 337 | 327 | 332 |
| 7 | 1 | -1 | 1 | 1 | -1 | -1 | 1 | -1 | 1913 | 1989 | 1951 |
| 8 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2216 | 2043 | 2129.5 |

According to Gashaw [17], biogas yield increase proportionately with organic loading rate, it exists a specific rate which will not produce more gas. It has been proved that there is an optimum feed rate for a particular size of plant, which will produce maximum gas. A lab-scale digester was operated in different organic loading rate and produced a maximum yield of 0.36 $m^3$/KgVS at an organic loading rate of 2.91 Kg.$m^3$/day.

The highest amount of biogas in digesters TH2, TH8 and TH3 could be attributed by organic loading rate and particle size. It could be seen that it is best to use the conditions of TH2 for optimizing biogas production from cassava peels. The slight low biogas rate in digester TH8 comparatively to TH2, could be attributed to the increase of the particle size of peels which could reduce biogas production because of the difficult access of bacteria to degrade substrate.

When compared biogas yield of digesters which used cassava peels and urea as co-substrate with those with cassava peels compost with cow dung, biogas yields were respectively 80.79 and 16.50 L/kgTS [7,8]. Thus, the highest amount of biogas was from digesters with urea. The results confirm our previous hypothesis that urea is a good supplement for enhancing biogas production than manure [7]. The highest biogas yielded from digesters using urea could be attributed to the availability of urea's nitrogen to be degraded by microorganisms comparatively to nitrogen from manure [7,14].

### 3.3 Model Coefficients Calculation

Assuming that the third order interaction between different factors was insignificant, model coefficients were calculated from first order equation using XLSTAT 2019 software as shown in Table 4.

From model coefficients obtained, it is possible following the first order polynomial equation to study the effect of each factor to the yield of biogas production

$$Y=1420.6875+48.4375X_1+419.9375X_2-181.1875X_3-242.8125X_1X_2-57.1875X_1X_3+380.8125X_2X_3+340.8125X_1X_2X_3 \quad (2)$$

### 3.4 Statistical Analysis of Regression Equation

Significant assessment of coefficients has been done according Yahiaoui [19] and Djilali [20]. The results are shown in Table 5.

When using bilateral student table with α=0.05 with the degree of freedom 8, tα=2.31. As we see, $t_1$ and $t_{13}$ are lower than 2.31, it means that the corresponding coefficients (Initial pH and his interaction with particle size) are insignificant and can be done away with. The results show that organic loading rate, particle size and co-substrate type have a great influence on biogas yield. The interaction between initial pH, organic loading rate and particle size have also a great influence on biogas production followed by interaction of initial pH-particle size. While the interaction of initial pH and organic loading rate decrease biogas production followed by particle size when it is increased from -1 to +1. From those reasons, the reduced first order regression equation can be re-written as:

$$Y=1420.6875+419.9375X_2-181.1875X_3-242.8125X_1X_2+380.8125X_2X_3+340.8125X_1X_2X_3 \quad (3)$$

The reduced equation (Eq.3) illustrates the actual impact of each model term with positive and negative coefficients which contribute to the overall or antagonist biogas production.

From Table 5 three factors (organic loading rate, particle size and co-substrate type) and two interactions (initial pH-particle size, OLR-particle size) have a great influence on biogas yield. So, organic loading rate increase biogas yield by 15.052% (7.526 X 2=15.052) from 5 to 10%, while particle size decrease biogas by -6.494% (-3.247*2=-6.494), from ≤2 mm to >2 mm of particle and then co-substrate type increase gas yield by 12.216% (6.108 * 2=12.216) from urea to cow dung.

Fisher test is a statistic hypothesis which helps to test the equality of residual and reproducibility variances. It has been shown that reproducibility variance was 24968.0625, residual variance was 14977.6042 and F value was 49.0876968. It means that variables retained in the model have a significant effect on the response. The results of analysis of variance of the model are presented in Table 6.

From the results of Table 6, Fisher value of 49.0877 means that the variability of the response is attributed by the effect of various treatments in different digesters (TH1-TH8).

### 3.5 Regression Significant Test

The Fig. 2 gives R square predicted response vs experimental response. According to the

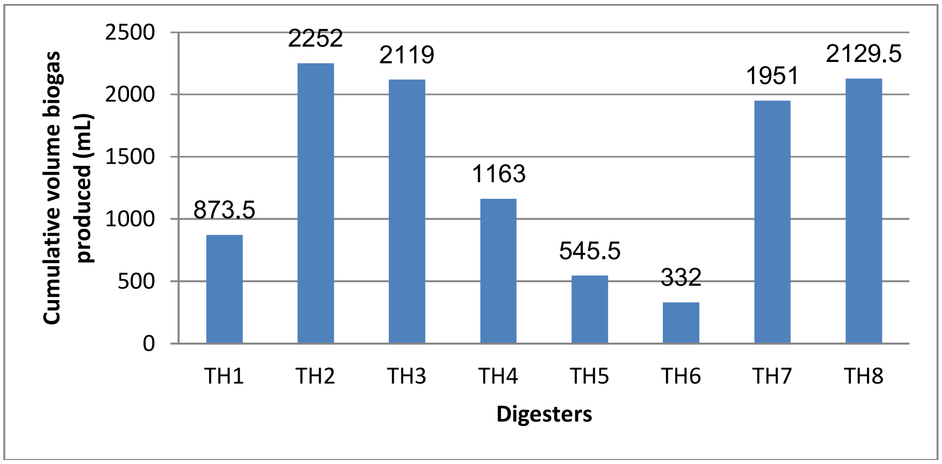


**Fig. 1. Biogas cumulative volume of various digesters (TH1-TH8)**

**Table 4. Model coefficients calculated from first order equation**

| Intercept term | Principal effects | | | Interaction effects | | | |
|---|---|---|---|---|---|---|---|
| $a_0$ | $a_1$ | $a_2$ | $a_3$ | $a_{12}$ | $a_{13}$ | $a_{23}$ | $a_{123}$ |
| 1420.6875 | 48.4375 | 419.9375 | -181.1875 | -242.8125 | -57.1875 | 380.8125 | 340.8125 |

*Where $a_0$ is the average response, $a_1$, $a_2$ and $a_3$ are the linear model coefficients, $a_{12}$, $a_{13}$, $a_{23}$ and $a_{123}$ are the factors interaction coefficients of the model (equation 1)*

**Table 5. Assessment of significant effects**

| Intercept | Principal effects | | | Interaction effects | | | |
|---|---|---|---|---|---|---|---|
| $t_0$ | $t_1$ | $t_2$ | $t_3$ | $t_{12}$ | $t_{13}$ | $t_{23}$ | $t_{123}$ |
| 25.461 | 0.868 | 7.526 | -3.247 | -4.352 | -1.025 | 6.825 | 6.108 |

*Where $t_0$, $t_1$, $t_2$, $t_3$ are respectively the significant values of the model coefficients $a_0$, $a_1$, $a_2$ and $a_3$ while $t_{12}$, $t_{13}$, $t_{23}$ and $t_{123}$ are the significant values of $a_{12}$, $a_{13}$, $a_{23}$ and $a_{123}$*

**Table 6. Variance analysis of response(Y)**

| Source | DF | Sum of square | Average of square | F | Probability | Critical F value |
|---|---|---|---|---|---|---|
| Model | 7 | 8558755.94 | 1222679.42 | 49.0877 | 6.0049E-06 | 3.50046386 |
| Residual | 8 | 199264.5 | 24908,0625 | | | |
| Total | 15 | 8758020.44 | | | | |

*Calculated versus model (Y=Average)*

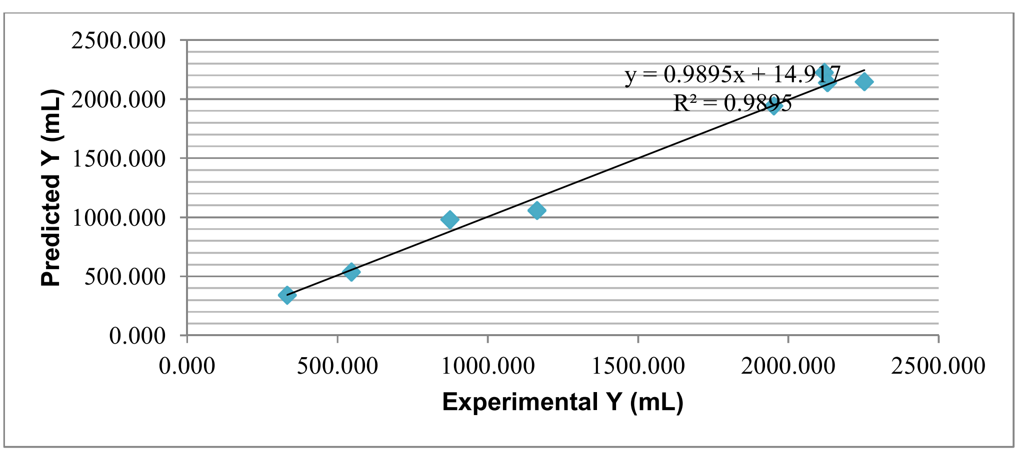


**Fig. 2. Predicted vs experimental biogas values**

results of Fig. 2, the regression equation is Y=0.9895x+14.917 and R-square value is 0.9895. It means that 98.95% of the variability in the response could be explained by the following variables: organic loading rate, particle size, co-substrate type and also by initial pH-organic loading rate interaction and organic loading rate-particle size and then by initial pH-organic loading rate and particle size interaction. The adjusted R-square is 0.9755.

## 4. CONCLUSION

Fractional factorial design experimental methodology was used to assess parameters affecting biogas production from cassava peels. The effects of some factors such as initial pH, organic loading rate, particle size and co-substrate type have been investigated. Analysis using fractional factorial design experiment showed that relation (2) is the approximate model equation for production rate and the reduced model is:

$$Y=1420.6875+419.9375X2-181.1875X3-242.8125X1X2+380.8125X2X3+340.8125X1X2X3 \quad (3)$$

Three factors: organic loading rate, particle size and co-substrate type have been found to be most significant variables followed by two interactions: initial pH-organic loading rate and organic loading rate-particle size.

From experiments performed, the highest volume of biogas (2252 mL) was obtained in digester TH2 under the following conditions: initial pH of 7.8, 5% TS and ≤2mm of particle and urea as co-substrate; while digester TH8 had slightly low biogas yield (2129.5 mL). They two experiments were run under the same operational conditions except 10%TS and a particle size over 2 mm for TH8. It means that increasing particle size decrease biogas yield. So, the best conditions to produce biogas from cassava peels when using urea as co-substrate are those of TH2.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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