UNIZIK JOURNAL OF ENGINEERING AND APPLIED SCIENCES (UJEAS)

Research Article

Parametric determination of Ethanol yield from cocoyam and Cassava Peel Mix

Solomon Chukwuka Nwigbo, Okwuchukwu Innocent Ani, Emeka Chinedu Madubuko, Victor Mmerichukwu Mbachu, Uju Pauline Ojukwu, Calistus Princewill Odeh

Special Issue
A Themed Issue in Honour of Professor Onukwuli Okechukwu Dominic (FAS).

This special issue is dedicated to Professor Onukwuli Okechukwu Dominic (FAS), marking his retirement and celebrating a remarkable career. His legacy of exemplary scholarship, mentorship, and commitment to advancing knowledge is commemorated in this collection of works.

Edited by
Chinonso Hubert Achebe PhD.
Christian Emeka Okafor PhD.

UJEAS

UNIZIK JOURNAL OF ENGINEERING AND APPLIED SCIENCES

UNIZIK Journal of Engineering and Applied Sciences 4(2), March (2025), 2039-2050
Journal homepage: https://journals.unizik.edu.ng/index.php/ujeas
PRINT ISSN: 2992-4383 || ONLINE ISSN: 2992-4391

Parametric determination of Ethanol yield from cocoyam and Cassava Peel Mix

Solomon Chukwuka Nwigbo[1,2*], Okwuchukwu Innocent Ani[3], Emeka Chinedu Madubuko[4], Victor Mmerichukwu Mbachu[5], Uju Pauline Ojukwu[6], Calistus Princewill Odeh[1]

[1]Department of mechanical engineering, Nnamdi Azikiwe University Awka, Anambra State, Nigeria
[2]Tetfund centre for biomedical, engineering, agricultural transitional agriculture TCE-Beats.
[3]Department of mechanical and production engineering, Enugu State University of Science and Technology, Enugu
[4]Project Development Institute (PRODA) Enugu.
[5]Department of industrial and production engineering, Nnamdi Azikiwe University Awka
[6]Department of polymer and textile engineering, Nnamdi Azikiwe University Awka
[*]Corresponding Author's E-mail: sc.nwigbo@unizik.edu.ng

Abstract
The rising global demand towards sustainable energy has created a need for research into alternative biofuels. This study was carried out on parametric determination of ethanol yield from substrate of wild cocoyam (Colocasia esculenta) and cassava peel (Manihot esculenta) in mixture. This study used Box-Behnken Design (BBD) to opt for protein isolation from Cassava Peel Cellulose (CPC) and starch of Wild Cocoyam (WCS), were evaluated as glucose and ethanol. Carbohydrate composition of the substrates was determined by proximate analysis which revealed that cassava peel was higher in carbohydrate (87.69%) than wild cocoyam (77.37%) and an indication that both are good feedstock for bioethanol production. The Central Composite Design (CCD) was used for the optimization of fermentation. Cassava peel cellulose range of glucose yield from 8.96% to 45.5%, whereas, wild cocoyam starch range was from 6.07% to 42.28% as glucose. Quadratic regression models provided the best fit for predicting glucose yield, with high coefficients of determination (R^2 = 0.9977 for cassava peel and R^2 = 0.9967 for wild cocoyam), confirming the significance of the process variables. Ethanol yield was determined using standard ethanol density comparisons and a specific gravity meter, and bioethanol-gasoline fuel blends (E10, E15, E20, and E25) were assessed for potential alternative fuel applications. The findings indicate that CPC glucose yield ranged from (8.96%–45.5%), while WCS glucose yield ranged from (6.07%–42.28%). A quadratic model best explained variations, with R^2 values of (0.9977) for CPC and (0.9967) for WCS. ANOVA results confirmed model significance (F-values: CPC—339.92, WCS—232.81; $p < 0.0001$). Response surface plots showed optimal glucose yields within specific design boundaries. Regression equations identified acid concentration, temperature, and time as key influencing factors, with positive coefficients enhancing yield and negative coefficients reducing it. The study concludes that agro-waste materials can be harnessed for sustainable biofuel production, with future research recommended on enzymatic hydrolysis and large-scale bioethanol production feasibility.

Keywords: Ethanol yield, Cassava peel, Wild cocoyam, Fermentation, Biofuel, Optimization, Response Surface Methodology

1. Introduction

Cocoyam is an herbaceous perennial plant belonging to the family Araceae. About 30 – 40 species of cocoyam have been identified but only 5 – 6 species produce edible parts (Nwanekezi et. al., 2010). Various ethnic groups in Nigeria have different names which attest to its nationwide distribution and use. It is known as ede/akaso/uli in Ibo, guaza in Hausa, eje-jesu in Fulani, koko in Yoruba, eweibo in Edo, mkpon in Efik and ikereburu in Ijo. (Aiyeloja and Bello 2006). Wild Cocoyam (Caladium bicolor), which belongs to the Araceae family, is a tuberous perennial

plant with brightly colored foliage in warm, shady areas. It grows to a height of 20 cm. It has received inadequate attention due to the presence of calcium oxalate in the corm which produces an intense irritation if eaten, and therefore makes the plant inedible for humans. However, the irritant does not have any effect in its utilization for bioethanol production. The gainful uses of the corm of this crop will not only bring about the practical exploitation of this inedible abundant natural resource, which is wild and available; but also will encourage local farmers and boost their economies. In addition, the use of the biomass as a source for bio-ethanol will solve environmental problems. (Adelekan, 2012)

It is a root crop cultivated mainly for the edible corms (tuber), although the leaves, petioles and the flowers are used in soup preparation. It constitutes one of the basic food crops of major economic importance in Nigeria. Chukwu et. al., (2008) stated that it ranks the third after cassava and yam in terms of total production, land area under crop and consumption. According to a report by Ogunniyi (2008), Nigeria is the world's largest producer of cocoyam, accounting for about 40% of total world output as recorded by the Food and Agriculture Organization. The average production figure for Nigeria is 5,068,000mt accounting for about 40% of total world output as recorded by the Food and Agriculture Organization in 2007(FAO. 2007). The cocoyam tuber is rich in carbohydrate, containing about 77.9% starch (Akpata and Babalola, 2012). This starch can also be fermented by a suitable microorganism to produce organic acids such as citric acid, gluconic acid, oxalic acid and bioalcohols such as bioethanol and biobutanol (Amenaghawon and Aisien, 2016). Despite this, Nigeria and other developing nations are beset by the problem of lack of proper storage facilities for these tubers and as such, a large number of these tubers in the order of millions of tons are destroyed through pest infestation, deterioration, physical damage to the tubers, pilfering etc. (Omemu et. al., 2005).

Bio-ethanol is produced by hydrolysis and fermentation of carbohydrate feedstock. This ethanol may be used as a fuel as is, or in a mixture with fossil fuels, using various proportions. It has been established that production of bio-ethanol and other domestic forms of energy is economically viable and feasible with available technologies. Crops grown for energy production purposes is based on availability, competition between food and non-food products, and cost, thus making the search for an optimal feedstock of uttermost importance. The high productivity and yield of cocoyam, along with its ability to grow on marginal soils requiring a minimum of labor and management costs has placed it among the candidates for bio-ethanol production. This research work is aimed at investigating the possibility of transforming cocoyam and cassava peels to valuable product bi-ethanol thereby contributing towards alternative energy supply as well as creating employment opportunity especially in rural areas. There exists paucity of information on Caladium, as well as on cassava peels hence the relevance of this work to serve as baseline data.

However, the study looked at wild cocoyam and cassava peels as an energy crop for the supply of ethanol; a role which if fully developed can raise the profile of this crop in global energy economics. There are various parameters that influence the production of ethanol and include the temperature effect, time, pH, and the enzyme dosage. These parameters alongside local and international studies on bio-ethanol are discussed in detail in the literature review and will be investigated in this work. The use of cocoyam and cassava ethanol as a second-generation bio-fuel provides a starting point for improvement in cultivation and adoption of cocoyam and cassava. Furthermore, the study is in line with ongoing global research efforts at discovering more energy crops and developing other sources of renewable energy. The processes used for this research are natural, namely; fermentation and anaerobic bio-digestion, and these neither contribute to climate change nor deplete the earth's vital resources.

At present there is no commercial production of ethanol from cocoyam or cassava peels in Nigeria. It is evident in the feasibility of economy diversification to solve the problems due to high cost of importation of ethanol for medical, pharmaceutical, research and industries. In addition, to aid the harsh economic situation in the country it will be economically useful if government initiate a move towards the direction of producing ethanol from local raw materials (wild cocoyam) and or agricultural waste (cassava peels) to replace the imported ethanol and this can provide a cleaner environment, environmentally friendly fuel and stimulate community-based jobs and economic growth.

2.0 Materials and methods

2.1 Materials

The plants used in this research study were obtained from two areas in Enugu State, Nigeria. Wild coco yam tubers were obtained from a swampy area at Akpuoga, Eke Obinagu while cassava peels were obtained from the Garri processing plant at Eke-Nkwbor market square in Nchatancha Nike, both in Enugu East L.G.A. The apparatus, instruments and chemicals used were electrical shaker, hot plate, refractometer, autoclave machine, conical flasks, spatula, industrial oven, incubator, thermostat, test-tubes, thermometer, flash point apparatus, distillation apparatus, pH paper and meter, petri dish, dry active yeast, yeast extract, potassium diphosphate, calcium chloride, magnesium sulphate, iron II sulphate (nutrients), sodium hydroxide for pH correction, sulphuric acid for hydrolysis, 95% pure ethanol (used to prepare standard curve for ethanol), deionized water, pipette, buffer solution, and U-tubes capillary viscometer. The chemicals and reagents used in this work are all from commercial sources. In this research, sulfuric acid (H_2SO_4) was used because its higher affinity to break cellulose and starch present in the samples into d-glucose, for subsequent fermentation. The commercial industrial *Saccharomyces cerevisiae* yeast were of analytical grade and purchased from Sigma-Aldrich supplier in Ogbete Main Market, Enugu,

The samples were appropriately labeled and transferred to the Materials and Energy Technology Department, Projects Development Institute, Emene for subsequent laboratory analysis. The yeast utilized was savage *Saccharomyces cerevisiae* strain line, cultivated in microbiology laboratory. This yeast was chosen because it is a microorganism widely used today in the production of ethanol and biotechnological processes. The yeast was cultivated in agar-malt slant. The agar slant consisted of malt extract (3 g/L), yeast extract (3 g/L), peptone (5 g/L), agar (20 g/L) and distilled water (up to 1L). Before use as an inoculum for the fermentation, the culture was aerobically propagated in 500 ml flasks in a shaking bath at 30 °C for 48 h and then separated by centrifugation. The liquid consisted of yeast extract (3 g/L) glucose (10 g/L) and distilled water. (Horst and Petter, 2011).

2.2 Methods

After harvesting, the samples were cleaned to remove foreign matter, dust and dirt. For the experiment the samples were randomly selected and extra care was ensured to select good cocoyam and cassava peels without any sign of blemish, so as to eliminate getting incorrect results. Then the corms were hand-peeled, thoroughly washed with deionized water, cut into 5 cm pieces, then were spread in separate trays in an open sun and air-dried to remove initial moisture and ground using a food processor (Magimix Cuisine System 5000), dried in an air oven (GallenKamp, model OV -160, England) to remove final moisture to constant weight. The oven-dried material was screened through a 100 µm-mesh Tyler screen to obtain a fine biomass.

2.3 Research Design/Experimental Design

2.3.1 Hydrolysis of the wild coco-yam and cassava peel substrates

2.3.2 Acid Hydrolysis

The central composite design (CCD) of response surface methodology (RSM) of MINITAB software (version 17) was used in this study to design the experiment and to optimize the acid hydrolysis conditions for both substrates. The experimental design employed in this work is a two-level three factor full factorial design, including 20 experiments (2^k+2k+ 6). Temperature, Time, and acid concentration are selected as independent factors for the optimization study. The empirical equation is represented as shown below:

$$Y = \beta_0 + \sum_{i=1}^{3} \beta_i X_i + \sum_{i=1}^{3} \beta_{ii} X^2{}_i + \sum_{i=1}^{3} \sum_{j=i+1}^{3} \beta_{ij} X_i X_j$$

Selection of levels for each factor will be based on the experiments performed to study the effects of process variables on the acid hydrolysis of wild coco-yam and cassava peels.

2.3.3 Enzymatic Hydrolysis

Based on the result of the screening of factors, an optimization experiment was carried out to determine the optimum parameters for the enzymatic hydrolysis of cassava peels and wild coco-yam. The Central Composite Design (CCD) was applied for the optimization experiment. The empirical equation is represented as shown below:

$$Y = \beta_0 + \sum_{i=1}^{4} \beta_i X_i + \sum_{i=1}^{4} \beta_{ii} X^2{}_i + \sum_{i=1}^{4} \sum_{j=i+1}^{4} \beta_{ij} X_i X_j$$

Selection of levels for each factor was based on the experiments performed to study the effects of process variables on the enzymatic hydrolysis of wild coco-yam and cassava peels.

2.3.4 Fermentation of the hydrolyzed wild coco-yam and cassava peel substrates

The fermentation was carried out in 250 cm^3 conical flask containing 30-cm^3 of medium obtained from either enzymatic hydrolysis. The medium was inoculated with 5% (v/v) growth medium containing the activated *Saccharomyces cerevisiae* and incubated on a shaker with agitation rate of 300 rpm at 30˚C for 5 days at pH of 5.5. The effects of the operating parameters of temperature, pH and time were reported to be effective. However, the optimization of the fermentation process was carried out using a response surface methodology at temperature levels of 25, 30, 35, 40 and 45˚C; pH levels of 1.5, 3.5, 5.5, 7.5 and 9.5 and time levels of 3, 5, 7, 9 and 11 days. At the end of each run, the fermented liquor was decanted, distilled and the yield of ethanol measured.

2.3.5 Optimization of the Fermentation Process

An optimization experiment was carried out to obtain the optimum parameters for the fermentation of the hydrolyzed substrate. The Central Composite Design (CCD) will also be used for this study. The empirical equation is represented as shown below:

$$Y = \beta_0 + \sum_{i=1}^{3} \beta_i X_i + \sum_{i=1}^{3} \beta_{ii} X^2{}_i + \sum_{i=1}^{3} \sum_{j=i+1}^{3} \beta_{ij} X_i X_j$$

Selection of levels for each factor was based on the experiments performed to study the effects of process variables on the fermentation of hydrolyzed wild coco-yam and cassava peels.

2.3.6 Determination of Ethanol Produced

The distillate collected was measured using a measuring cylinder and expressed as quantity of ethanol produced in g/l by multiplying the volume of the distillate by the density of ethanol (Igbokwe *et al.,* 2015). Ethanol concentration can be determined by comparing the density of the ethanol produced with the standard ethanol density curve (Ighodaro, 2012) or by (using a specific gravity meter (Model DA-130N, Available in PRODA, Enugu) which can measure the percentage of ethanol directly.

Ethanol yield determination:

The ethanol yield was estimated by calculation using the formula:

$$\text{Ethanol yield} = \frac{\text{Ethanol Produced}}{\text{Sugar Consumed}} \times 100$$

The test machine for the experimental evaluation of system performance

Table 1: Engine Specifications

Components	**Values**
Type	Ford 4:108
Bore	79.735mm
Stroke	88.9mm
Swept volume	1.46litres/cycle
Compression ratio	6:1
Maximum BHP	36
Maximum speed	5000rpm
Number of cylinder head	4
Diameter of exhaust	$1\frac{1}{2}''$
Length of exhaust pipe	$36''31'$
DYNAMOMETER	
Capacity	112kw/150hp
Maximum speed	7500rpm
KW	(N_mx rev/min)/9549.305
FUEL GUAGE	
Capacity	50-100 cc
AIR BOX	
Orifice size	58.86mm
Coefficient of discharge	0.6

Source: Department of Mechanical Engineering University of Nigeria, Nsukka.

The mixture of bio-ethanol and gasoline fuel were formulated in various proportions and characterized. The various formulations are shown in Table 2.

Table 2: Bio-ethanol/Gasoline Fuel Blends

S/N	Sample Code	Mixture Proportions (%)
1	E10	10% Bio-ethanol + 90% Gasoline
2	E15	15% Bio-ethanol + 85% Gasoline
3	E20	20% Bio-ethanol + 80% Gasoline
4	E25	25% Bio-ethanol + 75% Gasoline
5	E0	Pure Gasoline (Control)

2.3.7 Statistical Analysis

The tools used for computation and comparison of the data collected were evaluated using Microsoft Excel 2008 and Minitab version 17 software to determine variations across the samples. The comparison of the significant effect of ethanol yield was made using Analysis of Variance (ANOVA). In addition, the response surface methodology was successfully applied to the optimisation of sequentially combined acid and enzymatic hydrolysis of the samples. The regression models developed to represent the acid and enzymatic hydrolysis steps were statistically significant ($p<0.05$) and did not show lack-of-fit (R^2 >0.9) and were thus the proposed models accounted for how enzyme concentration relate with time in determining ethanol yield.

3.0 Result and Discussion

This section deals with analysis of data and presentation of results based on the research questions and objectives that guided the study. The percentage distribution method was used to characterize the proximate analysis data while the research questions were answered using the measures of central tendency and analysis of variance (ANOVA) with Microsoft Excel and Minitab software respectively. In discussing the results of this study, efforts were made to focus attentions on the objectives stated and this section presents the summary of the descriptive statistics used in the study.

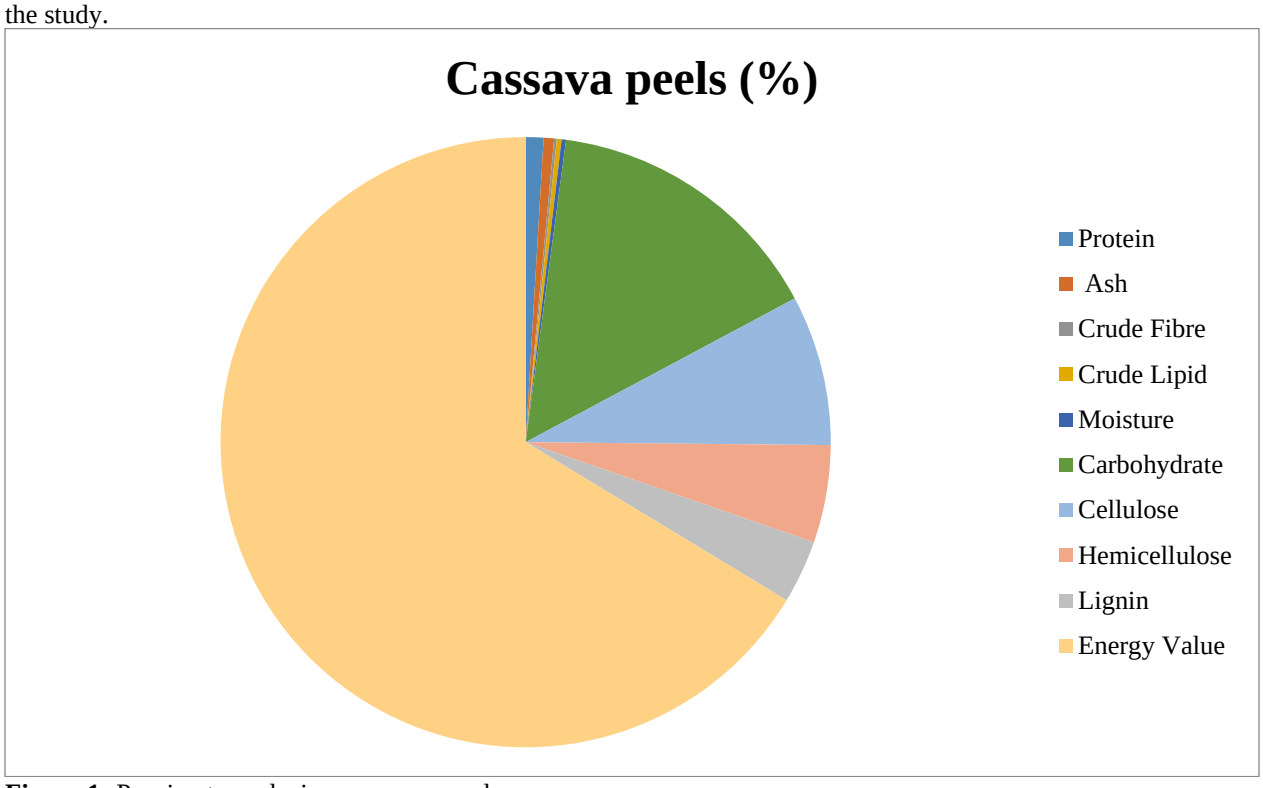


Figure 1: Proximate analysis on cassava peels

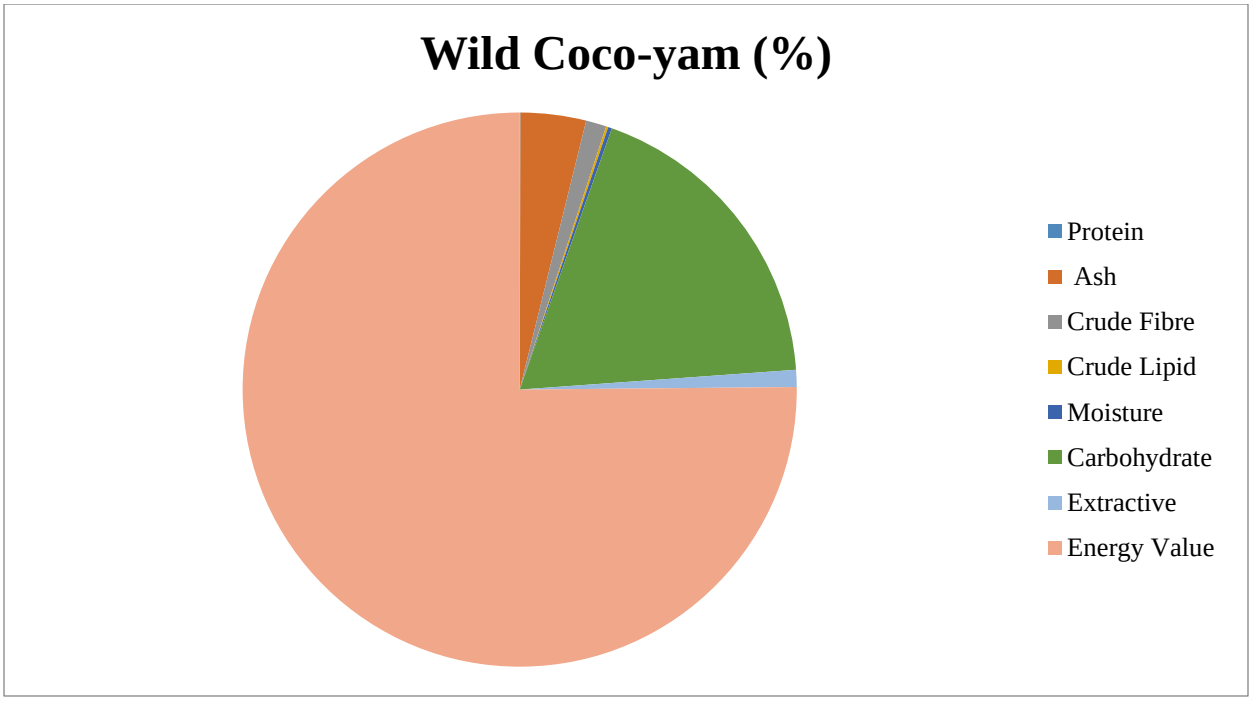


Figure 2: Proximate analysis on wild cocoyam

Table 3: Comparative proximate analysis of wild cocoyam and cassava peels

Sample Test		Composition (%)	
S/N	**Proximate Analysis**	**Wild Coco-yam (%)**	**Cassava peels (%)**
1	Protein	0.18	5.46
2	Ash	16.00	3.21
3	Crude Fibre	5.00	0.81
4	Crude Lipid	0.53	1.47
5	Moisture	0.92	1.36
6	Carbohydrate	77.37	87.69
7	Cellulose	-	46.3
8	Hemicellulose	-	30.06
9	Lignin	-	19.48
10	Extractive	4.16	-
11	Energy Value	314.97	385.83

Statistical studies of cassava peel cellulose (CPC) and wild cocoyam starch (WCS) glucose yield

The Box-Behnken design (BBD) was employed to assess the impact of acid concentration, temperature, and time on the glucose yield of cassava peel cellulose and wild cocoyam starch. The study found that the glucose yield values for cassava peel cellulose ranged from 8.96% to 45.5%, whereas the glucose yield for wild cocoyam starch ranged from 6.07% to 42.28%.

Table 4: The design matrices for the experimental and predicted values using BBD

Std	**Run**	**Acid concentration**	**Temperature**	**Time**	**Cassava Glucose Yield**		**Cocoyam Glucose yield**	
		Mol/dm3	deg C	Min	%		%	
					Actual value	Predicted value	Actual value	Predicted value
1	1	1	30	35	8.96	8.39	7.0	6.48
7	2	3	40	10	30.37	30.00	25.8	25.51
10	3	2	40	35	45.5	43.96	42.3	40.04
16	4	3	30	35	27.8	27.86	22.6	22.09
14	5	1	50	35	24.7	24.64	19.5	19.98
11	6	2	40	35	44.5	43.96	39.3	40.04
2	7	3	40	60	19.5	19.24	14.3	14.51
8	8	2	50	60	13.6	13.28	10.5	9.71
13	9	2	50	10	21.3	21.10	18.2	17.90
4	10	1	40	60	14.7	15.07	11.6	11.84
6	11	2	30	60	9.2	9.40	6.1	6.34
5	12	2	40	35	42.5	43.96	39.4	40.04
17	13	3	50	35	25.1	25.67	22.0	22.51
9	14	1	40	10	13.4	13.66	10.3	10.04
12	15	2	30	10	10.6	10.92	6.6	7.35
15	16	2	40	35	44.1	43.96	40.1	40.04
3	17	2	40	35	43.2	43.96	39.2	40.04

Upon performing regression analysis on the experimental data, it was determined that the quadratic model was the most suitable for evaluating the glucose yield of both cassava peel cellulose and wild cocoyam starch (as shown in Table 5). This is because the model optimised the statistically adjusted R^2, R^2, and predicted R^2 values to their maximum. The coefficient of determination (R^2) for the cassava peel cellulose and wild cocoyam starch glucose yield responses were obtained using a statistical method based on ANOVA. The R^2 values were 0.9977 and 0.9967, respectively. Che-Sulaiman et al. (2017) state that a regression model is considered to have a strong fit with a high correlation when its R^2 value exceeds 0.9. The resulting R^2 values show that over 99% of the response variables can be explained by the RSM model.

Table 5: Model summary statistics showing quadratic model as the most suited model

Source	Std. Dev.		R^2		Adjusted R^2		Predicted R^2		PRESS		Remark
	CPC glucose yield	WCS glucose yield	CPC glucose yield	WCS glucose yield	CPC glucose yield	WCS glucose yield	CPC glucose yield	WCS glucose yield	CPC glucose yield	WCS glucose yield	
Linear	14.15	13.93	0.1193	0.1075	-0.0839	-0.0984	-0.3055	-0.3119	3860.02	3705.78	
2FI	15.72	15.57	0.1639	0.1417	-0.3377	-0.3732	-1.0588	-1.0970	6087.50	5923.70	
Quadratic	**0.9820**	**1.16**	**0.9977**	**0.9967**	**0.9948**	**0.9924**	**0.9898**	**0.9814**	**30.16**	**52.59**	**Suggested**
Cubic	1.16	1.30	0.9982	0.9976	0.9927	0.9904			*	*	Aliased

The predicted R-square (Pre. R^2) value measures the accuracy of a regression model in predicting response values. On the other hand, the adjusted R-square (Adj. R^2) measures the explanatory power of the regression model when accounting for multiple factors. Adding any variable to a model will invariably boost the R^2 value, irrespective of its statistical significance. Hence, it is crucial to assess the appropriateness of the model by analyzing the Adj. R^2 value, as this value only increases if the variables improve the model beyond what would typically be expected by chance. When the adjusted R^2 values exceed 0.9, it suggests that the model is suitable or appropriate. Moreover, a discrepancy of less than 0.2 between the Adjusted R-squared and Predicted R-squared indicates the efficacy of the model (Nwuzor et al., 2023) model. The investigation found that the discrepancy between the values of Adj. R^2 and Pre. R^2 for all the responses was smaller than 0.2.

Table 6: ANOVA for the quadratic models

Source	Sum of Squares		df		Mean Square		F-value		p-value		
	CPC glucose yield	WCS glucose yield	CPC glucose yield	WCS glucose yield	CPC glucose yield	WCS glucose yield	CPC glucose yield	WCS glucose yield	CPC glucose yield	WCS glucose yield	
Model	2950.08	2815.41	9	9	327.79	312.82	339.92	232.81	< 0.0001	< 0.0001	significant
A-Acid concentration	210.23	164.52	1	1	210.23	164.52	218.01	122.44	< 0.0001	< 0.0001	
B-Temperature	98.98	96.82	1	1	98.98	96.82	102.65	72.06	< 0.0001	< 0.0001	
C-Time	43.57	42.41	1	1	43.57	42.41	45.18	31.56	0.0003	0.0008	
AB	85.01	42.77	1	1	85.01	42.77	88.15	31.83	< 0.0001	0.0008	
AC	37.03	40.96	1	1	37.03	40.96	38.40	30.48	0.0004	0.0009	
BC	9.92	12.89	1	1	9.92	12.89	10.29	9.59	0.0149	0.0174	
A^2	286.67	308.79	1	1	286.67	308.79	297.28	229.81	< 0.0001	< 0.0001	
B^2	833.39	792.09	1	1	833.39	792.09	864.23	589.50	< 0.0001	< 0.0001	
C^2	1107.23	1078.28	1	1	1107.23	1078.28	1148.21	802.50	< 0.0001	< 0.0001	
Residual	6.75	9.41	7	7	0.9643	1.34					
Lack of Fit	1.36	2.62	3	3	0.4527	0.8749	0.3358	0.5161	0.8016	0.6932	not significant
Pure Error	5.39	6.78	4	4	1.35	1.70					
Cor Total	2956.83	2824.81	16	16							

Table 3 depicts the analysis of variance (ANOVA) results for the quadratic model that was fitted, along with the significant terms in the model that are related to the dependent variable. The F-values of 339.82 and 232.81 for cassava peel cellulose and wild cocoyam starch glucose yield, respectively, indicate that the results are statistically significant. In addition, the probability that such a significant F-value is a result of random variation is merely 0.01%. Moreover, p-values below 0.05 indicate that the terms in the model are statistically significant. All model terms are significant for both cassava peel cellulose and wild cocoyam starch glucose yield. The F-values of 0.34 and 0.52, and p-values of 0.80 and 0.69 for lack of fit for cassava peel cellulose and wild cocoyam starch glucose yield respectively suggest that the lack of fit is minimal in comparison to pure error. This indicates that there is an 80.16% risk of noise creating a significant Lack of Fit F-value in cassava peel cellulose and a 69.32% chance of noise causing a significant Lack of Fit F-value in wild cocoyam starch glucose yield. Furthermore, this demonstrates the suitability of the model for the experiment. Both yields were equally represented by a quadratic polynomial model, as evidenced by the equations below. The equations established a clear empirical correlation between the dependent and independent variables. The presence of positive coefficients indicates that the factors exert a favourable influence on the response variable, whilst the negative signals imply that the factors have an opposing impact on the response.

$$CPC\ glucose\ yield = 43.96 + 5.13A + 3.52B - 2.33C - 4.61AB - 3.04AC - 1.57BC - 8.25A^2 - 14.07B^2 - 16.22C^2$$

$$WCS\ glucose\ yield = 40.04 + 4.53A + 3.48B - 2.30C - 3.27AB - 3.2AC - 1.8BC - 8.56A^2 - 13.72B^2 - 16C^2$$

Effect of the parameters on the yield

The experimental results were shown through three-dimensional response surface plots, which illustrate the relationship between two variables while keeping one variable constant. Each response surface plot exhibited a distinct peak in the design boundary, indicating that the highest glucose yield could be achieved within this region. The figures below illustrate the relationship between acid concentration, reaction temperature, and time on the glucose yield of cassava peel cellulose and wild cocoyam starch. Figures 3 (a & b) depict the correlation between temperature and acid concentration and their impact on the glucose yield. It was noted that the glucose yield rises with increasing temperature and acid concentration, however, a decrease in glucose production was seen at temperatures above 40 ^{O}C. High temperatures may inhibit acid hydrolysis activity. At a temperature of 40 ^{O}C and an acid concentration of 2.0 mol/dm^3, the cassava peel cellulose produced approximately 45.5% glucose, while the wild cocoyam starch yielded around 42.4% glucose under the same processing conditions. A study by Ajani et al. (2011) has also found a similar observation regarding the acid hydrolysis of waste cellulose derived from Agricultural Derived Biomass. This phenomenon can be explained by the fact that when the acid concentration is high and the temperature is relatively high, glucose can undergo a conversion process into organic acid. This conversion results in a decrease in the concentration of glucose. Consequently, it can be inferred that the highest yield of glucose can be achieved when the acid concentration is low to moderate.

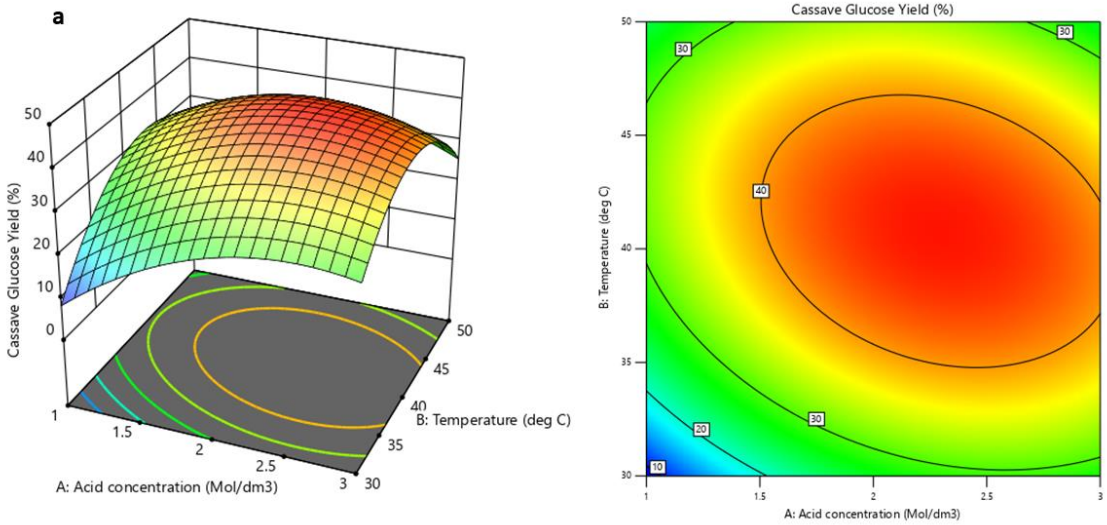


Figure 3a: 3D and contour plots of the effect of acid concentration and temperature on the glucose yield of cassava peel cellulose

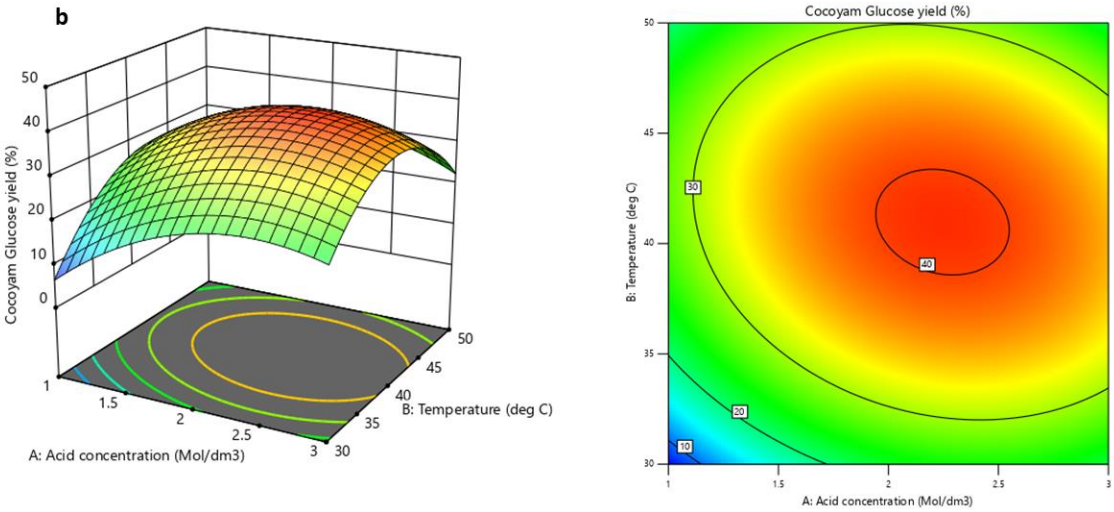


Figure 3b: 3D and contour plots of the effect of acid concentration and temperature on the glucose yield of wild cocoyam starch.

Figures 4a and b illustrate the correlation between the yield of glucose produced and the combined effect of acid concentration and time during the acid hydrolysis of cassava peel and wild coco-yam. The Figures clearly demonstrate that the yield of glucose increased with both time and concentration. However, there was a decrease in glucose yield when the period exceeded 30 minutes and the acid concentration reached 2.0 mol/dm^3. The yield achieved after 30 minutes with an acid concentration of 2.0mol/dm^3 was decreased. This could be attributed to the high acid concentration, which perhaps led to the digestion of the substrates.

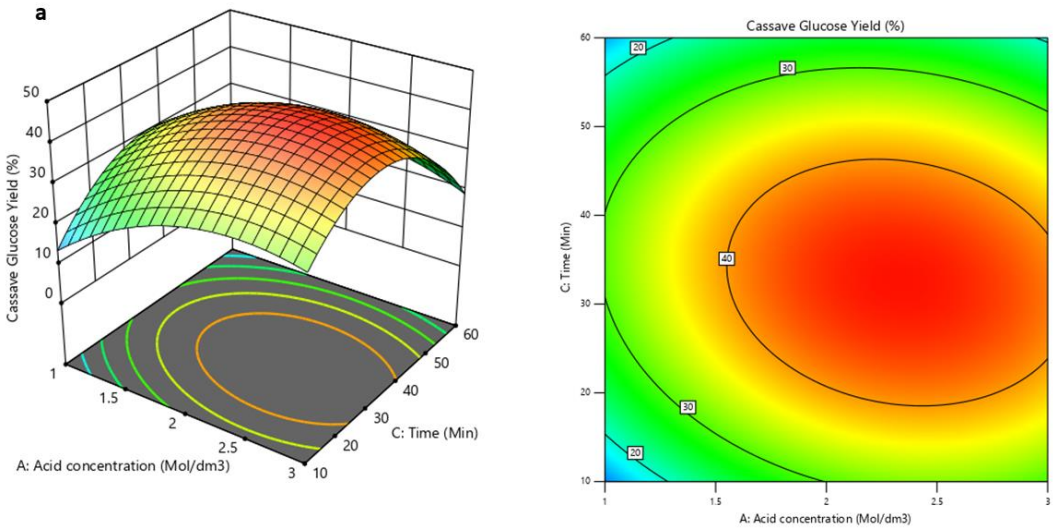


Figure 4a: 3D and contour plots of the effect of acid concentration and time on the glucose yield of cassava peel cellulose

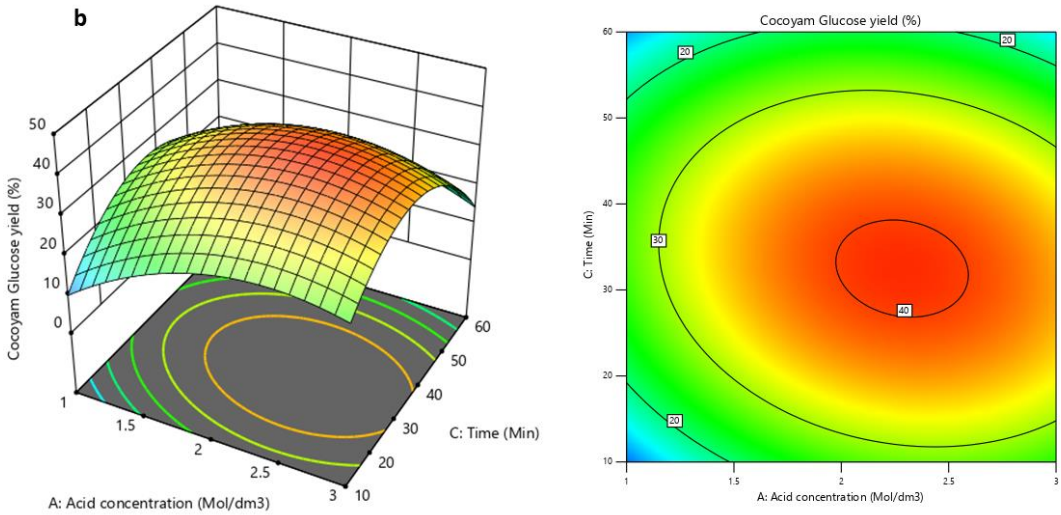


Figure 4b: 3D and contour plots of the effect of acid concentration and time on the glucose yield of wild cocoyam starch.

Figures 5 (a & b) depict the correlation between temperature and time in relation to the amount of glucose produced by the acid hydrolysis of cassava peel cellulose and wild cocoyam starch. An increase in both temperature and time was found to result in an increase in glucose yield. However, a decrease in glucose yield was reported at temperatures above 40 ^{O}C. The high temperature may impede the acid activity on the substrates, resulting in a decrease in the yield of glucose from the substrates. Igbokwe et al. (2016) achieved a comparable outcome.

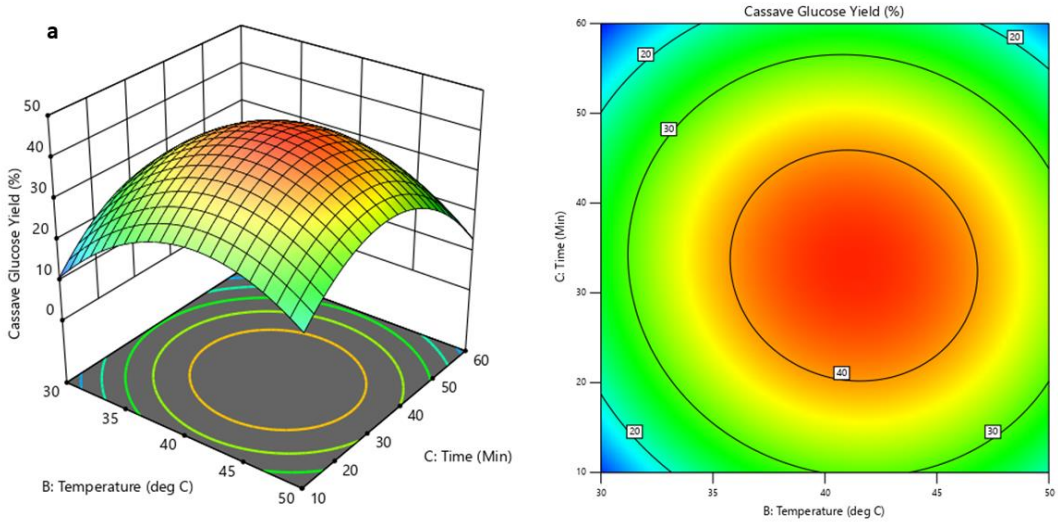


Figure 5a: 3D and contour plots of the effect of temperature and time on the glucose yield of cassava peel cellulose

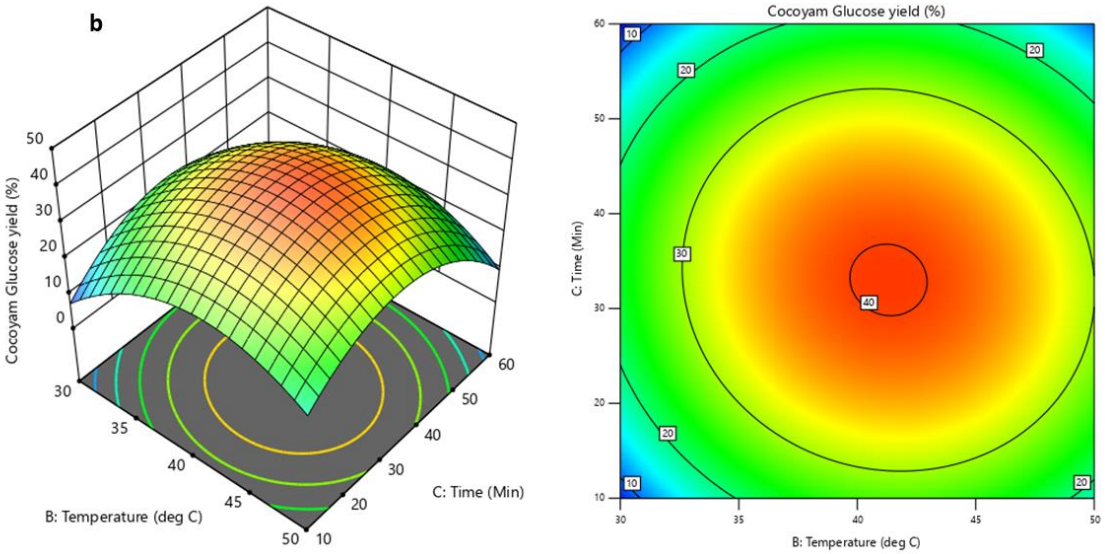


Figure 5b: 3D and contour plots of the temperature and time on the glucose yield of wild cocoyam starch

Optimization and verification of the experiment

The experimental design was used to optimize the glucose yield for both cassava peel cellulose and wild cocoyam starch. The optimum yield for cassava peel cellulose was obtained at an acid concentration of 2.3 mol/dm^2, temperature of 40 ^{O}C, and time of 32 minutes, while the optimum yield for wild cocoyam starch was obtained at an acid concentration of 2.26 mol/dm^2, temperature of 41 ^{O}C, and time of 32 minutes. The predicted optimal glucose yield was 45% and 40.9% for cassava peel cellulose and wild cocoyam starch respectively. Also, the desirability of the experiment was 98.8% and 96.3% for cassava peel cellulose and wild cocoyam starch respectively. Confirmation experiments were carried out, and the findings were compared to the model's prediction. The average experimental glucose 43.53% and 39.01% for cassava peel cellulose and wild cocoyam starch respectively. The percentage error between predicted and experimental values was 3.26% and 4.62 for cassava peel cellulose and wild cocoyam starch respectively, which was less than 5%, suggesting satisfactory agreement. Therefore, this study design models are critical in understanding glucose yield from cassava peel cellulose and wild cocoyam starch.

4.0. Conclusion

These findings have both theoretical and practical implications. This study contributes to the extant literature on this topic and helps broaden our understanding on how to harness our agricultural wastes to help our developing country and make efficient use of available resources alongside improving the environment. While research interest into the use of agricultural biomass to produce biofuel is increasing, largely due to the global awareness of the inadequacies of the almost total reliance on fossil fuels as energy sources, it is important to investigate the ethanol productivity of such important tropical crops as cocoyam and cassava. Due to low aromatic content and pure nature of the biofuel, the unhealthy gas pollution in our environment caused by petrol from the exhaust of vehicles can be reduced to the lowest level because of bioethanol complete combustion in motor engines.

Acknowledgements

The author would like to thank the Tertiary Education Trust Fund (TETFund), Nigeria

References

Adelekan. A. 2012. An Evaluation of the global potential of cocoyam. (Colocasia and Xanthosoma species) as an energy crop. British Journal Applied Science and Technology, 2(1), 1-15. African Journal of Envr. Science & Technology, 4(7): 465-470.

Aiyeloja, A.A. and Bello, O.A. 2006 Ethnobotanical Potentials of Common Herbs in Nigeria: A Case Study of Enugu State. Educational Research and Review, 1: 16-22.

Ajani, A. O., Agarry, S. E. and Agbede, O. O. 2011 A Comparative Kinetic Study of Acidic Hydrolysis of Wastes Cellulose from Agricultural Derived Biomass Journal of Applied Sciences and Environmental Management 15(4): 531 – 538.

Akpata, D. F., & Babalola, T. O. 2012. The use of cassava, sweet potato and cocoyam, and their byproducts by non-ruminants. International Journal of Food Science and Nutrition Engineering, 2(4): 54-62.

Amenaghawon, N. A., Osagie, E. I. and Ogbeide, S. E. 2016 Optimisation of Combined Acid and Enzymatic Hydrolysis of Cocoyam Starch to Produce Fermentable Hydrolysate Pertanika J. Sci. & Technol. 24(1): 123-136.

Che-Sulaiman, I. S., Basri, M., Fard Masoumi, H. R., Chee, W. J., Ashari, S. E. & Ismail, M. 2017. Effects of temperature, time, and solvent ratio on the extraction of phenolic compounds and the anti-radical activity of Clinacanthus nutans Lindau leaves by response surface methodology. *Chemistry Central Journal,* 11**,** 1-11.

Chukwu, G. O. and Nwosu, K. I. 2008 Cocoyam rebirth. The renaissance of giant crop. Paper presented at the 17th Annual conference of Nigeria rural sociological Association at NRCRI Umudike. p: 11.

FAO 2007 FAOSTAT Statistics Division of the Food and Agriculture Organization, http://faostat.fao.org

Igbokwe, P. K., Idogwu, C. N. & Nwabanne, J. T. 2016. Enzymatic hydrolysis and fermentation of plantain peels: optimization and kinetic studies. *Advances in Chemical Engineering and Science,* 6**,** 216-235.

Igbokwe, P. K., Idogwu, C. N. and Nwabanne, J. T. 2015 Enzymatic hydrolysis and fermentation of plantain peels: Optimization and Kinetic studies. Advances in Chemical Engineering and Science 6(2): 216-235

Ighodaro, O.M. 2012 Evaluation Study of Nigerian Species of Musa paradisiaca Peels. http://www.sciencepub.net/researcher

Nwanekezi EC, Owuamanam CI, Ihediohanma NC, Iwouno JO 2010 Functional, particle size and sorption isotherm of cocoyam cormelflours. Journal of nutrition; 9: 973-979.

Nwuzor, I. C., Oyeoka, H. C., Nwanonenyi, S. C. & Ihekweme, G. O. 2023. Biodegradation of low-density polyethylene film/plasticized cassava starch blends with central composite design for optimal environmental pollution control. *Journal of Hazardous Materials Advances,* 9**,** 100251.

Ogunniyi, L. T. 2008. Profit efficiency among cocoyam producers in Osun State, Nigeria. International Journal of Agricultural Economics & Rural Development, 1(1): 38-46.

Omemu, A. M., Akpan, I., Bankole, M. O., and Teniola, O. D. 2005. Hydrolysis of raw tuber starches by amylase of Aspergillus niger AM07 isolated from the soil. African Journal of Biotechnology, 4(1): 199-205.