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ANALYSIS OF COSTS OF ENERGY IN CASSAVA PEELS HYDROLYSIS

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ABSTRACT

In this study, acid and enzymes were used to hydrolyze cassava peels to get reducing sugars. The values of energy and chemicals were calculated to determine cost expended on the hydrolysis. The results showed that the total energy used in acid and enzymes hydrolyses were 14.78 MJ and 3.45 MJ, respectively. The amount of reducing sugar recovered from acid and enzymes hydrolyses were 90.13% and 83.55%, respectively. Therefore, the study showed that recovery of sugar from cassava peels was better in terms of percentage yield and cost using acid hydrolysis. However, cost of energy consumption was better using enzyme hydrolysis.

KEYWORDS: Cassava-peel, sugar, energy, cost, enzyme, acid.

NOMENCLATURE

Q	heat energy applied to the cassava peel (kJ)
m_p	mass of cassava peel (kg)
m_w	mass of water (kg)
c_p	specific heat of cassava peel (kJ/kg ^{o}C)
c_w	specific heat of water (kJ/kg ^{o}C)

ΔT Applicable temperature change of the process (^{o}C)

A_{in} inner area of the fermenter (m^2)

A_{out} outer area of the fermenter (m^2)

A_{top} top area of the fermenter (m^2)

U overall heat transfer coefficient (W/m^2K)

h_{in} heat transfer coefficient inside the fermenter (W/ m^{-2}°K)

Δx thickness of insulation (m)

N_u Nusset number

Pr Prandit number

Gr Grassof number

K_w thermal conductivity of water (W/m ^{o}C)

L Length of the fermenter (m)

L_{out} outside height of the fermenter (m)

ρ density of water (kg/m^3)

g acceleration due to gravity (m/s^2)

µ viscosity (Nsm^{-2})

K Thermal conductivity of the fibre glass (W/m ^{o}C)

h_{out} heat transfer coefficient outside the fermenter (W/ m^{-2}°K)

K_a Thermal conductivity of the air (W/m ^{o}C)

L_t Height (thickness) of the top and bottom of the fermenter (m)

h_f heat transfer coefficient outside the top and bottom fermenter (W/ m^{-2}°K)

Q_t total heat energy

1.0 INTRODUCTION

Cassava peels are wastes generated during peeling operation of cassava tubers. Nigeria is the highest producer of cassava worldwide (Iyasere, 2015), the food chain and the economy of the people are webbed around cassava. Various industries that specialize in the production of items such as starch, gari, lafun, fufu, ethanol processors and other domestic usage of cassava generate tremendous wastes of cassava peels daily. This is because most often, efforts of cassava processors are concentrated on cassava tubers but other bye products especially the peels are and always discarded around the environment indiscriminately. The peels generated are sources of environmental pollution and there is need to curb this by finding alternative use to this waste. Ojo and Akande (2013) reiterated the contamination arising from indiscriminate disposal of cassava peels which has resulted in offensive smell, surface and ground pollution. Monday *et al.* (2017) recommended as a way of reducing this pollution the use of cassava peels in food formulation for livestock, and as a manure to improve soil nutrient. However, Iduogbe *et al*. (2015) asserted the limitation of cassava peels in animal feed due to its cyanide content. Therefore, there is need for alternative use so as to reduce the pollution resulting from this waste. One of the ways to reduce this is through conversion to organic acids such as citric acid, lactic acid and fumaric acid (Adenise *et al.,* 2002). For instance, Nigeria is known for importation of citric acid from various countries such as Brazil, China, the European Union and the United States (USDA) (2014/2015). Another area of using cassava peels is in the production of reducing sugar which could be useful as metabolite in submerged fermentation. This is possible because of the high percentage of starch present in the peels as shown in Table 1. To obtain any value added product such as citric acids from cassava peels there must be first conversion of starch to simple sugar mainly glucose proportional to the availability of starch content in the peels. Although, production of reducing sugar can be derived from other sources such as molasses and citrus; they are costlier in terms of availability in Nigeria and hence not a viable means of producing reducing sugars.

The production of reducing sugars is energy and reagents intensive. the cost of energy and reagents for production are major issues to be considered critically because if production is not cost effective, the purpose would be defeated unless environmental sanitation advantage is considered.

Table 1: Proximate composition of Cassava peels.

Components	Values (%)
Protein	2.84 ±0.02
Fat	0.46±0.07
Fibre	5.44±0.47
Ash	3.04±0.07
Carbohydrate	76.20±0.14
Moisture content	69.33±0.02

Source: Monday *et al.*, (2017)

The cost of energy may imply the cost of electricity or diesel as the means of energy; Felix and Joel (2013) asserted that the cost of energy is a significant part of total cost of food processing. Other cost is the cost of chemical/reagents in the production. Therefore, the objectives of this paper was to evaluate an economic study vis a vis energy cost in the production of reducing sugar from cassava peels.

2.0 MATERIALS AND METHODS

2.1 Materials

Fresh cassava peels were obtained from Ladoke Akintola University of Technology processing factory, Ogbomoso, Nigeria. The peels were fermented for three days and dried in tunnel dryer at temperature of 60^{o}C. The peels were then milled into flour and packaged for further analysis.

2.2 Reagents

Sodium hydroxide, D-glucose, calcium chloride, distill water, Benedict reagent, sodium carbonate, hydrochloric acid, alpha amylase and gluco-amylase were used for the experiments.

2.2.1 Acid hydrolysis

About 20 g of cassava peels flour were mixed with 100 ml solutions containing acid. The solutions of HCl were varied from 0.5- 1.5% concentration. The substrate obtained was heated at temperature range of 100 ^{o} C in 20 minutes. 10 g of the substrate was mixed with 100 ml of distil water and filtered with Whatman filter paper No 1. The filtrate was then titrated with the solution of Benedict’s reagent to determine the sugar level. Box Behnken design was used in the experimental design.

2.2.2 Enzyme hydrolysis

About 20 g of cassava substrate was mixed with 35 ml distil water and buffered to 6.5 with 0.1 M NaOH and heated to a temperature of 60 ^{o} C. Enzymes (α- amylase and gluco-amylase) were procured from Federal Institute of Industrial Research (FIIRO, Oshodi, Nigeria). The first enzyme α -amylase was introduced into the pulp. The amount of a-amylase added to the substrate ranged from 8-10% of the substrate. The optimal pH and temperature of the enzymes were 6.5 and 60 ^{o} C. After 20 minutes, the second enzyme gluco- amylase was introduced into the pulp at the concentration range of 8-10 % of the pulp. The condition of temperature of 60 ^{o} C and pH of 6.5 of the pulp was maintained for 5 hours. 10 g of the solution was dissolved in 100 ml of distil water and filtered with Whatman filter paper No 1. The filtrate was then evaluated for reducing sugar obtained. Heating time, temperature, mass of starch and enzyme concentrations were determined using Box Behnken experimental design.

2.3 Determination of Reducing Sugar in Cassava Peels

Reducing sugar was determined using titration method as reported by Yusuf *et al.*, (2004). The equation for determining reducing sugar is as written in Equation 1

$$\%\ glucose\ in\ sample = \frac{0.032}{v} x100 \quad (1)$$

Where v = titre value

2.4 Energy Analysis using Acid and Enzymes

The values of energy used to produce the reducing sugars from the cassava peel pulp using acid and enzymes were calculated based on thermodynamics of heat and mass transfer for the process. The hydrolysis took place in 250 ml conical flask placed inside a rectangular fermenter made of galvanized steel. The fermenter was 0.425, 0.278 and 0.273 m in length, breadth and height respectively and insulation thickness of 0.025 m.

2.5 Cost Analysis using Acid and Enzymes

The cost of chemicals and enzymes for hydrolyzing the starch was calculated in US dollars.

2.6 Time Analysis of the Process

The time taken for the production of reducing sugar was evaluated using acids and enzymes. Conclusion was made based on the percentage of sugar recovered.

2.7 Heat needed for the Process

Heat needed for the process was in three stages namely (i) heat needed for raising the temperature of cassava pulp to gelatinization (ii) heat needed to maintain the experiments till the pulp was hydrolyzed in the fermenter and (iii) heat loss to the surrounding during the process

i. Heat needed to raise the cassava peel pulp

$$Q = m_p c_p \Delta T + m_w c_w \Delta T \quad (2)$$

Where

m_p = 0.400 kg which represent 27% of total mass,

m_w = 1.10 kg which represent 73% of total mass,

c_p= 3.9 kJ/kg ^{o}C

c_w= 4.18 kJ/kg ^{o}C

ΔT= Applicable temperature change of the process(^{o}C)

ii. Heat needed to maintain the process to get reducing sugar

The heat needed to maintain the process was related to the convective heat in the fermenter which equals the heat loss to the surrounding of the fermenter

Heat loss through the rectangular wall

$$Q = UA_{out}\Delta T \quad (3)$$

A_{out} =0.1617 m^2

The component of U can be further explained arising from the fact that it was made of different layers of composite slab. The heat passed through the surface first, then through the insulator of the composite slab.

$$\frac{1}{U} = \frac{1}{h_{in}} + \frac{\Delta x}{k} + \frac{1}{h_{out}} \quad (4)$$

Δx= 0.025 m

The first term was the heat transfer coefficient (h_{in}) related by Equation 5

$$h_{in} = N_u.\frac{K_w}{L} = \quad (5)$$

K_w=0.682 (W/m^oK) at 100 ^{o} C, for acid hydrolysis (Table A.4.1 Paul and Heldman 2009)

K_w=0.658 at 60 ^{o} C, for enzyme hydrolysis (Table A.4.1 Paul and Heldman 2009)

$$N_u = k(P_r.G_r)^m \quad (6)$$

P_r= 1.75 for acid**, (**Table A.4.1 Paul and Heldman 2009)

P_r=3.00 for enzyme (Table A.4.1 Paul and Heldman 2009)

k=0.53

m=0.25

$$G_r = \frac{L^3\rho^2 g\beta\Delta T}{\mu^2} \quad (7)$$

L = 0.42m

ρ =1000 kg/m^3

g= 9.81 m/s^2

For acid,

$T_{surface}$ = 60 ^{o} C = 273+60= 333 ^{o} K

β=1/T$_{suface}$, =1/60 ^{o} = 1/333 ^{o}K

β = 0.00303/k

μ = 277.528 x10^{-6} Nsm^{-2} (Paul and Heldman 2009)

For Enzyme**,**

T$_{surface}$ = 40 ^{o} C = 273+40= 313 ^{o} K

β = 1/313 ^{o} K= 0.0032 k)

μ =471.65x10^{-6} Nsm^{-2} (Table A.4.1 Paul and Heldman 2009)

The second parameter was the conductive heat transferred through the insulator of the fermenter related by the equation $(\frac{\Delta x}{k})$

Δx= Thickness of the insulator (fibre glass) = 0.025 m

K = 0.048 W/m ^{o}C

iii. Heat loss to the surrounding

The 3rd parameter was the convective heat loss to the surrounding air outside the fermenter through the outer wall of the fermenter.

$$h_{out} = N_u . \frac{K_a}{L_o} \quad (8)$$

k_a =0.0258 W/m ^{o}C at 32 ^{o} C

L_o=0.306 m

$N_u = k(P_r . G_r)^m$

P_r = 0.71 Table A.4.1 (Paul and Heldman 2009)

$$G_r = \frac{L^3 \rho^2 g \beta \Delta T}{\mu^2} \quad (9)$$

L$_{out}$ = 0.306m

ρ =1.127 kg/m^3

g= 9.81 m/s^2

T$_{suface}$ = 32 ^{o} C = 313 ^{o} K

β=1/T$_{suface}$, 1/305= 0.0032/k,

μ = 17.6 x10^{-6} Nsm^{-2}

Also, heat lost through the top equals the heat loss through bottom insulator of the fermenter to the surrounding air

$$Q = UA_{top}\Delta T \quad (10)$$

$$\frac{1}{U} = \frac{\Delta x}{k} + \frac{1}{h_{fo}} \quad (11)$$

The first term is the heat loss through the insulation

Δx= 0.025 m

K = 0.048W/m ^{o}C

The second term is the convection outside the top and bottom wall of fermenter

$$h_f = N_u.\frac{K_a}{L_t}$$

$$N_u = 0.53(\mathrm{Pr.Gr})^{0.25}$$

P_r= as above

G_r = as above

Total heat energy for the process was got considering each time the experiment lasted for each process

$$Q_t = Q.time \quad (12)$$

3.0 RESULTS AND DISCUSSION

The proximate composition of cassava peels used in this work is as shown in Table 2. The peels samples had carbohydrate content of 75.99%. This provided the basis for hydrolyzing the samples to get sugar. The effects of cassava peel concentration, heating time and enzyme concentration on the production of reducing sugar are demonstrated in Figures 1a and b. The maximum sugar recovered from 20 g of cassava peel was 12.7 g which represented 83.55%. Furthermore, figures 2a and b show the influence of hydrolysis time and temperature on the samples to get sugar using acid hydrolysis. The maximum reducing sugar recovered from 20 g of cassava peel sample was 13.7 g representing 90.13 %. It was observed that increase in acid concentration, heating time and enzyme concentration favoured increase in sugar recovery from peels. Such observation was earlier reported by Ram *et al.*, (2015).

Table 2: Proximate composition of cassava peels.

Components	Values (%)
Protein	1.84 ±0.02
Fat	1.89±0.07
Fibre	3.44±0.17
Ash	3.94±0.07
Carbohydrate	75.99±4.14
Moisture content	12.53±0.02

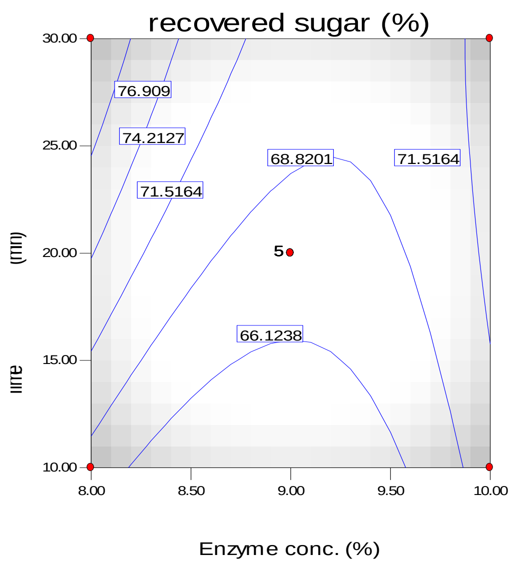

Figure 1a: Effect of time and enzyme concentration on recovered sugar

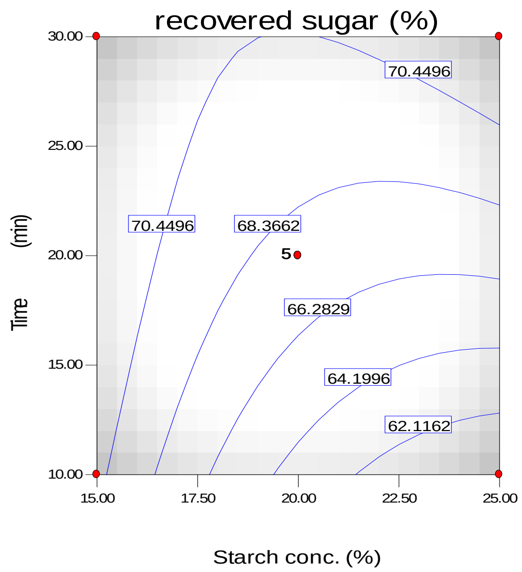

Figure 1b: Effect of time and starch concentration on recovered sugar

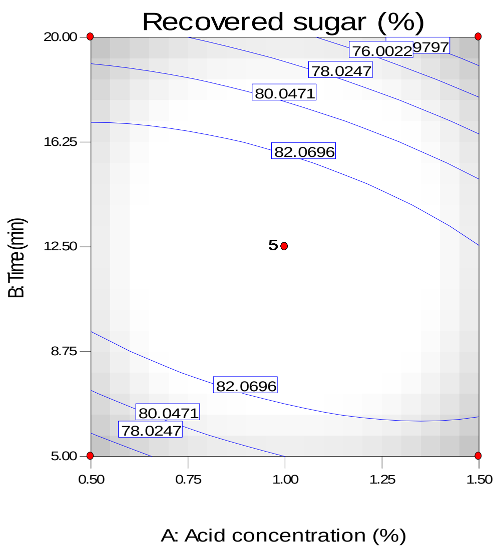

Figure 2a: Effect of time and acid concentration on recovered sugar

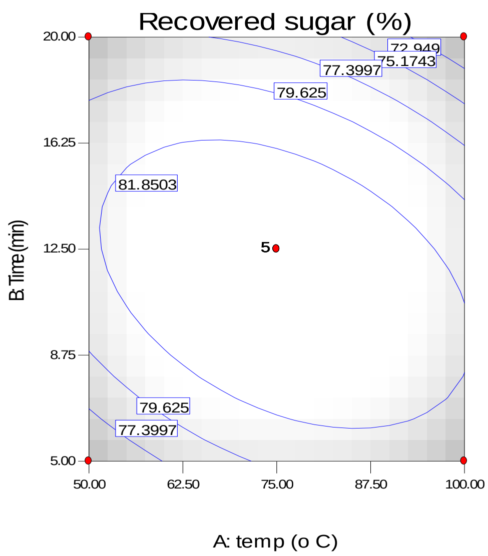

Figure 2b: Effect of time and temperature on recovered sugar

Figure 1a. The influence of processing time and the concentration of enzymes is significant in the hydrolysis of cassava peels to get reducing sugar. Increase in time and enzyme increased the recovered sugar.

Figure 1b. The influence of sample size of cassava peels which determined starch concentration is significant in the production of sugar in the hydrolysis.. Increase in starch concentration favoured increase in the recovered sugar.

Figure 2a. The influence time of hydrolysis and the concentration of acid is significant in the hydrolysis of cassava peels to get sugars. Increase in time and acid concentration increased the production of reducing sugars.

Figure 2b. Time and temperature of hydrolysis is significant in the hydrolysis of cassava peels to get sugars. Increase in time and temperature increased the production of reducing sugars.

3.1 Energy Expended on Cassava Peels to Recover Reducing Sugar Using Acid and Enzymes

3.1.1 Energy Cost Using Acid for Hydrolysis 100 ^{o} C

Energy to heat cassava peel from 29 to 100 ^{o} C = 14.03MJ a

Heat Loss to the environment = 624.68 J/s

Hydrolysis Time = 20 minutes

Total heat loss =749.62kJ b

Total heat required = a+b = 14.78 MJ =4.1kWh

3.1.2 Energy Cost Using a-Amylase for Hydrolysis (60 ^{o} C, pH 6.5)

Energy to heat cassava peel from 29 to 60 ^{o} C = 1.951MJ a

Heat Loss to the environment = 13.62J/s

Hydrolysis Time = 20 minutes

Total heat loss =16.342kJ b

Total heat required = a+b = 1.967 MJ= 0.546kwh

3.1.3 Energy Cost Using Gluco-amylase for Hydrolysis (60 ^{o} C, pH 6.5)

Heat Loss to the environment = 13.62 J/s

Hydrolysis Time = 5 hours = 18,000 s

Total heat required = 245.16 kJ

3.1.4 Energy Cost for Enzyme inactivation

Energy to heat cassava peel from 60 to 100 ^{o}C = 1.48 MJ a

Heat Loss to the environment = 12.79 J/s

Deactivating Time = 10 minutes

Total heat loss = 7.674 kJ b

Heat required = (a+b)= 1.49 MJ = 0.413 kwh

Total heat required = (1.967+ 0.000245 +1.49)MJ = 3.45MJ=1.1kWh

From the above calculations, analysis of energy to hydrolyse samples to get reducing sugars showed that 14.78 MJ was used for acid hydrolysis whereas a total energy of 3.45 MJ was used during enzyme. This shows that energy used in acid hydrolysis was 4 times over enzyme hydrolysis meaning that acid hydrolysis was energy intensive compared to enzyme hydrolysis. Although, the time taken in acid hydrolysis was shorter than enzyme's, but the temperature of operation was higher which accounted for higher energy used. Other disadvantages of acid hydrolysis as reported by Martin and Christopher (2014) are corrosiveness of fermenting vessel, high colour, higher energy for heating and difficult process control. The implication of energy cost using electricity in Nigeria is as demonstrated in Table 3. From this table, the cost of hydrolysis using acid was $20.5 while that of enzyme was $5.0. This implies that enzyme hydrolysis is cost effective when considering energy used.

Table 3: Cost of energy used in 0.4 kg cassava peels hydrolysis.

Hydrolysis mode	Energy used (kwh)	Unit price (US$)	Total cost (US$)
Acid	4.10	5	20.5
Enzyme	1.10	5	5

4.0 CONCLUSION

The research had shown that acid hydrolysis of cassava peels produced higher reducing sugar recovery while enzymatic hydrolysis utilized lower energy in the process.

5.0 ACKNOWLEDGEMENT

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