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RESEARCH ARTICLE

ENERGY BALANCE, MATERIAL BALANCE AND COST BENEFIT ANALYSIS FOR THE PRODUCTION OF BIOETHANOL FROM NON-FOOD PARTS OF BITTER CASSAVA

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ABSTRACT

Bio energy is the predominant renewable energy source in most low-income countries though mostly with inefficient production and utilization technologies. The versatility and flexibility of bioenergy offers a variety of clean energy options. Bioethanol and biodiesel have received the most attention as alternative cooking and vehicle biofuels. Research on the production of bioethanol from the non-food parts of cassava including the leaves, stems and peelings has yielded promising results. However, the energy balance, material balance and cost benefit analysis usually lack in these studies. It is against this background that this study compared the dynamics of energy and material balance and their effect on the cost of bioethanol production from both cassava roots (without peelings) and non-food parts. A bitter variety and sweet variety were used. Bioethanol was produced from leaves, peelings, stems and roots by Simultaneous Saccharification and Fermentation followed by a two-step distillation and dehydration using zeolite. On average, the roots required 500 ml of distilled water per 50 g of a sample to produce 39.7 ml of 96% bioethanol, 464.8 ml of waste water and 17.4g of solid waste. The leaves, peelings and stems required 250 ml of $D.H_20$ per 50 g of a sample to produce 80.9 ml of 95.3% bioethanol, 506.3 ml of waste water and 56.5g of solid waste. A negative energy balance and cost benefit ratio greater than one were obtained.

KEYWORDS

Cellulose, Starch, SSF, Biomass, Biofuels.

1. INTRODUCTION

In order to combat climate change, renewable energy technologies have been promoted worldwide to replace fossil fuels. Uganda is endowed with renewable energy sources such as biomass, wind, geothermal, hydropower and solar (London Economics International, 2021). Just like most low- and middle-income countries, bioenergy remains the primary energy source though usually unsustainable and inefficient. The versatility and flexibility of bioenergy offers a variety of clean energy options (Röder et al., 2020).

Unprocessed biomass takes over 85 percent of the cooking fuels used in Uganda followed by charcoal which is used by 13 percent of the population, mainly in urban and peri-urban areas. LPG and kerosene are used in small portions of less than 0.5 percent each and about 0.8 percent is a mix of fuels produced from small enterprises and electricity (Katutsi et al., 2020). There is persistent reliance upon charcoal even when household income increases since the upfront costs for the improved cookstoves and LPG bottles hinder modernizing of cooking methods (Lee, 2013).

Uganda's transport sector entirely depends on imported petroleum products which are routed through Kenya and Tanzania with the current daily consumption at 550,000 m^3 (Marembo et al., 2018). Additionally, the Albertine graben was discovered as the most probable field for high petroleum exploration prospects in Uganda and the government recently collaborated with Tanzania government to build a crude oil pipeline. However, this is still in its early stages with exploration and development still going on (Marembo et al., 2018).

Bio-ethanol and biodiesel have received the most attention as alternative cooking and transport fuels and are currently used as neat fuels and blends in countries such as Sweden, Australia, Canada, Brazil and USA (Capodaglio & Bolognesi, 2019). Efforts to produce biofuels from baggase, molasses, jatropha oil and waste vegetable oil have mostly been on small scale (Okello et al., 2013). Besides being a transport fuel, bioethanol in particular can be used for cooking, in the production of biodiesel, beverages, tinctures, pharmaceuticals, antiseptics and perfume as well as a solvent and preservative (Ritslaid et al., 2010).

Bitter cassava roots (starch component) and non-food parts (cellulose component) of both sweet and bitter cassava varieties can be utilized for bioethanol production with limited effect on food security (Yesmin et al., 2020). In Uganda, bitter cassava is usually preferred for flour production, brewing local beer and distilling into local gin (Andama & Oloya, 2017). Uganda's National Crop Resources Research Institute, (NaCRRI), Namulonge has developed over 40 varieties of cassava, and among these is NASE 3 (Migyera), a high yielding, high cyanide variety that was

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specifically bred for industrial purposes (Manano et al., 2017).

To reduce processing time and energy consumption, saccharification and fermentation are carried out in a single step (Simultaneous Saccharification Fermentation) (Saggi & Dey, 2019). Glucoamylase and yeast are added at the same time so that as glucoamylase produces glucose, yeast immediately turns it into ethanol therefore no glucose is accumulated throughout the fermentation period (Althuri et al., 2018).

Normal distillation allows up to about 95% bioethanol and 5 % water therefore other methods must be opted for to obtain 100% bioethanol concentration. Molecular sieves (zeolite), specifically type 3A, can be used for bioethanol dehydration through adsorption of water molecules while excluding the bioethanol molecules (Chopade et al., 2015). Molecular sieves can be regenerated, have high dehydration rates, low energy consumption and no emissions associated.

Bioethanol production from the cassava roots (without peelings) is already being carried out on industrial scale either by using extracted cassava root starch or the whole unpeeled root presenting a direct threat to food security (Quintero et al., 2015). Research on the production of bioethanol from the non-food parts of cassava including the leaves, stems and peelings yielded promising results (Nuwamanya et al., 2012). However, the cost implications, energy balance and material balance were not studied.

It is against this background that this study focused on comparison of the dynamics of energy and material balance and their effect on the cost of bioethanol production from both cassava roots (without peelings) and non-food parts. Material balance for the bioethanol batch processes was determined over a period of time (integral balance) (Doran, 1995). On the other hand, energy balance for bioethanol involved the comparison of the energy released by burning bioethanol to the energy used in the processing of the bioethanol.

2. Materials and Methods

A bitter cassava variety, NASE 3 (Migyera) and a sweet cassava variety Nyaraboke were used for this study in order to compare the quality and quantities of their bioethanol. Nyaraboke samples were obtained from the NaCRRI field in Kamuli District while the NASE 3 samples were obtained from the NaCRRI field at Namulonge. Feedstock preparation and Simultaneous Saccharification and Fermentation and bioethanol dehydration were carried out in the Bioscience Laboratory of NaCRRI. Distillation was carried out in the Chemistry laboratory at Kyambogo University. Standard solutions of the enzymes used in the study were made from Uganda Industrial Research Institute (UIRI) while the molecular sieves were purchased from eBay (USA).

2.1 Bioethanol Production and Characterization

2.1.1 Preparation of feedstock

Fresh leaves, stems, peelings, and roots (without peelings) samples for both varieties were collected in quantities of 5 kg each and then stored in a refrigerator at 4°C. The cassava stems, peelings, and roots samples were washed, chopped, dried in a screen house for a week and then milled using an industrial blender. Leaf samples were washed and oven dried at 60°C for 24 hours and then ground. The subsequent dry samples were weighed and then analyzed in triplicates.

2.1.2 Composition analysis of the samples

The treated samples were analyzed for protein, total carbohydrates and reducing sugars. The protein test was carried out by adding 0.1 ml of the sample to 5 ml of distilled water and boiling for 30 minutes at 80°C. On cooling, 3 ml of Bradford reagent was added to 0.1 ml of the clear sample solution, mixed well and read at 595 nm absorbance (Kruger, 2009).

Total carbohydrates were analyzed by adding 0.1 g of the sample to 5 ml of 10% H_2SO_4 and incubating at 80°C for 30 minutes in a thermostatic water bath. On cooling and filtering, 0.5 ml of supernatant was mixed with 5 % phenol, 1 ml distilled water and 1 ml of H_2SO_4. This was followed by shaking well, waiting for 10 minutes and then taking the reading at 490 nm absorbance (Dubois et al., 1956).

Reducing sugars were obtained by boiling 0.1 g of a sample in 2 ml of distilled water for 30 minutes. This was followed by adding 1 ml of distilled water, 0.5 ml of 5% phenol solution and 1ml Conc. H_2SO_4 to 0.5 ml of the boiled solution. On cooling, the absorbance was read at 490 mm on a spectrophotometer (Dubois et al., 1956).

2.1.3 Liquefaction and Simultaneous Saccharification and Fermentation (SSF)

The procedure for SSF of starch was obtained from Saggi & Dey (2019) and Antonio, Kimura, Shimizu, & Shiiba (2006) with slight modification based on experimental trials. A 500 ml slurry was made by mixing 50 g of cassava flour with distilled water. The slurry was liquefied at for two hours in the presence of 100 U/g-flour of α-amylase enzyme. This is usually carried out to rupture the starch granular structure. The pH and temperature were then adjusted to 4.5 (using NaOH) and 35°C, respectively, to create a suitable environment for yeast fermentation.

The procedure for SSF of cellulose was obtained from Saggi & Dey (2019) and Otulugbu (2012) with slight modification based on experimental trials. Stem, leaves and peelings samples (50 g each) were added to separate conical flasks and 500 ml of 2 M H_2SO_4 added to each. The mixture was placed in the oven at 120 °C for 30 minutes, and then cooled to 30 °C and the pH was adjusted to 4.61 by adding 10M NaOH.

This was followed by adding 100 U/g-flour of enzymes (amyloglucosidase for starch samples and cellulase for cellulose samples) as well as 10g baker's yeast (Saccharomyces cerevisiae), 5 g of D-glucose and 10 g peptone. Simultaneous Saccharification and fermentation was then conducted for all the samples at 35°C for 5 days with mild agitation while testing for the amounts of reducing sugars in the mixture once a day.

2.1.4 Distillation and dehydration of brew

The distillation setup was made of conical flasks, condensation units, thermometers and glass filters. The brew was poured into a distillation flask, placed on a hot plate and connected to a condensation unit. The first distillation took place at 93°C for two hours and the second distillation took place at 80°C for 30 to 45 minutes.

The distilled bioethanol was dehydrated to 95% using molecular sieves (zeolite) (Figure 1). Molecular sieves of 25 g weight were soaked in each distilled sample overnight and then filtered to separate the soaked sieves from the dehydrated bioethanol (Chopade et al. , 2015).

2.1.5 Characterisation of bioethanol

The quality of bioethanol produced from the different samples was obtained by testing for the calorific value, bioethanol concentration, pH and presence of chlorides and sulphates. The calorific value was obtained using a bomb calorimeter IKA C2000 model, the pH using a Thermo Scientific Orion 3 Star pH bench top model pH meter and the bioethanol concentration was calculated using equation 1& 2 (Nuwamanya et al., 2012).

$$m=(a)(sga) + (v-a)(sgb) \quad (1)$$

$$a/v = (m - v * sgb)/(sga - sgb)/v \quad (2)$$

Where a = volume of ethanol

(v-a) = b = volume of water

sga = specific gravity of ethanol = 0.789

sgb = specific gravity of water = 1

m = mass of the mixture

v = Volume of the mixture

The presence of chlorides was determined by adding 0.5 ml of 0.1M Silver Nitrate solution to 0.5 ml of the bioethanol. The presence of sulphates was determined by adding 0.5 ml of 0.1M barium chloride solution to 0.5 ml of the bioethanol (Nuwamanya et al., 2012). Formation of a precipitate on addition of silver nitrate and barium chloride indicates the presence of chlorides and sulphates, respectively.

2.2 Material Balance

The mass of raw materials were compared to the products generated, wastes and stored material were measured at the different unit processes (Balance, 1987). The reagents, brew, waste water and solid waste were measured for Simultaneous Saccharification and Fermentation. For the first and second distillation, the bioethanol and bottoms (waste water) were measured. For dehydration, the bioethanol, waste water and molecular sieves (before and after dehydration) were measured. The quantity of carbon dioxide was not measured in this study.

2.3 Energy Balance

The energy balance was conducted from feedstock preparation to

dehydration without considering energy used in growing the cassava. Drying of the feedstock during pretreatment and molecular sieves after dehydration was done using solar drying. Equations 4, 5 and 6 were used to calculate energy used for pretreatment, SSF, distillation and dehydration. Equation 7 was used to determine the energy content of the bioethanol produced per feedstock (Halder, 2014).

Energy used for oven drying of the molecular sieves;

$$Q=m \times L \tag{4}$$

Where m is the mass of fuel and L is the latent heat of vaporization.

Energy supplied by electricity during milling and distillation;

$$Q=kWh \times t \tag{5}$$

Where t is the time and kWh is the power rating for the blender and electric heater.

Energy utilized by the water bath for Simultaneous Saccharification and Fermentation (SSF);

$$Q=IVt \tag{6}$$

Where I is the current in Amperes, V is the voltage in volts and t is the time in seconds.

Energy contained by the bioethanol produced from each feedstock was calculated using Equation 7. The density of Ethanol was used as 0.8 g/cm^3 or 0.0008 kg/ ml.

$$Q=CV*\text{Volume of ethanol} \tag{7}$$

Where CV is the calorific value in MJ/kg.

2.4 Cost Benefit Analysis

The cost of materials, reagents and energy for production of bioethanol in this study was calculated for every 50 g of each of the starch and cellulose feedstock. This was then compared with the benefits from selling the bioethanol produced.

2.5 Data Analysis

Data analysis was carried out through ANOVA and regression analysis using R Studio statistical software. ANOVA was used to establish whether there was a significant difference in the quantity of bioethanol produced from the different feedstock. Regression analysis was used to determine the relationship between bioethanol yield and feedstock composition (protein, carbohydrates and reducing sugars).

3. Results and Discussion

3.1 Feedstock Composition

Leaves for both varieties had the highest carbohydrate levels followed by the peelings, stems and the roots. Protein and reducing sugar levels were generally low in all the feedstock. NASE 3 leaves and roots had more carbohydrates than the Nyaraboke variety leaves and roots. On the other hand, Nyaraboke peelings and stems had more carbohydrates than NASE 3 (figure 1).

Results from ANOVA indicated a significant difference in amounts of carbohydrates, proteins and reducing sugars for the different feedstock at 0.05 significance level. The P values for carbohydrates, reducing sugars and proteins were 3.1×10^{-12}, 2×10^{-16} and 3.17×10^{-10} respectively (table 1, 2, 3).

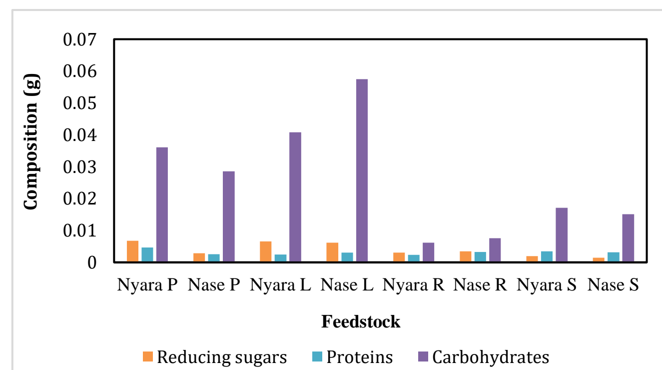

Figure 1: Composition analysis for the different feedstock

Table 1: ANOVA for reducing sugars

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	9	0.16665	0.018516	972.7	<2e-16 ***
Residuals	14	0.00027	0.000019		

Table 2: ANOVA for Carbohydrates

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	9	11.834	1.3149	144.2	3.1e-12 ***
Residuals	14	0.128	0.0091		

Table 3: ANOVA for Proteins

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	9	0.019377	0.0021530	73.34	3.17e-10 ***
Residuals	14	0.000411	0.0000294		

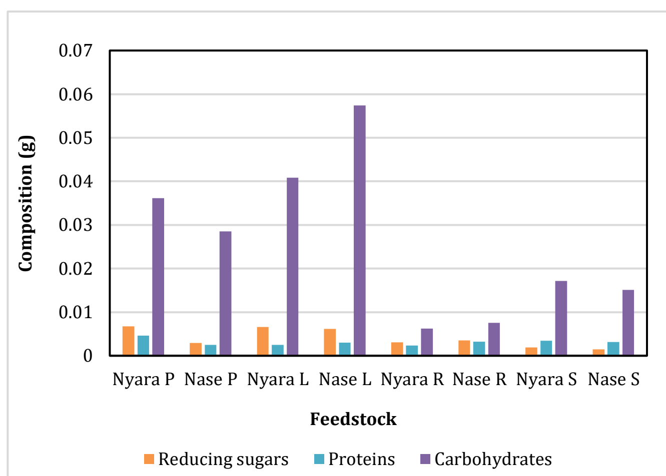

Figure 2: Composition analysis for the different feedstock

According to Wiratno et al. (2014) reducing sugars and proteins act as carbon and nitrogen sources, respectively, which are vital in the growth of yeast cells during fermentation. Carbohydrates are hydrolyzed using either enzymes, acid or alkalis into simple sugars which can easily be fermented into bioethanol as indicated in (Muktham et al., 2016).

Therefore, feedstock with higher amounts of carbohydrates are expected to have a higher bioethanol yield and those with higher proteins and reducing sugars were expected to sustain fermentation longer (Permatasari et al., 2020). Since all the feedstock had low quantities of proteins, an external source of nitrogen such as peptone was required to sustain the fermentation process (Tilahun et al., 2019).

3.2 Feedstock Conversion Rates

SSF reduced the amount of time required for conversion of both starch and cellulose feed stock to bioethanol. Figures 2 and 3.3 show the concentration of reducing sugars as the time of SSF increases. For all cassava parts, the amounts of reducing sugars reduced as the time of SSF increased. At the start of the SSF, roots had the highest amounts of reducing sugars while the leaves had the lowest amounts of reducing sugars.

Roots had the highest reducing sugar levels on day 0 and the sugar levels are lowest on day 5 hence the highest conversion rate. On the other hand, leaves and stems had the lowest reducing sugar levels on day 0 and the highest reducing sugars on day 5. Among the non-food (cellulosic) feedstock, peelings had the best conversion efficiency for reducing sugars.

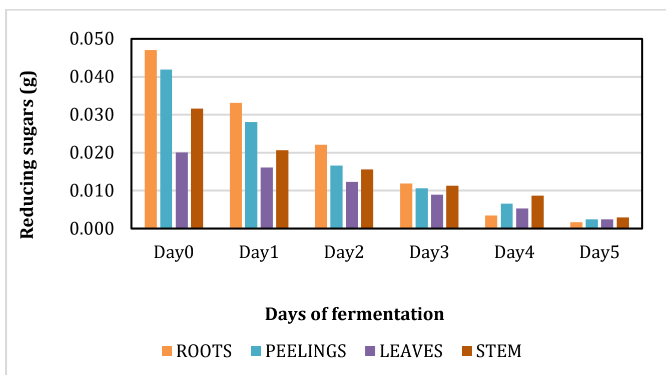

Figure 3: Conversion rates for the different cassava parts

The sweet variety (Nyaraboke) had more reducing sugars than the bitter variety (NASE 3) on all the days of SSF. For both varieties, the quantity of reducing sugars reduced as the days of SSF increased. However, the rate of fermentation was faster on the first days of SSF compared to the last days (Figure 3).

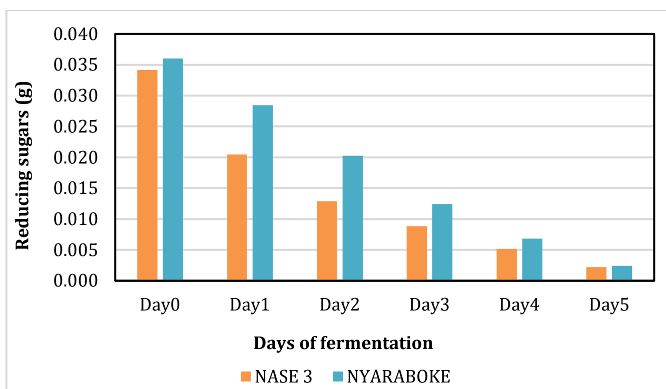

Figure 4: Conversion rate for NASE 3 and Nyaraboke

According to (Permatasari et al., 2020) and , reduction of reducing sugars as the time for SSF increased was observed because feedstock were hydrolyzed into simple sugars that were immediately fermented into bioethanol. This helped to keep the concentration of sugars low enough to prevent enzyme inhibition according to Llamoso, Babaran, Ebreo, Hernandez, & Mahia (2015). Osmotic stress and enzyme inhibition occur when the concentration of simple sugars is too high for the enzymes to continue the fermentation process.

The rate of fermentation increased due to the increased growth of yeast cells as the days of SSF increased. The rate of bioethanol production later on reduced towards the fifth day of SSF because yeast cells started dying as a result of increased concentration of bioethanol, increased temperature and osmotic stress as reported in Mohd Azhar et al. (2017).

In addition to having a higher sugar content, it was easier to hydrolyze the starch in roots into simple sugars. This presence of high initial reducing sugars in roots facilitated rapid yeast growth and the high conversion efficiency of the reducing sugars to bioethanol. Among the cellulosic feedstock, peelings had the most initial reducing sugars and thus the best conversion efficiency to bioethanol.

3.3 Bioethanol Yield and Quality

Table 4 shows the bioethanol yield and quality for the different feedstock. Leaves for the bitter variety (NASE 3) had the highest bioethanol yield followed by stems, roots and lastly the peelings. On the other hand, stems had the highest bioethanol yield followed by peelings, leaves and lastly the roots for the sweet variety (Nyaraboke). Results from ANOVA indicate that there was a significant difference between the bioethanol yield from the feedstock at a significance level of 0.05 (P = 0.00188).

The roots had the best quality of bioethanol in terms of bioethanol percentage and pH for both varieties as shown in Table 1. Bioethanol from all the feedstock had no chlorides and sulphates detected. Equation 8 is the regression model for the relationship between bioethanol yield and feedstock composition. Since proteins had the highest coefficient in the regression equation 8, they had the greatest effect on the amount of ethanol produced.

$$\text{Ethanol yield} = 3\text{-}115.6 \text{ sugars} + 623.9 \text{ proteins} + 20.7 \text{ carbohydrates} \quad (8)$$

Stems and peelings would be a better choice of feedstock for both the bitter and sweet varieties. Despite the fact that leaves for the bitter variety had the highest bioethanol yield, the second highest bioethanol yielding feedstock (stems), is easier to obtain in large quantities as a raw material when compared to the leaves. The roots would be an ideal feedstock if only they were not a direct threat to food security as reported by Quintero *et al*. (2015).

Table 4: Bioethanol yield and quality

Part *	Bioethanol Yield (ml/50g feedstock)	Bioethanol Percentage	pH	Chlorides and Sulphates	Appearance
Nyaraboke Roots	34.3	96.14	6.9	None detected	Visibly free of suspended or precipitated contaminants
Nyaraboke Stems	96.7	95.05	6.2	None detected	Visibly free of suspended or precipitated contaminants
Nyaraboke Peelings	94	95.05	6.6	None detected	Visibly free of suspended or precipitated contaminants
Nyaraboke Leaves	55.3	95.30	6.1	None detected	Visibly free of suspended or precipitated contaminants
Nase Stems	66	95.05	6.2	None detected	Visibly free of suspended or precipitated contaminants
Nase Roots	44.3	96.14	6.4	None detected	Visibly free of suspended or precipitated contaminants
Nase Peelings	40	95.81	6.2	None detected	Visibly free of suspended or precipitated contaminants
Nase Leaves	83	95.30	6.2	None detected	Visibly free of suspended or precipitated contaminants

The low ethanol yield from the roots in both varieties compared to other feedstock can be attributed to the difference in the method of hydrolysis (Aditiya et al., 2015). The roots were hydrolyzed using alpha amylase enzyme whereas the rest of the feedstock were hydrolyzed using 2M sulphuric acid. Additionally, the root sample had low amounts of both proteins and reducing sugars which boost the growth of yeast cells which is similar to what is reported in Wiratno *et al*. (2014).

According to the USA standards for denatured ethanol, the minimum volume percentage of ethanol is 92.1%, maximum inorganic chloride content is 40 ppm, maximum sulphates content is 4 ppm and recommended pH is between 6.5-9.0 (Rutz & Janssen, 2006). Apart from Nyaraboke peelings and roots, the rest of the feedstock had ethanol below the recommended pH. According to Brazil (2008), absence of inorganic chlorides and sulphates indicates that there is no threat of corrosion on engine parts and creation of deposits that may lead to blockage in fuel lines and injector nozzles.

3.4 Material Balance

On average, the roots required 500 ml of distilled water (D.$H_2$0) per 50 g of a sample to produce 39.7 ml of 96% bioethanol, 464.8 ml of waste water and 17.4g of solid waste (figure 4). On the other hand, the leaves, peelings and stems required 250 ml of D.$H_2$0 per 50 g of a sample to produce 80.9 ml of 95.3% bioethanol, 506.3 ml of waste water and 56.5g of solid waste (Figure 5). The amount of carbon dioxide was not measured in this study.

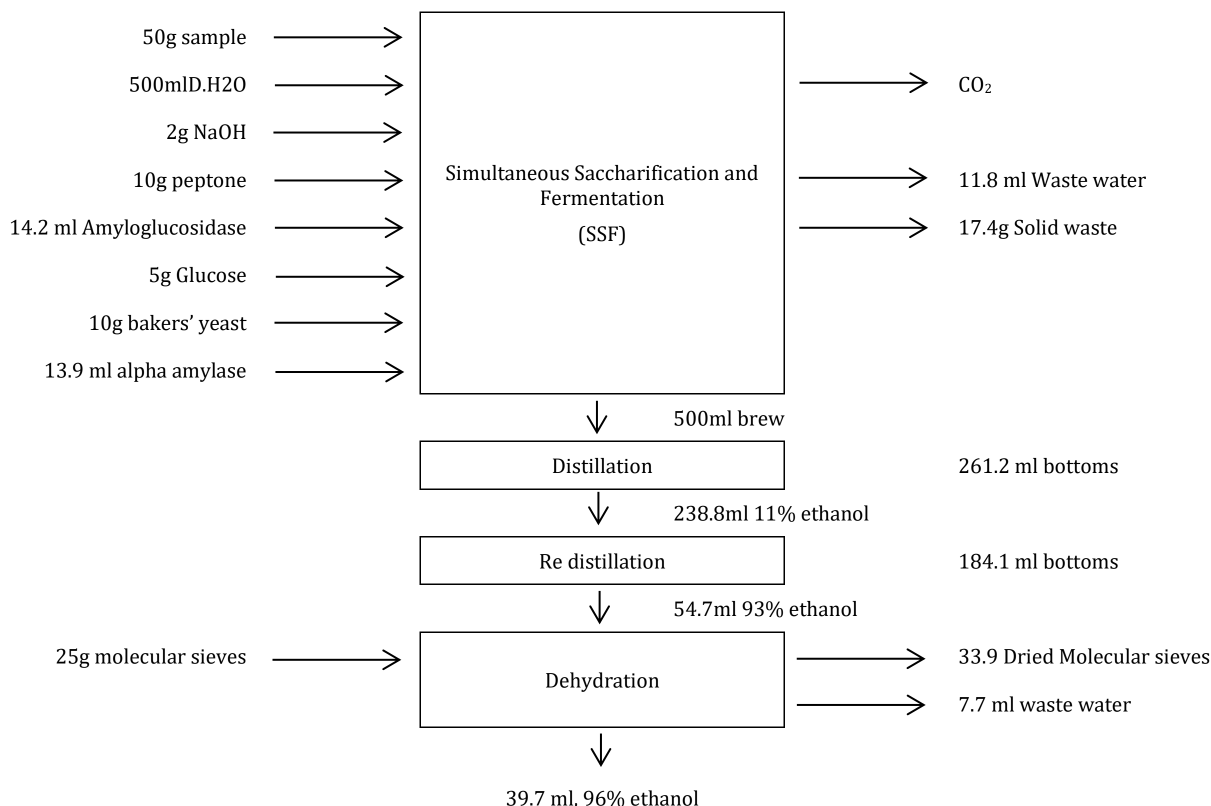

Figure 5: Material balance for bioethanol production from root sample

The amounts of waste water and solid waste produced as byproducts indicated the need for proper waste management. The solid waste and waste water produced in both cases can be used for production of animal feed, biogas or used as fuel by direct burning (Cesaro & Belgiorno, 2015). Alternatively, the waste water can be treated and used for irrigation of the cassava farms or recycled for use in the bioethanol plant as is in Keeney & Muller (2006). On commercial scale, the carbon dioxide produced can also be collected, purified and bottled for sell to manufacturers of soft drinks, beer and frozen foods.

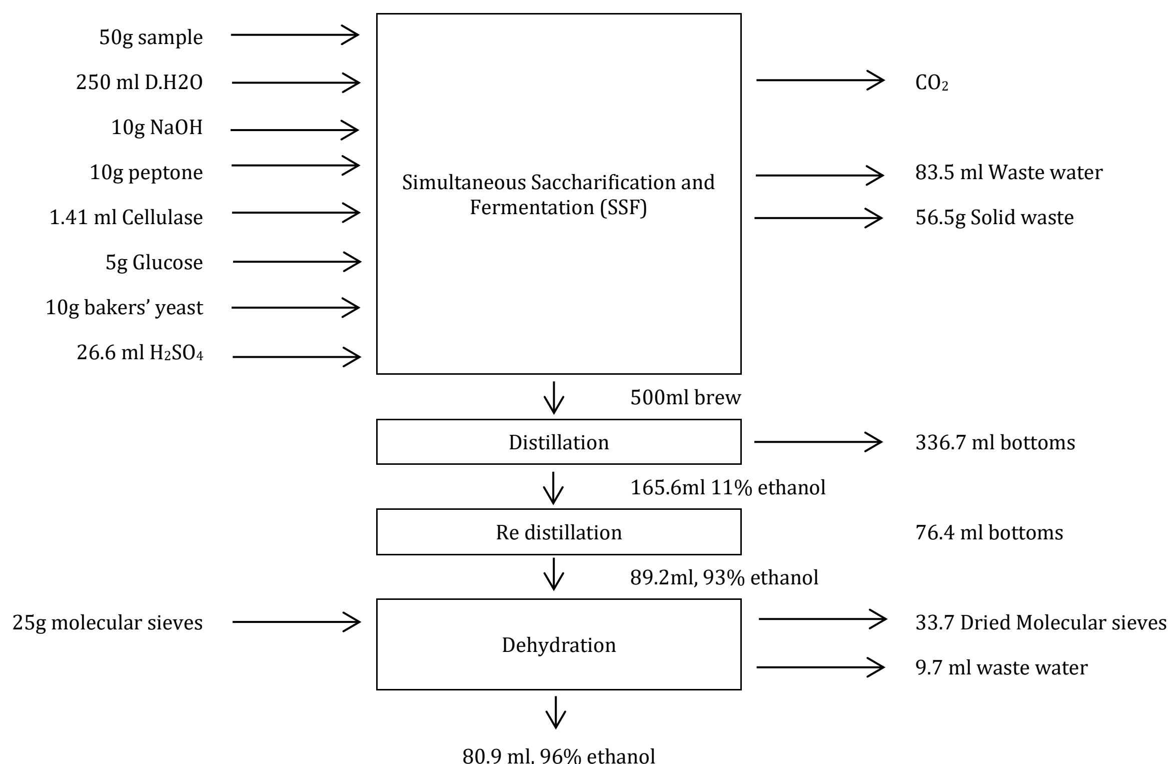

Figure 6: Material balance for bioethanol production from peelings, stems and leaves samples

Despite the fact that starch (root samples) were easily hydrolyzed to reducing sugar, their bioethanol yield was low compared to the cellulosic samples. This is because the cellulosic samples were hydrolyzed using 2M sulphuric acid yet the starch sample underwent enzyme hydrolysis. Additionally, hydrolysis using sulphuric acid in the cellulosic samples reduced the amount of water required for bioethanol production. However, the pH was lowered greatly thus requiring a lot of Sodium hydroxide to neutralize it to the ideal pH of 4.6.

3.5 Energy Balance

A negative energy balance was obtained for all the feedstock indicating that the methods used in this study required more energy than that contained in the bioethanol produced. Distillation, which was carried out in two stages, consumed the most energy followed by simultaneous Saccharification and fermentation (Table 5). The energy used to dry (regenerate) the molecular sieves is not included since they were not dried for reuse in this study. In other words, regeneration of molecular sieves makes the energy balance even more negative.

Table 5: Energy balance for cassava-based bioethanol

Feedstock **	Energy Used for Milling (MJ)	Energy Used for SSF (MJ)	Energy Used for Distillation (MJ)	Total Energy Utilized (MJ)	Bioethanol Produced (ml)	Heating Value (MJ/kg)	Bioethanol Energy Content (MJ)	Net Energy Balance (MJ)
Nyaraboke Roots	0.048	15.55	24.26	39.9	34.3	19.8	0.54	-39.36
Nyaraboke Leaves	0.048	3.89	24.26	28.2	55.3	23.5	1.04	-27.16
Nyaraboke Stems	0.048	3.89	24.26	28.2	96.7	22.5	1.74	-26.46
Nyaraboke Peelings	0.048	3.89	24.26	28.2	94	22.6	1.70	-26.50
Nase Leaves	0.048	3.89	24.26	28.2	83	22.1	1.47	-26.73
Nase Stems	0.048	3.89	24.26	28.2	66	22.0	1.16	-27.04
Nase Roots	0.048	15.55	24.26	39.9	44.3	21.4	0.76	-39.14

The root samples required more energy for bioethanol production compared to the leaves, peels and stem samples for both varieties (Table 2). Roots samples required more energy because they were dissolved in distilled water and effective hydrolysis of the feedstock required higher temperatures and longer heating. On the other hand, samples for the cellulosic feedstock were dissolved in sulphuric acid which required less heating for hydrolysis as is in Nwakaire, Ezeoha, & Ugwuishiwu (2013).

In order to improve the energy balance, acid hydrolysis can be opted for in place of enzyme hydrolysis. A more efficient distillation column and SSF reactor can be utilized during commercial production of bioethanol. Drying of feedstock and molecular sieves can be done by open drying or using solar thermal technologies. Additionally, recycle and reuse of waste energy in the production system can also be opted for.

3.6 Cost Benefit Analysis

The benefit cost ratio for the production of bioethanol from cassava roots was 0.035 while that for the cellulosic feedstock was 0.135 (Tables 3 and 4). The cost of bioethanol production from starch was increased mainly by the enzymes (alpha amylase and amyloglucosidase) and peptone. On the other hand, the cost of producing cellulose-based bioethanol was increased by the cost of peptone, sulphuric acid and cellulase enzyme.

Table 5: Cost Benefit analysis for root-based bioethanol

COST				
Item	**Quantity Used**	**Unit s**	**Unit Cost**	**Total (UGX)**
Feedstock	50	g	10	500
Sodium hydroxide	2	g	100	200
Peptone	10	g	1320	13200
D-glucose	5	g	70	350
Bakers' yeast	10	g	40	400
Amyloglucosidase	14.2	ml	800	11360
alpha amylase	13.9	ml	800	11120
D.H_2O	500	ml	1.4	700
Total cost				**37830**
BENEFIT				
Item	**Quantity**	**Unit**	**Unit cost**	**Total (UGX)**
Bioethanol	39.7	ml	33	1310
BENEFIT COST RATIO				**0.035**

Table 6: Cost benefit analysis for bioethanol from cassava leaves, stems and peelings

COST				
Item	**Quantity used**	**Units**	**Unit cost (UGX)**	**Total (UGX)**
Feedstock	50	g	10	500
Sodium hydroxide	10	g	100	1000
Peptone	10	g	1320	13200
D-glucose	5	g	70	350
Bakers' yeast	10	g	40	400
Cellulase	1.41	ml	800	1128
Sulphuric acid	26.6	ml	100	2660
D.H_2O	250	ml	1.4	350
Total cost				**19588**
BENEFIT				
Item	**Quantity**	**Uni t**	**Unit cost (UGX)**	**Total (UGX)**
Bioethanol	80.9	ml	33	**2670**
BENEFIT COST RATIO				**0.136**

Contrary to what is observed by Dwivedi, et al. (2009), the analysis indicates that the cost of producing bioethanol from starch (roots) was higher than that of cellulose (non-food parts). This was mainly caused by quantity enzymes required for effective saccharification of the starch samples. Therefore, acid saccharification was a cheaper option than enzyme saccharification in this study.

The cost of production can be reduced by improving the energy balance and opting for natural peptone sources such as avocado other than using commercial peptone. Reuse and recycling of solid waste and waste water for energy production is also an option. Additionally, cellulase, amylase and amyloglucosidase enzymes can be made locally at a lower cost than their current market price. Industrially produced bioethanol can also be subsidized by government in order to make it affordable.

4. Conclusion

The composition of reducing sugars, proteins and carbohydrates not only affected the conversion rate but also determined the quantity and quality of bioethanol produced. Faster bioethanol production was achieved with simultaneous saccharification and fermentation. The study further indicated that the use of enzyme saccharification increases both the

energy requirement and the cost of production when compared to acid saccharification.

The quality of bioethanol produced was generally acceptable for use both as a cooking fuel and an automotive fuel. However, the conversion pathway selected determined the quantity and quality of bioethanol produced, the quantity of raw materials required, the nature and quantity of byproducts and the energy requirement which in turn affected the associated costs. The potential for production of bioethanol should not only focus on the quality and quantity of ethanol produced. Therefore, there is need to identify a sustainable set of conversion processes for the production of bioethanol especially from the non-food parts.

An industrial setup involving large scale flour or starch production coupled with the production of bioethanol from the cassava waste presents a more viable opportunity. Additionally, the solid waste and waste water can be used to produce biogas thus improving the energy balance for the bioethanol production. Since Uganda's legal framework on biofuels is lacking, current production of bioethanol can first focus on producing bioethanol for cooking rather than as a vehicle fuel. Alternatively, fuel bioethanol can be produced solely for export to the countries that have compulsory blending of gasoline with bioethanol.

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