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Full Length Research Paper

Techno-economic analysis of fuel ethanol production from cassava in Africa: The case of Tanzania

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The abundance of low-cost feedstock is of great importance for reinforcing industrialization of bioethanol as a sustainable source of eco-friendly energy. This paper describes improved techniques that increase the root productivity of cassava (*Manihot esculenta*) and its conversion to bioethanol. A variety of models and analytical approaches were used to choose the best technologies, considering various levels of in-country technological access and development for the proposed processing technology configurations. Different technologies and process configurations with potential for application in Tanzanian conditions were then selected based on the results. A commercial process simulator was used to analyse specific stages of the production process, that is, fermentation and distillation. An analysis on the energy consumption of various proposed technological schemes was carried out and production cost per liter of biofuel was estimated. These results serve as the basis to draw recommendations on technological and economic feasibility aspects for the implementation of a national biofuel production in Tanzania.

Key words: Fuel-ethanol, cassava, Tanzania, process modelling.

INTRODUCTION

Cassava, a tropical crop and one of the 12 most important food crops grown in the world, provides subsistence to more than 500 million people (Adelekan, 2010; Brocas, 1987; Silalertruksa and Gheewala, 2009; Yu and Tao, 2009). In Tanzania, cassava is one of the most important food crops. Major producing areas are the coastal strips along the Indian Ocean, around Lake Victoria, Lake Tanganyika and along the shores of Lake Nyasa. Tanzania is the sixth producer of cassava in Africa, after Nigeria, Congo, Angola, Ghana and Mozambique. The annual roots production is estimated at 5.4 m tonnes from 950,000 hectares (FAOSTAT, 2013).

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Table 1. Levels of technological development for bioethanol production in Tanzania (FAO, 2010).

Level of development	Remarks	Complexity	Investment in equipment and strain development
1	Conventional technologies	Low	Low-medium
2	Current technologies with higher efficiency	Medium	Medium
3	Technologies under development	High	High

Five cassava varieties (NDL 90/034, HBL 95/05, Kibaha, Kiroba and Mumba) have been officially released in Tanzania. Tanzania's average cassava fresh root yield is about 8 t/ha (FAO, 2001). Yield is influenced by many factors including genetically low yielding potential of local varieties, existence of abiotic stress factors (low soil fertility, drought and weed infestations) and biotic stresses (Mkamilo and Jeremiah, 2005). The adverse climatic conditions in most parts of the country necessitate cultivation of cassava varieties which can tolerate drought, poor soils, many pests and diseases and not compete with other food crops for inputs and time during planting and harvesting.

Cassava roots are the main source of food for non-ruminants and the crop is comparable to other calories sources but such feeds require protein, mineral and vitamin fortifications when fed to pigs and poultry (Ubalua, 2007). However, the high market value of fresh cassava hinders its use for feeding livestock (Aisien et al., 2010). Use of cassava as livestock feed is limited by its high price and low nutritive value and it is produced in dry areas where intensive livestock production is not practiced and the main livestock species are ruminants (FAO, 1988).

Tanzania is categorized as an undeveloped and low-income food deficit country. The economy depends heavily on agriculture, which accounts for approximately 25% of gross domestic product (GDP), provides 85% of exports, and employs 80% of the work force (FAO, 2010). The Food and Agriculture Organization of United Nations (FAO) report stated that land in Tanzania is highly suitable for cassava production and investment in biofuels can have positive impacts on poverty reduction in support of governmental policy without impairing the country's food security (FAO, 2010).

The present study analyses the situation and conditions in Tanzania for biofuel production. It is particularly important for setting up the scenarios for bioethanol production and for carrying out the various technical-economic calculations. This study is analysed in the context of implementing a national 10% blending gasoline oxygenation programme with fuel-grade alcohol. The objective of the blending mandate is on one hand an opportunity to reduce fossil fuel imports and on the other to promote rural development. Rural development dimension is considered from the perspective to have the participation of small scale producers as feedstock suppliers in the various production systems considered in the study. To meet a national 10% bioethanol blending mandate, the country needs to produce an estimated of 160,000 L of fuel-grade alcohol per day (Quintero et al., 2012). To meet this demand various alternatives are considered. This paper aims to evaluate the different technologies available for producing bioethanol from cassava. The comparison of the alternative technologies for producing fuel-grade alcohol is based on modern process-engineering tools for modelling and process analysis simulation.

The three technological levels were assessed under Tanzanian conditions (Table 1) that comprise a series of conditioning factors and requirements for their implementation in the country (FAO, 2010). The first technological development level represents the easiest level to be implemented in Tanzania since it implies already mature conventional technologies proven worldwide but overall less efficient technologies. For the second level of technological development, a suitable transfer of technology and an appropriate degree of investment from private sector should be ensured in Tanzania in order to guarantee the success of the production process. In theory, there is a potential for implementing technologies from the three levels, including the newly available commercial technologies. However, the country will need superior investments and intensive program to develop the local capacity to absorb newer and more advanced technologies, which at this stage is considered to be an obstacle.

MATERIALS AND METHODS

Cassava as feedstock for fuel ethanol production

The first scenario considers using fresh cassava as feedstock. Here, the production of ethanol from cassava starts by chopping and then grinding fresh cassava roots. Water is then added to the ground roots to start the starch hydrolysis process to convert it into glucose, which is then transformed into ethanol using yeasts (Adelekan, 2010; Ado et al., 2009; Oparaku, 2010; Sánchez and Cardona, 2008). The produced alcohol is dehydrated to convert it into fuel-grade alcohol. Caution should however be exercised to ensure that cassava uses for fuel do not compete with its use in food consumption. To this end, opportunities exist in Tanzania to improve cassava production to increase yields from 4 to 8 tonnes/hectare per year. The surplus output can then be used for fuel-grade ethanol while the production for local food consumption is guaranteed (FAO, 2010). Nevertheless, it should be taken into

Table 2. Main scenarios for producing fuel ethanol in Tanzania.

Scenario	Parameters	Description
1	Standalone medium feedstock	Production Plant capacity 160,000 L/day increased fresh cassava yield (single plant)
2	Standalone medium feedstock	Production Plant capacity 160,000 L/day increased dry cassava yield (single plant).
3	standalone large scale feedstock	Production Plant capacity 303,030 L/day (100 m litres per year) increased dry cassava yield (single plant).

account that extra costs may appear by increasing yields. This effect was not considered in this work.

The second scenario for producing ethanol from cassava considers the drying of cassava prior to processing it to ethanol. This scenario consists of small-scale cassava producers associated to set up small chopping plants in which the fresh roots are peeled, chopped and sun-dried (brought to 14% moisture content) on cement or similar surfaces. The dried cassava chip is then delivered to the ethanol manufacturing facility for processing to bioethanol (Table 2).

The production cost estimated for fuel grade ethanol from cassava in Tanzania is slightly higher than the values reported by major producers such as Thailand and Vietnam (0.34 to 0.40 US$/L), but close to production prices reported by Brazil (0.45-0.47 US$/litre) (FAO, 2010; Molony and Smith, 2010; Zhang et al., 2003). However, cassava is also the second most important staple food crop in the country, therefore, caution should be taken to avoid competition of cassava production for fuel versus food (Molony and Smith, 2010). Thus, to avoid displacing cassava for food uses, an estimated 11% or higher increase in the current cassava yield is necessary. Increase in cassava yield through better crop husbandry, good knowledge on technical aspects of cassava planting including optimal spacing arrangements, timing of planting and efficient weeding, can offer an opportunity to improve productivity.

Technologies for fuel ethanol production

The process was broken down into the following industrial production steps: conditioning and pre-treatment, biological transformation, separation and purification, and effluent treatment. Multiple technologies for each step were analysed to make up the overall process for the conversion of biomass feedstock into fuel ethanol. The configurations were chosen considering maturity, technological development for operations and processes for each step and a processing pathway that considered all the steps altogether was chosen.

For fuel ethanol production from cassava as feedstock, different technologies were selected for each step in the production process taking into account the technological access criteria. The technological access criteria is based on the human skills that are necessary to support a biofuel processing operation including both skilled and unskilled labour and the access to technologies from local markets and services. The schemes for processing cassava to fuel ethanol considered the treatment of this raw material in two ways. The first one consists on the extraction of the starch contained in the cassava for converting it into ethanol, which implies the previous separation of the main cassava components (peel, fibre, moisture and starch). The second alternative is based on the utilization of the whole cassava for producing ethanol. Thus, all the components of the feedstock enter into the production plant. Most of the cassava non-starch components are concentrated in the fibrous residue and vinasse. However, it is considered that ethanol from cassava can have better economic indicators if the whole tuber is used instead of the starch extracted from cassava, especially if small holders are involved (Sánchez and Cardona, 2008).

To produce ethanol from whole cassava, the feedstock should be transported rapidly from cropping areas to the production facility because of the accelerated deterioration of cassava root due to its high moisture content which is nearly 70% (Table 3). Therefore, the cassava roots should be processed within 3 to 4 days after harvesting. One of the solutions to this problem is the use of sun-dried cassava chips (Sriroth et al., 2007). In this case, the small holders send the fresh cassava roots to small chopping facilities located near the cassava plots. In these facilities, the cassava is peeled and chopped into small pieces. The chips are sun-dried for two to three days reducing the moisture down to 14% and increasing the starch content up to 65-75%. Then, the dried cassava chips are delivered from the different chopping facilities to the ethanol production plant where the collection of this raw material is centralized. Consequently, in the present paper, two scenarios for ethanol production from cassava are proposed: utilization of fresh cassava roots or use of dried cassava chips.

The selected processing pathway for conversion to ethanol (either from fresh cassava or dried chips) corresponding to the first level of technological development is shown in Figure 1. In this case, the cooking of the starch contained in cassava at high temperatures is required to gelatinize and dissolve it from the polysaccharide to be more susceptible to the attack of hydrolysing enzymes (amylases) which break it into glucose (Okorondu et al., 2009). In a second pretreatment step, the cooked starch undergoes an enzymatic treatment with α-amylase to obtain partially hydrolysed starch (liquefied starch), which is then sent to a bioreactor where the glucoamylase enzyme is added to convert the starch fragments into glucose. The glucose solution is directed to a bioreactor where the sugar is converted into ethanol using *Saccharomyces Cerevisiae* (Ahmad et al., 2011; Akponah and Akpomie, 2012). The yeast biomass is separated by conventional sedimentation obtaining a culture broth with an ethanol content of 8-10% by weight.

Centrifugation operation is contemplated for separating the yeast cells from culture broth. The process for ethanol dehydration by

Table 3. Composition of fresh cassava roots in Tanzania.

Component	Reference component	Percentage by mass
Water	Water	69.80
Starch	Starch	22.00
Sugars	Glucose	5.10
Protein	Lysine	1.10
Fats	Glycerol	0.40
Fiber	Cellulose	1.10
Ash	Ash	0.50

Sources: Sánchez and Cardona (2008) and Institute (2013).

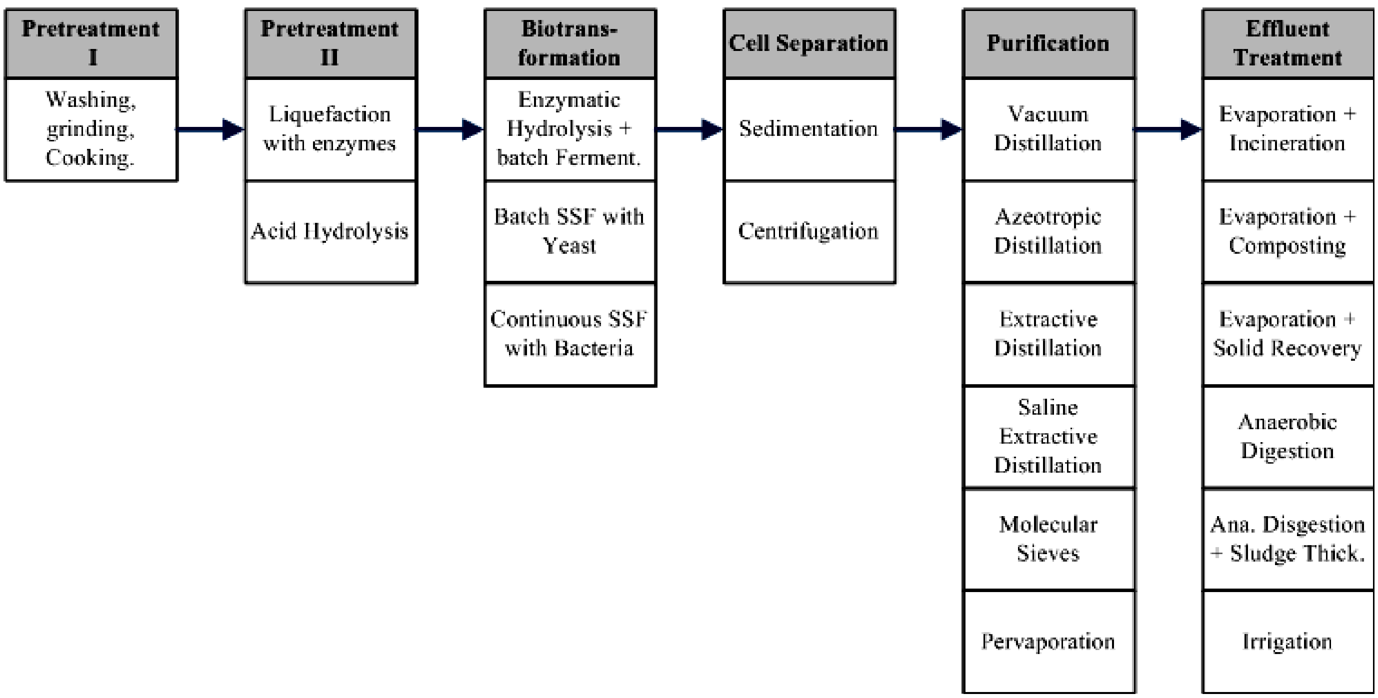

Figure 1. Processing pathway for production of fuel ethanol from cassava corresponding to the first level of technological development.

adsorption with molecular sieves was selected. This technology has demonstrated high efficiency during the production of anhydrous ethanol in different countries (Colombia, India and USA) and is applicable to the Tanzanian conditions through an appropriate transfer of technology. The liquid effluents from the process are treated by combining the evaporation of the vinasse up to a 30% solids concentration with the subsequent utilization of this vinasse stream in a composting process. For this, the evaporated vinasse is mixed with the filter cake in order to accomplish an aerobic fermentation in solid medium, typical for composting process. Likewise, it should be noted that there is no possibility for cogeneration from the effluent treatment in this case since a solid fibrous residue with an easy combustion and high energy content is not obtained. Something important to add, is that the sequences shown in this technology are commercially available. For instance the case of USA, which uses corn starch as raw material. Also, the fermentation is done by using the commercial strain *S. cerevisiae*, widely used in Colombia, Brazil, USA and Europe to produce fuel ethanol. The second and third technological levels, are proposed to improve the overall efficiency of the fermentation step of the current commercial technologies (technology level 1), however, they are not implemented on a commercial level yet.

An integrated process of batch simultaneous saccharification and fermentation (SSF) that represents one of the main advances in the industry of fuel ethanol in USA which can be implemented in Tanzania was considered for the second level of technological development (Figures 2 and 3). This technology implies the realization of both the hydrolysis of the liquefied starch and the alcoholic fermentation in the same single unit (Ado et al., 2009). In this way, a higher efficiency is obtained considering the fact that glucose has an inhibition effect on the gluco-amylase. If the glucose is converted into ethanol as it is formed by yeasts, this inhibitory effect is drastically reduced. On the other hand, the effluent treatment step includes the anaerobic digestion of the obtained vinasse.

The third level of technological development during the

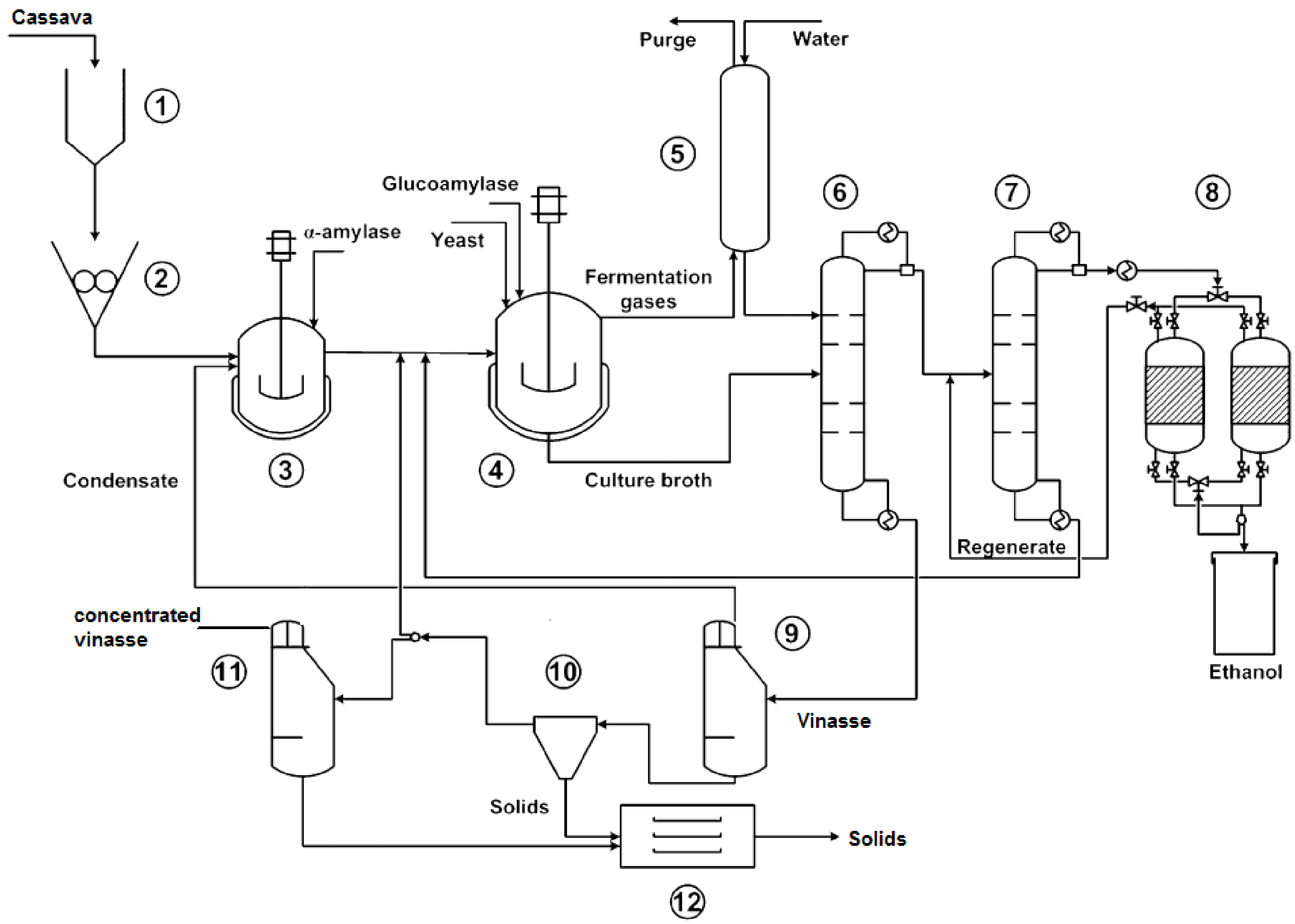

Figure 2. Simplified flowsheet of fuel ethanol production from cassava (Technological level 2). 1, Washing tank; 2, crusher; 3, liquefaction reactor; 4, SSF reactor; 5, ethanol absorber; 6, concentration column; 7, rectification column; 8, molecular sieves; 9, first evaporator train; 10, centrifuge; 11, second evaporator train; 12, dryer.

production of bioethanol from cassava implies a technological scheme where the SSF process is accomplished in a continuous way using the bacterium *Z. mobilis* (Oyeleke et al., 2012). In addition, the anaerobic digestion is complemented with the separation of solids from the whole vinasse to be utilized as fibrous residue for animal feed or combustion (Figure 3).

Simulation procedure

Each one of the proposed technological schemes was simulated employing the approach described above. The main objective of this procedure was to generate the mass and energy balances from which the requirements for raw materials, consumables, service fluids and energy needs were defined.

The tasks and procedures of simulation and modelling were performed employing different commercial packages as well as specialized software (Aspen Plus version 12.0). The simulation of different technological flowsheets included all the processing steps for conversion of feedstocks into bioethanol. For this, the main simulation tool was the package Aspen Plus version 12.0 (Aspen Technology, Inc., USA), although some preliminary simulations were carried out with the simulator SuperPro Designer version 7.0 (Intelligent, Inc., USA). Special packages for performing mathematical calculations such as Matlab, Octave and Polymath were also employed. Some specific optimization tasks were accomplished using the package GAMS (GAMS Development Corporation, USA). In addition, software especially designed and developed by our research group as ModELL-R was used for performing specific thermodynamic calculations as the determination of thermo-physical properties not found in the available literature for certain components involved in the process. Some data on physical properties of the components required during the simulation were obtained from the work of Wooley and Putsche (Wooley and Putsche, 1996).

One of the most important issues to be considered during the simulation is the appropriate selection of the thermodynamic models that describe the liquid and vapour phases. Thus, the Non-Random Two-Liquid (NRTL) thermodynamic model was applied to calculate the activity coefficients of the liquid phase while the Hayden-O'Conell equation of state was used for the description of the vapour phase.

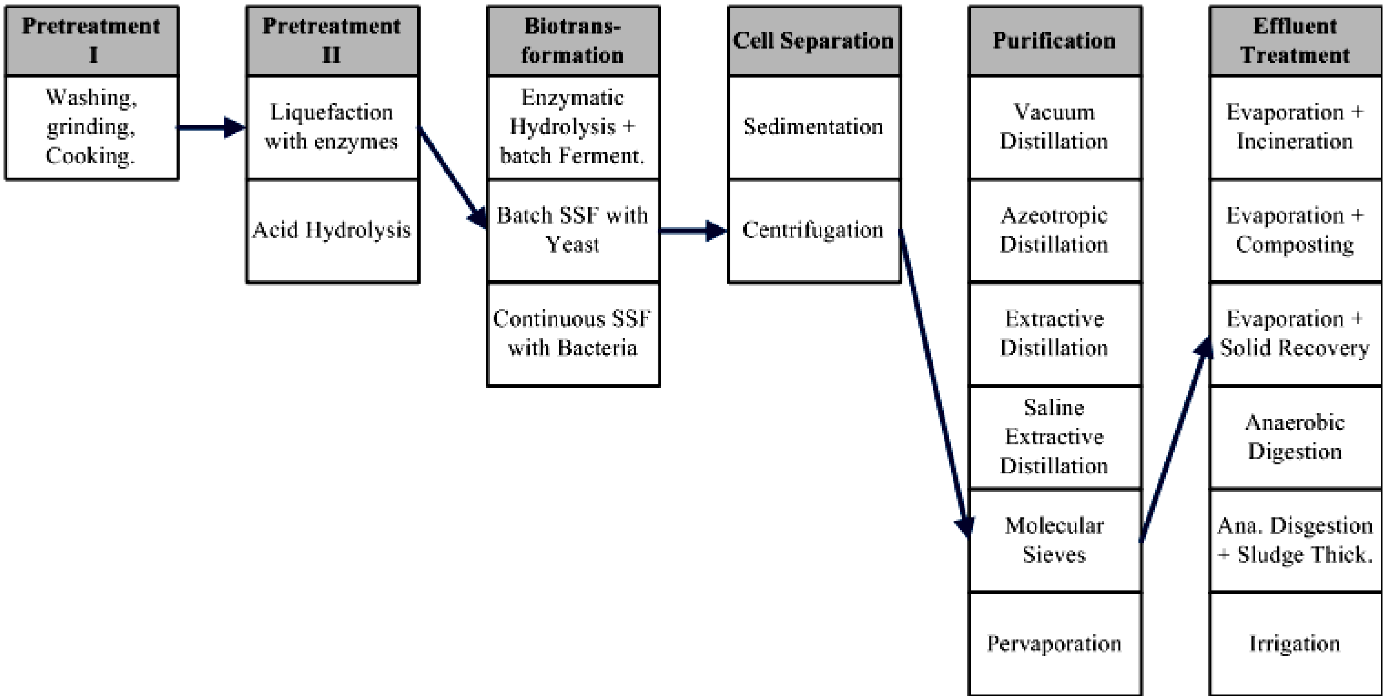

Figure 3. Processing pathway for production of fuel ethanol from cassava corresponding to the second level of technological development.

Types of fermentation and hydrolysis models

To start the different simulation procedures in ethanol production, a suitable description of the different process steps is required. For this, it was necessary to define the level of detail for the models used. This is particularly relevant in the case of the fermentation and enzymatic hydrolysis. For the detailed simulation of the overall process, the fermentation was described through kinetic models which structure depends on the type of sugars derived from the conditioning and pretreatment of feedstock. For cassava, models used were based on the transformation of glucose into ethyl alcohol. The steps prior to the starch hydrolysis were described by a stoichiometric approach. The kinetic models used were chosen based on the corresponding literature review taking into account the ease of their implementation but seeking that the nature of the studied phenomenon was contemplated in a complete way. Thus, structured and segregated models of metabolic character, whose level of detail does not correspond to the problem of evaluating global technologies, were discarded. Therefore, non-structured, non-segregated models were used. These models were selected if they took into account the following key aspects: substrate limitation, substrate inhibition, product inhibition, and cell growth.

Types of separation models

The analysis of those conventional separation methods for distillation was carried out with the help of the corresponding modules of the process simulators. For this, both short-cut methods and rigorous models available in the simulation package were employed. For simulation of the different technologies involving the operation of distillation, the short-cut method DSTWU incorporated in the package Aspen Plus was applied. This method uses the equations and correlations of Winn-Underwood-Gilliland in order to provide an initial estimation of the minimum number of theoretic stages, minimum reflux ratio, location of the feed stage, and components distribution. The rigorous calculation of the operating conditions in the distillation columns was performed using the module RadFrac based on the equilibrium method that employs the MESH equations (Mass balance equations, phase Equilibrium equations, Summation of the compositions, and Heat balance equations) using the inside-out algorithm. Residue curve maps were used for the conceptual design of the distillation schemes applying the principles of topological thermodynamics (analysis of the statics) (Pisarenko et al., 2001). Sensitivity analyses were performed in order to study the effect of the main operating variables (reflux ratio, temperature of the feed stream, ratio between the distillate and the feed, etc.) on the purity of ethanol and the energy consumption of this operation. The final result is the determination of operating conditions that allow developing energetically efficient processes for concentration and dehydration of ethanol.

During the analysis of the ethanol dehydration processes by adsorption using molecular sieves, the mathematical description for dehydration of ethanol in the vapour phase at high pressures according to the technology of pressure swing adsorption (PSA) proposed by Guan and Hu (2003) (Guan and Hu, 2003) was employed. For simulation of this dehydration process, it was considered that the adsorption was carried out in the vapour phase. For this reason, the distillate of the rectification column is not condensed and is superheated at 116°C in order to send it to the adsorption column. The operating cycle of the two adsorption columns comprises the pressurization of the column (that was carried out using the overhead vapours from the rectification column), adsorption of water (in this period the product is removed), and desorption of water (that was carried out with a fraction of the

Table 4. Yield and energy consumption of ethanol production based on cassava.

Technology	Yield (Litres of EtOH/tonne of cassava)	Heat (MJ/L)	Electricity (kW)	Cogeneration		Net balance	
				Heat (MJ/L)	Electricity (kW)	Heat (MJ/L)	Electricity (kW)[b]
Fresh cassava 160.000 L/day (scenario1)							
Level 1	164.47	23.28	115.17		-	-	-
Level 2	184.07	23.36	6.60		-	-	-
Level 3	181.03	23.53	11.24	0.14	-	23.39	-
Dried cassava 160,000 L/day (scenario 2)							
Level 1	471.79	23.12	105.95		-	-	-
Level 2	527.67	23.36	6.57		-	-	-
Level 3	519.35	22.21	11.24	0.14	-	22.08	-
Dried cassava 303,030 L/day (scenario 3)							
Level 1	466.38	22.49	204.82		-	-	-
Level 2	513.95	22.26	12.66		-		-
Level 3	518.43	21.41	20.15	0.14	-	21.27	-

vapours of the product). For PSA technology, desorption was simulated at 0.14 atm of pressure. Vapours resulting from the desorption process were recycled back to the rectification column where the ethanol used was recovered. While one of the adsorption columns operates under pressure obtaining 99.5% by weight of ethanol, the other one is regenerated. The length of the whole cycle is ten minutes.

Cost estimation

The estimation of the energy consumption was performed based on the results of the mass and energy balances generated by the simulation. For this, the thermal energy required in the heat exchangers and reboilers was taken into account, as well as the electric energy needed by the pumps, compressors, mills and other equipment. The capital and operating costs were calculated through the software Aspen Icarus Process Evaluator (Aspen Technologies, Inc., USA). On the other hand, specific aspects regarding to the Tanzanian conditions were considered in order to calculate the production costs of one litre of fuel ethanol including the costs of the raw materials, income tax, labour costs, among others.

RESULTS AND DISCUSSION

Simulations of the different technological schemes studied were used to produce their respective material and energy balance sheets which are the basic input for analysing the different configurations. The data showed that the production flow compositions calculated by the simulation are in line with those reported for actual commercial processes. This is shown in the composition of by-products generated in each of the proposed technological schemes.

As cassava is the second most important staple food in Tanzania, careful attention should be paid to ensure that its use for fuel production does not have negative effect on food security. In this context, it is envisioned that if cassava is to be used as a raw material for producing fuel-grade ethanol, its productivity will need to be increased to safeguard the country's food security. Table 4, shows the yield in litres of ethanol produced per tonne of cassava. Levels 2 and 3 do not have significant differences in yield but are more than 15 points above level 1. Level 3 technology is different from the other two because it includes an anaerobic process for distilling the vinasse to produce methane, which is then used to generate steam and reduce energy consumption by 0.26 MJ per litre of ethanol.

The technological levels proposed directly affects the overall yields of the process and thus also the production costs. Production costs are shown in (Table 5) (scenario 1). In the case of fuel-grade ethanol produced from cassava, the raw material accounts for 64.78% and 62.19% of the total cost for technology levels 1 and 2, and 70.47% for level 3 technology. The cost of producing ethanol in Tanzania from cassava with technology level 3 is US$0.5597/litre, which is higher than that reported in China (Zhang et al., 2003). Although the production costs using level 2 and 3 technologies are higher, these technologies can still be attractive in the Tanzanian context.

Cassava, which corresponds to the configuration proposed in scenario 2, is reported in Table 6. In the production of fuel-grade ethanol from chopped cassava, the raw material accounts for 66.14%, 60.19% and 70.57% of total production costs for level 1, 2 and 3 technologies, respectively.

Another major expenditure category is service fluids which accounts for 12.96% of total costs under level 3

Table 5. Estimation of the cost of producing fuel-grade alcohol from cassava under Tanzanian conditions (scenario 1).

Category	Level 1		Level 2		Level 3	
	US$/L	Share of total cost (%)	US$/L	Share of total cost (%)	US$/L	Share of total cost (%)
Raw materials	0.2310	51.26	0.2064	49.11	0.2099	58.24
Service fluids	0.0851	18.87	0.0859	20.43	0.0731	20.29
Labour	0.0003	0.07	0.0003	0.08	0.0004	0.11
Maintenance	0.0264	5.87	0.0248	5.91	0.0079	2.20
Operating charges	0.0001	0.02	0.0001	0.02	0.0001	0.03
Indirect plant expenses	0.0134	2.97	0.0126	2.99	0.0042	1.16
General and administrative costs	0.0285	6.32	0.0264	6.28	0.0237	6.56
Capital depreciation[1]	0.0659	14.61	0.0638	15.17	0.0411	11.40
Total	0.4506	100.00	0.4203	100.00	0.3604	100.00

[1]Calculated using the straight line method. Price of fresh cassava: 0.038 USD/kg.

Table 6. Estimation of the cost of producing fuel-grade alcohol from dried cassava chips under Tanzanian conditions (scenario 2).

Category	Level 1		Level 2		Level 3	
	US$/L	Share of total cost (%)	US$/L	US$/L (%)	Share of total cost (%)	US$/L
Raw materials	0.2819	56.04	0.2520	53.68	0.2560	61.37
Service fluids	0.0834	16.58	0.0858	18.28	0.0767	18.39
Labour	0.0003	0.06	0.0003	0.07	0.0004	0.10
Maintenance	0.0262	5.21	0.0248	5.29	0.0091	2.18
Operating charges	0.0001	0.02	0.0001	0.02	0.0001	0.02
Indirect plant expenses	0.0133	2.64	0.0126	2.68	0.0048	1.14
General and administrative costs	0.0324	6.44	0.0300	6.40	0.0278	6.66
Capital depreciation[1]	0.0654	13.00	0.0638	13.59	0.0423	10.14
Total	0.5029	100.00	0.4695	100.00	0.4172	100.00

[1]Calculated using the straight line method.Price of dried cassava chips: 0.133 USD/kg.

technology. Capital cost for this technology level is 7.15%, significantly lower than those obtained with technologies 1 and 2. Level 3 is the lowest-cost technology per litre of ethanol produced. The per litre production cost of ethanol produced from slices of dried cassava is very high in Tanzania, owing to the high cost of the raw material (US$0.133 per kilogram).

For this analysis, as in the economic evaluations, a price of US$0.038 was assumed for 1 kg of fresh cassava roots. For chopped sun-dried cassava, the price assumed was US$0.133 per kilogram. This includes the cost of transporting the cassava to the production plant, valued on average as 30% of the sale price for each raw material (Match_Maker_Associates_Ltd., 2008). Nonetheless, the use of cassava as a raw material to produce fuel-grade ethanol should be restricted until the yield of the crop can be increased and the population's food security assured.

Scenario 3 analysed the scale effect on production costs of bioethanol from dry pieces of cassava from both large and small holders. For this, a plant having double the production capacity than in scenario 2 was simulated. The results (Table 7) indicate that the production cost is reduced by more than 21%.

Overall, the simulated production costs for ethanol from using technology levels 1 and 2 are slightly higher than the cost estimated (LMC International Starch and Fermentation Raw Materials Monitor 2007 Report) for medium scale wet milling production in Thailand and Vietnam (US$0.34 to U$0.40 per litre). These are less than the production prices in Brazil (0.45-0.47 US$/litre), and much lower than those in India (US$0.65 per litre). On the other hand, level 3 exhibits the lowest production cost using dried cassava chips. Hence, these technologies can be attractive in the Tanzanian context. Moreover, the simulated production of cassava-ethanol

Table 7. Estimation of the cost of producing fuel-grade alcohol from dried cassava chips under Tanzanian conditions. (Scenario 3).

Category	Level 1		Level 2		Level 3	
	US$/L	Share of total cost (%)	US$/L	Share of total cost (%)	US$/L	Share of total cost (%)
Raw materials	0.2093	53.58	0.1900	51.52	0.1883	60.39
Service fluids	0.0791	20.26	0.0786	21.32	0.0686	22.00
Labour	0.0002	0.04	0.0002	0.05	0.0002	0.07
Maintenance	0.0200	5.12	0.0203	5.50	0.0058	1.85
Operating charges	0.0000	0.01	0.0000	0.01	0.0001	0.02
Indirect plant expenses	0.0101	2.58	0.0102	2.77	0.0030	0.96
General and administrative costs	0.0255	6.53	0.0239	6.49	0.0213	6.82
Capital depreciation[1]	0.0464	11.88	0.0455	12.34	0.0246	7.90
Total	0.3907	100,00	0.3687	100,00	0.3118	100.00

[1]Calculated using the straight line method. Price of dried cassava chips from smallholders: US$0.1330/kg. Price of dried cassava chips from large holders: US$0.0741/kg.

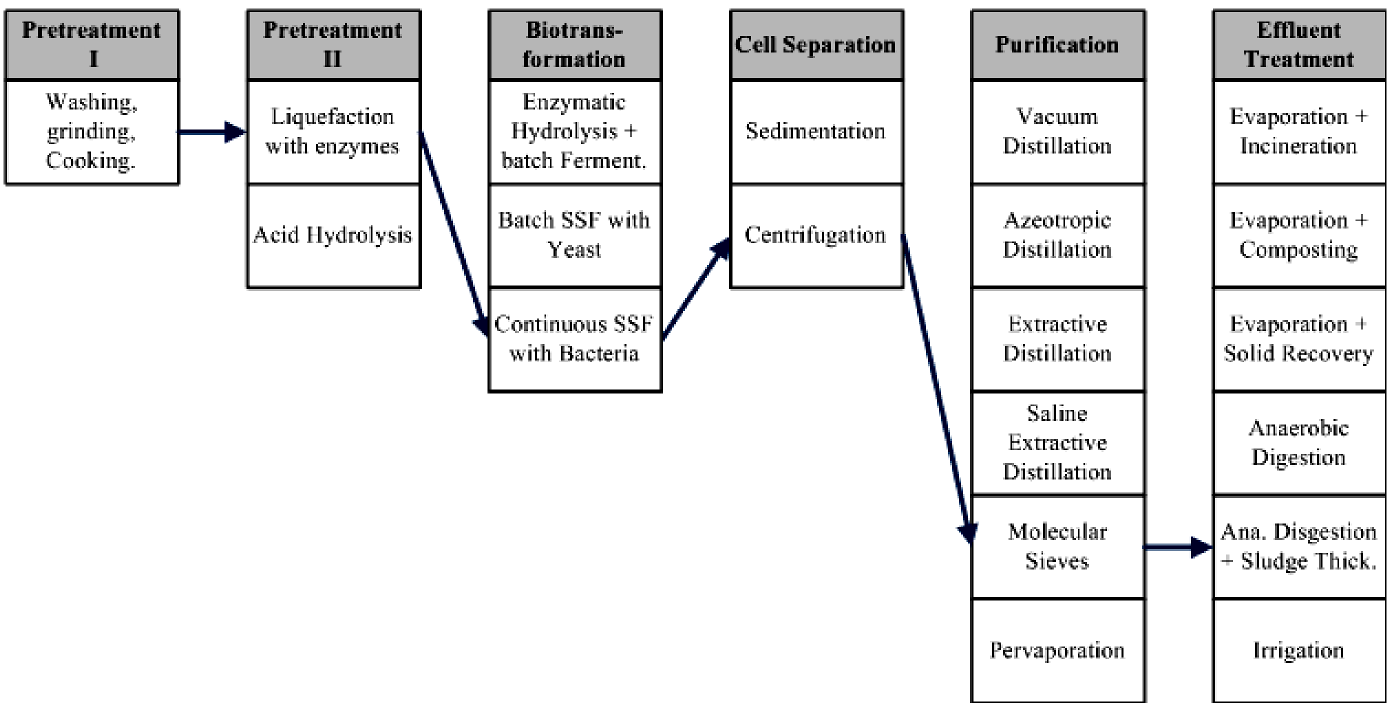

Figure 4. Processing pathway for production of fuel ethanol from cassava corresponding to the third level of technological development.

considered the participation of small-farmers illustrating the opportunities for them in isolated rural areas to become engaged, in particular in production systems using dry cassava as feedstock (Figure 4).

Sensitivity analysis on price of feedstock for alcohol production

Since the largest%age of the production cost for ethanol production is spent on raw material and since the feedstock price data came from secondary information sources, the sensitivity on the feedstock prices was undertaken to evaluate how an overestimation of the assumed feedstock price could impact the competitiveness of bioethanol production (Molony and Smith, 2010).

The impact of a reduction on feedstock price on ethanol production costs from cassava was assessed for the technological and production conditions for scenarios 1 and 2. The objective here was twofold, for one to highlight how a reduction on feedstock price could affect the biofuel production cost estimated in our analysis and secondly to assess local bioethanol production competitiveness to global bioethanol producers as function of feedstock price reduction.

For cassava-ethanol, the production price estimated was closer to international levels. If in the analysis the feedstock price was overestimated by 25%, this implies that cost for Tanzania cassava-ethanol production is already along the reported ranges for Thailand and Vietnam. A 50% or greater reduction in feedstock price will also make ethanol production cost very competitive with global prices (estimated at about US$0.40-0.50). These highlight the importance of reducing the feedstock material price to make the production cost of fuel-grade alcohol economically viable in global markets. The bioethanol production cost from cassava in Tanzania is low at technological development level 3.

Conclusions

A pre-requisite for Tanzania to implement a successful and long term sustainable biofuel program is a well-designed technology transfer that comprises universities and technical centres for the production of biofuels using different technologies and raw materials. An initial joint venture is suggested with universities on using and preparing texts, which in conjunction with simulation tools will enable various university groups to investigate technological and scientific issues relating to biofuel production. While this does not require high levels of investment, it is fundamental for solving one of the main technological access barriers facing Tanzania.

The recommended technologies for producing fuel-grade alcohol from cassava in Tanzania correspond to the second level of technological development. This takes into account the fact that technology access, transfer conditions and adaptation of technologies in Tanzania make it more difficult (and involves a higher initial investment) to set up and implement technological schemes based on level 3 development, that is, schemes with high-performance technologies that are proven worldwide generally at the pilot plant level. Moreover, level 1 technologies, while feasible to implement in Tanzania with the lowest level of conditioning and requirements, produce lower yields and have higher production costs.

New ways to exploit the by-products generated during ethanol production and convert them into value-added co-products need to be supported. The sale of these co-products has major potential to defray the costs of ethanol production, although this is largely depends on the market conditions for these co-products in Tanzania. In particular, the evaporated vinasse can be used as a high-performance biofertilizer.

Cassava is an important alternative for producing ethanol in Tanzania, with significant socioeconomic implications. The formation of associations of small-scale cassava producers would lead to small-scale agribusiness being set up to process fresh cassava roots in sun-dried slices. This would ensure adequate supply of this raw material for bioethanol production; while at the same time would improve incomes for peasant farmers. This point is crucial in the case of cassava, since ethanol production using the fresh roots of this tuber requires a constant supply of raw material, which is difficult because the roots deteriorate rapidly during storage. Fresh cassava roots are a suitable raw material in the case of medium- and large-scale producers with plantations in the neighborhood of a single distillery.

Conflict of interests

The authors did not declare any conflict of interest.

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