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Economic feasibility of on-farm fuel ethanol production from cassava tubers in rural communities

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A simple process for on-farm bioethanol production from cassava, using cassava *koji* supplemented with crude liquid enzyme and yeast was described. On a small scale, a fed-batch mode where 4 kg of *koji,* 2 kg of gelatinized cassava flour and 30 g of yeast cells were mixed and allowed to ferment for two days, followed by addition of 1.5 kg of cassava flour and fermenting for another three days, gave higher ethanol concentration of 7.05% (0.34 g-ethanol/g-cassava flour) than when 3.5 kg of gelatinized cassava flour, 4 kg of *koji* and 30 g of yeast cells were mixed at the same time and allowed to ferment for five days. The process was scaled up 100 times and economic feasibility was evaluated. The total investment cost was seven million, five hundred thousand Nigerian naira (₦) (US$46,875). With a payback period of five years, the cost of cassava tubers represented 71.73% of the total production cost. At a market price of fresh cassava tubers of ₦10,000/ton, the ethanol production cost was ₦102.5/l (US$0.641/l), which is not profitable considering the current market price of ethanol (US$0.597-0.748/l). The process becomes profitable only when the price of fresh cassava tuber is reduced to ₦5,000/ton (US$31.25/ton). At this price, the ethanol production cost would be ₦58.53/l (US$0.366/l). The process is recommended for vertically integrated system (on-farm process) where the cassava produced in the farm is used, thereby shielding it from high and fluctuating market prices of cassava.

Key words: Fuel ethanol, bioenergy, *koji*, economic analysis, cassava ethanol.

INTRODUCTION

Due to the non-renewable nature of fossil fuels and various environmental problems associated with their exploration, production and use, a lot of efforts are being made to develop renewable and environmentally friendly bio-energies (Ogbonna et al., 2001; Zhang et al., 2003). Among the various bio-energies, fuel ethanol is already commercially produced in many countries where it is used as octane enhancer, blended with gasoline in various ratios to produce gasohol or used directly in specially designed ethanol engines. Gasohol containing less than 10% ethanol (E10) can be used in most engines without modifications. A major advantage of bio-ethanol is that the feedstock (agricultural materials) is varied, renewable and can be produced in many places.

Most African countries have large areas of fertile land that is not currently used for production of food crops (World Bank Report, 2013). Although opinion vary as to whether such land should be used for energy crop production, with good policy on land use, lands not currently used for food production can be used to grow energy crops. With appropriate technologies and economically viable processes, ethanol production from agricultural biomass would not only help to encourage farming in these countries but will also be a source of foreign earning. Unfortunately, there are only a few commercial fuel ethanol production plants in the continent. South Africa is the only African country within the top 15 ethanol-producing countries in the world

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(Sánchez and Cardona, 2008). This is partly because there is no simple fuel ethanol production technology that can be operated in rural areas without some basic infrastructures.

Raw materials investigated or already used for commercial production of fuel ethanol include sugar crops such as sugar cane, sugar beet, and sweet sorghum (Worley et al., 1992; Sheoran et al., 1998; Ergun and Muttu, 2000; Ogbonna, 2004); cereals such as corn, millet, and sorghum (Sree et al., 1999; Nam et al., 1988; Montesinos and Navarro, 2000); root crops such as potatoes, sweet potatoes, sago, and cassava (Abouzied and Reddy, 1986; Amutha and Gunasekaran, 2001; Roble et al., 2003; Dai et al., 2006); molasses, as well as various types of lignocellulosic materials (Sun and Cheng, 2002; Lau and Dale, 2009; El-Zawaway et al., 2011; Balat, 2011).

The choice of feedstock is very crucial in commercial production of fuel ethanol since the cost of feedstock makes up a significant percentage of the total production cost. Technological issues such as easy with which the material can be converted to ethanol, the ethanol yield and productivity are taken into consideration in the choice of the feedstock for fuel ethanol production. The choice of the feedstock depends on the suitability of available land for their production, the productivity of the crop, the production cost (requirement for fertilizers, and other agrochemicals), environmental sustainability of the crop, social factors (food use and the effects on the prices of food), and on the whole, the economic feasibility. For example, while sugar cane is the main substrate used for bioethanol production in Brazil, most ethanol produced in the United States is from corn.

Bioethanol production from cassava has very high potential in Nigeria as well as in many other African countries because of its ability to give moderate yield even in poor soils. Although cassava yield per hectare is still low in Nigeria (about 11 ton/h), Nigeria has remained the largest cassava producing country in the world (FAOSTAT, 2012). Cassava can be grown on marginal lands where other crops cannot grow. It is therefore suitable for poor rural farmers who cannot afford to buy fertilizers for increased yield. In addition, it can be cultivated two to three times in a year since it does not require so much rain (Hillocks et al., 2002). Thus, we have been working on development of technologies for fuel ethanol production from cassava (Ogbonna and Okoli, 2007, 2009, 2010a, 2010b, 2011). The present study is on a simple process for on-farm fuel ethanol production from cassava and its economic feasibility for commercial on-farm fuel ethanol production in rural communities.

MATERIALS AND METHODS

Microorganisms

Aspergillus awamori IAM8928 and *Saccharomyces cerevisiae* IR2 (Kuriyama et al., 1985) were obtained from the Department of Microbiology, University of Tokyo, Japan. *A. awamori* was maintained in potato dextrose agar (PDA) while *S. cerevisiae* was maintained in nutrient agar. Each microorganism was maintained in slant cultures and was sub-cultured once every two to three weeks.

Preparation of cassava flour

Tubers from cassava variety 98/2101 were harvested at the age of 12 months from Ebonyi State Agricultural Development Program (EBADEP), Nigeria. They were peeled, washed and soaked in water over night. The next day, they were removed from water, drained, sliced and sun dried to a moisture content of about 15% in palm basket trays. The trays were taken inside at night and during bad weather. The dry slices were ground into flour using a manual grinding machine and sieved using a muslin cloth.

Preparation of *koji*

The cassava *koji* was prepared by solid state cultivation of *A. awamori* using the cassava flour supplemented with 20% rice bran (Ogbonna and Okoli, 2010a). The cassava flour (80 g) was mixed with 20 g of rice bran. The mixture was wetted with 60 ml of water and steamed over a moderate flame for 30 min. They were allowed to cool to room temperature and then inoculated with 5 ml of *A. awamori* spores (6.6 x 10^6 spores/100 g). It was properly mixed, wrapped in a muslin cloth and incubated at room temperature for 24 h. It was mixed again, incubated for another 24 h and the resulting *koji* was used as enzyme source for cassava flour hydrolysis.

Preparation of crude enzyme

An airlift bioreactor was used for preparation of crude enzyme (Ogbonna and Okoli, 2010b). The composition of the medium used for enzyme production consisted of (in g/l) cassava starch, 20; polypeptone, 5; yeast extract, 2; KH_2PO_4, 1; $CaCl_2.2H_2O$, 2; $MgSO_4.7H_2O$, 1; and anti-foam agent, 0.1 ml. The medium (3.0 l) was autoclaved and transferred into the sterilized bioreactor. The bioreactor was sterilized by washing very well and filling with 0.1% sodium hypochlorite overnight, followed by rinsing with sterilized distilled water. The reactor containing medium was then inoculated with *A. awamori* spores (initial concentration = 6.6 x 10^6 spores/ml). Aeration was controlled at 0.2 vvm using an air flow meter. After 96 h, the liquid medium was centrifuged at 3000 rpm and the supernatant was decanted into sterile flasks and used as the crude enzyme.

Production of yeast inoculum

Yeast inoculum was prepared in an airlift bioreactor. The medium used for yeast cultivation was composed of (in g/l) yeast extract, 2.5; polypeptone, 2.5 and glucose, 20. All the media components were dissolved in tap water in a 5000 ml flask and then autoclaved at 121°C for 15 min. The autoclaved medium was transferred into sterilized bioreactor. Sterilization of the bioreactor, and aeration rates were as described for crude enzyme preparation. After the 72 h of cultivation, the yeast cells sedimented at the bottom of the bioreactor and the cells were then harvested by decanting and blotting to remove free water.

Ethanol production from cassava flour

Based on our previous works (Ogbonna and Okoli, 2010a, 2011),

Table 1. Optima conditions for bioethanol production from cassava flour.

Factor	Optima condition
Substrate for *koji* preparation	80% cassava flour + 20% rice bran
Ratio of water (l) to substrate (kg) for wetting before steaming	60 :100
Spore inoculum concentration	6.6 x 10^6 spores/100 g substrate
Length of *koji* cultivation	48 hours (with mixing after 24 hours)
Ratio of *koji* to cassava flour (the cassava flour should be gelatinized in 4.56 volumes of water before mixing)	20 g *koji* :17.5 g cassava flour
Amount of crude liquid enzyme	1.0 l/kg of *koji*
Amount of yeast cells	3 g wet weight per 200 g *koji*
Length of fermentation after yeast inoculation	5 days

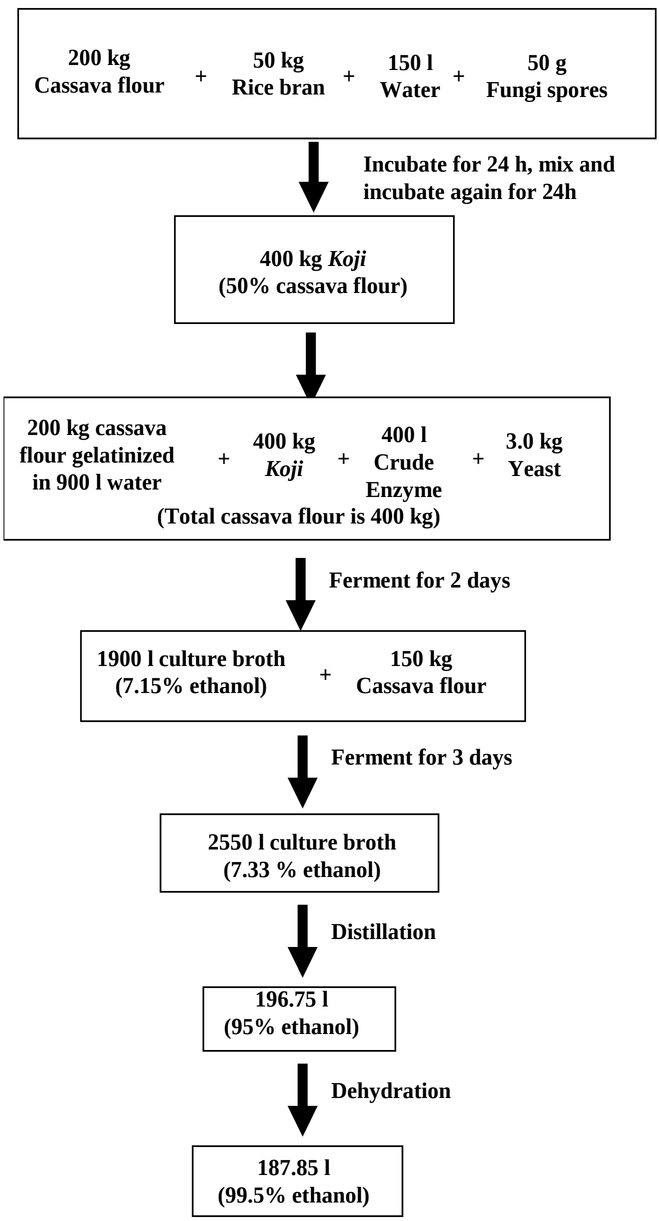

Figure 1. Schematic flow diagram of a process for production of 187.85 l of ethanol from cassava.

the optimal conditions for ethanol production from cassava, using cassava *koji* and *A. awamori* culture broth (crude enzymes) for hydrolysis are summarized in Table 1. Ethanol production from cassava flour under the optima conditions was done as follows: Cassava *koji* was prepared by mixing 4 kg of cassava flour with 1.0 kg of rice bran and 3.0 l of water. The mixture was steamed and inoculated with 2.64 x 10^8 spores of *A. awamori*. After incubating the *koji* for 48 h, the wet weight was 8.6 kg. In case A, *koji* (4.0 kg), 3.5 kg of cassava flour gelatinized in 16.0 l of water and crude enzyme (4 l) were added into a 50 l fermentation vessel. This was followed by addition of 30 g of yeast paste and 5 capsules of 250 mg chloramphenicol. The total volume of culture broth in the fermentation vessel was about 27.5 l. Starch hydrolysis and ethanol fermentation were allowed to proceed for five days with manual mixing once a day. In another fermentation vessel (case B), 4 kg of *koji* and 2 kg of cassava flour gelatinized in 9 l of water were mixed. Crude liquid enzyme (4 l), 30 g yeast paste and 5 capsules of 250 mg chloramphenicol were added to the vessel. Starch hydrolysis and ethanol fermentation were allowed to proceed for two days. At the end of the 2^{nd} day, 1.5 kg of cassava flour was gelatinized in 7 l of water and added to the fermentation vessel. Starch hydrolysis and fermentation were allowed to proceed for another 3 days. Ethanol concentrations in the fermentation vessels were determined on the second, third and fifth day.

Measurement of ethanol concentration

Ethanol concentration in the culture broth was determined as described previously (Ogbonna and Okoli, 2010a).

Economic analysis of the developed process

Economic analysis of a process for production of 563.55 l (187.85 l x 3) of 99.5% ethanol per day was made. The developed process was scaled up 100 times with three batches per day and the effects of cost of fresh cassava on the ethanol production costs and relative contributions of other cost components were determined.

The flow chart of the process for production of 563.55 l of 99.5% ethanol per day is shown in Figure 1. *Koji* is prepared by mixing 600 kg of cassava flour with 150 kg of rice bran, 450 l of water and 150 g of *A. awamori* spores. This is incubated in *koji* tray for 24 h, mixed and incubated for another 24 h. The resulting cassava *koji* (about 1200 kg) is divided into three. Each part (400 kg of cassava *koji*) is mixed with 200 kg of cassava flour, gelatinized in 900 L of water. This is followed by addition of 400 l of crude enzyme (or 1.0 kg of commercial amylase suspended in 400 l of water), and 3 kg (fresh weight) of active yeast pre-culture. The total amount of cassava flour in this broth is 400 kg. This is fermented for two days,

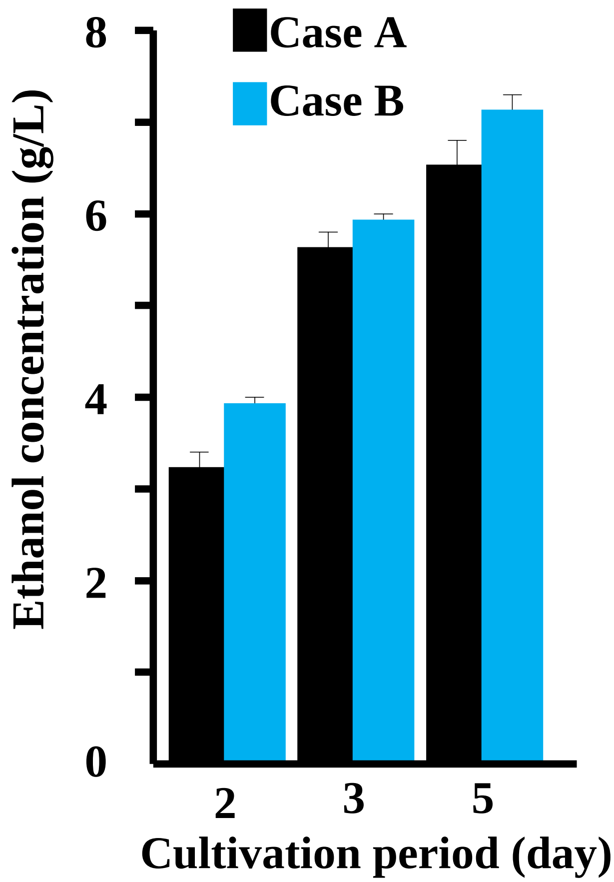

Figure 2. Effect of mode of cultivation on ethanol production. In case A, 3.50 kg of cassava flour was gelatinized and added to the *koji* and yeast cells but in case B, 2.0 kg of cassava flour was gelatinized and added initially, followed by addition of gelatinized 1.50 kg cassava flour after two days of fermentation.

days, resulting in 1900 l broth with 7.15% ethanol (Estimated from Equation 1). Another 150 kg of cassava flour gelatinized in 500 l of water is added, bringing the total amount of cassava flour to 550 kg. This is fermented for a further 3 days, giving 2550 l of broth with 7.33 % ethanol (Estimated from Equation 1). It is then distilled to yield 196.75 l of 95% (Estimated from Equation 2) ethanol, and dehydration of the ethanol by passing through molecular sieve column will yield 187.85 l of 99.5% ethanol per batch, giving a total of 563.55 l for the three batches.

$$E\% = (Q \times Y \times 100)/V \quad (1)$$

where, E% is the ethanol concentration in the broth; Q is the total quantity of cassava flour used for the cultivation; Y is the ethanol yield from cassava flour; and V is the total volume of the culture broth. The value of ethanol yield (Y) used in the calculation was 0.34 g-ethanol/g-cassava flour, which is the value obtained in this work. The volume of ethanol produced after distillation (Ev) was estimated from Equation 2.

$$Ev = (C_1 \times V)/C_2 \quad (2)$$

Where, C_1, is the concentration of ethanol in the culture broth before distillation; C_2, is the concentration of ethanol after distillation; and V is the total volume of the culture broth before distillation.

RESULTS

Small scale ethanol production from cassava flour

The results obtained when the 3.50 kg of cassava flour was gelatinized and added at the same time (case A) was compared with the values obtained when 2.0 kg of cassava flour was gelatinized and added initially, followed by addition of gelatinized 1.50 kg cassava flour after two days of fermentation (case B). As shown in Figure 2, the ethanol concentrations on the second, third and fifth day for case A were 3.24, 5.6, and 6.5 %, respectively. These compared with 3.9, 5.9 and 7.05% obtained for case B for day 2, 3 and 5, respectively. The final ethanol concentrations (on the fifth day) correspond to ethanol yields of 0.29 g-ethanol/g-cassava flour and 0.34 g-ethanol/g-cassava flour for case A and case B, respectively. Thus, the method used in case B was adopted.

Economic analysis of a process for production of 563.55 l of 99.5% ethanol per day

Investment costs

The estimated investment costs of a process for on-farm production of 563.55 l of 99.5% ethanol per day are shown in Table 2. *Koji* is produced daily and since each batch lasts for 48 h, two *koji* trays are required to ensure daily production and each is estimated to cost ₦20,000. Three fermentation tanks will be required per day (one for each batch). One production cycle comprise 5 days of fermentation and one day for cleaning and sterilization of the tanks. Thus, the total number of fermentation tanks required for daily production is 18 (3 x 6 days). Each locally fabricated galvanized metal tank is estimated to cost ₦50,000. The distillation system comprises a 1,500 l-pot still, a rectification column and two molecular sieve (zeolite 3a) columns for ethanol dehydration. The pot still, the condenser and molecular sieve columns are locally fabricated while the rectification column and the molecular sieve (zeolite 3a) will be imported. Zeolite 3a now costs between US$0.7 to US$1.01/kg. Thus the estimated cost of the distillation system is ₦3,000,000 (US$18,750). Storage tank for the dehydrated ethanol, cassava milling machine and a tank for gelatinization of cassava flour are also required and the estimated costs are shown in Table 2. A fairly used truck vehicle will be purchased at ₦2,000,000 for transportation of raw materials and finished product. An on-farm open hall building will be constructed at a cost of ₦1,000,000 while an additional ₦150,000 is provided for purchase of minor equipment such as buckets, floor washing equipment and office equipment. The total investment cost is seven million, five hundred thousand naira only (US$46,875).

Operation costs

A breakdown of the operating costs is shown in Table 3.

Table 2. Estimated investment costs for ethanol production from cassava flour.

Item	Cost (Naira)
Wooden *koji* tray (2 at ₦20,000 each)	40,000
Fermentation tanks (made of coated galvanized metal sheets (18 at ₦50,000 each)	900,000
A 1,500 l pot distiller with two molecular sieve columns	3,000,000
Storage tank	100,000
Chip milling machine	100,000
Gelatinization tank	50,000
A truck vehicle	2,000,000
Construction of an open hall building	1,000,000
Other minor equipment	150,000
Total	7,500,000

Currently, US$1 = N160.

Table 3. The operation costs used for economic analysis.

Component	Cost (Naira)
Cassava flour	10,000/ton
Depreciation value	125,000/month
Auxiliary materials	900/ton
Distillation	300/ton
Labour	105,000/month
Utilities	30,000/month
Co-products	-20/Litre

Currently, US$1 = N160.

Table 4. Composition of 1000 kg of fresh tuber.

Part	Weight (kg)	Percentage
Water	594.2	59.42
Outer skin	10.4	1.04
Inner skin	32.5	3.25
Pulp	337.6	33.76
Chaff	25.3	2.53

The cost of cassava tuber was ₦10,000 per ton. Depreciation value was based on 5 year payback period. Straight line depreciation was used with no salvation and thus calculated as the total investment cost divided by the payback period (the expected life expectancy of the equipment), giving ₦125,000 monthly. If the initial capital is borrowed, the monthly depreciation value will be used to pay back the loan. Interest on loan was not considered since Nigerian Federal Government, through Bank of Agriculture and Bank of Industry provides interest-free or low interest loans (See discussion for details).

The auxiliary materials included the costs of rice bran (30.3 kg/ton), amylase enzyme (1.0 kg), and active dry yeast (1.0 kg). Currently, rice bran is collected free from rice mills in Nigeria, thus a price of ₦380 was budgeted for collection. Technically, it will be easier and even cheaper to purchase enzymes and active yeasts rather than in-house production. Active dry yeast is sold at US$5.99 per 8.0 kg pack and 1.0 kg (US$0.749 = ₦120) is sufficient to replace 1.8 kg of wet yeast paste used in this experiment. Furthermore, 1.0 kg of amylase (currently sold at US$2.5/kg = ₦400) is sufficient to supplement the *koji* enzymes. Thus the total cost of the auxiliary materials is ₦900/ton of cassava tuber. The cost of distillation shown in the table represents the cost of propane gas used for the distillation and dehydration.

A 50 kg of gas (₦6,000) can distill 12 batches (19.8 tons of cassava) and consequently, the cost of distillation is estimated to be ₦300/ton. The cost of utilities (water and electricity) is ₦30,000 per month while the labour cost is ₦105,000/month. This includes four people for peeling of the tubers with monthly salary of ten thousand naira per month each (total of ₦40,000 per month), two secondary school leavers (₦12,000 per month), one driver (₦15,000 per month) and one HND or graduate (₦26,000 per month). The major co-product is the organic manure from the composting of cassava peels and other solid wastes.

As shown in Table 4, about 43 kg of wastes (the outer and inner skins) are produced per ton of fresh tubers. The remnant of the total solid matter in the effluent from distillation pot after separation of the solid distillers wastes is poured into the farm directly as manure. Organic manure is now sold at about one hundred naira per 20 kg (poultry manure is sold at two hundred naira per bag of about 20 kg).

Thus, two hundred naira can easily be realized from manure from one ton of cassava tuber. Another major co-product is the dried distiller's waste (DDW) which is the dried residual solid waste from distillation. It is high in protein, carbohydrate and minerals and used as animal feed.

Table 5. Effect of cassava fresh tuber cost on ethanol production costs.

Fresh cassava tuber (N/ton)	Annual costs (x N1000/year)							Total ethanol produced (l) (h)	Unit cost (₦/l) (i)	Value of co-products (₦/l)	Final production cost (₦/l)
	Cassava (a)	Utilities (b)	Auxillary (c)	Distillation (d)	Labour (e)	Depreciation (g)	Total cost				
10,000	11385	360	1024.65	341.55	1260	1500	15871.1	129616.5	122.5	-20	102.5
9,000	10246.5	360	1024.65	341.55	1260	1500	14732.6	129616.5	113.7	-20	93.7
8,000	9108	360	1024.65	341.55	1260	1500	13594.1	129616.5	104.9	-20	84.9
7,000	7969.5	360	1024.65	341.55	1260	1500	12453.6	129616.5	96.1	-20	76.1
6,000	6831	360	1024.65	341.55	1260	1500	11317.1	129616.5	87.31	-20	67.31
5,000	5692.5	360	1024.65	341.55	1260	1500	10178.6	129616.5	78.53	-20	58.53
4,000	4554	360	1024.65	341.55	1260	1500	9040.1	129616.5	69.74	-20	49.74

(a), 550 kg of cassava flour (1650 kg of fresh cassava tubers) is used per batch and with three batches per day, a total of 4.95 tons of fresh cassava is used per day. If we operate for 20 days in a month, 99 tons are used per month, and operating for 11.5 months per year gives 1138.5 tons of fresh cassava tubers per year. The total cost of cassava is thus 11385 x cost of cassava tubers per ton (column 1); (b), calculated as ₦30,000 x 12; (c), calculated as ₦900 x 1138.5; (d), Calculated as ₦300 x 1138.5; (e), calculated as ₦105,000 x 12; (f), calculated as ₦15,000 x 12; (g), calculated as ₦125,000 x 12; (h), calculated as 187.85 x 3 x 20 x 11.5 (Figure 1); (i), calculated as total cost divided by the total volume of ethanol.

It is used to replace a part of corn and soybean meals in animal feed. Starch content of the pulp is 75% and the remaining 25% is mainly lingnocellulosic materials which are not hydrolyzed during hydrolysis and fermentation. This will amount to 84.4 kg (25% of 337.6) per ton of fresh tuber. This can be mixed with the 25.3 kg of chaff (Table 4) giving a total of 109.4 kg.

The market prices for comparable products (brewers' grains, soybean meal, and palm kernel cake) range from twenty to thirty thousand naira per ton. If a conservative price of fifteen thousand naira per ton is taken, then one ton of fresh cassava will yield DDW worth one thousand six hundred and thirty five naira ((109.4 x 15,000)/1000).

The total amount that can easily be realized from co-products from one ton of cassava is thus one thousand eight hundred and thirty five naira (₦200 + ₦1,635). Since one ton of fresh cassava tubers yields about 90 l of ethanol, manure and DDW will reduce the cost of ethanol by more than twenty naira per liter (₦20/l).

Effects of cost of fresh cassava tubers on ethanol production costs

The effects of cost of fresh cassava tubers on various cost components are summarized in Table 5. With a price of ₦10,000 per ton of fresh cassava, the production cost is ₦102.5 per liter. Thus, the process is not economical if cassava tubers are purchased at ₦10,000/ton. The cost of production decreases sharply with decrease in the cost of the fresh cassava tubers. If the price of fresh cassava tubers can be reduced to ₦5,000 per ton (for example, by vertical integration of cassava farming and ethanol production), the production cost will be ₦58.53/l. With the current gasoline pump price in Nigeria as ₦97/l, ethanol can be sold at ₦64/l (since the energy content is 66%). Under this condition, the actualized internal rate of return (calculated quarterly for five years by using online IRR calculator (www.pinegrove.com), is 17.0255% with a gross return of 47.27%, total return of ₦11,045,020 and net cash return of ₦3,545,020.

Effect of cost of fresh cassava tuber on the relative contributions of various cost components

As shown in Table 6, as the cost of cassava tuber decreases, the relative contributions of auxiliary costs, distillation and labour costs increase. The cost of fresh cassava tubers has an overwhelming effect on the final ethanol production costs.

The final ethanol production cost decreases linearly with decrease in the cost of fresh cassava tubers (Table 5). The cost of cassava makes up between 50.38 and 71.73% of the final production cost.

The relative contribution of other cost components increase with decrease in the cost of cassava tubers.

The auxiliary and labour costs increase up to 11.33 and 13.94%, respectively, when the cost of cassava tubers decrease to ₦4,000 per ton. The relative contribution of distillation cost remains very low regardless of the cost of fresh cassava tubers.

Table 6. Effects of cassava cost on relative contributions of various components on ethanol production costs.

Cost of fresh cassava tubers (₦/ton)	Contribution to overall production costs (%) cost components			
	Auxiliary	Distillation	Labour	Cassava
10,000	6.46	2.15	7.94	71.73
9,000	6.95	2.32	8.55	69.55
8,000	7.54	2.51	9.27	67.0
7,000	8.23	2.74	10.12	63.98
6,000	9.05	3.02	11.13	60.36
5,000	10.07	3.36	12.39	55.93
4,000	11.33	3.78	13.94	50.38

Other components such as utilities, and depreciation together make up 11.72 to 20.57% of the total production cost, depending on the cost of fresh cassava tubers. These values were calculated as the values for each component in Table 5 divided by the total production cost at each cassava tuber price.

DISCUSSION

The results of ethanol production from cassava flour, using cassava *koji* supplemented with crude liquid enzyme showed that instead of adding 3.5 kg of gelatinized cassava flour at the start of the experiment, adding 2 kg initially and then the remaining 1. 50 kg after two days (fed-batch culture) gave higher ethanol concentration and yield. When the whole 3.50 kg was added initially, the viscosity of the broth was very high and this would reduce mass transfer and thus ethanol productivity. The process for fuel ethanol production from cassava flour shown in Figure 1 is simple, and can be operated even in rural communities without electricity supply.

The above economic analysis has shown that at the current market fresh cassava tuber cost of ₦10,000, the cost of cassava accounts for 71.73% of ethanol production costs. Other workers have also noted that the cost of raw materials accounts for 70 to 76% of ethanol production (Krishna et al. 2000; Zhang et al., 2003, Li and Chan-Halbrendt, 2009). Even though Nigeria has remained the world largest producer of cassava for many years now (FAO-STAT, 2012), the cost of cassava tubers in Nigeria (ten thousand naira per ton = US$62.5) is much higher than the US$24.1 to US$27.71/ton reported for China (Zhang et al. 2003) and the current international prices of US$36 to 40/ton (₦5,760 - 6,400).

The process described in this paper is not economically viable if cassava tubers are to be purchased from the open market at the current prices. However, there is a sharp seasonal and annual fluctuation in the costs of cassava tubers in Nigeria. Generally, the cost during the rainy season can be less than half of the price during the dry season. It has also been reported that with new cassava varieties, the total cost of production of cassava tubers ranges from ₦3701.56/ton to 4,555.769/ton, depending on farm location within the South-South and South-East parts of Nigeria (PIND, 2011). Furthermore, the farm gate price is usually much lower than the market prices and in some rural areas, cassava tubers are sold for as low as ₦3000/ton, especially during the rainy seasons (April to October). On-farm ethanol production in a vertically integrated system, where the investor also operates a cassava farm, is therefore recommended. In such a case, the cost of cassava will be much cheaper and the influence of cassava tuber market fluctuation on profitability can be avoided. The cost of transportation of the finished products to petrol stations or central blending facility has not been included. The company truck will be used for the transport and the small quantity (5,610 l per month) can easily be sold within the locality. The additional costs due to transportation will depend on the transportation distance. Furthermore, interest on loan was not included in this economic analysis. However, in some cases, loans from the Bank of Agriculture or Bank of Industry attract 2% interest (cost of borrowing, risks and expenses). Furthermore, the interest rate on loans from commercial banks in Nigeria is currently about 20%. Thus, depending on whether a 2% interest loan is obtained from Bank of Industry/Bank of Agriculture or 20% interest loan is obtained from a commercial bank, the cost of production will increase by either ₦1.157/l or ₦11.57/l respectively.

The production costs of ₦58.53/l at ₦5,000/ton is lower than the €0.38 0.54/l for ethanol production from starchy crops but higher than the production cost from sugar cane in Brazil (€0.23-0.28/l) (Budimir et al., 2011). It also compares with US$0.235-0.365/l for ethanol production from dry corn mills in United States (Kwiatkowski et al., 2006). Generally, the production cost depends on the raw material and the country (because of differences in the labour, utility and fixed costs) and ranges from US$0.211/l for sugar cane in Brazil to US$0.762/l for sugar beet in EU (Li and Chan-Halbrendt, 2009). The international price of fuel ethanol is currently between US$0.596/l and 0.747/l. Thus, local production, even at the current fresh tuber price of ₦10,000/ton, is better than importation and will also provide employments (both in the farm and ethanol production plants) and thus help in socio-economic development of the rural communities. Currently, Nigeria and many countries provide subsidies on fuels. Thus, fuel ethanol production will even be more profitable if such subsidies are extended to fuel ethanol.

The above results have shown that African nations must make effort to improve agricultural productivity if they are to benefit from the huge potentials of bio-energy production. The yields of most crops in Africa is less than 30% of the yields in the United States and other developed countries (FAO-STAT, 2009) and Governments should encourage both local and foreign investors in Agriculture as a means of improving productivity, reducing prices, and improving food security level. African nations must emulate many developed and even developing countries who support Agriculture and Bioenergy industries by providing subsidies and various forms of incentives.

One argument against the use of food crops for fuel ethanol production is that it can adversely affect food security. It is very important to point out that food security cannot be discussed without energy security. Food production and distribution are highly depended on energy supply. In Nigeria, for example, increase in fuel prices often results in sharp increases in the prices of all other items including all the food items. World bank (2013) report showed that there are more than 202 million hectares of usable uncultivated land in Africa and blamed land governance on the inefficiency on land use in Africa. Gnansounou et al. (2007) reported that in some countries only about 6% of arable land is under effective cultivation. Thus, with proper planning and land use management, energy crops can be produced on large scales without putting constraint on land availability for food crop production.

In conclusion, the simple process described in this paper for fuel ethanol production from cassava can be economically viable and feasible for rural communities in many African countries provided that the investor(s) also establish cassava farms and that the production is sited within the farm to ensure steady supply of cassava at less than ₦5,000/ton. Commercial bioethanol production in rural communities will reduce the present high unemployment rates, thereby leading to socio-economic development of the rural communities.

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