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PROFITABILITY OF BIOETHANOL PRODUCTION USING CASSAVA (*MANIHOT ESCULANTUS* CRANTZ) AND SWEET POTATO (*IPOMEA BATATAS*) AS RAW MATERIAL

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ABSTRACT

Ethanol imports into developing countries such as Ghana over the past decade have been on the increase. Corn, sugarcane and wheat are major crops that are normally used globally to produce bioethanol. The use of cassava and sweet potato as raw materials for ethanol production has also been demonstrated. Cassava and sweet potato, which grow excellently in Sub-Saharan Africa, could therefore be used as excellent and readily available local raw material for ethanol production to replace the seventy (70) million litres and more of ethanol imported into Ghana in 2016 for various uses. The search for the optimum processing conditions to hydrolyse and ferment sugars from the starches in cassava and sweet potato had been the major focus of all the studies in the past. The price of ethanol produced with cassava and sweet potato compared to the price of ethanol produced with other feedstock in the global market would largely determine the competitiveness and sustainability of producing ethanol with cassava and sweet potato. The objective of this work is to evaluate the cost benefits of ethanol production using cassava and sweet potato as raw materials. *Sika bankye* (cassava variety) and *Apomuden* (sweet potato variety) were cultivated and harvested at ten (10) months and three (3) months maturity respectively for the study. Liquefaction, saccharification and fermentation of the cassava and sweet potato varieties to produce ethanol were carried out with *Liquozyme SC DS,* combination of *Spirizyme Fuel and Viscozyme L* and *Bio-Ferm XR* (Lallemand) yeast, respectively. The study indicates that the production of ethanol with a 1:1 mixture of cassava and sweet potato using a 10,000 litres per day capacity ethanol distilling plant generates a net profit of between 9% and 30% over a period of five years. The findings indicate that ethanol production with cassava and sweet potato is a profitable venture.

Key words: Cassava, Profitability, Bioethanol processing, Sweet potato, Fermentation, Alcohol yield, Feedstock

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INTRODUCTION

Ethanol, also called ethyl alcohol, is a volatile, colourless, flammable liquid which belongs to a class of organic compounds that are given the general name alcohols [1, 2]. Ethanol for industrial use as a solvent or chemical intermediate is largely obtained by acid-catalyzed (H_3PO_4) hydration of ethylene at a high temperature of 250ºC [2]. Ethanol is also produced via biological processes by fermenting sugars with yeasts and bacteria, the method used for alcoholic beverages [3, 4, 5]. Ethanol is the most widely used biofuel today with production and consumption of over 40 billion litres based primarily on corn [6, 1, 2]. Ethanol is also used as a solvent, extractant, antifreeze, fuel supplement and an intermediate feedstock in the synthesis of innumerable organic chemicals [4]. Bimolecular dehydration of ethanol gives diethyl ether, which is employed as a solvent, extractant and anaesthetic. These and other ethanol-derived chemicals are used in dyes, drugs, synthetic rubber, adhesives, explosives and pesticides [4]. Biochemical ethanol production has some advantages over thermochemical ethanol production as the ethanol is produced from a renewable resource, having economic relevance, and that starchy crops can readily grow in poorer hotter climates [7]. Relatively less amounts of energy is required during bioethanol production since the saccharification and fermentation temperatures are relatively low. Biochemical method of ethanol production could therefore be considered as the best to employ in developing countries where starchy crops such as cassava and sweet potato abound as raw material.

Starch-based feedstocks include grains, such as corn and wheat, and tubers such as cassava and sweet potato. These feedstocks contain long complex chains of sugar molecules that can easily be converted to fermentable sugars. The sugar can then be converted to ethanol. Corn, sugarcane and wheat are major crops that are normally used globally to process ethanol [1, 2, 6,]. The use of cassava and sweet potato as raw materials for ethanol production in the recent past has been demonstrated [8, 9, 10, 11, 12]. Cassava and sweet potato grow well on marginal soils, need low inputs and improved soil productivity, and can be used in crop rotation systems. The starch content of these crops is relatively high to produce substantial amounts of ethanol. The search for the optimum processing conditions to hydrolyse and ferment sugars from the starches in cassava and sweet potato had been the major focus of all the studies in the recent past. The effects of substrate, temperature, enzyme types and concentrations, the reaction times of saccharification and fermentation had all been investigated on ethanol yield.

Cassava (*Manihot esculenta*) is a perennial woody shrub with an edible root which grows in tropical and subtropical areas of the world. Cassava is consumed as a staple crop in many regions of the developing world. It has become the most important root crop in Ghana and is becoming an increasingly important staple food. Cassava's combined abilities to produce high yields under poor conditions and store its harvestable portion underground until needed makes it a classic "food security crop". The potential of cassava is large because it offers the cheapest source of food calories and the highest yield per unit area [13, 14]. It also has multiple roles as a famine reserve, food and cash crop, industrial raw material and livestock feed [15]. The

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diversity of secondary products cassava offers, makes it a very useful root crop. However, once harvested, cassava roots are highly perishable and signs of deterioration begin to appear. Cassava is a perishable commodity with a shelf life of less than 3 days after harvest [15]. Due to the high perishability of cassava, early processing of the roots is an inevitable option once they are harvested. Processing involves different combinations of grating, dewatering, drying, soaking, boiling and fermentation of whole or fragmented roots to remove cyanogenic compounds which impart toxicity to the roots. More than 40% of cassava is currently processed, mainly into traditional food products [15]. Processing provides a means of producing shelf stable products (thereby reducing losses), adding value and reducing the bulk to be marketed. Apart from its use as food, cassava is very versatile and its derivatives and starch are applicable in many types of products such as foods, confectionery, sweeteners, glues, plywood, textiles, paper, biodegradable products, monosodium glutamate and drugs [15,16]. Cassava chips and pellets are used in animal feed and alcohol production [17]. According to the Ministry of Food and Agriculture, Ghana agriculture data [18], Ghana produced 17,213,000 tonnes of cassava in 2015. Out of this production figure, 60-70% was used to meet subsistence needs leaving a surplus production of 30 to 40%. Much of this excess cassava is either wasted or remains un-harvested, and can be captured for industrial use without any effect on food security [19]. This suggests a large opportunity for industrial growth.

Sweet potato (*Ipomoea batatas*) is a dicotyledonous plant that belongs to the morning glory family Convolvulaceae. The edible tuberous root is long and tapered, with a smooth skin and flesh colour that ranges between yellow, orange, red, brown, purple and beige. Sweet potato is a native American plant that was the main source of nourishment for early homesteaders and for soldiers during the revolutionary war [20]. The crop is cultivated throughout the tropical and warm temperate regions wherever there is sufficient water to support growth. Sweet potato has several agronomic characteristics such as drought resistance, high multiplication rate and low degeneration of the propagation material, short growth cycle, low illness incidence and plagues, cover rapidly the soil and therefore protect it from the erosive rains and controlling the weed problem [14, 21]. Sweet potato is the 6th principal world food crop [20] and approximately 90% of the world's crop is grown in Asia. Asia and Africa regions account for 95% of the world's production. China is by far, the world's leading producer of sweet potatoes and accounted for 81% of global sweet potato production in 2007 [20]. Sweet potato is an attractive raw material for fuel ethanol, since up to 4800L ethanol per hectare can be obtained [22]. Sweet potato has been considered a promising substrate for alcohol fermentation since it has a higher starch yield per unit land cultivated than grains [13, 14, 23, 24]. It has been reported that some industrial sweet potato breeding lines developed could produce ethanol yields of 4500–6500 L/ha compared to 2800–3800 L/ha for corn [14, 24].

Ethanol imports into developing countries such as Ghana over the past decade have been quite high. The over seventy (70) million litres of ethanol imported into Ghana for the various industries in 2016 [25] could have been produced in Ghana using cassava and sweet potato as raw materials. This may only be made possible if the cost of ethanol production is competitive compared to the cost of importing ethanol into

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Ghana. Ethanol produced from cassava and sweet potato would therefore need to be priced competitively in order to compete favourably with ethanol produced globally from corn and other raw materials. The current cost of one litre of ethanol on the international market is US$0.44 [24].

The aim of the paper is to evaluate the cost benefits of ethanol production using cassava and sweet potato as raw material.

MATERIALS AND METHODS

Materials

Flour processed from 10 months old *Sika bankye* (cassava variety) cultivated at Caltech Ventures Ltd farms, Ho, in the Volta region, Ghana and sweet potato flour processed from 3 months old *Apomuden* (sweet potato variety) cultivated at Mantsi, in Greater Accra region, Ghana was used for ethanol production in the laboratory. Freshly harvested *Sika bankye* (10 months old) and 3 months old *Apomuden* (1:1 mixture) was used for pilot scale ethanol production at Caltech Ventures Ltd. Enzymes used for the work were starch degrading enzymes; *Liquozyme SC DS, Viscozyme L and Spirizyme Fuel* supplied by Novozymes, Denmark. Yeast type used for fermentation was Bio-Ferm XR (unique yeast strain of *Saccharomyces cerevisiae)* produced by Lallemand, Georgia, USA.

Methods

Cassava and sweet potato cultivation and yield determination

One hectare of land at Caltech Ventures Ltd farms, a private commercial cassava production and processing company located at Ho in the Volta region of Ghana, was acquired for the production of the cassava. The expertise of the Farm Manager of the company was tapped to assist in the production of the cassava to ensure good yield. The one hectare land was cleared, ploughed, composted, harrowed and ridged for cassava planting. *Sika bankye* (cassava variety) was planted in August (start of the minor rain season) in rows (1m by 1m) on the one hectare piece of land after the land preparation. Weed control was carried out by spraying with pre-emergent herbicide before planting followed by manual weeding one month after planting and finally by post emergent herbicide spraying two months after the manual weeding. There was no inorganic fertilizer application and the plants were rain fed throughout the ten months period. The roots were harvested at ten months old maturity based on study by Komlaga *et al.* [27] which indicate that the prime cassava harvesting age for ethanol production is 10 months. The total weight of roots harvested from the one hectare piece of land and the number of plant stands harvested was documented.

One hectare piece of land acquired at Mantsi in the Greater Accra region of Ghana was used for the production of the sweet potato for the study. The expertise of a Ministry of Food and Agriculture Extension Officer stationed at Pokuase, Ghana close to the production field was sought to assist with the application of best agronomic practices to ensure the best yield of sweet potato from the farm. The land was cleared, ploughed, composted, harrowed and ridged for sweet potato planting. *Apomuden* (sweet potato variety) vines were planted in June in rows on the one hectare piece of land after the

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land preparation. Weed control was carried out by spraying with pre-emergent herbicide before planting followed by manual weeding one month after planting. There was no inorganic fertilizer application and the plants were rain fed throughout the three months period. The roots were harvested at three months maturity period, based on a study by Komlaga *et al.* [27] which indicates that the prime age for harvesting sweet potato for ethanol production is three months. The total weight of roots harvested from the one hectare piece of land was documented.

Cost of production of one (1) hectare of cassava and sweet potato
The cost of production of one hectare of cassava and sweet potato was determined by noting all the expenditure from land acquisition to the harvesting of the crops. The cost elements included hiring of the land, land clearing, ploughing, composting, ridging, cost of planting material, manual planting labour, cost of pre-emergence herbicide application, labour for manual weeding, cost for post-emergence herbicide application (for cassava farm only) and labour for harvesting.

Processing of *Sika bankye* and *Apomuden* flours
Ten (10) and three (3) months old lots of freshly harvested *Sika bankye* and *Apomuden* respectively were weighed, washed, sliced thinly (average of 2 mm thick) with peels on, dried immediately at 62°C in a forced air oven for 6 h, cooled and milled with a hammer mill through a sieve (motorized sifter) with 350µ mesh size. The flour samples were subsequently used for ethanol production in the laboratory.

Ethanol production from *Sika bankye* and *Apomuden*
Alcohol content of 50 g mixture of 10 months old *Sika bankye* flour and 3 months old *Apomuden* flour in the ratio 1:1 was determined in the laboratory using the method described by Komlaga *et al.* [27] followed by alcohol yield by weight calculation using the [28] formula: $A_{w/w} = 0.38726^* (OE - AE) + 0.00307^* (OE - AE)^2$, where, $A_{w/w}$ is Alcohol content by weight, OE is original extract and AE is the apparent extract. The alcohol by volume conversion was done using the Probrewer conversion table [29]. Pilot scale ethanol production trial was conducted at Caltech Ventures Ltd using a 10,000 litres capacity per day ethanol processing plant at Ho in the Volta region of Ghana. Ten (10) tonnes of freshly harvested *Sika bankye* (10 months old) and 3 months old Apomuden (1:1 mixture) was used for ethanol production. The enzyme combinations and yeast used for the laboratory alcohol production were applied for the saccharification and fermentation of the pilot scale production. Ethanol yield (volume per 1 tonne of the raw material) from the trial was recorded and used for the profitability analysis.

Cost benefit analysis of ethanol production with *Sika bankye* and *Apomuden*
Ethanol yield from one tonne mixture of 10 months old *Sika bankye* and 3 months old *Apomuden* in the ratio 1:1 was used for the profitability analysis. The cost of the 10,000 litres per day capacity ethanol plant, the production cost of 1 tonne of cassava/sweet potato, total labour costs of staff operating the ethanol plant, the utilities cost (energy and water), Consumables (Enzymes, Yeast, Cleaning agents), Communication, Tax and other incidental costs were used to determine the profitability of ethanol production using a combination of cassava and sweet potato.

The study used Net Profit Margin as a proxy for profitability. Absorption costing principles were adopted to estimate profitability of ethanol processing with cassava and sweet potato. Absorption direct expenses as well as indirect expenses (overhead) were taken into account in evaluating profitability. This is achieved by allocating overhead cost that is fixed to cost of item or goods produced and closing stock. Absorption costing ensures more accurate accounting for closing stocks as the expenses, which are associated with these stocks and linked to the total cost of production. The procedure also accounted for expenditure items more accurately particularly those in the unsold stock. These lead to accurate accounting for expenses, which are reported in any given period. The formula for the determination of Net profit is presented as follows:

GP= TR - CP, NP= GP - Exp

Where: GP- Gross profit, TR- Total Revenue, CP- Cost of production/cost of sales, NP- Net Profit, Exp.- Expenses.

Net profit margin was used as a proxy for profitability as it gives better indication of profitability. Net profit margin is estimated as the net profit expressed as a percentage of the Total Revenue. The higher the net profit margin the more profitable the venture is [30].

RESULTS AND DISCUSSION

Alcohol yields from *Sika bankye* and *Apomuden*

The mean alcohol yields from *Sika bankye* and *Apomuden* mixture (1:1) are shown in Table 1. The alcohol values observed in the study were 16.2% v/v and 15.5% v/v for the laboratory analysis and pilot scale trial respectively. The alcohol yields observed were slightly higher compared to ethanol yields of 10.22% v/v, 8.3% v/v and 15.18% v/v reported by [8, 32, 33] respectively from cassava and agricultural waste bio-fermentation. The relatively higher alcohol yields from the combination of the cassava and sweet potato could be exploited to process the 30 to 40% cassava surplus reported in 2015 in Ghana by the Ministry of Food and Agriculture Statistics[18]. Much of this excess cassava is either wasted or remains un-harvested, and could be captured for industrial use such as ethanol production without any effect on food security [19]. The over seventy million litres of ethanol imported into Ghana for various industries in 2016 [23] could have been produced in Ghana using cassava and sweet potato as raw materials. This could only be possible if the cost of alcohol production or price of ethanol from cassava and sweet potato was competitive compared to prevailing ethanol price in the international market. A study by El Sheikha and Ray [34] indicates that bioprocessing of sweet potato offers novel opportunities to commercialize the crop by developing a number of functional foods and alcoholic drinks through either solid state or submerged fermentation. Sweet potato has also been considered a promising substrate for alcohol fermentation since it has a higher starch yield per unit land cultivated than grains [13, 14, 23,24].

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Cost-benefit analysis/profitability of ethanol production using *Sika bankye* and *Apomuden*

A study by Komlaga *et al.* [31] using a mixture of *Sika bankye* flour and *Apomuden* flour in the ratio of 1:1 resulted in alcohol yield of 16.2% v/v, a higher alcohol yield compared to processing *Sika bankye* flour and *Apomuden* flour separately. The study provided the basis for the use of cassava and sweet potato (mixture) for ethanol production for this cost benefit analysis. Table 2 shows the production cost (GH¢100) of one tonne of *Sika bankye* roots and the production cost (GH¢138) of one tonne of *Apomuden* tubers. The cost of production of one tonne of 1:1 combination of *Sika bankye* and *Apomuden* is therefore Gh¢119 (GH¢50 + GH¢69). Table 3 and 4 show the information on the ethanol processing plant, and the income and expenditure of ethanol production respectively over five (5) years period using *Sika bankye* and *Apomuden*. Pilot scale ethanol production trial with *Sika bankye* and *Apomuden* (1:1 mixture) resulted in yield of 155 litres of ethanol per 1 tonne of raw materials at 95% purity. This ethanol yield compares with the 16.2% v/v ethanol in the study by Komlaga *et al.* [31].

The financial performance, based on the pilot scale trial results, of the ethanol production from *Sika bankye and Apomuden* for 5 years with some underlying assumptions was carried out. Ethanol production on the 10,000 litres per day capacity processing facility is expected to start from 70% capacity in year 1 to peak at about 85% production capacity by year 3. The total capital required for this project is in the sum of GH¢15,234,900 which will cover the cost and installation of the ethanol plant which would be funded by debt (loan). It is envisaged that the enterprise can borrow this amount at an estimated cost of capital of 10% per year over a five (5) year period. At this cost of borrowing, the cash flows generated are adequate to service both principal and interest payments. The key revenue line was the sale of ethanol. The revenue assumptions included average price increases of 10% year on year. Average price per litre of ethanol was estimated at GH¢4.70. Installed production capacity of 10,000 litres ethanol per day with one set of equipment each operating at 8-hour shift and one shift a day was used for the analysis. Optimal product mix is 100% ethanol and base case assumption was expected to remain unchanged. The cost assumptions included the cost of raw material in year one at GH¢119.00 per tonne with an average increase year after year at 10%. The primary cost element in the production cycle was the cost of fresh cassava and sweet potato which could be sourced either from the enterprise's own farm or from out-grower or block farmers. Direct cost for the analysis comprised of raw material, labour and fuel cost as illustrated in Table 3.

Based on the analysis of the field data collated on the production of the cassava and sweet potato, the proposed staff wages and other production costs (Table 3), the income from sales of ethanol and other assumptions made, the profit to be generated in the first year of operations is Gh¢740,330 (Table 3). This is derived from gross sales revenue of Gh¢7,896,000. For subsequent years, the business operation would generate more profit after tax in all years increasing from an initial profit after tax of Gh¢1,630,716 in year 2 to Gh¢2,977,695 in year 3 and peaking at approximately Gh¢4,195,480 at the end of the fifth year (Table 3). Gross profit margin averaged 57% over the five-year period. The net profit margin was 9% in year one and increased to 30% at the end of year five (5). This is because the percentage increase in revenue was more than the percentage increase in total cost. The production of ethanol using combination of *Sika bankye* and *Apomuden* in the ratio of 1:1 is therefore a profitable venture. This profitable venture when exploited would expand the end use of cassava and sweet potato which in return will spur increased industry and market demand and reduce drastically the problem of post-harvest loss of the two crops.

CONCLUSION

Production of ethanol using a mixture of *Sika bankye* and *Apomuden* in a 1:1 ratio resulted in 15.5% v/v ethanol yield per 1 tonne of raw material. The cost per 1 tonne of the raw materials at the time of the study was GH¢119.00 and the selling price of 1 litre of ethanol was GH¢4.7. The study reveals that processing ethanol using a 1:1 mixture of cassava and sweet potato with 10,000 litres per day capacity ethanol distilling plant generates a net profit of between 9% and 30% over a period of five years. This suggests that ethanol production with cassava and sweet potato is a profitable venture. This profitable venture when exploited would expand the end use of cassava and sweet potato which in return will spur increased industry and market demand and reduce drastically the problem of post-harvest loss of the two crops.

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Table 1: Mean alcohol yields from *Sika bankye* and *Apomuden* samples

Sample	Alcohol yield (% v/v)
Sika bankye:*Apomuden* flour mix (1:1), **Laboratory analysis**	16.2 ± 0.3
Sika bankye:*Apomuden* fresh roots mix (1:1), **Pilot scale trial**	15.5 ± 0.1

Table 2: Production cost and yield of fresh *Sika bankye* and *Apomuden*

	Sika Bankye	*Apomuden*
Production cost per hectare (GH¢)	3,300	2,900
Yield per hectare (tonnes)	33	21
Production cost per tonne (GH¢)	100	138

Table 3: Details of the ethanol processing plant

Cost of ethanol plant (GH¢)	15,234,900*
Capacity of plant (Litres per day)	10,000
Debt (10% per anum dollar rate)	15,234,900
Raw material (fresh cassava and sweetpotato) intake (tonnes/day)	50
Days of processing (Per month)	20
Energy consumption at full load (Kw/hr)	225
Personnel (Number)	19
Price of ethanol (GH¢/litre)	4.7
Inflation (%)	10

*Exchange rate of GH¢: USD is 1: 0.23

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Table 4: Income and Expenditure on production of ethanol for five (5) years

	Amounts (GH¢)				
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Revenue from Ethanol sales	7896000	9306000	11601480	12761628	14037791
Raw material cost	-1428000	-1683000	-2098140	-2307954	-2538749
Staff cost	-512400	-614880	-737856	-885427	-1062513
Direct Expenses (Consumables/Utilities)	-1419935	-1631922	-1879106	-2167807	-2505536
Repairs and Maintenance	-60000	-66000	-72600	-79860	-87846
Cost of sales	-3420335	-3995802	-4787702	-5441048	-6194644
Gross Profit	4475665	5310199	6813778	7320580	7843147
Gross Profit margin	57%	57%	59%	57%	56%
Sales and Marketing Expenses	-157920	-186120	-232030	-255233	-280756
Administration costs	-120000	-144000	-172800	-207360	-248832
Depreciation	-1523490	-1371141	-1234027	-1110624	-999562
Earnings before interest and tax	2396335	3278818	4770092	5284771	5784409
Interest charges on loan	-1409228	-1104530	-799832.3	-495134	-190436
Profit before tax	987107	2174287	3970260	4789636	5593971
Tax (25%)	-246777	-543572	-992565	-1197409	-1398493
Profit after tax	740330	1630716	2977695	3592227	4195480
Net Profit margin	9%	18%	26%	28%	30%

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