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ALTERNATIVE FOR DIRTY COOKING FUELS IN GHANA: EXPLORING THE POTENTIAL OF CASSAVA ETHANOL

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ABSTRACT

Fossil fuels are a major contributor to climate change, and as the demand for energy production increases, alternative sources (e.g., renewables) are becoming more attractive. Kerosene and conventional solid fuels, which are used to cook, have detrimental effects on people's health, the environment, and the economy. This study seeks to explore the potential of cassava ethanol as an alternative to dirty cooking fuels in Ghana. The study revealed that the prices of electricity and liquefied petroleum gas (LPG) are on the rise and this is making their adoption very low. The use of ethanol, an alternative clean cooking fuel that can be produced locally and reasonably priced, should be encouraged. Cassava was selected as the most viable crop for ethanol production because it is highly underutilized and can be grown on most Ghanaian land. The study also revealed that the Crop Research Institute-Agra (CRI-Agra) Bankye, a variety of cassava, will give an optimum ethanol yield. It has the potential to produce one litre of ethanol from about 7kg of fresh roots. Approximately 147 Ha of agricultural land may be used to produce 1 ton of cassava ethanol. Since cassava ethanol for cooking offers major potential for climate change mitigation, there should be an adoption strategy. This work serves as input for decision-making for industrializing the cassava sector.

Contribution/Originality: This study contributes to the existing research on clean cooking fuels. Cassava ethanol offers a better replacement for dirty cooking fuels like; wood fuel and charcoal compared to other clean cooking fuels. We demonstrate this by comparing the rising prices of LPG and electricity to a cheap large-scale production of cassava ethanol.

1. INTRODUCTION

Climate change is defined as the shift in climate patterns mainly caused by greenhouse gas emissions from natural systems and human activities. Climate change indicators such as temperature, precipitation, sea-level rise, ocean acidification and extreme weather conditions pose hazards such as droughts, floods, hurricanes, severe storms, heatwaves, wildfires, cold spells and landslides [1]. Fossil fuels are a major contributor to climate change, and as the demand for energy production increases, alternative sources (e.g., renewables) are becoming more attractive.

Around the world, household air pollution from cooking with conventional fuels causes more than 4.3 million premature deaths yearly. More than three billion people use kerosene and conventional solid fuels to cook, which has detrimental effects on people's health, the environment, and the economy. In Sub-Saharan Africa alone, illnesses associated with indoor air pollution, such as lung cancer, ischemic heart disease, and acute lower respiratory infections, result in at least 581,000 early deaths every year [2].

Ethanol and biodiesel are two most common biofuel products used around the world [3]. Biofuels such as bioethanol reduce reliance on fossil fuels and can be compatible with the existing fleet of internal combustion engines and cooking stoves. Liquid fuels produced from biomass have been more attractive in recent decades due to the high energy densities they possess, coupled with the fact that they can be stored in light-weight tanks. They have particularly risen to prominence around the globe as with the potential to provide solutions to issues such as climate change and dwindling fossil fuel deposits. Bioethanol offers many positive properties as a renewable, efficient, and largely safe household cooking fuels. The incorporation of bioethanol in cooking can reduce carbon dioxide emissions from cooking stoves. Bioethanol is typically produced via microbial fermentation of fermentable sugars, such as glucose, to ethanol. Traditional feedstocks (e.g., first-generation feedstock) include cereal grains, sugar cane, sugar beets and cassava [4, 5]. Ethanol is commonly derived from sugar and starchy feedstock such as sugarcane, sweet sorghum, maize and cassava [2, 3]. The cassava starch has a competitive advantage for ethanol production than other materials [6].

Cassava (*Manihot esculenta Crantz*) is a suitable climate-smart crop for the production in arid and semi-arid conditions where the land is fragile and the changing weather patterns often result in erratic rainfall and persistent drought [7]. Therefore, when it comes to production volume, Ghana ranked second in Africa and sixth overall in 2016 [8]. It produced roughly 17.8 million metric tons (MT). It also has multiple roles as a famine reserve, food and cash crop, industrial raw material and livestock feed [9]. For the vast majority of people in the areas where it is grown, its edible starchy, tuberous root provides their main source of carbohydrates. It can be consumed raw by cooking, crushed into fufu (cooked and pounded fresh roots), or semi-processed into forms like gari (granulated roasted fermented cassava), tapioca, kokonte (dried fermented cassava chips for flour), or as animal feed.

The cassava industry has a lot of potential to raise incomes for those involved in the supply chain, improve food security for households, and reduce poverty in rural Ghana as well as its bioethanol potential for both industrial domestic and transport use. However, a number of barriers prevent the Ghanaian cassava value chain from operating effectively. Because cassava output is frequently high during the rainy season and the crop is underutilized in Ghana, 34% of the harvest is wasted during the value chain. This leads to wastage of surplus across the country [8]. To fully fulfill the potential of the cassava sub-sector, cassava bioethanol must be incorporated into the value chain and much emphasis must place on industrializing the sector.

Over dependence on wood fuels traditionally in Ghana and other African countries is a mojor contributor top Greenhouse Gas Emission [10]. Greenhouse gas emissions from transportation in Africa is growing at a rate of 7% annually [11]. Liquid ethanol offers a cooking experience similar to that of modern fuels like kerosene and LPG. When used in quality ethanol stoves, bioethanol fuel provides a clean cooking experience [2]. Bioethanol is derived from cassava [12, 13]. However, these studies did not consider the potential of the varieties of cassava to produce clean bioethanol for cooking. Some authors worked on production of bioethanol from dates [14], production of ethanol from some varieties and maturity of sweet potato [15].

Cassava ethanol production can serve as a fuel for cooking as well as industrial application. Pelizan, et al. [16] revealed that only 5.4% of cassava produced in 2017 could be used to produce the ethanol needed to implement an E10 blending policy. Also the residue generated from cassava processing has a huge potential for the production of major products such as ethanol [17]. About 30% of the estimated residue from the current total cassava production would be sufficient to fulfil the E10 obligation. However, an effective planning would be needed to avoid competition with the usage of the crop for food [16]. Also a demand-driven approach should be implemented to stimulate and develop cassava-based industries ascertaining prospects and limitations of cassava production and utilization. Therefore the varieties of cassava needs to be investigated in order to reveal those that will give the optimum ethanol yield. This study seeks to explore the potential of cassava ethanol as an alternative for dirty cooking fuels in Ghana.

2. METHODOLOGY

2.1. Study Area Description

Ghana is located in West Africa and has borders with Burkina Faso to the north, Togo to the east, Cote d'lvoire to the west, and the Atlantic Ocean to the south. Latitude 7°57′9.97"N and longitude 1°01′50.56"W are the coordinates for Ghana. Ghana has a total land area of 238,535 km2 and a population of 30.8 million [18]. On the basis of climatic factors, geology, and soil, Ghana is categorized into six agro-ecological zones: Sudan savanna (SS), Guinea savanna (GS), Forest-savanna Transition (FT), Deciduous Forest (DF), Rain Forest (RF), and the Coastal Savanna (CS) zones [19]. Cassava (*Manihot esculenta*), cocoyam (*Xanthosoma spp.*), yam (*Dioscorea spp.*), maize (*Zea mays*), millet (*Pennisetum glaucum*), rice (*Oryza sativa*), and *sorghum spp.* are the major starchy crops farmed in Ghana.

2.2. Average, Achievable and Starch Yield

Data was obtained from Crop Research Institute (CRI), Kumasi, for the following elements: Varieties, Average yield, Fresh Root Starch Content, Dry matter starch content and Uses. CRI- Essam banke was released in 2005, CRI-Sika Bankye in 2010, CRI-Duade Kpakpa, CRI-Agra bankye, CRI- Lamesese and CRI- Abrabopa were released in 2015 [20].

2.3. Share of Household Cooking Fuel and Prices

Data on the share of households cooking fuel by type in Ghana was taken obtained from the Ghana Statistical Service (GSS). The price of LPG in Ghana between January 2018 and April 2022 was obtained from Public Utilities Regulatory Commission (PURC).

2.4. Data Analysis

The data was analysed using Excel in Microsoft Office to obtain graphs for easy comparison.

3. RESULTS AND DISCUSSION

3.1. Status of Cooking Fuels in Ghana

The production and consumption of cooking fuels in developing countries such as Ghana has been a major source of greenhouse gas emissions. It is estimated that almost 2.6 million residents in developing countries depends on dirty cooking fuels [21]. A lot of socio-demographic factors account to the type of cooking fuel and technology used by households in Ghana. Factors such as household size, level of education, access to electricity and standard of living have a significant impact on the choice of cooking fuel used in Ghana. A study by Makonese, et al. [22] revealed that access to electricity though named among the socio-demographic factors, it does not implied that households with electricity access will desist from the use of traditional fuels. Statistical evidence indicates that the proportion of the Ghanaian population with access to clean cooking fuels have increased with just about 19% between 2010 and 2021. The consumption of wood fuel by the Ghanaian household in the year 2019 was estimated at around 20 million tons, with the supply mainly coming from the natural forest [23]. The 2021 population and housing census indicate that as of 2021, about 4.5 million households in Ghana depends on dirty cooking fuels and technologies [18].

Thus, despite the promotion of clean cooking fuels, the growth in the use of clean cooking fuels over the past decades has been marginal [24]. Figure 1 demonstrate the share of households cooking fuel by type in Ghana.

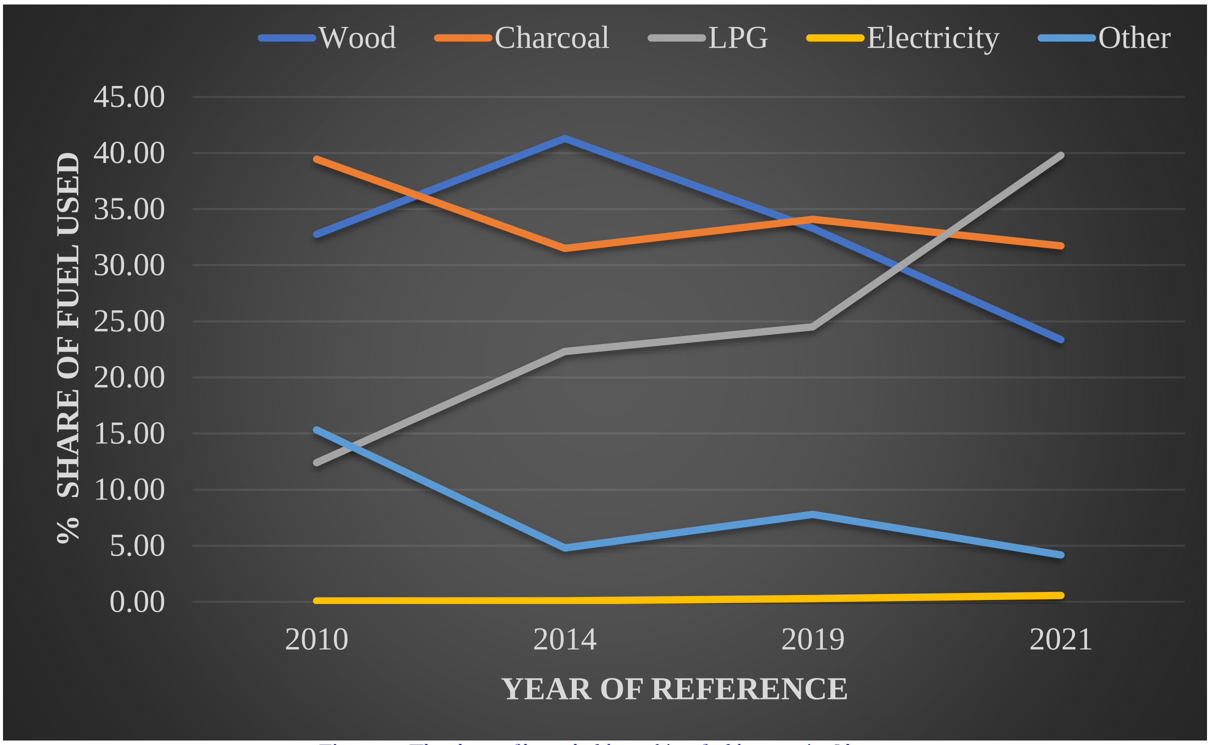

Figure 1. The share of households cooking fuel by type in Ghana.

The graph shows a sharp decline in the use of wood fuel but a slow decline in the use of charcoal since 2019. Also there is a sharp increase in liquefied petroleum gas (LPG) fuel since 2019 and this may be attributed to current environmental concerns with the use of wood and charcoal. The marginal increase in the use of electricity as cooking fuel is due to the high electricity price as well as the high cost of electric cook stoves. The other cooking fuels used in some households include crop and animal residue, saw dust, kerosene and ethanol also saw a decrease in use due to high urbanization rate. Ethanol-based fuels only a negligible proportion (0.04%) of household cooking fuels in GSS [18]. This current trend in growth (with business as usual projections) suggests that the proportion of the population with access to clean cooking technologies will be about 49% of the population by 2030, about 51% short of the Sustainable development goal (SDG) 7 target.

3.2. Bioethanol as A Potential Replacement for Cooking Fuels in Ghana

The feasibility of replacing the traditional cooking fuels in Ghana with ethanol depends on the availability, the affordability and the acceptability of ethanol compared to the other clean competitors like LPG and electricity cooking fuels. One of the major challenges identified by Boakye and Ofori [24] is that the available ethanol cook stoves is not suitable for the cooking dough-like foods such as banku and kokonte which are among the major delicacies in Ghana. On the flip side even though the price of LPG and electricity are sky rocketing households may go back to the traditional cook fuels which are dirty. Figure 2 demonstrates the rise in the price of LPG and electricity between January, 2018 and September, 2022.

Figure 2. The price of LPG in Ghana between January 2018 and April 2022.
Source: Boakye and Ofori [24]; PURC [25].

The average price of LPG and electricity increased from 5.5 Ghana Cedes (GHS 5.5) per kg and 0.59GhC per kWh in January, 2019 to GHS 12.2 per kg and 0.79GhC per kWh as of September, 2022 respectfully See Figure 2. The rise is affected mainly by rising crude oil prices and currency depreciation. The serious impact of this situation is that most households will return to the use of dirty cooking fuels if the price of LPG and electricity continues to increase because most households may not be able afford these fuels. Therefore, the adoption of a more affordable alternative fuel source such as ethanol cooking fuel which can be locally produced will complement the efforts to accelerate Ghana's drive towards universal access to clean cooking fuels. Also a study on the emissions reduction potential ethanol stoves showed an 83% and 91% carbon reduction of charcoal and kerosene stoves respectively [26]. This shows that bioethanol is a cleaner and a cheaper alternative to all the cooking fuel options. Local production of bioethanol would be more sustainable replacement for both dirty cooking fuels and expensive cooking fuels.

Table 1. The starchy crops that can compete for the production of bioethanol.

Crop (reference)	Starch content (%)	Average yield in (Mt/Ha)	Achievable Yield (Mt/Ha)
Cassava	22	13.8	48.7
Maize	61.7	1.7	6
Sweet Potato	78	3.3	40
Yam	19	15.3	49

Note: Komlaga, et al. [9]; Osei, et al. [27].

3.3. Bioethanol Production from Common Starchy Crops in Ghana

Approximately, 70 million litres and more of ethanol were imported into Ghana in 2016 for various uses and over the past years, the value has increased. Corn, sugarcane and wheat are the major crops that are normally used globally to produce bioethanol. The use of cassava, yam maize and sweet potato as feedstock for ethanol production has also been demonstrated [20, 27, 28]. Table 1 demonstrates the starchy crops that can compete for the production of bioethanol.

3.4. Bioethanol Production Potential from Cassava

Various varieties of cassava can be processed into different intermediate and finished food products involving cassava dough (agbelima), flour for instant fufu (poundable), cassava flour, starch, gari, chips on a huge scale. Based on the starch and amylose content of the cassava, products such as beverages, glucose, high fructose syrups are being introduced [29]. Starch from cassava is widely used for dyeing and sizing in the textile industries to increase the brightness and weight of the cloth whereas in the pharmaceutical industries, it is used as a filler material and bonding agent for making. It is used by Guinness Ghana Brewery Limited (GGBL) and Accra Breweries Limited (ABL) to produce alcoholic beverages [8]. The rising demand for cassava starch at both the local and international market presents a great opportunity for Ghana to enhance foreign exchange revenue through export and improve farmers' livelihood through improved income [6]. The currently best starch-yielding cassava varieties released by Crop Research Institute (CRI) is illustrated in Table 2. The yields ranges between 19.63% and 25.4 % for fresh root and between and 74.1 % for dry matter respectively of its total root weight in Ghana [30]. Ethanol can be produced from cassava in two ways. The first is by using fresh cassava as feedstock. Here, the production of ethanol from cassava starts by chopping and then grinding fresh cassava roots. The second considers the drying of cassava (to about 14% moisture content) prior to processing it to ethanol [31]. Thus, separation of the main cassava components (peel, and dried cassava chips). The ethanol production begins with the milling and mixing of the cassava chips with water into a homogenous slurry. Filtration of the slurry is done to obtain filtrate mixture which is allowed to rest for two hrs for the sedimentation. The starch and liquid at the top was decanted and discarded. Percentage of extraction yield is calculated using the formula shown in Equation 1 as follow;

$$\text{Starch (\%)} = \frac{Starch\ Weight\ (g)}{Cassava\ weight\ (g)} \times 100\% \qquad 1$$

The industrial production of ethanol goes through the steps shown in Figure 3 as; pre-treatment, hydrolysis, fermentation, distillation. Factors such as starch content, average yield of cassava per hectare of land cultivated are summarized in Table 2. The starch passes through the hydrolysis and fermentation tanks where enzymes are dosed at 2 mL/L of starch [32]. The starch consists of two types of α-glucan, amylose and amylopectin. However the amount of amylose, the main quality attribute of starch, defines the various properties of the starch and finally determines the end user [33]. The hydrolysis involves liquefaction of the starch with the enzyme, α-amylase and scarification with glucoamylase to produce glucose suitable for ethanol production by yeast fermentation. The efficiency of the liquefaction and scarification steps determines final ethanol yield at the end of fermentation and overall efficiency of the fuel ethanol production process [17, 34].

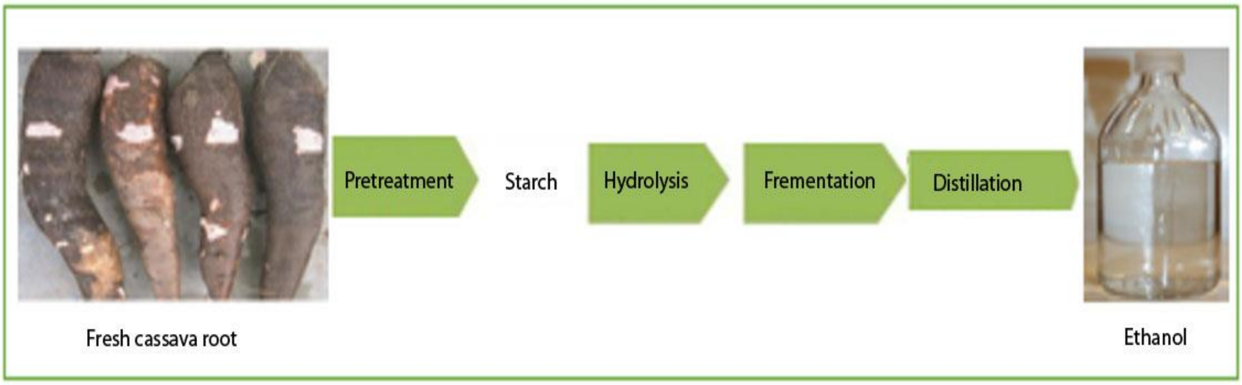

Figure 3. Stages in the industrial production of ethanol from cassava.

Table 2. Starch component of some high yielding cassava varieties obtained from the Crop Research Institute (CRI).

Variety	Average yield (Mt/Ha)	Fresh Root starch content (%)	Dry matter starch content (%)	Uses
CRI-Sika Bankye	45	19.63	57.26	Starch, flour
CRI-Essam Bankye	45	19.8	58	Flour
CRI-Duade Kpakpa	60	23.5	68.54	Fufu, starch, flour, alcohol.
*CRI-Agra	60	24.21	70.62	Starch, flour
CRI-Lamese	50	13.37	39	Fufu, Beta corotine, Flour
CRI-Abrabopa	46	25.4	74.1	Hi-starch

Note: *CRI-Agra – selected variety.

3.5. Estimation of Ethanol from High Starch Yielding Cassava Variety

The feasibility of replacing the traditional wood fuels in Ghana with ethanol depends on the availability, the affordability and the acceptability of ethanol compared to the wood fuels. In starch crops the higher the starch content cassava, the higher bioethanol yield of the crop. By using Leen Kuiper's estimate for cassava ethanol yield, which says one litre of ethanol can be produced from 5 - 6 kg of fresh roots (containing 30% starch). The selected CRI-Agra variety will produce one litre of ethanol from about 7kg of fresh roots, containing 24.21% starch [13]. Therefore, about 8.6L of ethanol can produced from 1Ha of land annually. On the availability (local production), about 147 Ha of agricultural land can be used to produce 1 ton of cassava ethanol from the selected cassava variety. Since the heating energy content of ethanol is almost twice that of wood fuel, 10 million tons of ethanol can replace the about 20million tons of wood fuel consumed by the household sector in Ghana [23]. Therefore replacing wood fuel with bioethanol for cooking can reduce greenhouse gas emissions from wood fuel use providing a great opportunity for climate change mitigation. However, an average of 1470 million Ha of land will be required for cassava ethanol production necessary to replace household wood fuel consumption in Ghana. On the cost of the cost of production, cassava ethanol also stands the chance of becoming the cheapest cooking fuel if produced locally. This is because cassava has low labour cost compared to other crop competitors.

4. CONCLUSION

The objective of this work is to evaluate the potential of cassava based ethanol as cooking fuel alternative in Ghana. The study compared the cooking fuels used in Ghana and identified that even though electricity and LPG are clean cooking fuel alternatives, their increasing prices makes their adopting very challenging for most households in Ghana. Ethanol a clean cooking fuel sources that can be produced locally and affordable should be adopted. Therefore, the study shows the potential of crops such as yam, potato, corn and cassava as the top ethanol feedstocks in Ghana. Among these, cassava is the most sustainable crop because of the following reasons. Some varieties of cassava, mostly underutilized have high starch and dry matter content suitable for ethanol production. Cassava has high achievable yield per hectare of land, it can grow in most lands/areas in Ghana. Cassava production has low capital and operational cost compared to the other crops. Thus ethanol production from cassava will be both technically, environmentally and economical beneficial. The study also shows that among all the six major starch yielding cassava varieties obtained from CRI, the CRI-Agra Bankye will give the optimum ethanol yield. The selected CRI-Agra variety will produce one litre of ethanol from about 7kg of fresh roots (containing 24.21% starch). Therefore about 8.6L of ethanol can produced from 1Ha of land annually. About 147 Ha of agricultural land can be used to produce 1 ton of cassava ethanol from the selected cassava variety. However, an average of 1470 million Ha of land will be required for cassava ethanol production necessary to replace household wood fuel consumption in Ghana. Since replacing wood fuel with bioethanol for cooking can reduce greenhouse gas emissions from wood fuel use providing a great opportunity for climate change mitigation, there should be ethanol adoption policy that can provide a road map for the production of ethanol from cassava. This work serve as an input for decision making for industrializing the cassava sector.

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